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School of Civil and Environmental Engineering

Comparative Evaluation of Pavement Performance

A Case Study on Bus stop stations in Addis Ababa

A thesis submitted to the School of Graduate Studies of

Addis Ababa University

In partial fulfilment of the requirements for the Degree of

Master of Science in Civil Engineering

(Road and Transport Engineering)

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Declaration

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Dr. Habtamu Melese and has not been presented as a thesis for a degree in any other university. All sources of materials used for this thesis have also been duly acknowledged.

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"COMPARATIVE EVALUATION OF PAVEMENT PERFORMANCE A CASE STUDY ON BUS STOP STATIONS IN ADDIS ABABA"

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List of Abbreviations

AACRA	Addis Ababa City Road Authority
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
ADT	Average Daily Traffic
ASTM	American Society for Testing Materials
BC	Binder Coarse
BRB	Bituminous Road Base
BST	Bituminous surface treatment
CBR	California Bearing Ratio
CDV	Corrected Deduct Value
CESA	Cumulative Equivalent Standard Axles
CPR	Concrete Pavement Restoration
CRCP	Continuously Reinforced Concrete Pavements
DV	Deduct value
EF	Equivalency Factor
ERA	Ethiopian Road Authority
ESAL	Equivalent Standard Axle Load
EUAC	Equivalent Uniform Annual Cost
GC	Granular capping layer
GRB	Granular Road Base

GS	Granular Sub Base
HDV	Highest Individual Deduct Value
HMA	Hot Mix Asphalt
JRCP	Jointed Reinforced Concrete Pavements
JUCP	Jointed Unreinforced Concrete Pavements
LCCA	Life Cycle Cost Analysis
LTPP	Long Term Pavement Performance Program
NPV	Net present value method
PCC	Portland Cement Concrete
PCI	Pavement Condition Index
PSI	Present Serviceability Index
PSR	Present Serviceability Rating
PW	Present Worth
TDV	Total Deduct Value
VIM	Voids in the Mix
VOC	Vehicle Operating Costs
WC	Wearing Course

Abstract

A pavement surface should be durable material, laid down on an area intended to sustain vehicular traffic load without any significant fail in any palace in the road network. Distresses are manifestation of pavement failure. Different types of distress are visible on bus stops areas of Addis Ababa roads with different level of surface condition. The present road condition of Addis Ababa bus stops areas shows rapid deterioration. The severity of pavement distresses is even more critical on the major bus-depots were the traffic volume of busses is comparatively higher than other bus stops found on the road network. This study cover on making assessment of asphalt pavement condition on bus stops areas, identifying causes of pavement distress. Visual distress assessment were carried out on selected test sections in order to have better understanding of the pavement on bus stop areas. The visual survey analysis indicates that almost all bus stops found in test roads have very low PCI value which rated as poor pavement surface but the bus-depots PCI values indicate that the pavement is failed.

The study also covers the design of both a cement concrete and flexible pavement with and without geogrid material and computation of respective costs over a study period of 30 years for the sections, to inform whether it will be cheaper to introduce concrete pavement on the bus stop or retain the flexible pavement. In addition to cost the study shows the performance of concrete pavement relative to flexible pavement using Kenpave software analysis.

To design the pavements and to do LCCA both primary and secondary data were collected. The traffic count data was used to come up with the pavement design details which included respective pavement layers, materials used and ultimately used for computation of unit costs for each pavement which was used for Present Worth economic evaluation method for life cycle cost comparison. From the evaluation of the study, flexible pavement was cheaper in initial construction however, over the analysis period, a concrete pavement are found more economical. And also in Kenpave software analysis concrete pavement is better in performance than flexible pavement. Addition of geogrid material to the pavement layer increase both the cost and performance of the pavement. It is therefore recommended that in the bus stop sections of the road, it would be preferably cheaper to introduce concrete pavement and have also good performance.

Keywords: *Flexible pavement, Cement concrete pavement, Geogrid, Pavement distress, Life cycle cost comparison between concrete pavement and flexible pavement, Pavement performance.*

Chapter One

Introduction

A road surface or pavement is a durable surface material laid down on an area intended to sustain vehicular or foot traffic, such as a road or walkway. All hard surfaced pavement types can be categorized into two major groups, flexible and rigid. Flexible pavements are those which are surfaced with bituminous or asphalt materials. On the other hand, rigid pavements are composed of a concrete surface course. Such pavements are substantially stiffer than flexible pavements due to the high modulus of elasticity of the concrete material. Further, these pavements can have reinforcing steel, which is generally used to reduce or eliminate joints.

Flexible pavements generally require reconstruction or rehabilitation every 10 to 20 years and also the maintenance cost is high (research has shown that heavy vehicles are mainly responsible for pavement damage and costs incurred to rectify the damage [6]). Rigid pavements, on the other hand, has a design life up to 60 years, but 40 years is the most common design period with little maintenance or rehabilitation [11]. Thus, it should come as no surprise that rigid pavements are often used in urban, high traffic areas.

This study seeks to carry out both a comparative design and LCCA for a rigid and flexible pavement with and without geo-grid, focus on the bus-stop sections of roads that found in Addis Ababa. Bus stop Sections after observations indicated that, on those areas pavement deteriorate faster than in the same asphalt pavement structure away from that sections.

In Ethiopia, No similar studies have been undertaken to assess or compare the performance of rigid pavement and its life cycle cost compared to flexible pavement focusing on bus stop areas. This is mainly due to a lack of tradition and experience in the design and construction.

The study areas that will be considered as a case study are 2 bus depot, (i.e., Megenaga and Legehar stations) and also bus stops that found in the route from AratKilo to sheromeda and from Mexico to Piyassa. This study is focused on reviewing the existing pavements performance on the study road under the prevailing conditions and focusing on the design of the four types of pavements for the sections and deriving the unit cost for each to compare Life cycle cost analysis (LCCA) of concrete pavement as compared to flexible on sections of bus stop.

1.1 Statement of the Problem

There is a faster deterioration of the sections of the road which will be under study particularly on the sections (i.e., bus-stop) as compared to the same asphalt pavement structure away from this areas. This is despite consistent maintenance of the existing flexible pavement.

In these areas the traffic loads are typically higher comparing with common traffic loads because the time of loading is longer. Moreover, loads of these areas are static, accelerating and braking loads and such loads affect pavement. Consequently, it leads high pressure into the pavement and causes distress. This distress increase vehicle operating costs; maintenance cost; safety and comfort of the road user will compromised and the road does not serve for the design service time and it induce unexpected expenditure on pavement investment of the country. So the roads pavements in this areas need to be properly analyzed.

Practice has shown that; pavements which are affected by slow moving, static loads, accelerating and braking loads need structural rehabilitation or reconstruction much earlier than the projected design life. Since from previous studies, concrete pavements are known to have high performance and more durable than flexible pavements with little maintenance cost and distress. Hence, this study address the problem and show economic advantages of using concrete pavement for sustainable pavement construction on bus stops.

1.2 Objectives of the Study

1.2.1 General objective

The general objective of this study is to assess the effect of city buses on existing pavement at bus stop areas and to identify the suitable and economical pavement type in bus stops areas in Addis Ababa roads.

1.2.2 Specific objective

- To investigate pavement distresses type and quantify the severity level at bus-stop areas.
- To Design rigid and flexible pavement with and without geogrid material for the road sections.
- To conduct pavement analysis using Kenpave.
- To conduct LCCA for both flexible and rigid pavement with and without geogrid material.

1.3 Scope and Limitations of the Study

The study reported here are mainly focuses on bus stops areas. The case study is conducted on four different location of Addis Ababa city. The scope of the study is limited to only bus stops as initial trial sections due to economic factors in Ethiopia. A combination of both primary and secondary data was utilized in the study for costing and comparison of different pavements.

Road geometrics was not considered as both pavements are assumed to have the same alignment, so are the climatic/weather conditions, environmental impact and societal benefits from this different road construction projects will not be fully quantifiable in this study. Further, Variations in User Costs or Vehicle Operating Costs (VOC) are due to increased pavement roughness, extra delays and accident costs due to lane closures, maintenance and rehabilitation activities not considered because of technological differences, calibration problems and data availability limitations in our country.

1.4 Organization of the Study

In this study, the research work carried out is divided into different topics and presented in five chapters, they are as follows.

A brief introduction, statement of the problem, and the scope is presented in the first chapter with special emphasis on the objectives of the proposed study.

Chapter 2 of this thesis covers literature review made on the pavement performance, types and causes of pavement distress and distress survey, a detail description of the two types of pavement regarding design concepts and economic analysis etc.

Chapter 3 describes the methodology and investigation techniques employed in this research to fulfill the objectives set out in Chapter 1.

Chapter 4 illustrates the quantifying of distresses in terms of PCI values, the comparative analysis for both flexible and rigid pavements on especial emphasis of life cycle cost for economic analysis for 30 years design life and determination of the performance of the pavements using Kenpave.

The conclusions of the whole study and some recommendations for future research are presented in Chapter 6.

Appendixes are attached at the end of this report, which contains all raw data, graphs and various reports used in this research.

Chapter Two

Literature Review

2.1 Pavement Type

The transportation by road is the only way which could give maximum service to one all. This mode has also the maximum flexibility for travel with reference to route, direction, time and speed of travel. It is possible to provide door to door service only by road transport.

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favorable light reflecting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the subgrade.

Three major types of pavements are generally recognized as serving this purpose, namely flexible pavements, rigid pavements and Composite pavements.

2.1.1 Flexible Pavement

A flexible pavement structure is typically composed of several layers of material with better quality materials on top where the intensity of stress from traffic loads is high and lower quality materials at the bottom where the stress intensity is low. Flexible pavements can be analyzed as a multilayer system under loading.

A typical flexible pavement structure consists of the surface course and underlying base and subbase courses and capping layer (if used) as depicted in figure 1. Each of these layers contributes to structural support and drainage. When hot mix asphalt (HMA) is used as the surface course, it is the stiffest (as measured by resilient modulus) and may contribute the most (depending upon thickness) to pavement strength. The underlying layers are less stiff but are still important to pavement strength as well as drainage and frost protection. When a seal coat is used as the surface course, the base generally is the layer that contributes most to the structural stiffness. A typical structural design results in a series of layers that gradually decrease in material quality with depth. Flexible pavement is the most preferred and used pavement type in Ethiopia currently.

2.1.2 Rigid Pavement

A rigid pavements structure is composed of a hydraulic cement concrete surface course, and under lying base and subbase courses (if used) as depicted in figure 1. Another term commonly used is Portland cement concrete (PCC) pavement. The surface course (concrete slab) is the stiffest and provides the majority of strength. The base or subbase layers are orders of magnitude less stiff than the PCC surface but still make important contributions to pavement drainage, frost protection and provide a working platform for construction equipment.

Rigid pavements are substantially 'stiffer' than flexible pavements due to the high modulus of elasticity of the PCC material resulting in very low deflections under loading. Rigid pavements can have reinforcing steel, which is generally used to handle thermal stresses, to reduce or eliminate joints and maintain tight crack widths.

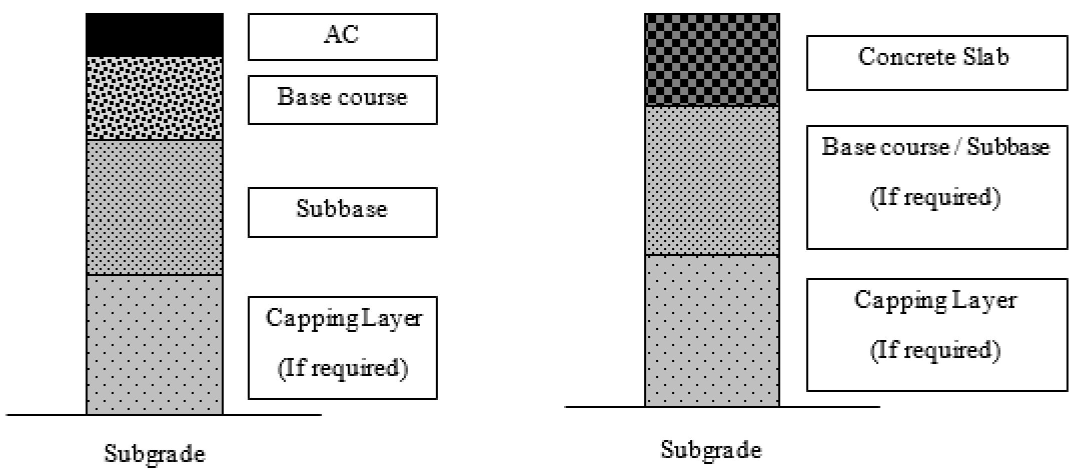


Figure 1: Cross sections of flexible Pavements and rigid Pavements

2.1.2.1 Types of rigid pavement

ERA Manual defined concrete pavement surfaces into three common types: Jointed Unreinforced Concrete Pavements (JUCP) Jointed Reinforced Concrete Pavements (JRCP) and Continuously R0einforced Concrete Pavements (CRCP).

a) Jointed Unreinforced Concrete Pavement

In Jointed Unreinforced Concrete Pavements (JUCP) the pavement consists of unreinforced concrete slabs cast in place and divided into bays of predetermined dimensions by the construction of joints. The dimensions of the bays are made sufficiently short to ensure that they do not crack through shrinkage during the concrete curing process. In the longitudinal direction the bays are usually linked together by dowels to prevent vertical movement and to help maintain aggregate interlock across the transverse joints. The bays are also connected to parallel slabs by tie bars, the main function of which is to prevent horizontal movement (i.e. the opening of warping joints). [13]

b) Jointed Reinforced Concrete Pavement

In Jointed Reinforced Concrete Pavements (JRCP) the pavement consists of cast in place concrete slabs containing steel reinforcement and divided into bays separated by joints. The reinforcement is to prevent cracks from opening and this allows much longer bays to be used than for JUCP. The bays are linked together by dowels and tie bars as in JUCP. Although longitudinal reinforcement is the main reinforcement, transverse reinforcement is also used in most cases to facilitate the placing of longitudinal bars. [13]

c) Continuously Reinforced Concrete Pavement

Continuously Reinforced Concrete Pavements (CRCP) are made of cast in place reinforced concrete slabs without joints. The expansion and contraction movements are prevented by a high level of sub-base restraint. The frequent transverse cracks are held tightly closed by a large amount of continuous high tensile steel longitudinal reinforcement. [13]

2.1.3 Comparison of Flexible and Rigid Pavements

Besides, there are many other advantages of rigid pavement over flexible pavement. Rigid pavement requires significantly less construction time; less number of heavy equipment; consumes less fuel and lubricant and is environmentally safe. Also flexible asphalt pavement requires more aggregate materials than rigid pavement. Rigid pavement enhances protection of ecology and conservation. It provides better visibility, skid resistance, higher abrasion, and enhances cross drainage over pavement, better road environment and surface condition etc.

Flexible pavements generally require reconstruction or rehabilitation every 10 to 20 years and also the maintenance cost is high (research has shown that heavy vehicles are mainly responsible for pavement damage and costs incurred to rectify the damage **[8]).** Rigid pavements, on the other hand, has a design life up to 60 years, but 40 years is the most common design period with little maintenance or rehabilitation. **[1]** Thus, it should come as no surprise that rigid pavements are often used in urban, high traffic areas.

Each of these pavement types distributes load over the sub grade in a different fashion. Rigid pavement, because of concrete's high elastic modulus stiffness, tends to distribute the load over a relatively wide area of subgrade. The concrete slab itself supplies most of a rigid pavement's structural capacity. Flexible pavement uses more flexible surface course and distributes loads over a smaller area. It relies on a combination of layers for transmitting load to the subgrade. Figure 2 below indicates the variation in load transfer for the two pavements.

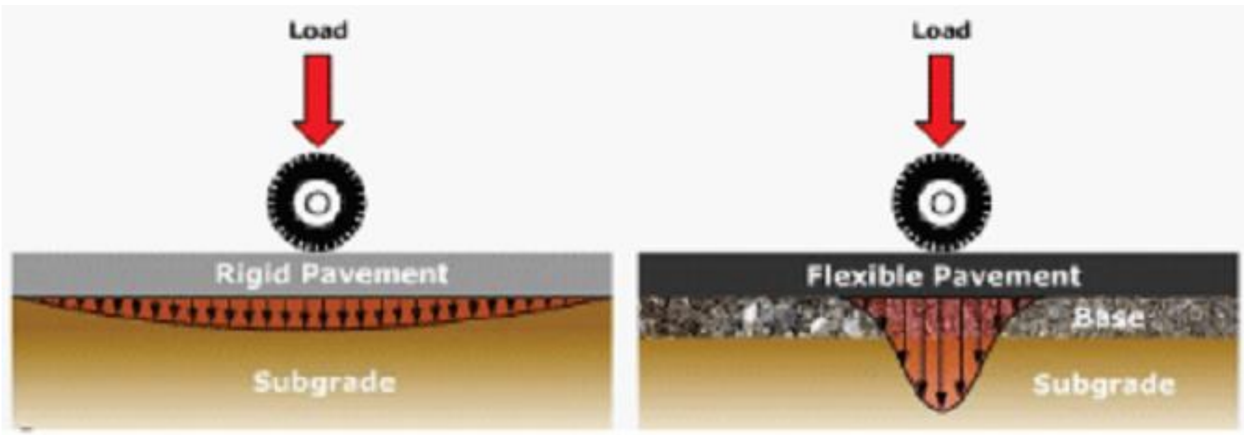


Figure 2: Rigid and flexible pavement load distribution

2.2 Pavement Type Selection Guidelines

Pavement-type selection is one of the challenging engineering decisions that highway administrators and designers face today. They must balance issues of both short- and long-term performance with initial and long-term costs, as well as highway user impacts. The traveling public generally does not express strong feelings on the type of pavement constructed, as long as reasonable levels of service, safety, and ride quality are provided. [22]

Pavement type & selection involves many factors, one thought, however, must always take precedence: that is, pavements are intended to serve highway users. To the extent that the pavement selection serves users, by ensuring that they travel on pavements that are safe, smooth, quiet, durable, economical, and constructed of sustainable materials, the designer has succeeded in meeting this important objective.

Pavement type selection processes are universally utilized by any transportation agencies responsible for roadway construction to identify and select the most durable, cost-effective, highest-performing pavement structure for a new roadway. These processes are intended to be free of bias and provide an analytical review of environmental and performance factors such as soil type, climate, traffic volume, life cycle, constructability, and cost. All these factors are weighted in a uniform, repeatable process with the singular goal of selecting the best pavement type at the greatest overall value to the taxpayer and with a service life which provides the maximum return on the public's investment.

In addition to technical and performance factors, roadway owners have been confronted with the need to consider secondary qualitative factors while selecting a pavement material type. These factors include consideration of such issues as tire-pavement noise generation, surface smoothness, and environmental sustainability.

In making a decision concerning the type of pavement to use on a roadway, an agency is obligated to get the best value for the taxpayers. It is up to contractors to provide the pavement that gives the best possible performance at the lowest possible price. Thus, pavement type selection should be a road user-oriented process, not an industry-oriented process. [6]

The evaluation should be based on good engineering judgment utilizing the best information available during the planning and design phases of the project together with a systematic consideration of the following project specific conditions:

- Pavement design life
- Traffic considerations
- Soils characteristics
- Weather (climate zones)
- Existing pavement type and condition
- Availability of materials
- Recycling
- Maintainability
- Constructability
- Cost comparisons (initial and life-cycle)

The above factors should be thoroughly investigated when selecting a pavement structure and addressed specifically in all project documents. The final decision on pavement type should be the most economical design based on life-cycle cost analysis. [9]

2.3 Pavement Performance

Pavements should be designed and constructed to provide, during the design life, a smooth and safe riding quality acceptable for both private and commercial vehicles. The assumption is often made that road pavements begin to deteriorate as soon as they are opened to traffic. However, there should be no visible premature deterioration at the early stage of the design life and perform well except due to faulty design. [11]

Performance is a general term for how pavements change their condition or serve their intended function with accumulating effects. Overall concepts of pavement performance include some consideration of functional performance and structural performance.

Functional performance is the ability of a pavement to provide a smooth, safe ride to its users. It can be summed up as "the measure of a pavement's ability to serve the function for which it was designed". [2]

Structural performance is a measure of a pavements ability to withstand the traffic and environmental loadings to which it is subjected. It is related to its physical condition; i.e., occurrence of cracking, faulting, raveling, or other conditions which would adversely affect the load-carrying capability of the pavement structure or would require maintenance. Poor structural performance is measured by the presence of distresses that are caused by loads. Moreover, the structural performance of a bitumen bounded pavement can be affected under high temperature and long loading time, under repeated applications of wheel loads.

Pavement condition involves the following four major components: (1) ride comfort (2) load carrying capacity (3) safety, and (4) aesthetics. In general, a good pavement rides well, carries traffic satisfactorily, and provides a safe tire interface for both rolling and stopping, and have pleasing appearance to the pavement manager and user as well. As there is no formula for considering all the above components in a precise manner, different people give more or less emphasis on any of the above factors depending on their particular situation. [18]

The performance of a pavement can be enhanced by different method from this geosynthetic materials application are one of them**.** This materials are used for many different applications throughout a roadway design. Not only are they used in asphalt paving installations, they are used for slope stability, drainage enhancement, and as strengthening layers within the pavement section.

2.3.1 Geogrids

Geogrids are one types of Geosynthetic polymer materials and roads are sometimes reinforced with it to increase performance. Geogrids are single or multi-layer materials usually made from extruding and stretching high-density polyethylene or polypropylene or by weaving or knitting and coating high tenacity polyester yarns. The resulting grid structure possesses large openings (called apertures) that enhance interaction with the soil or aggregate. The high tensile strength and stiffness of geogrids make them especially effective as soil and aggregate reinforcement. They are commonly placed between the subgrade and base or base and sub-base layers of roads to add strength and stiffness and to slow deterioration. The use of geogrids in road foundations clearly benefits pavement performance, potentially leading to longer service lives for roads, reduced maintenance costs and also increase structural capacity. Generally they are cost savings; Geosynthetic materials are generally less costly to purchase, transport and install than soils and aggregates [21, 17].

2.3.2 Methods of pavement performance evaluation

The performance of a pavement can be evaluated in deferent option. The evaluations includes: - (1) Pavement roughness (ride ability), (2) pavement deflection (structural failure), (3) skid resistance (safety), and (4) pavement distress (surface condition). [24]

1) Pavement Roughness

Pavement roughness refers to irregularities in the pavement surface that affect the smoothness of the ride. The serviceability of a roadway was initially defined in the AASHTO road test: a national pavement research project. Two terms were defined: (1) present serviceability rating (PSR) and (2) present serviceability index (PSI).

PSR is a number grade given to a pavement section based on the ability of that pavement to serve its intended traffic. The PSR rating is established by observation and requires judgment on the part of the individual doing the rating. The ratings ranged between 0 and 5, with 5 being very good and 0 being impassable. Serviceability ratings are based on the user's perception of pavement performance and are determined from the average rating of a panel of road users. PSI is a value for pavement condition determined as a surrogate for PSR and is based on physical measurements. PSI is not based on panel ratings, as the primary measure of PSI is pavement roughness. The PSI is an objective means of estimating the PSR, which is subjective. [24]

2) Pavement Structural Condition

The structural adequacy of a pavement is measured either by nondestructive means which measure deflection under static or dynamic loadings, or by destructive tests, which involve removing sections of the pavement and testing these in the laboratory. [24]

3) Skid Resistance

Safety characteristics of a pavement are another measure of its condition, and highway agencies continually monitor this aspect to ensure that roadway sections are operating at the highest possible level of safety. The principal measure of pavement safety is its skid resistance. Other elements contributing to the extent in which pavements perform safely are rutting (which causes water to collect that creates hydroplaning) and adequacy of visibility of pavement markings.

Skid resistance data are collected to monitor and evaluate the effectiveness of a pavement in preventing or reducing skid-related accidents. Skid data are used by highway agencies to identify pavement sections with low skid resistance, to develop priorities for rehabilitation, and to evaluate the effectiveness of various pavement mixtures and surface types. [24]

4) Pavement Distress

The term pavement distress refers to the condition of a pavement surface in terms of its general appearance. A perfect pavement is level and has a continuous and unbroken surface. In contrast, a distressed pavement may be fractured, distorted, or disintegrated. These three basic categories of distress can be further subdivided. For example, fractures can be seen as cracks or as spalling (chipping of the pavement surface). Cracks can be further described as generalized, transverse, longitudinal, alligator, and block. A pavement distortion may be evidenced by ruts or corrugation of the surface. Pavement disintegration can be observed as raveling (loosening of pavement structure), stripping of the pavement from the subbase, and surface polishing. [24]

2.4 Major Causes of Pavement Distress

The major causes for distresses can be grouped in to three categories. The first is due to overloading that includes excessive gross loads and high tire pressure. Second climatic and environmental conditions may cause surface irregularities and structural weaknesses on the pavement (but when we designed Highways we consider the effect of climatic and environmental conditions based on historic climate, however during their design life they could well be subjected to a very different climate that why it's considered as a major causes of pavement distress). The climate often interacts with other factors which further influence deterioration, for example, heavy traffic and extreme temperatures combining to cause more severe rutting. A third causes may be disintegration of the paving materials due to method of construction and quality of construction material. Use of contaminated aggregate and inadequate construction supervisor are also factors that may aggravate pavement distress. Lack of maintenance will further aggravate pavement distress. [16]

From the three major causes of distress heavy traffic, like trucks and busses, causes damage to pavement of at-grade Street, bus stop and road intersections perhaps more than any other location. Heavy vehicles at stopping and turning can stress the pavement surface severely along the approaches to bus stop and intersection. At busy intersections, the added load and stress from heavy vehicles often cause asphalt pavements to deteriorate prematurely. Asphalt surfaces tend to rut and shove under the strain of busses and trucks stopping and turning. These deformed surfaces become a safety concern for drivers and a costly maintenance problem for the roadway agency. Concrete pavements better withstand the loading and turning movements of heavy vehicles. As a result USA city's, county and state roadway agencies have begun rebuilding deteriorated asphalt intersections with concrete pavement. These agencies are extending road and street system maintenance funds by eliminating the expense of intersections that require frequent maintenance.[3]Using Cement concrete pavement for roundabout and intersection areas has been practice in United States of America and European countries. [3, 4, 19, 20]

2.4.1 Method of pavement condition survey

Pavement condition surveys play a vital role in the management of a pavement network. The pavement condition survey provides the most valuable information for pavement performance analysis, and is vital in order to forecast pavement performance, anticipate maintenance and rehabilitation needs, establish maintenance and rehabilitation priorities, and allocate funding. Therefore, it is critical to collect accurate pavement condition data in an efficient and safe manner. In the past the only method of completing a pavement condition survey was to walk or drive down the road and collect the data manually. This method is time consuming, hazardous, and subjective. Therefore, over the past two decades an effort has been made to fully automate the data collection process. [14]

An automated pavement condition survey consists of driving down the road at or near highway speeds while collecting data. The vehicles used to collect the data are outfitted with numerous technologically complex systems. Each system is designed to collect a specific type of data and some of the systems work in conjunction with each other. Some of the data that are commonly collected by automated data collection vehicles include, but are not limited to: rut depth, ride quality, texture, global positioning, position orientation, and numerous types of surface distress. Surface distresses such as cracking are commonly the most difficult type of data to detect and classify automatically. [14]

Hence, the most widely used method of detecting and classifying surface distresses is still with the human eye. However, in recent years, technological advancements in computer hardware and imaging recognition techniques have provided the means to successfully detect and classify surface distresses automatically in a cost-effective manner. These technological advancements include pavement imaging systems such as digital line-scan cameras that have the capability of capturing pavement images that can exceed a resolution of 6,000 pixels per line, as well as surface distress classification software that has the capability to classify surface distresses in real time. [14]

When doing distress survey using any methods that discussed above, the information gathered are:

Distress Type - Identify types of physical distress existing in the pavement. The distress types should be placed in categories according to their casual mechanisms.

Distress Severity - tells how bad the damage is and note level of severity for each distress type present to assess degree of deterioration.

Distress Amount - Denote relative area (percentage of the project) affected by each combination of distress type and severity.

All three of these factors are required to get a full picture of the damage that has developed on the pavement surface and are used to determine the type and timing of maintenance, rehabilitation and for future reconstruction it will help to identify the type of pavement which has a good performance.

2.4.2 Types of failures in flexible pavement

It is necessary to have a clear understanding of the type of pavements distress to evaluate the performance of a pavement. The different types of distress/failure in flexible pavement are tabulated in table 1. [23]

Table 1: types of distress in flexible pavement (Neero Gumsar Sorum, Pavement Distress: A case study, 2013)

No.	Type of failure	Description
1	Fatigue (alligator) cracking	Series of interconnected cracks caused by fatigue failure under repeated traffic loading.
2	Bleeding	Film of asphalt binder on the pavement surface
3	Block cracking	Interconnected cracks that divide the pavement up into rectangular blocks (approx. 0.1 $m^2$to 9 m^2)
4	Corrugation and shoving	A form of plastic movement typified by ripples(corrugation) or an abrupt wave (shoving) across the pavement surface
5	Depression	Localized pavement surface areas with slightly lower elevations than the surrounding pavement
6	Joint reflection cracking	Cracks in a flexible overlay of a rigid pavement which occur directly over the underlying rigid pavement joints
7	Longitudinal cracking	Cracks parallel to the pavement's centerline or laydown direction (a type of fatigue cracking)
8	Patching	An area of pavement that has been replaced with new material to repair the existing pavement
9	Polished aggregate	Areas where the portion of aggregate extending above the asphalt binder is either very small or there are no rough or angular aggregate particles
10	Potholes	Small, bowl-shaped depressions in the pavement surface that penetrate all the way through the HMA layer down to the base course
11	Raveling	The progressive disintegration of an HMA layer from the surface downward as a result of the dislodgement of aggregate particles
12	Rutting	Surface depression in the wheel path
13	Slippage cracking	Crescent or half-moon shaped cracks generally having two ends pointed into the direction of traffic
14	Stripping	The loss of bond between aggregates and asphalt binder that typically begins at the bottom of the HMA layer and progresses upward
15	Transverse (thermal) cracking	Cracks perpendicular to the pavement's centerline or lay down direction is usually a type of thermal cracking.
16	Water bleeding and pumping	Water bleeding occurs when water seeps out of joints or cracks or through an excessively porous HMA layer. Pumping occurs when water and fine material is ejected from underlying layers through cracks in the HMA layer under moving loads

In general the study of flexible pavement distress is advantageous for the highway engineers because of the following reasons:-

- It gives us the most accurate reason for the pavement distress/failure which makes the repairing work easy.
- The knowledge about pavement distress enables us able to make more efficient and high performance pavement.
- Hence, high performance pavement ensures efficient traffic flow and safety to the passengers.
- Moreover, the study of pavement distress in an area helps in the improvement in design of the pavement, which may be so more effective in the area.

2.5 General pavement Design Principle and Procedure

Road pavements are designed to limit the stress created at the subgrade level by the traffic travelling on the pavement surface so that the subgrade is not subject to significant deformations. The pavement spreads the concentrated loads of the vehicle wheels over a sufficiently large area at subgrade level. At the same time, the pavement materials themselves should not deteriorate to any serious extent within a specified period of time. However, it is inevitable that road pavements will deteriorate with time and traffic, therefore, the goal of pavement design is to limit, during the period considered, the deterioration which affects the riding quality of the road, such as rutting, cracking, potholes and other such surface distresses, to acceptable levels. [13]

As indicated in Huang (2004); Design factors can be divided into four broad categories: traffic & loading, environment, materials and failure criteria. [28]

1) **Traffic**

Deterioration in paved roads caused by traffic is a function of the magnitude of the individual wheel loads and the frequency with which they are applied. For pavement design purposes, therefore, it was necessary to know not only the total number of vehicles using the road but also the configuration, magnitude, and repetitions of axle loads. Traffic loading is normally expressed in terms of ‘equivalent standard axles'. An axle carrying 80kN was arbitrarily defined as a ‘standard axle’, to which axles of different weights were correlated to derive equivalence factors, thereby obtaining an expression of the damaging effect.

The ultimate objective in traffic Analysis was thus to determine the Cumulative Equivalent Standard axles (ESAL) in the design period. This is achieved in a number of operations:

- Traffic Volume
- Traffic Forecasting
- Determining Design Period
- Axle Load Survey

2) Environment

The environmental factors that influence pavement design include temperature and precipitation, both affecting the elastic moduli of the various layers. In the mechanistic-empirical method of design, each year can be divided into a number of periods, each having a different set of layer moduli. [28]

Temperature: The effect of temperature on asphalt pavements is different from that on concrete pavements. Temperature affects the resilient modulus of bituminous layers and creates thermal stresses in cement concrete slabs. [28]

Precipitation: The precipitation from rain and snow affects the quantity of surface water infiltrating into the subgrade and the location of the groundwater table. Every effort should be made to improve drainage and alleviate the detrimental effect of water. If water from rainfalls can be drained out within a short time, its effect can be minimized, even in regions of high precipitation. [28]

3) Material

Pavement materials includes soils, aggregates, bituminous binders, and cement, etc. The properties of these materials under traffic loading in a given environmental conditions is fundamental for the proper design of pavement structures. And also the properties of materials must be specified, so that the responses of the pavement, such as stresses, strains, and displacements in the critical components, can be determined. These responses are then used with the failure criteria to predict whether failures will occur or the probability that failures will occur. [28] Moreover, if economically constructed facilities are to be obtained, locally available materials are to be used efficiently.

4) Performance and Failure Criteria

Fatigue cracking, rutting, and thermal cracking are the three principal types of distress generally considered for flexible pavement design. The fatigue cracking of flexible pavements is due to the

Horizontal tensile strains at the bottom of bituminous layer. Rutting is a permanent deformation that occurs on flexible pavements along the wheel path. Thermal cracking includes low temperature and thermal fatigue cracking. Low temperature cracking is usually associated with flexible pavements in cold regions where temperature fall below –23^{o}C. Thermal fatigue cracking can occur in much milder regions if an excessive hard bituminous binder is used or the binder becomes hardened duet ageing. [28]

Fatigue cracking, pumping and other distresses such as faulting and joint deterioration are recognized failures in rigid pavements. Fatigue cracking is most likely caused by the edge stress at the mid slab. It has long been considered the major criterion for rigid pavement design. Although permanent deformation is not considered in rigid pavements design, the resilient deformation under repeated wheel loads cause pumping. The resulting corner deflection has been used as a criterion in addition to the fatigue. [28]

2.5.1 Methods of Pavement design

In the design of flexible pavements, the pavement structure usually is considered as a multilayered elastic system, with the material in each layer characterized by certain physical properties that may include the modulus of elasticity, the resilient modulus, and the Poisson ratio. It is assumed initially that the subgrade layer is infinite in both the horizontal and vertical directions, whereas the other layers are finite in the vertical direction and infinite in the horizontal direction. The application of a wheel load causes stress and strain to the pavement layers. The design of the pavement therefore generally is based on strain criteria that limit both the horizontal and vertical strains below those that will cause excessive cracking and excessive permanent deformation. These criteria are considered in terms of repeated load applications because the accumulated repetitions of traffic loads are of significant importance to the development of cracks and permanent deformation of the pavement. [24]

Methods of pavement design in frequent use can be subdivided into two main groups: [15]

- ❖ Methods derived purely from empirical studies of pavement performance;
- ❖ Methods which make use of the calculated stresses and strains within the pavement (theory), together with studies of the effect of these stresses and strains on the pavement materials (mechanistic behavior). These are usually called ‘mechanistic methods’, ‘theoretical methods’ or, simply, ‘analytical methods’.

2.6 Life cycle cost analysis (LCCA)

LCCA is an analytical technique that uses economic principles in order to evaluate long-term alternative investment options. The analysis enables total cost comparison of competing design alternatives with equivalent benefits. The LCCA analytical process helps to identify the lowest cost alternative that accomplishes the project objectives by providing critical information for the overall decision-making process. However, in some instances, the lowest life-cycle cost option may not ultimately be selected after such considerations as available budget, constructability and maintainability issues, and environmental concerns are taken into account. [27]

It is important to understand that LCCA is an economic tool that determines which alternate has the best value and not an engineering tool that determines how long an alternate will last or how well it will perform. This does not mean that engineering is not an important element of the life cycle cost analysis. Proper engineering must be used to ensure that each rival alternate meets the design criteria and provides similar results. If the alternates do not provide similar performance then an economic assessment using LCCA to compare them is not realistic or reliable. [5]

2.6.1 Types of Economic Analyses

The results of a LCCA can be presented in several ways. The two most common are Present Worth (PW) and Equivalent Uniform Annual Cost (EUAC).

Present Worth: is the sum of all costs (and benefits) over the project life in today's money. It combines initial costs with discounted future maintenance costs, rehabilitation costs and a salvage value. The future costs are discounted to account for the time value of money using the discount (real interest) rate. Present worth analysis is limited to comparing alternates with equal analysis periods. [5]

$$NPV = \text{Initial Cost} + \sum_{k=1}^{N} \text{Rehab Cost}_k \left[\frac{1}{(1+i)^{n_k}} \right] \qquad \text{(Eqn.1)}$$

where: i = discount rate
n = year of expenditure

Equivalent Uniform Annual Cost (EUAC): spreads the cost of all items (initial, user, maintenance and anticipated rehabilitation costs) to an annual cost over the analysis period. An analysis using EUAC allows comparison with different analysis periods. However when making such comparisons the user must understand that the analysis is assuming that the same set of activities will be repeated indefinitely. [5]

$$EUAC = NPV\left[\frac{1(1+i)^n}{(1+i)^n - 1}\right]$$

where: i = discount rate
n = number of years into future

(Eqn. 2)

2.6.2 Steps in Performing a LCCA

There are six basic steps to performing a Life Cycle Cost Analysis. They are: [5]

1. Design equivalent pavement sections
2. Develop expenditure streams for the analysis period.
    a. Determine the maintenance and rehabilitation strategies (activities and timing) to be used on the pavement over the analysis period.
    b. Estimate agency costs for each activity.
3. Estimate user costs
4. Compute Present Worth or Equivalent Uniform Annual Cost
5. Analyze results
6. Re-evaluate strategies.

2.6.3 Basic Factors in LCCA

The factors affecting the results of a LCCA for pavement type selection are: [5]

- Agency costs (including engineering costs)
- User costs
- Discount rate
- Selection of rehabilitation activities
- Use of comparable sections
- Length of the analysis period

2.6.3.1 Agency costs

Agency costs are all direct costs incurred by the agency over the lifetime of the project. These include:

- Initial costs
- Operation and maintenance costs (including staffing)
- Rehabilitation costs (including engineering and traffic control for each rehabilitation)
- Salvage value.

When looking at agency costs it is only necessary to include costs that are specific to the individual alternates and set them apart. Common costs such as public hearing and informational meetings, permits, real estate and land development, legal fees etc. are incurred no matter which pavement alternate is selected. Therefore these costs do not affect the comparison results. [5]

2.6.3.2 User Costs

Best-practice LCCA calls for consideration of not only agency costs, but also costs to facility users. User costs include travel time costs and vehicle operating costs (excluding routine maintenance) incurred by the traveling public. User costs arise when work zones restrict the normal flow of the facility and increase the travel time of the user by generating queues or formal or informal detours. User costs are also incurred during normal operations, but they are not considered in LCCA because normal travel costs are not dependent on individual project alternatives. Additional user costs resulting from work zones can become a significant factor when a large queue occurs in a given alternative. [27]

2.6.3.3 Discount Rate

The discount rate accounts for the time value of money. It takes into account the fluctuation of the inflation and interest rates to show the actual or real rate of increase in the value of money over time. [5]

2.6.3.4 Comparable Sections

In order to perform a realistic and reliable life cycle cost analysis, the two alternates must have equivalent and comparable designs and should provide similar results over the analysis period. That is they should be designed for the same: [5]

- Structural (traffic-carrying) capacity
- Reliability
- Subgrade properties
- Terminal condition

2.6.3.5 Length of Analysis Period

The analysis period is the time frame over which all costs are compared. It does not have to be equal to the design or service life and in most cases it is not. The main criterion is that it be long enough to reflect the cost difference between the alternative pavements. [5]

Chapter Three

Research Methodology

The methodology that will be followed to achieve the research objective is:

3.1 Selection of Test Roads and Test sections

The Pavement evaluation under this research has concentrated on the two routes and two city bus depot. The selection process for the test route is done based on sub-city bus distribution of Addis Ababa. In Addis Ababa there are 10 sub-city and the distribution of number of bus and bus-route different in each sub-city. Table 2 below shows the distribution of city bus and their routes in each sub-city (Anbusa-Bus Public transport):-

Table 2: The distribution of city bus and their routes (Anbusa-Bus Public transport)

Sub-city	No. of Bus	% of Bus in Sub-city	No. of Route	% of Route in Sub-city	Ascending order by no of bus	Ascending order by no of route
Kirkos	242	15.35532995	54	13.70558376	1	1
Arada	196	12.43654822	48	12.18274112	2	2
A/ketema	173	10.97715736	46	11.6751269	3	3
Lideta	172	10.91370558	40	10.15228426	4	5
Lafto	170	10.78680203	43	10.91370558	5	4
Yeka	144	9.137055838	37	9.390862944	6	6
Gulele	129	8.185279188	32	8.121827411	7	8
Keraniyo	123	7.804568528	34	8.629441624	8	7
Bole	112	7.106598985	28	7.106598985	9	9
Akaki-Kality	60	3.807106599	14	3.553299492	10	11
Oromia	55	3.489847716	18	4.568527919	11	10
Total Sum	1576	100	394	100		

From the above table shown, the number of bus and route is higher in kirkos and Arada sub-city. For case study the following sections are selected from the two sub-city:

1. One route - that will connect the two sub-city [i.e., from Mexico to Piazza]
2. The other route will be from Arada sub-city [i.e., from Arat-killo to sheromeda]
3. One bus depot from kirkos sub-city [i.e., Legehar station]
4. And the other bus depot will be selected randomly from the remaining sub-city [i.e., Megenaga stations]

The criteria which were considered when making selection of the study routes are: The selected sections can be said free from heavy trucks that damage pavement a lot, so we can see purely the effect of bus-damage-only in this sections, Other than normal bus this routes has more articulated bus operated in it and these roads can fairly represent route that found in the selected Sub-city because those route are bridge for most residential, market, offices and schools that found in the area for that reason these roads are the most utilized sections and convey higher bus traffic loading.

Pavement inspection conducted on the selected routes and the number of inspection unit found in the section is identified and shown in below.

Table 3: Name of test roads and their corresponding number of test section

Test road no.	Test road name	Number of bus stations
1	Route from Mexico to Piazza	6
	Route from Piazza to Mexico	5
2	Route from AratKilo to Sheromeda	7
	Route from Sheromeda to AratKilo	6
Bus depot no.	Bus depot name	Test sections
1	Legehar	The entire bus depot
2	Megenaga	The entire bus depot

3.2 Data Collection and Field Investigation

The first phase has been designed to accomplish the collection of data parallel to the field investigation. Collection of both primary and secondary data was done.

The data collection was planned to obtain from the responsible authority of the city, i.e. secondary data; includes: one, Current pavement construction, maintenance and rehabilitation cost. Second, traffic growth rates and axle load data from AACRA or Consultants/ Construction Companies.

The field investigation, i.e. primary data; concerned with gathering of two elements. The first step was visual inspection that is the condition survey. The second step was counting traffic data of the study areas. Each of the procedures followed will be discussed separately as follow.

3.2.1 Visual Condition Survey

The main aim of conducting the condition survey was to gain knowledge about the general condition of the study sections, identify the dominant type of distress and classify the distress. The condition survey procedure offers a method for identifying pavement distress types and defining the levels of severity and extent associated with each distress. The visual survey is made using based on the procedures described on the long-term pavement performance program (LTPP) and ASTM D6433-07 manuals. The assessment method, measuring units, recording formats and guidelines for determining pavement condition that involves observing and recording the presence of specific types and severities of defects or distresses on the pavement surface made using this two manuals.

According to the LTPP manual for flexible pavement the distress that will be measured are generally Cracking; Patching and Potholes; Surface deformation and Surface defects. To determine this distresses the procedure followed for visual inspection of the road pavement is:

- ❖ Record the distresses types walking along the test road section.
- ❖ Measure distresses using proper parameters such as:
    - ▪ Cracking like Fatigue cracking and Block Cracking (Square meter); Edge Cracking and Longitudinal Cracking (linear meter); while Transverse Cracking (linear meter or number).
    - ▪ Patching and Potholes (number or Square meter).
    - ▪ Surface Deformation like rutting (millimeter) and while Shoving (number or square meters).
    - ▪ Surface Defects like Bleeding; Polished Aggregate and Raveling (Square Meters)
- ❖ Log the final results on the data collection form.

3.2.1.1 Data collection equipment

The following pieces of equipment will be utilized to carry out visual condition survey:

1. Data Sheets: for recording the following information: - Date, location, section, sample unit size and area, distress types, severity levels, quantities, and names of surveyors.
2. Digital Camera: for taking photos and videos.
3. Tape and ruler: for measuring the length, width and depth of occurring distress.
4. Safety equipment.

3.2.2 Traffic data

Manual classified traffic count was conducted for seven consecutive days, from this 2 days will be full 24hrs count with one from weekday and the other from a weekend day. The reset 5 days count will be 12hrs. The counts takes places between 6am and 6pm for day counts, while for night counts it was done between 6pm and 3pm. In the city of Addis Ababa (especially in selected sections) after 3pm in the night most vehicle stops its movements especially the heavy vehicles except cars. In design of pavements the damaging effects of car is neglected. So we use 15hrs volume count of the two days as 24hrs volume for the purpose of this research paper. In carrying out the traffic surveys, the vehicle classification system of AACRA was used. From Figure 3 up to Figure 6 shows the traffic count data.

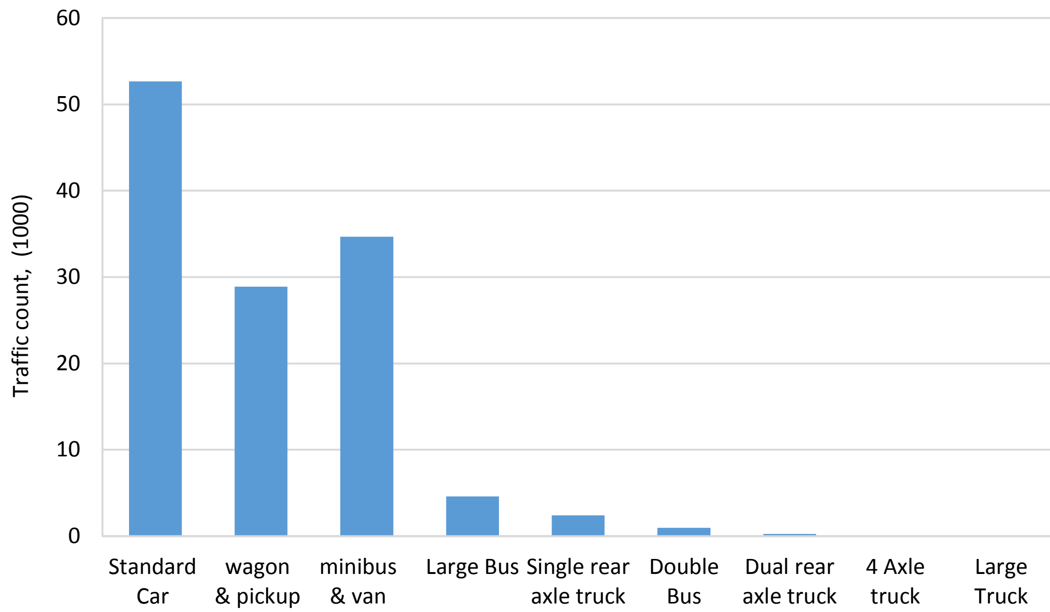


Figure 3: The traffic count data of AratKilo – Sheromeda

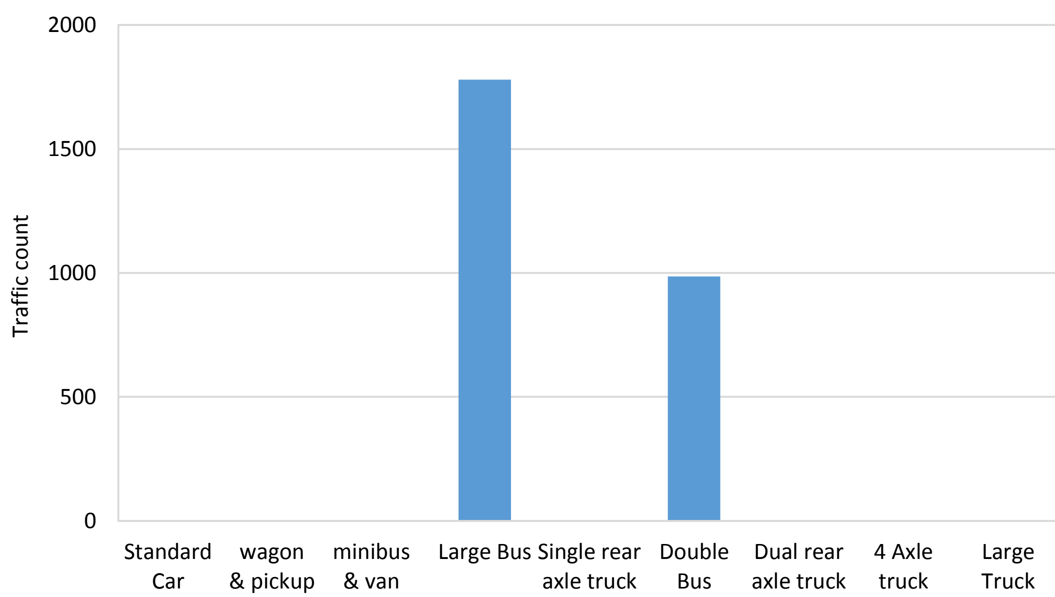


Figure 4: The traffic count data of Leghare Bus Depot

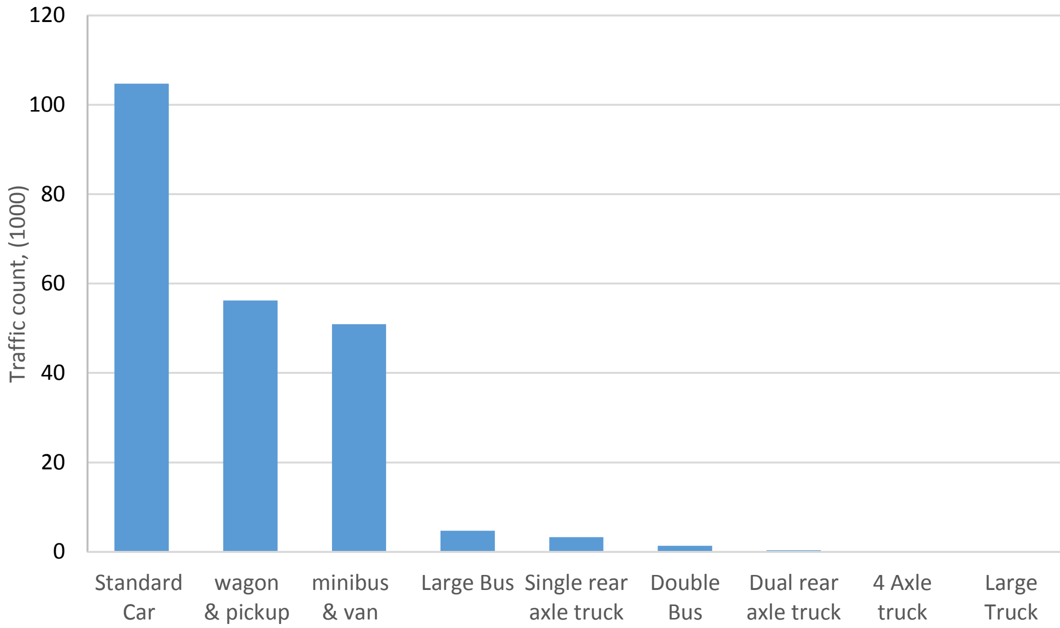


Figure 5: The traffic count data of Mexico - Piyassa

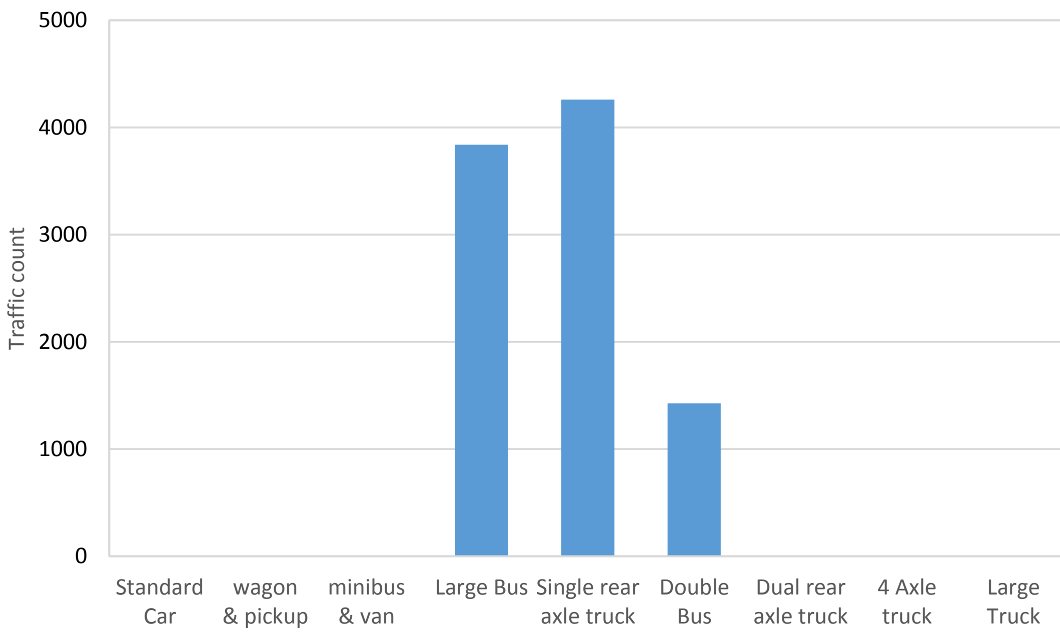


Figure 6: The traffic count data of Megenaga Bus Depot

3.3 Data analysis

3.3.1 Quantifying the distress and calculating Pavement Condition Index (PCI)

The gathered data in pavement condition survey is quantified and recorded using the following information:

- ❖ Distress type- identify types of physical distress existing in the pavement.
- ❖ Distress severity - estimating the distress items in three damage levels i.e. low (L), medium (M) and high (H) severity. This assessment helps to estimate degree of deterioration.
- ❖ Distress extent - calculate relative area (percentage of the road section) affected by each combination of distress type and divided it by the area of the sample unit.

Then the pavement condition is rated and scaled to know how much the damage existed. The method of scaling severity level using pavement condition index (PCI) is applied. The Pavement Condition Index (PCI) is determined by measuring pavement distress with a numerical indicator based on a scale of 0 to 100. According to ASTM D6433-07 manual the following pavement condition ranking values is given: 0-10(failed); 10-25(serious); 25-40(very poor); 40-55(poor); 55-70(fair); 70-85(satisfactory); 85-100(good).

Calculation of the PCI for Asphalt Concrete (AC) Pavement is done using the ASTM D6433-07 manual method which involves the following general steps:

Step 1: for each distress type found during inspection determine the total quantity distress level and record them.

Step 2: Find Percent Density of each distress type: - Divide the total quantity of each distress type at each severity level by the total area of the sample unit and multiply by 100 to obtain the percent density of each distress type and severity.

Step 3: For each distress type, determine the deduct value (DV) from the distress deduct value curves

Step 4: Find the Maximum Corrected Deduct Value (CDV). The following procedure must be used to determine the maximum CDV:

If none or only one individual deduct value is greater than 2, the total value is used in place of the maximum CDV in determining the PCI; otherwise, the maximum CDV is determined by the following procedures:

- ✓ List the individual deduct values in descending order.
- ✓ Determine the allowable number of deducts ,M, from Adjustment Number of Deduct Values curve or using the following formula:

$$\boldsymbol{M = 1 + (\frac{9}{98})(100 - HDV) \leq 10}$$ ………..……….. (Eqn. 3)

Where:

M = allowable number of deducts including fractions (must be less than or equal to ten), and

HDV = highest individual deduct value.

- ✓ The arranged deduct values will be adjusted according to the allowable number of deducts calculated using the above equation. If there is larger number of deduct value is available than the allowable number of deducts, then the deduct values has to be reduced to the M largest deduct value. For instance, a, b, c & d are N number of deduct values which are arranged in descending order.

  Therefore, If N > M, the last value of deduct value, i.e. d, will be reduced to d*(N-m)

  If N < M, all of the deduct values will be used

- ✓ Obtain the total deduct (TDV) value by summing each deduct value which is adjusted according to the M value.
- ✓ Count the number of deduct values which is greater than 2 and register the number as a 'q' value
- ✓ Obtain the CDV by reading from the correct deduct value curve based on TDV and q
- ✓ Find out CDV iteratively by reducing the smallest individual deduct value greater than 2 to 2 and repeat until q reduced to 1.
- ✓ Then pick the largest CDV from the iteration to obtain the maximum corrected deduct value (max CDV).

Step 5: Calculate PCI by subtracting the maximum CDV from 100.

$$\boldsymbol{PCI = 100 - max\ CDV}$$ ………..………………….. (Eqn. 4)

Step 6 – Obtain the PCI rating scale and rate the pavement.

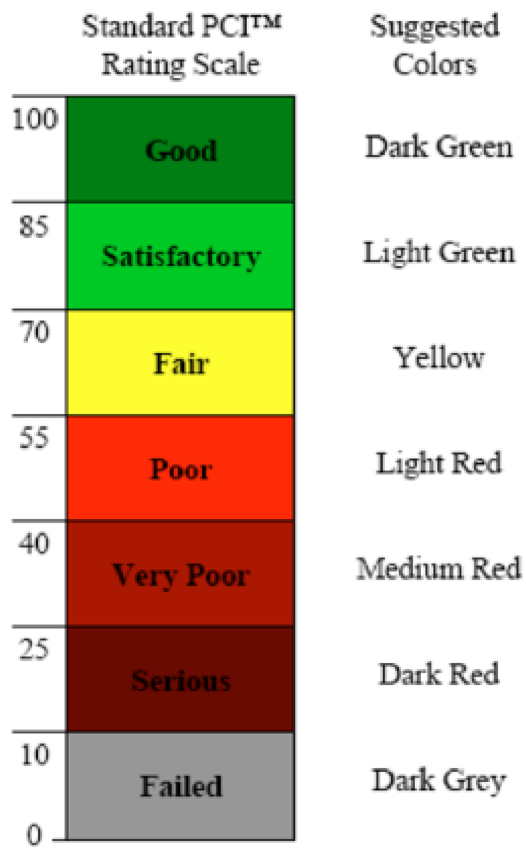


Figure 7: PCI rating scale and Suggested Colors [ASTM D6433-07]

3.3.2 Design of Pavement

3.3.2.1 Traffic Analysis

In order to determine the design traffic over the design period of the road, the following procedure will be followed:-

After conducting traffic count, determination of the daily traffic flow for each class of vehicle, ADT was carried out and adjusted to obtain the Annual Average Daily Traffic, AADT which used in traffic analysis. After finding of AADT, using traffic growth rate Base Line traffic determined. Then traffic projection for respective design year was carried out. Finally, the values of Equivalency Factor, EF, for each vehicle classes in conjunction with traffic forecasts used to determine the design traffic, Cumulative Equivalent Standard Axle, CESA. Figure 8 shows the flow chart of pavement design for this study.

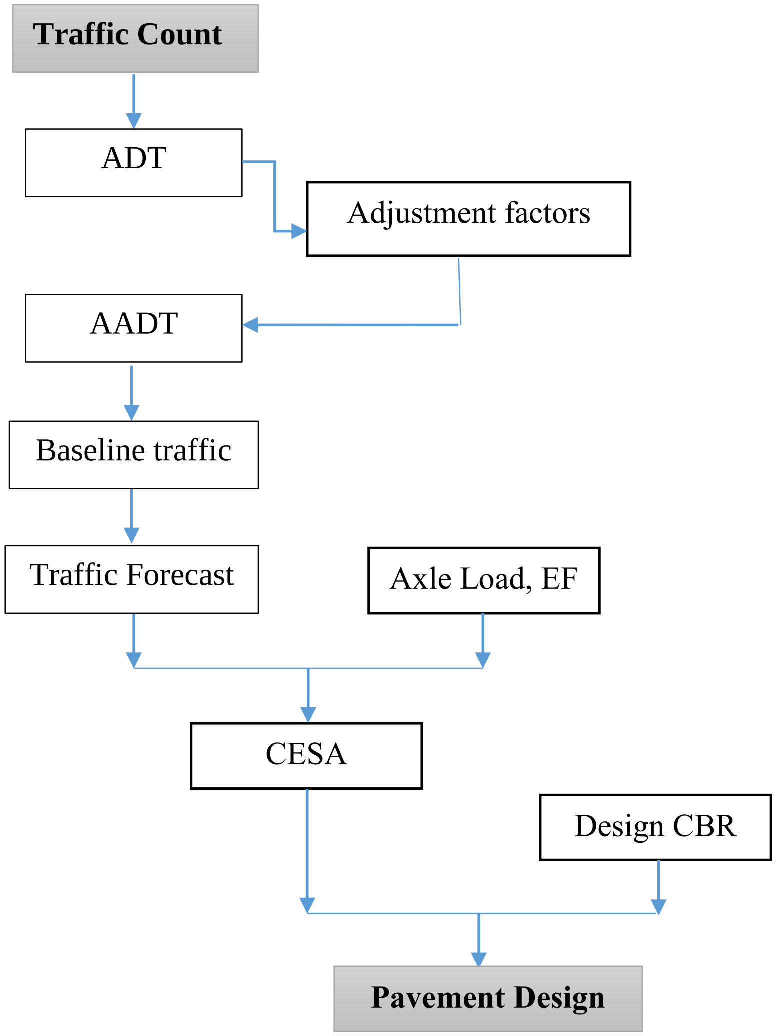


Figure 8: flow chart of pavement design

3.3.2.2 Pavement Design

a) Flexible pavement design

Using the calculated Design Traffic Loading and the Design Subgrade CBR the appropriate pavement structure will be selected from design chart according to the pavement design Manual of ERA 2013 Volume I.

b) Rigid pavement design

Capping and Sub-base

Because of high flexural strength, the performance of rigid pavements is more governed by the strength of the concrete slab and because of this vehicle load is distributed over a relatively wider area of the soil. So the concrete slab can reset on the subgrade without any pavement layers. According to ERA manual Volume II, a capping layer is required if the design CBR of the subgrade is less than 15%. The required thickness of capping layer and sub-base thickness under rigid pavement based on the subgrade CBR is taken from the table below:

Table 4: Thickness of Sub-base and Capping Layers, ERA 2013 Volume II

Subgrade Class	CBR range %	Sub-base thickness (mm)	Capping layer thickness (mm)
S1	2	200	400
S2	3,4	175	350
S3	5 - 8	150	250
S4	8 - 15	150	200
S5	15 - 30	175	0
S6	>30	0	0

Thickness and Reinforcement Design

Using the calculated design traffic loading, the appropriate slab thickness and reinforcement selected from design chart according to the rigid pavement design manual of ERA 2013 Volume II.

3.4 Kenpave Analysis

Using ken-pave software, pavement analysis will be done for both flexible and rigid pavement to study the performance and how they behave after applying the traffic load i.e. determining the stresses, strain and deflection occurs in the pavement system.

3.5 LCCA

LCCA will be conducted to compare the economic performance of designed flexible and rigid pavement with and without Geogrid material as per Net present value method (NPV).

$$NPV = Initial\ Cost\ + \sum_{k=1}^{n} Maintenace\ Cost[\frac{1}{(1+i)^n}] \quad \dots\dots\dots\dots\dots\dots\dots..(Eqn. 5)$$

Where: i = discount rate,

n = analysis Period, and

k = year of activity.

Chapter Four

Analysis and Results

4.1 Visual condition survey distress Assessment and Evaluation

The visual distress surveys were made on selected test sections following the methods as discussed in Section 3.2.1 and 3.3.1 above. The aim of conducting the condition survey was to know how much damage done to the pavement due to buses, gaining knowledge about the general condition of the study area, identify the dominant type of distress and classify the severity level of the distress. The length, size and depth of the distresses found in the test sections were measured. The total studies was divided into 4 days; in each day, each study section survey was carried out. The pavement distress survey was done for a total of 24 bus stop in the two routes and for two bus-depots. The bus stop length used as 45m long with a width of 4m area. Detail result of the visual survey of each section is discussed below and the calculation of PCI values for the distresses is attached in Appendix A.

4.1.1 AratKilo to Sheromeda Route

The Visual survey for this test road was carried out from AratKilo roundabout to the last bus stop in Sheromeda, which is about a total of 3.051km length. Thirteen bus stop found in this route and each were surveyed. The minimum and maximum block PCI values are 0 and 100 respectively. The weighted average PCI value (i.e. considering area of pavement) for this route is 44, which can be rated as poor pavement surface. The detail summary of PCI values for each bus stop is as shown in Figure 10 below. The most commonly found pavement distresses were pot holes and shoving followed by alligator cracks, patching, raveling and edge failure. All the distresses found in the highway were exceeding their maximum limits. The interval of the pavement distresses found was too frequent and well exceeded the standard limits. Figure 11 and Figure 12 shows some of the photographs of taken on AratKilo to Sheromeda Route.

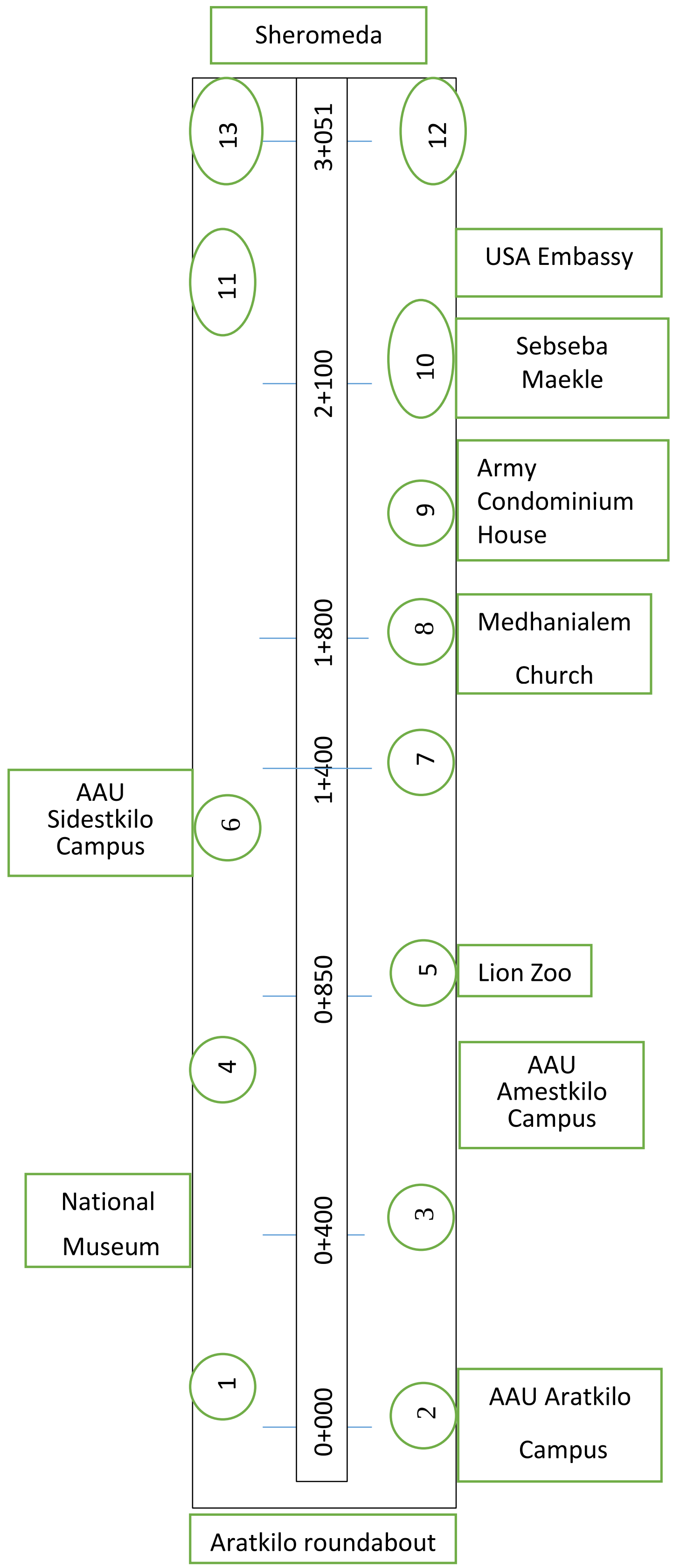


Figure 9: Bus Stop locations and stations in AratKilo - Sheromeda Route

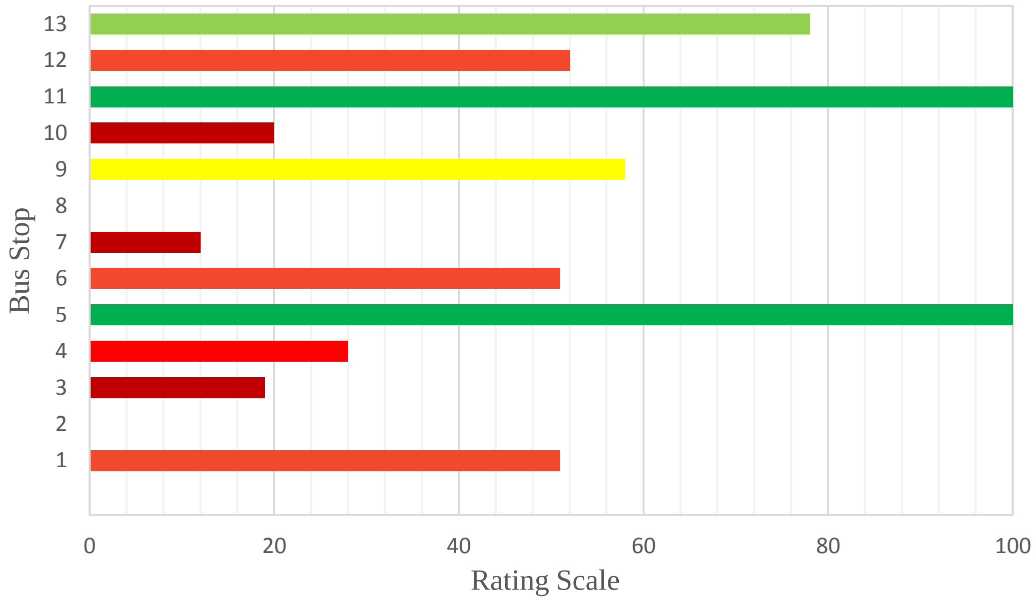


Figure 10: Summary of PCI for Aratkilo-Sheromeda.

(a) (b)

Figure 11: (a) Alligator Cracking and Potholes at bus stop 8, (b) Block Cracking at bus stop 7

(c) (d)

Figure 12: (c) Shoving at bus stop 2, (d) Raveling at bus stop 8

4.1.2 Mexico to Piyasa Route

The Visual survey for this test road was carried out from Mexico around Wabi-Shebele hotel to Piyassa, which is 2.85km length**.** Eleven bus stop found in this route and each were surveyed. The minimum and maximum block PCI values are 20 and 100 respectively. The weighted average PCI value for this route is 52, which can be rated as poor pavement surface. The detail summary of PCI values for each bus stop is as shown in Figure 14 below. The most commonly found pavement distresses were pot holes, alligator cracks, longitudinal cracks and patching followed by shoving, transversal and block crack. All the distresses found in the highway were exceeding their maximum limits. The interval of the pavement distresses found was too frequent and well exceeded the standard limits. Figure 15 and Figure 16 shows some of the photographs of taken on Mexico to Piyassa route.

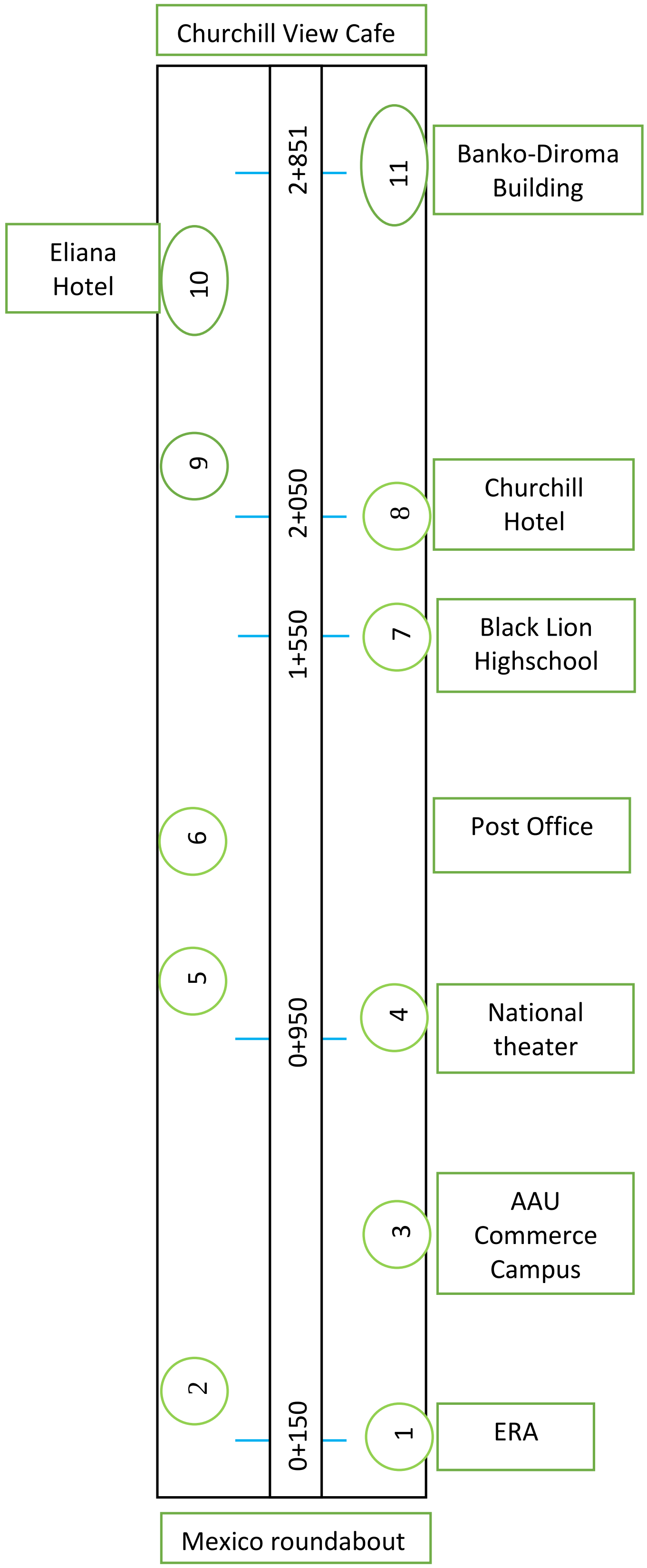


Figure 13: Bus Stop locations and stations in Mexico to Piyassa Route

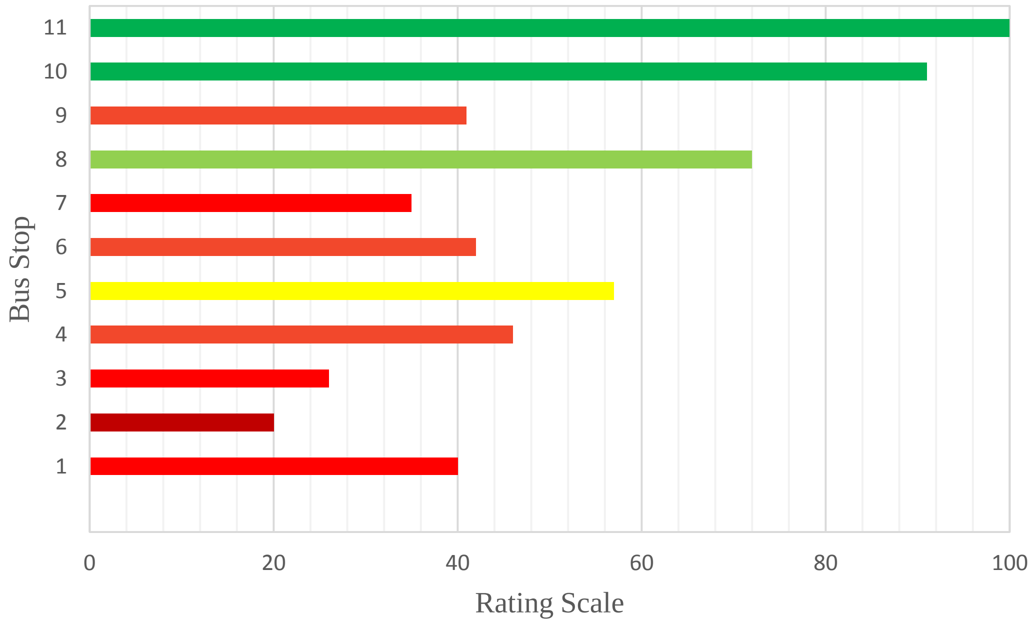


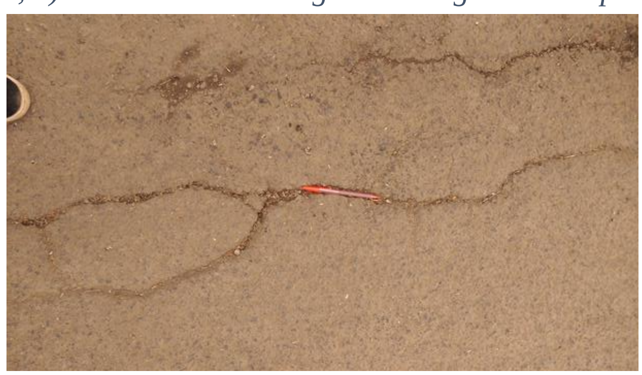
Figure 14: Summary of PCI values for Mexico to Piyassa Route

(a)

(b)

Figure15:a)Potholes and Raveling at bus stop 4, b)Transversal and Edge Cracking at bus stop 6

(c)



(d)

Figure 16: c) Transversal at bus stop 6, d) Longitudinal Cracking at bus stop 6

4.1.3 Leghare Bus-Depot

For Anbesa city bus, the most busy and utilized station in Addis Ababa is the Leghare bus-depot. It is located at the kirkos sub-city. It has a separate entry and exit lane. The Visual survey for this bus-station was carried out. The PCI value was determined and found as 0 and this value suggests that the pavement is failed. The most commonly found pavement distresses were pot holes, shoving, raveling and depression. The entire distresses found in bus-depot were exceeding their maximum limits. The interval of the pavement distresses found were too frequent and well exceeded the standard limits. Figure 17 and Figure 18 shows some of the photographs of taken on Leghare bus-depot.

(a)

(b)

Figure 17: a) Raveling and b) Potholes

(c)

(d)

Figure 18: c) Depression filled with water, d) Potholes

4.1.4 Megenaga Bus-Depot

This bus-depot is located at the Yeka sub-city. The Visual survey for this test bus-station was carried out. The PCI value determined and found as 0 and the value suggests that the pavement is Failed. The most commonly found pavement distresses were pot holes, patching, shoving, raveling and depression. The entire distresses found in bus-depot were exceeding their maximum limits.

The interval of the pavement distresses found were too frequent and well exceeded the standard limits. Figure 19 and Figure 20 shows some of the photographs of taken on Megenaga bus-depot.

(a) (b)

Figure 19: Potholes and Total failure of pavement

(c) (d)

Figure 20: c) Total failure of pavement and d) Raveling

4.2 Dominant Distresses

It was also tried to estimate the distribution of distresses in each test section and the whole test roads using the visual survey data. The distribution of major distresses in all test roads is as shown Figure 21. Details about intensity of individual distress densities on each test section can be referred in Appendix A.

Accordingly it is observed that 7 types of distresses contribute more than 92.17 % of the pavement defects in the all bus stop and station areas. They are shown in table below:-

Table 5: Dominant Distresses

Distress Type	Percentage of Distress, %
Rutting	4.58
Fatigue cracking	7.24
Longitudinal cracking	9.75
Patch/patch Deterioration	12.42
Potholes	18.36
Shoving	16.90
Raveling	22.93
Total	**92.17 %**

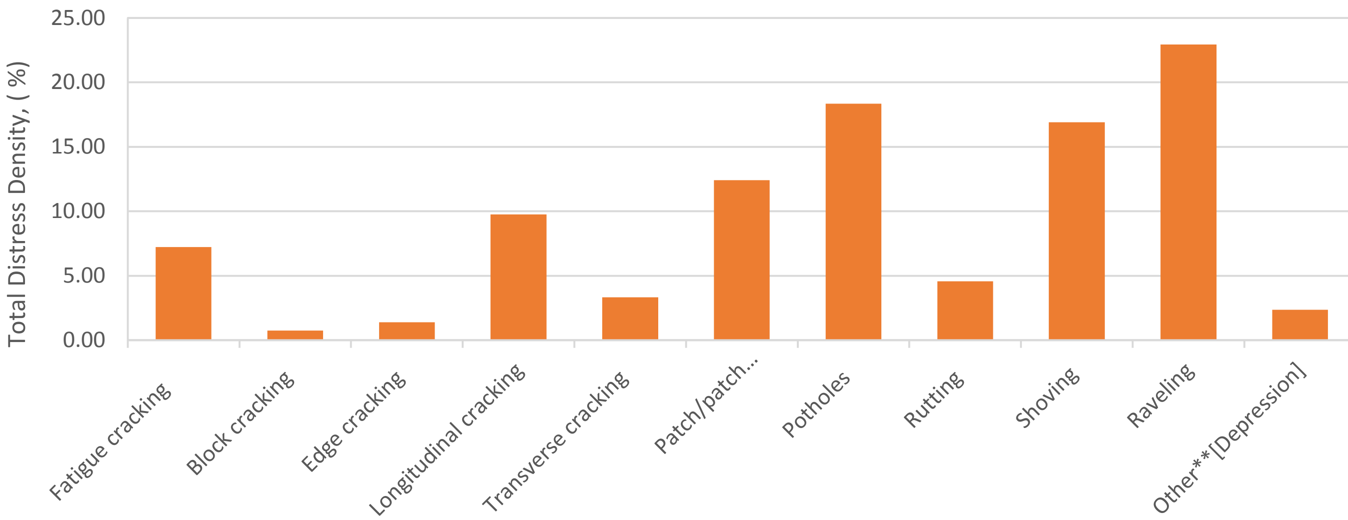


Figure 21: Pavement Distress Distributions in the total study area

4.3 Classification of Distresses by possible Causes

For every distress encountered there is a possible cause that relate to the specified distress. The major causes of distresses can be grouped in to three main categories. The first is due to traffic loading that includes excessive loads and high tire pressure. Second climate and environmental conditions may cause surface irregularities and structural weaknesses on the pavement. A third causes may be disintegration of the paving materials due to method of construction and quality of construction material. For Distresses whose extent and severity already measured during the visual survey can be classified in to this major groups. And this classification shown in the table below for each test section.

Table 6: Classification of distresses by possible causes for AratKilo – Sheromeda route

Distress No.	Distress Type	Total Distress Density	%age Distress	Probable cause for Study area
1	Fatigue cracking	31.55	17.55	Load
2	Block cracking	3.27	1.82	Enviroment
3	Edge cracking	1.53	0.85	Load
4	Longitudinal cracking	5.11	2.84	Enviroment
7	Patch/patch Deterioration	14.73	8.20	Material and Construction
8	Potholes	11.69	6.51	Load
9	Rutting	25.00	13.91	Load
10	Shoving	62.89	34.98	Load
13	Raveling	20.83	11.59	Load
16	Other**[Depression]	3.17	1.76	Material and Construction
Total		179.77	100.00	

Table 7: Total Percentage of Distress by Probable Cause for AratKilo – Sheromeda route

Total %age of Distress by Probable Cause		
Load	Enviroment	Material and Construction
85.39	4.66	9.96

Table 8: Classification of distresses by possible causes for Mexico - Piyasa Route

Distress No.	Distress Type	Total Distress Density	%age Distress	Probable cause for Study area
1	Fatigue cracking	7.97	3.47	Load
2	Block cracking	0.87	0.38	Enviroment
3	Edge cracking	6.06	2.64	Load
4	Longitudinal cracking	48.12	20.97	Enviroment
6	Transverse cracking	18.19	7.93	Enviroment
7	Patch/patch Deterioration	35.55	15.49	Material and Construction
8	Potholes	74.18	32.33	Load
10	Shoving	25.93	11.30	Load
13	Raveling	3.89	1.69	Load
16	Other**[Depression]	8.70	3.79	Material and Construction
Total		229.45	100.00	

Table 9: Total Percentage of Distress by Probable Cause for Mexico – Piyasa route

Total %age of Distress by Probable Cause		
Load	Enviroment	Material and Construction
51.44	29.28	19.29

Table 10: Classification of distresses by possible causes for Leghare Bus-Depot

Distress No.	Distress Type	Total Distress Density	%age Distress	Probable cause for Study area
8	Potholes	6.67	7.44	Load
10	Shoving	0.62	0.69	Load
13	Raveling	81.73	91.14	Load
16	Other**[Depression]	0.66	0.74	Material and Construction
Total		89.68	100.00	

Table 11: Total Percentage of Distress by Probable Cause for Leghare Bus-Depot

Total %age of Distress by Probable Cause		
Load	Enviroment	Material and Construction
99.27	0.00	0.74

Table 12: Classification of distresses by possible causes for Megenaga Bus-Depot

Distress No.	Distress Type	Total Distress Density	%age Distress	Probable cause for Study area
7	Patch/patch Deterioration	17.51	37.1	Material and Construction
8	Potholes	7.69	16.3	Load
10	Shoving	2.86	6.1	Load
13	Raveling	18.73	39.7	Load
16	Other**[Depression]	0.34	0.7	Material and Construction
Total		47.14	100.0	

Table 13: Total Percentage of Distress by Probable Cause for Megenaga Bus-Depot

Total %age of Distress by Probable Cause		
Load	Enviroment	Material and Construction
62.12	0.00	37.87

4.4 Traffic Analysis

4.4.1 Annual Average Daily Traffic, AADT

The AADT of the design section was determined based on the traffic count data above. The day and night counted traffic data were converted to Average Daily Traffic, ADT. The adjustment method for the estimation of 24 hour traffic volume adopted from Road note 40 manual using the formula below. The ADT is then multiplied by the seasonal adjustment to get Annual Average

Daily Traffic, AADT. The seasonal adjustment factor for Addis Ababa city is taken as 1.

$$Estimated\ fullday\ count = \frac{partial\ day\ count\ (6am\ to\ 6pm) the\ adjusted\ day * full\ 24hr\ count}{count\ from\ 6am\ to\ 6pm\ in\ the\ 24hr\ survey} \ldots\ldots \text{(Eqn. 6)}$$

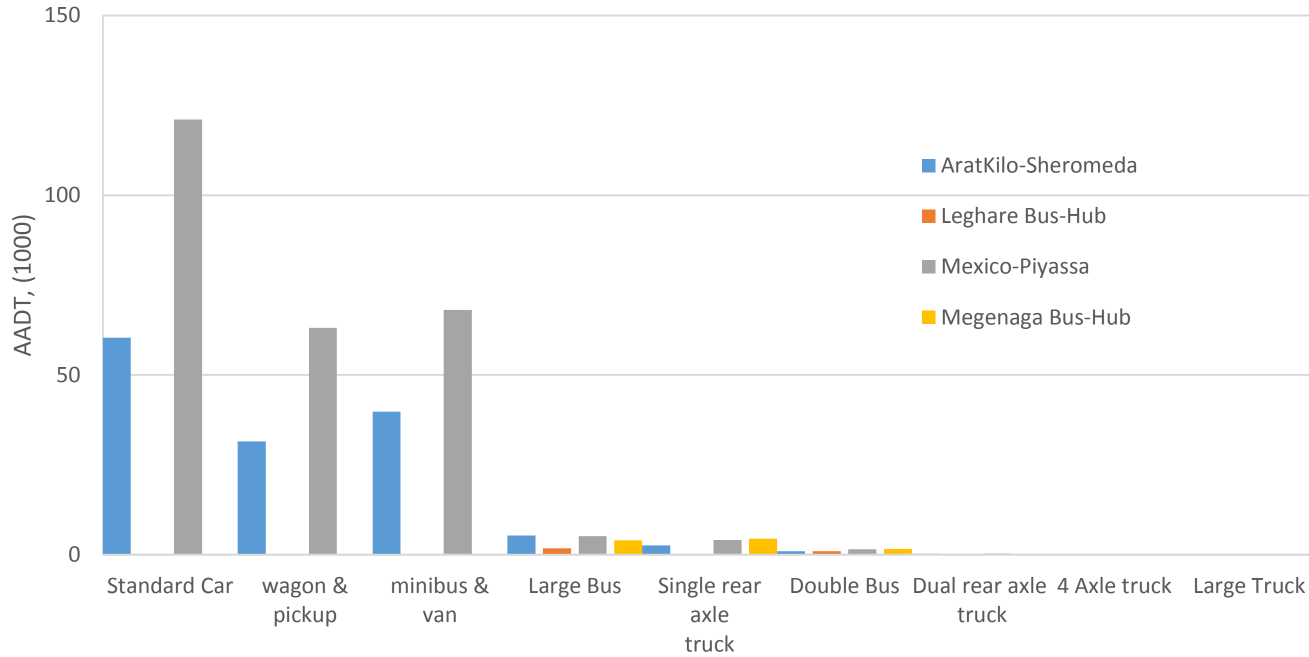


Figure 22: Annual Average Daily Traffic, AADT in Vehicle category for all study sections

4.4.2 Design Period

According to ERA 2013 pavement design manual, determining an appropriate design period is the first step towards pavement design. Many factors may influence this decision, including budget constraints. However, the designer should follow certain guidelines in choosing an appropriate design period, taking into account the conditions governing the project. Some of the points the manual suggests to consider include: Functional importance of the road, traffic volume, location and terrain of the project, financial constraints and difficulty in forecasting traffic

Further the manual says, usually it is economical to construct roads with longer design periods for important roads and for roads with high traffic volume. AACRA pavement design manual suggests a design periods for pavements in Addis Ababa to be: 20 years for flexible pavement and for rigid pavements 40 years

Bearing in mind the above considerations, the suggestion of the manuals and the current construction technology and manpower of our country, the following design periods are adopted. For flexible pavement 15years and for rigid pavements 30 years.

4.4.3 Traffic Forecasting

4.4.3.1 Traffic Growth Rates

For purposes of this study, the traffic growth rate adopted for traffic forecasting from AACRA.

Table 14: Traffic Growth Rates, AACRA

Traffic Growth									
Period	Cars			Light		Medium		Heavy	Articulated
	Standard Car	Wagon & pickup	minibus & van	Large Bus	Single rear axle truck	Double Bus	Dual rear axle truck	4 Axle truck	Large Truck
2016-2017	8.4	8.4	8.4	7	7.7	8.4	8.4	9.8	9.8
2018-2028	8.4	8.4	8.4	7	7.7	8.4	8.4	9.8	9.8
2029-2039	7.8	7.8	7.8	6.5	7.2	7.8	7.8	9.1	9.1
2040-2050	7.8	7.8	7.8	6.5	7.2	7.8	7.8	9.1	9.1

4.4.3.2 Baseline Traffic

The baseline AADT is computed by converting the current normal 2016 AADT to 2017 assuming that the construction of the road will be completed and opened for traffic by the year 2017, by using the above traffic growth rate.

$$AADT_b = AADT_{2016}\,(1+r)^{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eqn. 7)}$$

Where: $AADT_b$ = Baseline AADT

$AADT_{2016}$ = AADT at the time of traffic count

r = growth rate (fraction)

n = number of years elapsed from the time of counting to the period of opening of the road to traffic, equal to 1[because we construct the bus stop areas only, so one year construction period is assume].

Table 15: Baseline traffic

Year	Car	Light	Medium	Heavy	Articulated	Location
$AADT_{2016}$	105346	7376	1237	11	0	AratKilo – Sheromeda Route
$AADT_{2017}$	114195.0472	7892.128	1340.588	12.2976	0	
$AADT_{2016}$	201833	8405	1806	15	11	Mexico – Piyasa Route
$AADT_{2017}$	218787.4122	8993.096	1958.014	16.6896	11.8584	
$AADT_{2016}$	0	8519	1572	0	0	Megenaga Bus-Depot
$AADT_{2017}$	0	9115.221	1703.625	0	0	
$AADT_{2016}$	0	1780	986	0	0	Leghare Bus-Depot
$AADT_{2017}$	0	1904.6	1068.824	0	0	

4.4.3.3 Traffic Projection

The annual average daily traffic anticipated within the design period i.e. 2017- 2032 for flexible pavement and 2017 – 2047 for rigid pavement is projected by using the following relation (year to year growth rate).

$$AADT_n = AADT_b (1+r)^n \quad \text{……………………. (Eqn. 8)}$$

Where: $AADT_n$ = Projected AADT on the year n

$AADT_b$ = Baseline AADT

r = growth rate (fraction)

n = period between the base year and the n^{th} year

The Cumulative projected AADT are presented in the Figure 23 and Figure 24 shown in below for each design period and design section.

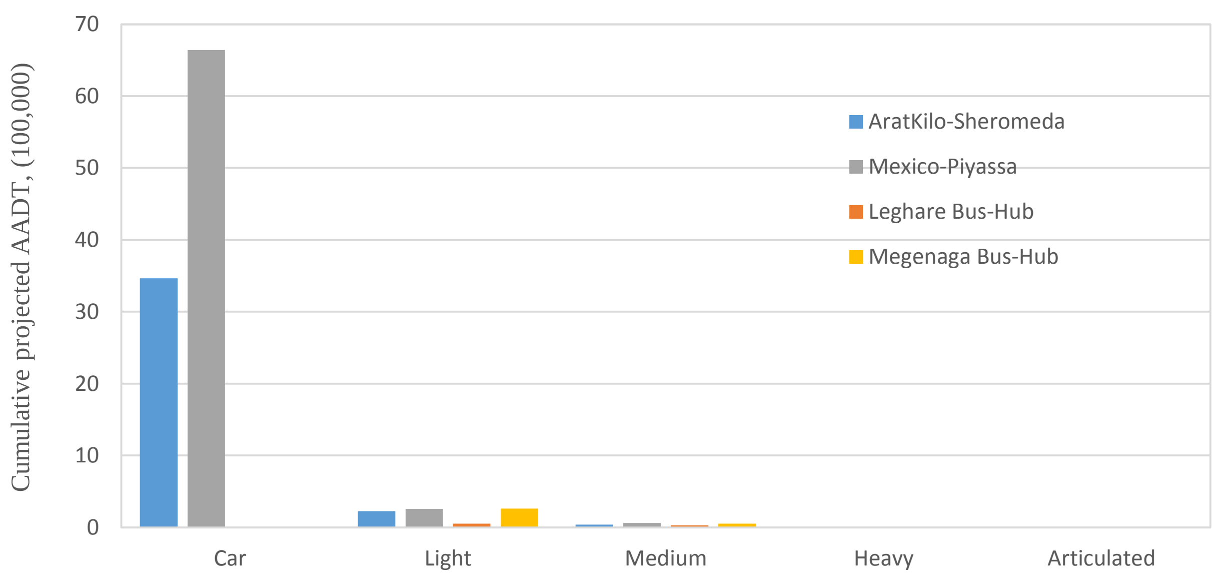


Figure 23: Cumulative projected AADT for 15years design period

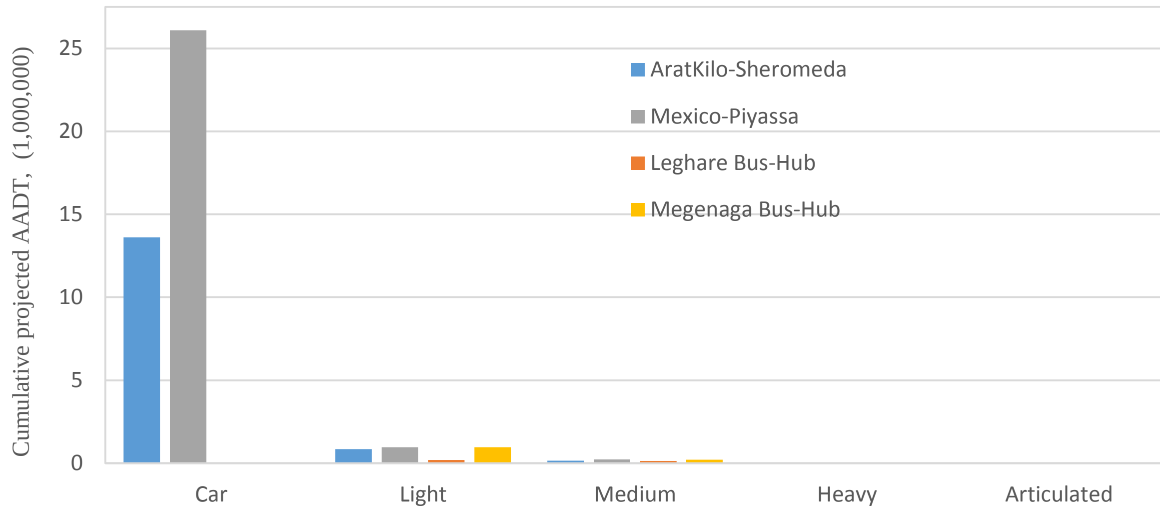


Figure 24: Cumulative projected AADT for 30 years design period

4.4.3.4 Axle Loads

The damage that vehicles do to a paved road is highly dependent on the axle loads of the vehicles. For pavement design purposes the damaging power of axles is related to a "standard" axle of 80KN using empirical equivalency factors. Axle loads can be converted and compared using standard factors to determine the damaging power or Equivalency Factor (EF) of different vehicle types, using the formula in Equation 9 below. [13]

$$EF = \left(\frac{L}{8160\ Kg}\right)^n \quad \text{(Eqn. 9)}$$

Axle load surveys must be carried out to determine the axle load distribution of a sample of the vehicles that use the road. Data collected from these surveys are used to calculate the mean Equivalency Factor (EF) for a vehicle in each class. These values are then used in conjunction with traffic forecasts to determine the predicted cumulative equivalent standard axles that the road will carry over its design life. For this research paper Axle load surveys didn't take place but it's taken from AACRA and given in the table below.

Table 16: Equivalency Factor (EF) for each class of vehicle

Car	Light	Medium	Heavy	Articulated
0	0.680225	0.31535	3.175325	5.73025

4.4.3.5 Design Traffic, Cumulative Equivalent Standard Axles (CESA)

With the above EF and the forecasted year-by-year AADT data, the cumulative number of equivalent standard axles expected over the design life of the pavement on the design lane was computed using the following formula.

$$\mathrm{CESA} = 365 * \mathrm{D} * \mathrm{L} * \sum_{n=0}^{n}(\mathrm{AADTi}) * \mathrm{EF} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eqn. 10)}$$

Where: CESA = Cumulative Equivalent Standard Axles

$AADT_i$= Annual average daily traffic on the i^{th} year

EF = Equivalence Factor

D = Directional Distribution Factor

L = Lane Distribution Factor

The directional distribution factor 0.5 and lane distribution factor 0.8 were taken for all vehicle category except bus, for the bus lane distribution factor 1 was used for AratKilo-Sheromeda, Mexico-Piyassa and Megenaga bus-depot referring to the actual condition and AASHTO manual suggestion, but for Leghare-bus-depot both the directional distribution factor and lane distribution factor were taken 1. The Cumulative Equivalent Standard Axles (CESA) in the design lane are presented in the Figure 25 and Figure 26 below.

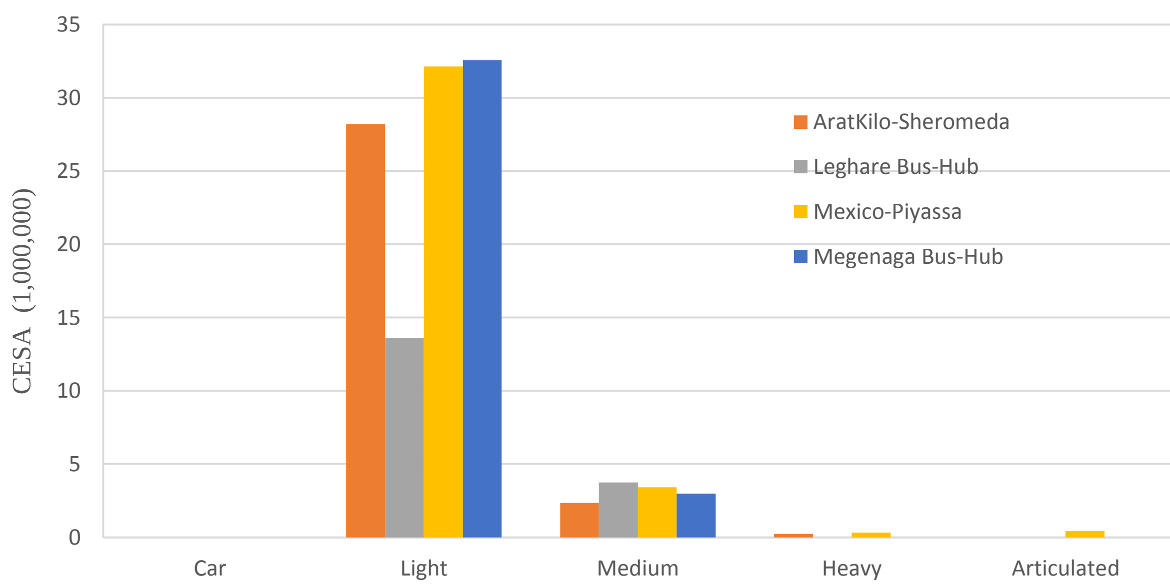


Figure 25: CESA in 10^6 of each Vehicle Category for 15years design period

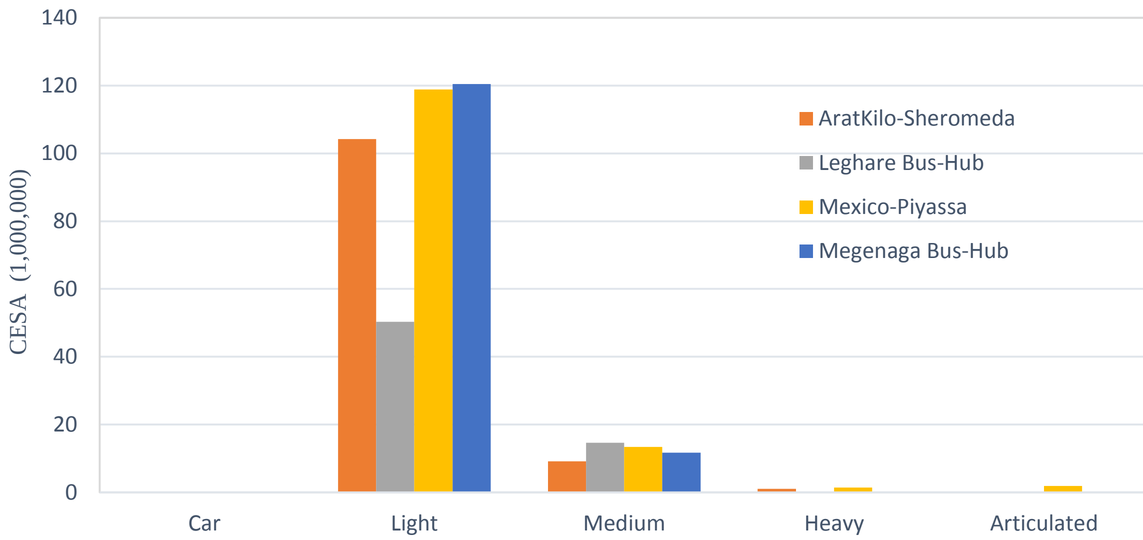


Figure 26: CESA in 10^6 of each Vehicle Category for 30years design period

4.4.3.6 Traffic Classes for Flexible Pavement Design

Accurate estimates of cumulative traffic are difficult to achieve due to errors in the surveys and uncertainties with regard to traffic growth, axle loads and axle equivalencies. As long as the estimate of cumulative equivalent standard axles is close to the center of one of the ranges, any errors are unlikely to affect the choice of pavement design. However, if estimates of cumulative traffic are close to the boundaries of the traffic ranges in Table 16, then the basic traffic data and forecasts should be re-evaluated and sensitivity analyses carried out to ensure that the choice of traffic class is appropriate. Depending on the degree of accuracy achieved, if in doubt, selecting the next higher traffic class may be appropriate [13]. Based on the above analysis, the road under study belongs to the traffic class T9 except for Leghare bus-depot, T8 for flexible pavement design.

Table 17: Traffic Classes for Flexible Pavement Design, ERA 2013 flexible design manual

Traffic Classes	Range of ESAs(millions)
LV1	<0.01
LV2	0.01 - 0.1
T1/LV3	0.1 - 0.3
T2/LV4	0.3 - 0.5
T3/LV5	0.5 - 0.7
T3	0.7 - 1.5
T4	1.5 - 3.0
T5	3.0 - 6.0

T6	6.0 - 10
T7	10 - 17
T8	17 - 30
T9	30 - 50
T10	50 -80
T11	> 80

*T10 is suitable for traffic up to 80 mesas. At this level the pavement is expected to be ‘long-life’ and suitable for higher traffic levels.

4.5 Design Subgrade Strength

The aim of the pavement design process is to protect the bearing capacity of the in situ subgrade material in order that the road pavement will be able to fulfill its service objective over the design period. The bearing capacity and quality of the subgrade is of prime importance in the selection of pavement type and its performance, in addition to the volume of traffic. The strength of the subgrade for design of pavements is commonly assessed in terms of the California Bearing Ratio (CBR). The design CBR value of 5% is taken for this research comparison purpose so as to include the worst scenario of subgrade values for the selected routes as one set of comparison and 15% and 31% CBR value is also taken for the second set of comparison to evaluate the effect of subgrade strength variations on the two competing pavement alternatives. Table 8 above shows sub-base and capping layer thickness requirements under cement concrete pavements in response to sub grade strength variations.

4.6 Pavement Design

The principal objective of structural design of pavement is provide a road surface, which can resist the expected traffic loading over a specified period of time without deteriorating below a predetermined level of service. This objective is achieved by designing a pavement layer with adequate thickness so that stresses on the sub grade that are induced by traffic are reduced to an acceptable level. The thickness of pavement layers will be determined for each type of roads using ERA 2013 Pavement Design manuals.

4.6.1 Flexible Pavement Design

The design of flexible pavements ERA 2013 manual volume-I is based on the catalogue of pavement structures published in TRL’s Overseas Road Note 31 but updated, improved and extended to higher traffic levels based on the latest research. The Catalogue comprises seven charts for seven different basic structural types of pavement corresponding to distinct combinations of surfacing and road-base materials. Each cell of each chart identifies the required thickness of the pavement layers and the materials for their construction based on cumulative traffic and the strength of the subgrade. [13]

Based on the design traffic volume carried above in Cumulative Equivalent Standard Axles, and the strength of the subgrade, the design of flexible pavement options according to ERA 2013 are done for each road section and summarized in Figure 27 and Figure 29 below.

a) For the three sections (i.e. Aratkilo – Sheromeda, Mexico – Pyassa and Megenaga bus-depot) the traffic classes, T9, are the same, so the pavement design thickness would be the same and shown below.

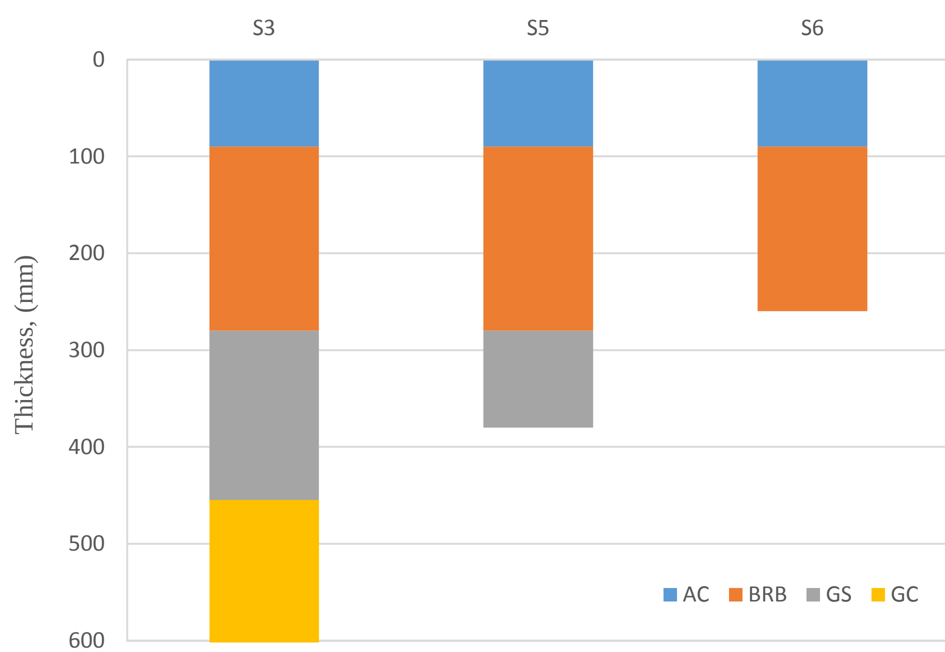


Figure 27 : Design pavement structure for Aratkilo-Sheromeda, Mexico-Pyassa and Megenaga Bus-Depot

b) For Leghare bus-depot, for the traffic class T8, there are two alternative for each subgrade class in ERA 2013 pavement design manual structural catalogue, Chart C1 and Chart D1. Each design thickness shown in the Figure 28 below. To select economical pavement structure cost comparison analysis between alternative pavement structures was done.

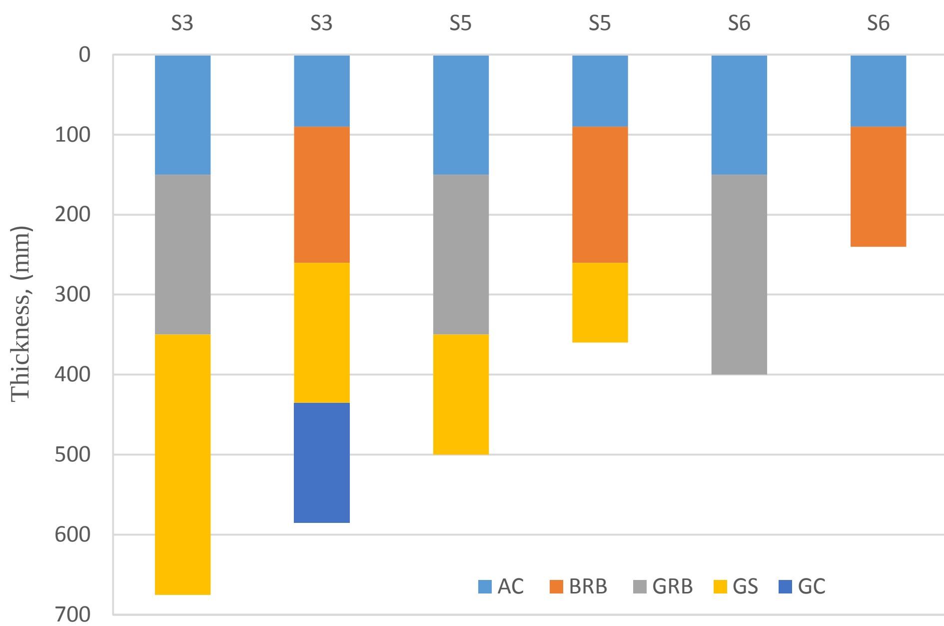


Figure 28:Designed Pavement Alternative Structure for Leghare Bus-Depot for T8

Cost Comparison between Alternative Pavement Structures

Latest unit rates shown in the table below, were utilized for Cost comparison between alternative pavement structures to select economical pavement structure for Leghare bus-depot.

Table 18: unit Price for Construction Materials in 2017

Material	Unit	Unit Rate(ETB/M^3)
WC	M^3	5200
BC	M^3	5300
BRB	M^3	2785.13
GRB	M^3	468
GS	M^3	422.5
GC	M^3	175

The detail Price Comparison of pavement structure is found in Appendix E. It indicated that the pavement structure which selected from Chart C1 was more economical and shown below in the figure for each subgrade layer.

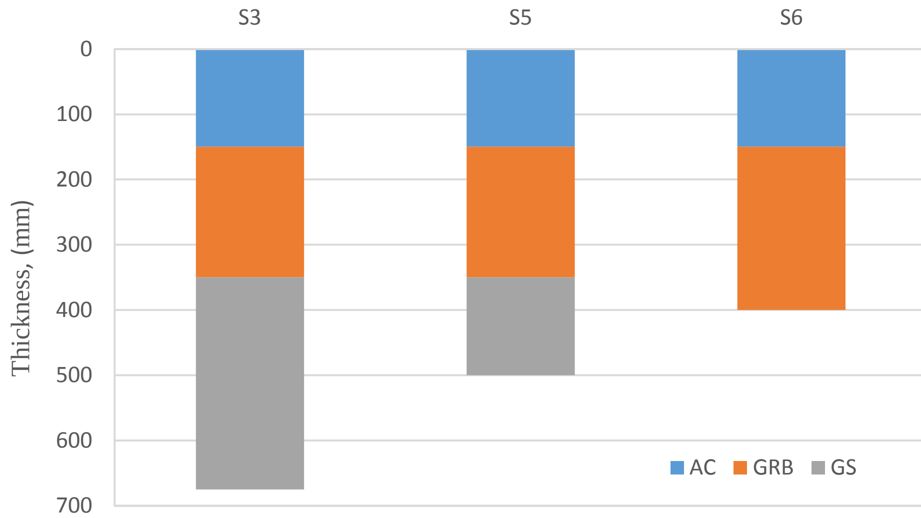


Figure 29 : Designed Pavement Structure for Leghare Bus-Depot

4.6.2 Rigid Pavement Design

The design charts for rigid pavement used from ERA Pavement Design Manual 2013, Volume II based on traffic classes and strength of concrete materials used. The design class of concrete was taken from alternatives suggested in ERA Pavement Design manual 2013, volume II and determined to be C-40 (40 MPa of the 28 days compressive strength).

Based on the design traffic volume calculated and the strength of the concrete, design of pavement was done for both JRCP and CRCP rigid pavement alternatives. The design thickness of JRCP for AratKilo-sheromeda road using traffic load of $114.55*10^6$ CESA and the longitudinal reinforcement of $700mm^2/m$ result in 260mm slab thickness, 150 mm subbase and 250 mm capping layers for subgrade class S3. Additional slab thickness of 25 mm is required for this long life pavement design according to the design manual. The transverse reinforcement consisting of 12 mm diameter steel bars at 600 mm spacing. Dowel bars of 25 mm in diameter, at 300 mm spacing and 400 mm long are required at the transversal joints.

Expansion joint are required at the junctions with other pavement types, dowels bar of 32 mm in diameter, at 300 mm spacing and 600 mm long at the expansion joints. Tie bars of 12 mm diameter at 300 spacing and 1000 mm long are also required at longitudinal joints.

The design of CRCP for the same road section, subgrade class and traffic load results in 218 mm slab thickness, 150 mm subbase and 250 mm capping layers. Longitudinal reinforcement in CRCP pavements should be 0.6% of the concrete slab cross sectional area, and consist of 16 mm diameter deformed steel bars. Transverse reinforcement should be provided at 600 mm spacing and consist of 12 mm diameter deformed steel bars to prevent the opening of any longitudinal cracks which may form. It is also required for ease of construction. At the connection to flexible pavement Dowel bars of 25 mm in diameter, at 300 mm spacing and 600 mm long at the expansion joint. Tie bars of 12 mm diameter at 300 spacing and 1000 mm long are also required at longitudinal joints. The design thickness and reinforcement bar for the other road sections and subgrade classes are summarized in Table 18 – Table 21 below.

In JRCP pavements, a separation membrane (such as a polythene sheet) is required between the sub-base and the concrete slab, mainly to reduce the friction between the slab and the sub-base and thus inhibit the formation of mid-bay cracks. The polythene sheet also reduces the loss of water from the fresh concrete. For CRCP pavements, a bituminous spray should be used on the sub-base instead of polythene because a high degree of restraint is required.

Table 19: Pavement Layer Thicknesses for subgrade class S3

Road Section	Subgrade Class	Traffic in CESA (10^6)	Type	Rigid Pavement Design Thicknesses, D (mm)		
				Slab	Sub-base	Capping
AratKilo - Sheromeda	S3	114.55	JRCP	285	150	250
			CRCP	218	150	250
Leghare Bus-Depot	S3	64.99	JRCP	249	150	250
			CRCP	200	150	250
Mexico - Piyassa	S3	135.62	JRCP	290	150	250
			CRCP	222	150	250
Megenaga Bus-Depot	S3	132.10	JRCP	289	150	250
			CRCP	220	150	250

Table 20: Pavement Layer Thicknesses for subgrade class S5

Road Section	Subgrade Class	Traffic in CESA (10^6)	Type	Rigid Pavement Design Thicknesses, D (mm)	
				Slab	Sub-base
AratKilo - Sheromeda	S5	114.55	JRCP	270	175
			CRCP	218	175
Leghare Bus-Depot	S5	64.99	JRCP	234	175
			CRCP	200	175
Mexico - Piyassa	S5	135.62	JRCP	275	175
			CRCP	222	175
Megenaga Bus-Depot	S5	132.10	JRCP	274	175
			CRCP	220	175

Table 21: Pavement Layer Thicknesses for subgrade class S6

Road Section	Subgrade Class	Traffic in CESA (10^6)	Type	Rigid Pavement Design Thicknesses, D (mm)
				Slab
AratKilo - Sheromeda	S6	114.55	JRCP	270
			CRCP	218
Leghare Bus-Depot	S6	64.99	JRCP	234
			CRCP	200
Mexico - Piyassa	S6	135.62	JRCP	275
			CRCP	222
Megenaga Bus-Depot	S6	132.10	JRCP	274
			CRCP	220

Table 22: Design Reinforcement Bar for JRCP and CRCP

<table>
<tr><td rowspan="2">Type of Pavement</td><td colspan="2">Main Reinforcement Bar</td></tr>
<tr><td>Longitudinal</td><td>Transverse</td></tr>
<tr><td>JRCP</td><td>700mm^2/m</td><td rowspan="2">Ø12mm c/c 600mm</td></tr>
<tr><td>CRCP</td><td>0.6% * slab cross-sectional area</td></tr>
<tr><td colspan="3">Reinforcement Bar for Joint</td></tr>
<tr><td colspan="3">Transverse Joint</td></tr>
<tr><td colspan="2">Contraction Joint</td><td>Expansion Joint</td></tr>
<tr><td colspan="2">D<239mm, Ø20mm, c/c 300mm and 400mm long</td><td>D<239mm, Ø25mm, c/c 300mm and 600mm long</td></tr>
<tr><td colspan="2">D>240mm, Ø25mm, c/c 300mm and 400mm long</td><td>D>240mm, Ø32mm, c/c 300mm and 600mm long</td></tr>
<tr><td colspan="3">Longitudinal Joint</td></tr>
<tr><td colspan="3">Ø12mm, c/c 600mm and 1000mm long</td></tr>
</table>

To select economical rigid pavement structure cost comparison between alternative pavement structures was done.

Cost Comparison between Alternative Pavement Structures

Cost comparison was conducted between JRCP and CRCP to select economical pavement structure. Latest unit rates shown in the following table, were utilized for comparison of the pavement structures.

Table 23: unit Price for Construction Materials in 2017

Material	Unit	Unit Rate(ETB)
Concrete	M^3	3925.5
Sub-Base	M^3	422.5
Capping Layer	M^3	175
Reinforcement Bar	Kg	27

The detail price comparison of rigid pavement structure is found in Appendix E. The cost comparison indicated that the pavement structure from CRCP was more economical. This due to JRCP has higher concrete slab thickness than CRCP. Therefore, the selected pavement structure is shown below in figure for each subgrade layer.

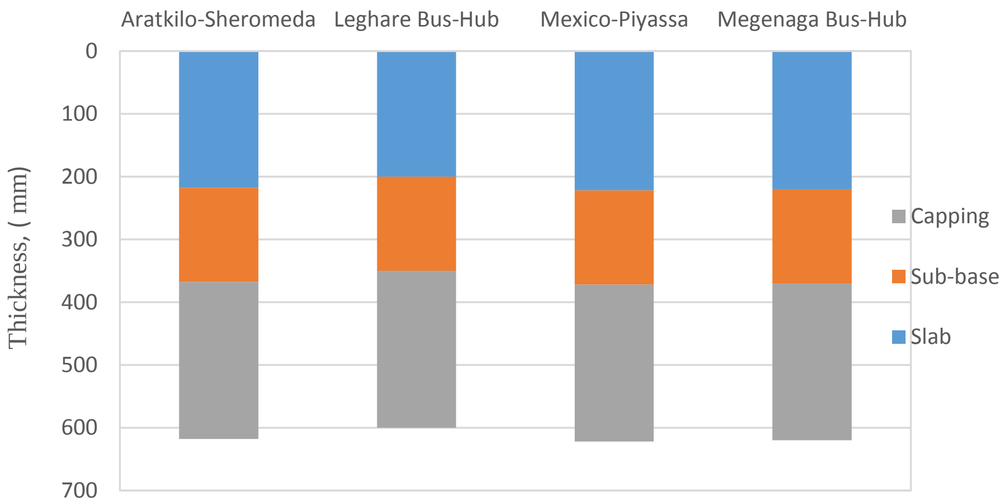


Figure 30: The selected Pavement Layer Thicknesses for subgrade class S3

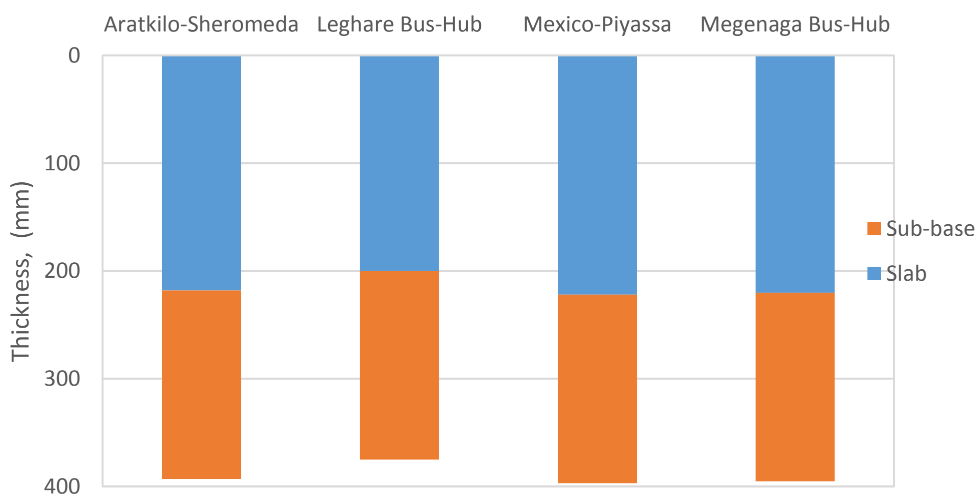


Figure 31: The selected Pavement Layer Thicknesses for subgrade class S5

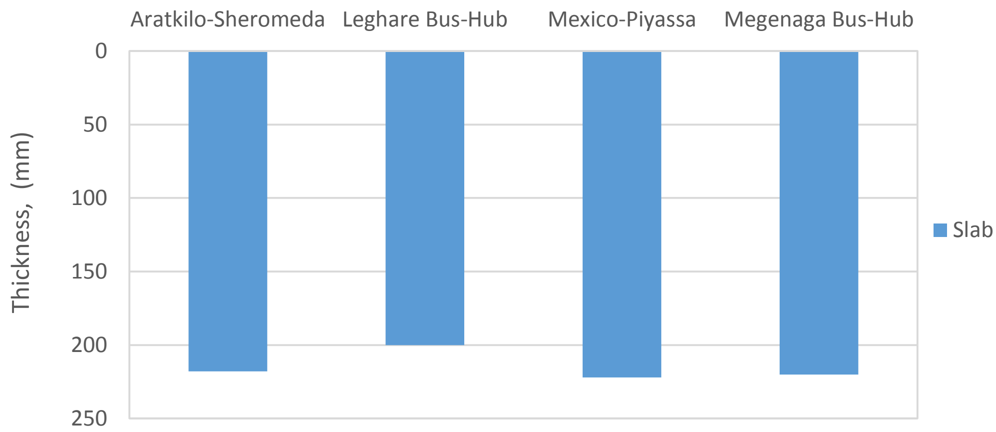


Figure 32: The selected Pavement Layer Thicknesses for subgrade class S6

4.7 Pavement performance Comparison using KENPAVE

KENPAVE is a multilayer analysis computer software package is used to analyze pavement and it's developed by Huang (1993). It consists of two packages, namely, KENLAYER and KENSLABS for flexible and rigid pavement analyses respectively. Kenlayer program is designated to work in an elastic multilayer system under a circular loaded area. Kenlayer could be applied in multilayer systems under single or dual wheel while each layer have a different response like linear elastic, nonlinear elastic or viscoelastic. This application is designed to perform damage analysis too. The KENSLABS computer program is based on the finite-element method, in which the slab is divided into rectangular finite elements with a large number of nodes. Both wheel loads and subgrade reactions are applied to the slab as vertical concentrated forces at the nodes. When the modulus of elasticity of the pavement is much greater than that of the foundation and the load is applied in the interior of pavement far away from edges and corners, both Kenlayer and Kenslab should yield about the same results. Therefore, the results obtained by KENLAYER can be used to check those by KENSLABS. [28] On this research paper, for simplicity purpose Kenlayer analysis only was done.

Using Kenpave we can study the relation between the depth and the stress, strain and deformation relation and also show how the different layer affected by the changing of wheel load, tire pressure, modulus of elasticity and thickness sub base.

In this study the effect of traffic load due to bus (only the rear axle and one dual tire considered) on pavement deflections, stress and strain for different design pavement alternatives was done by kenpave. The responses to be compared include the vertical deflection, the horizontal tensile strain, the vertical stress and the vertical compressive strain. The reason behind only this four responses selected was; the surface deflection is a good indication of the overall strength of a pavement. The tensile strain at the bottom of the asphalt layer and the compressive strain at the top of the subgrade have frequently been used as design criteria. The vertical stresses contribute to the consolidation of each layer and the rutting on the surface.

To work on kenpave software, parameters such as tolerance for integration, maximum limit of integration cycles, number of period per year, number of load group and material property…etc., were defined and input to the kenpave application and analysis was performed. The general material input data and traffic load for all pavement alternatives are tabulated below in Table 23 and Table 24. And also the output (vertical deflection, the horizontal tensile strain, the vertical stress and the vertical compressive strain against changes in vertical coordinate) from the software for all pavement type and study sections shown from Figure 33 - Figure 44 below.

The output curves shows that for AratKilo - Sheromeda route with subgrade strength S3 for flexible pavement, greater than 90% of the vertical stresses dissipates at a depth of 60.5cm below the top of layer but for rigid pavement the same amount of vertical stresses dissipates at a depth of 21.8 cm only. For the same study section and subgrade strength, for vertical deflection curve we can see that the top pavement layer of rigid pavement deflect less than flexible pavement by 38.4%.

And also we can see from all charts that; when we increase the subgrade strength for the same traffic load, the responses i.e. the vertical deflection, the horizontal tensile strain, the vertical stress and the vertical compressive strain reduces. Second: there is no much difference between the Geogrid pavement alternatives with that of none Geogrid pavement alternatives.

Therefore, rigid pavements with or without Geogrid material are more feasible and better resistance to the applied load as compared to that of flexible pavement.

Table 24: Material input data for Kenpave analysis

Material Input Data		
Material Type	E, kpa	v
AC	$3.105*10^6$	0.3-0.4
BRB	$2.415*10^6$	0.3-0.4
GRB	$2.07*10^5$	0.3-0.4

GSB	$1.035*10^5$	0.3-0.4
GC	$8.28*10^4$	0.3-0.4
Subgrade	$5.175 - 10.35*10^4$	0.3-0.45
Geogrid,(Medium)	$1.97*10^6$	0.03-0.04
Concrete	$29.95*10^6$	0.15-0.20

Table 25: Traffic input data for Kenpave analysis

Traffic Input Data	
Input Type	Input Values
Tyre Pressure	750 kpa
Tyre c/c Spacing	34 cm
Contact Radius	12 cm

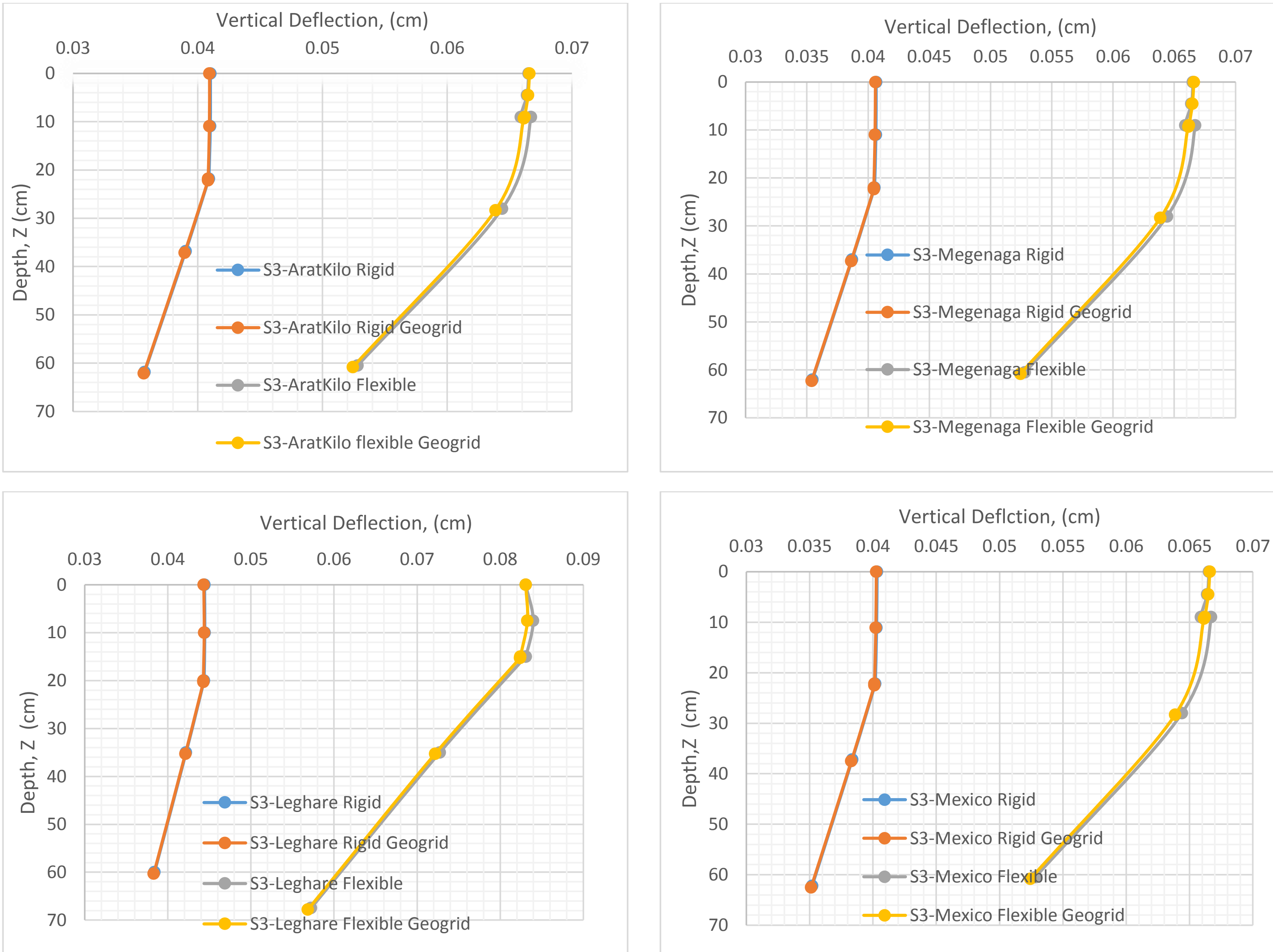


Figure 33: Variation of the vertical displacement against changes in vertical coordinate for S3

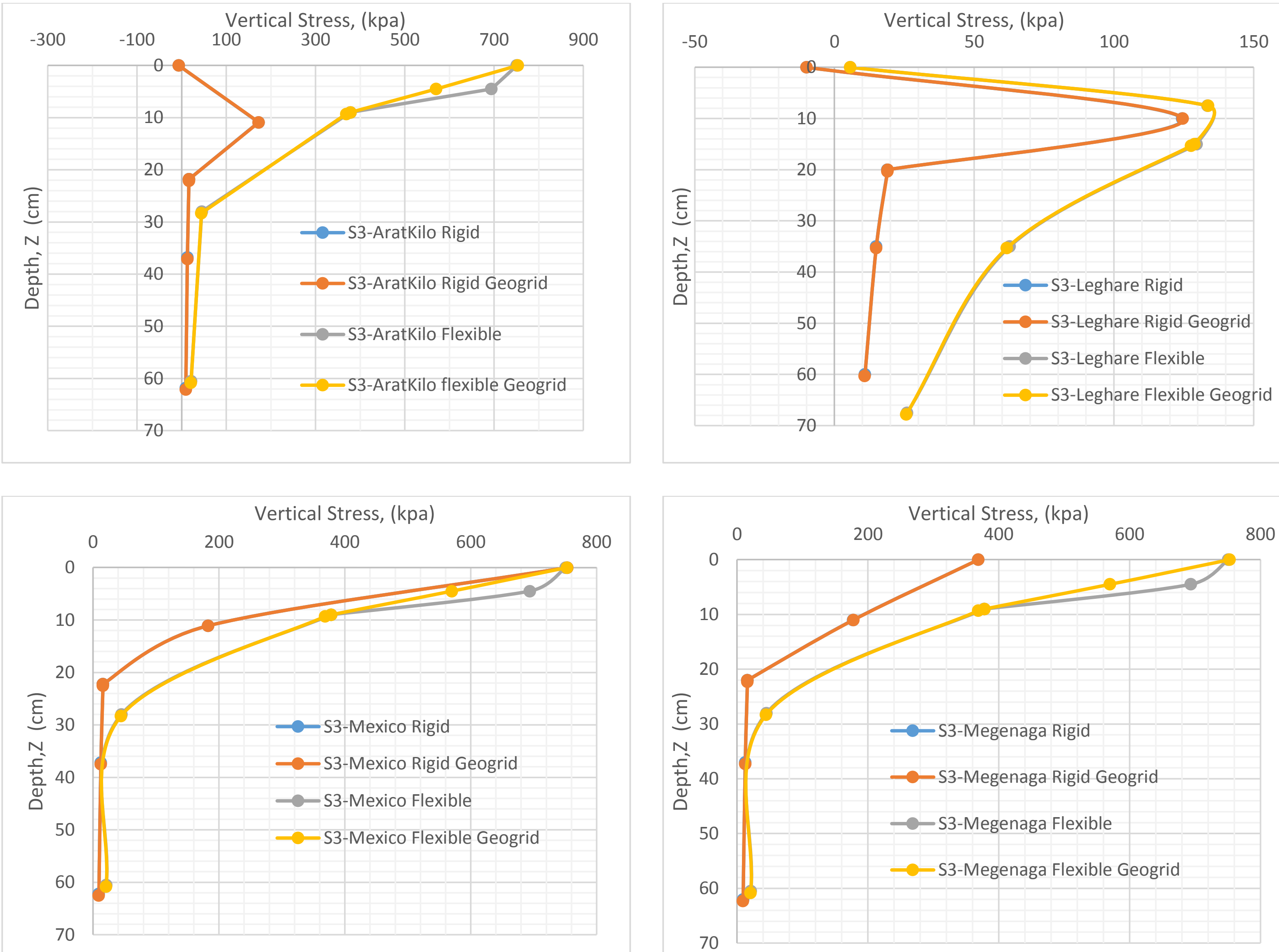


Figure 34: vertical stress against changes in vertical coordinate for S3

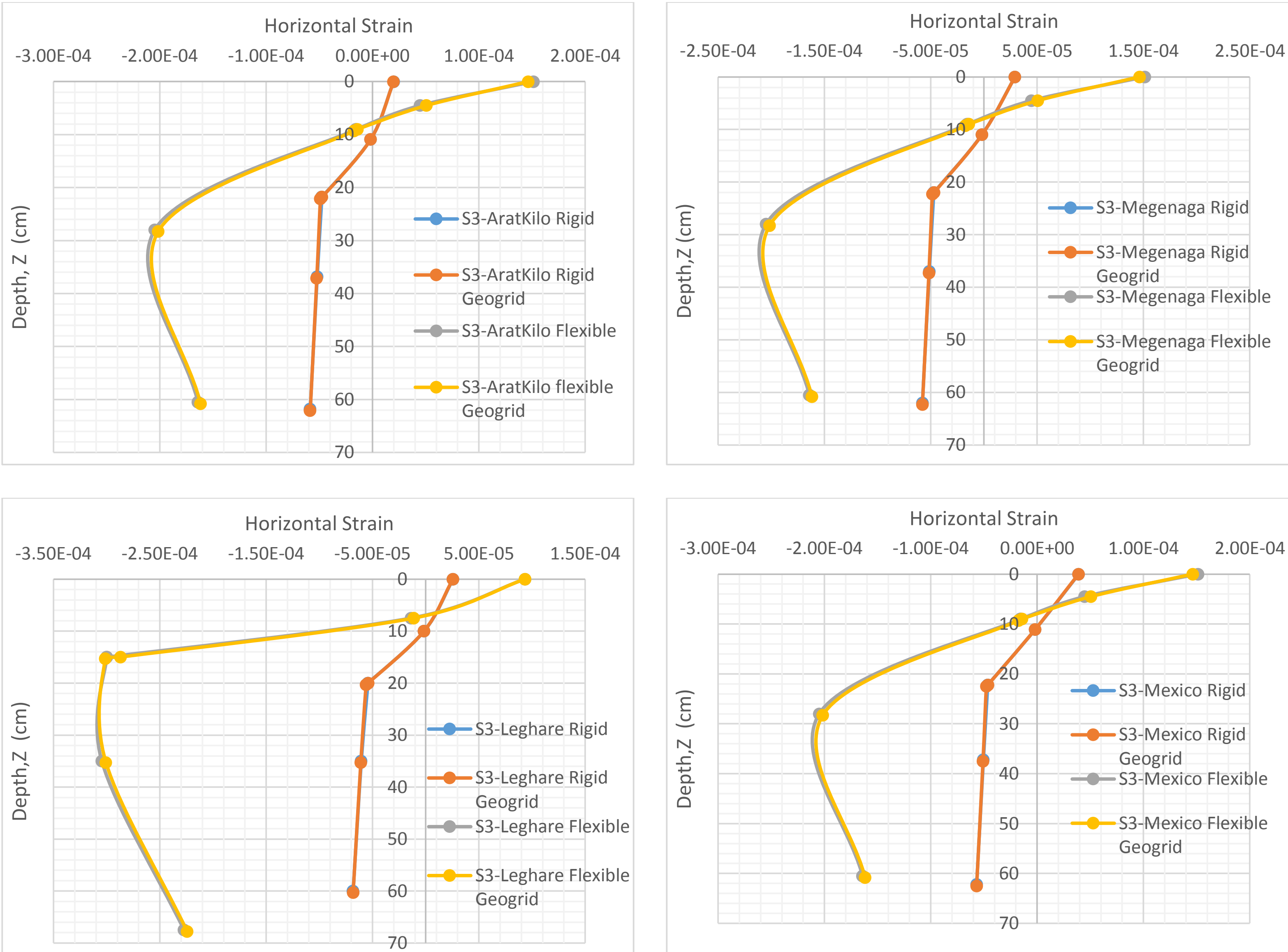


Figure 35: horizontal principal strain against changes in vertical coordinate for S3

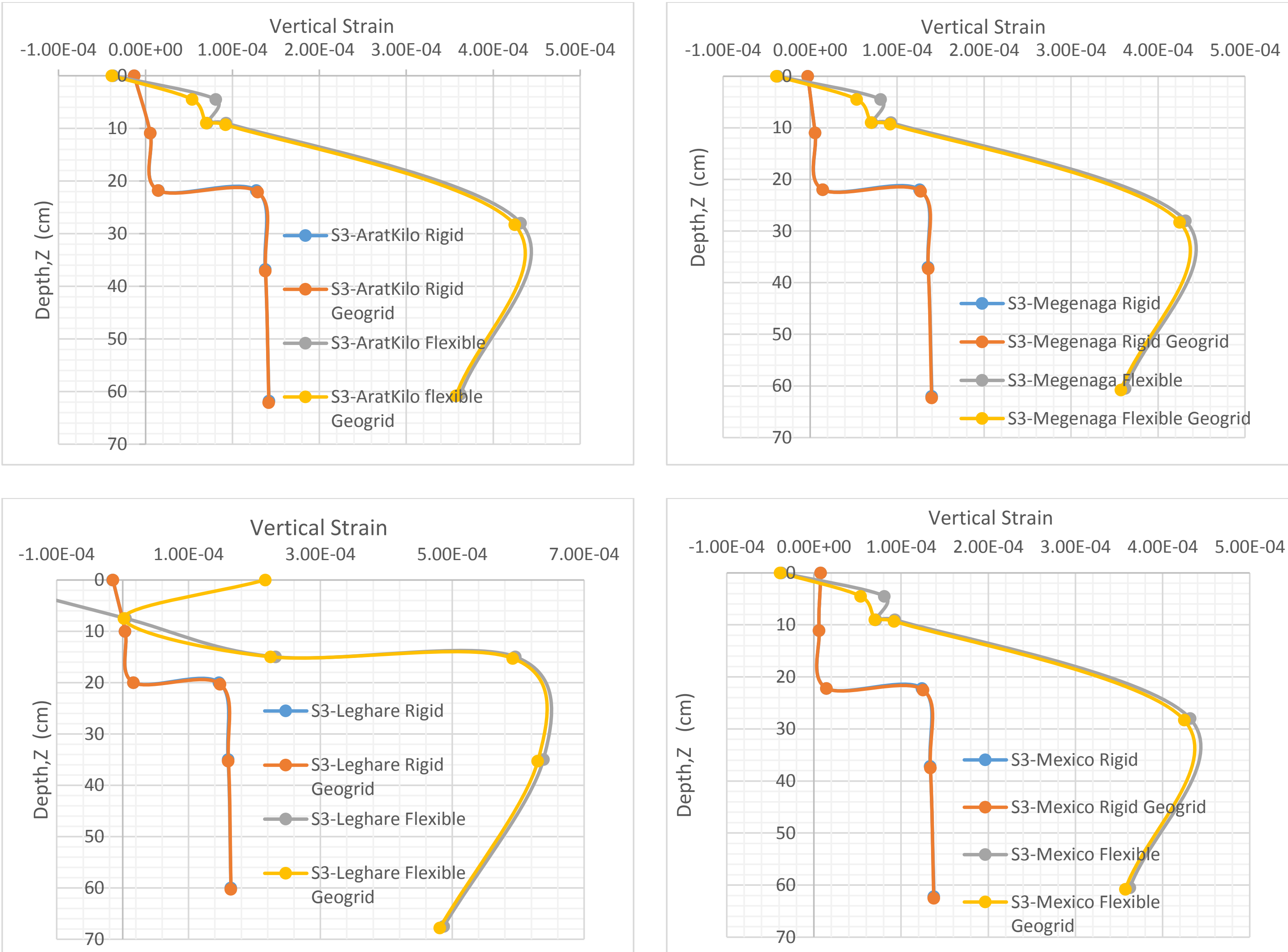


Figure 36: vertical strain against changes in vertical coordinate for S3

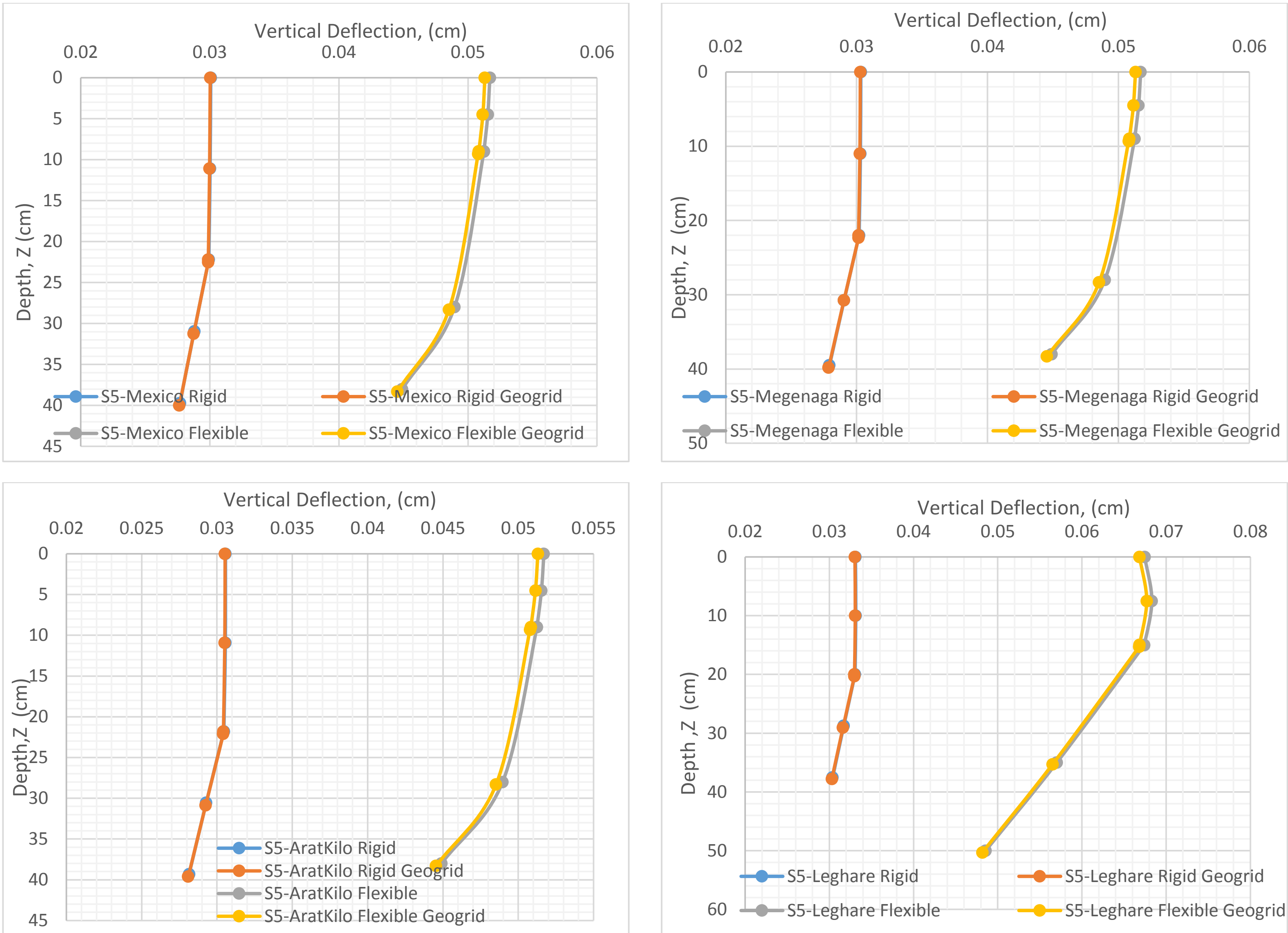


Figure 37: Variation of the vertical displacement against changes in vertical coordinate for S5

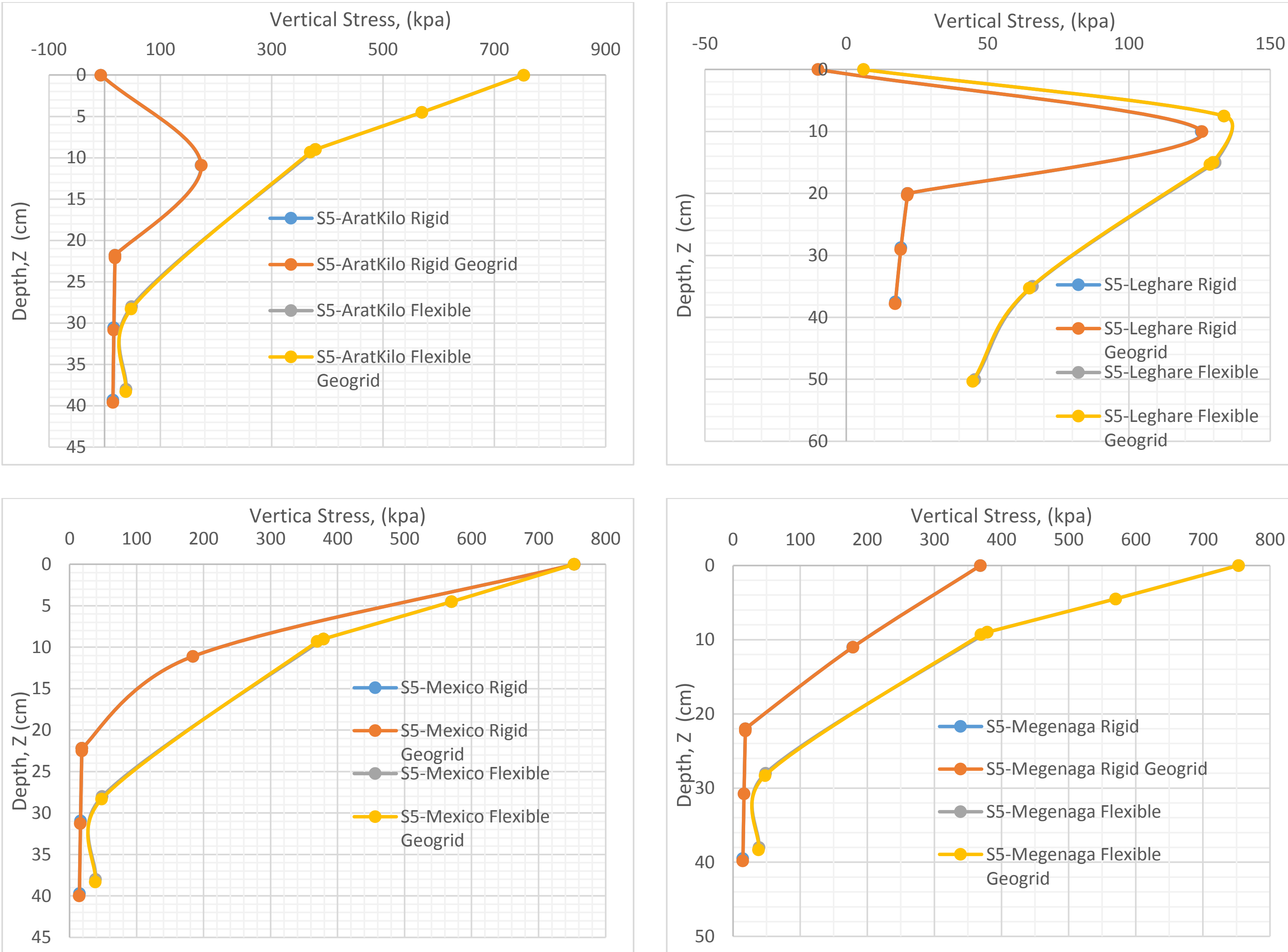


Figure 38: vertical stress against changes in vertical coordinate for S5

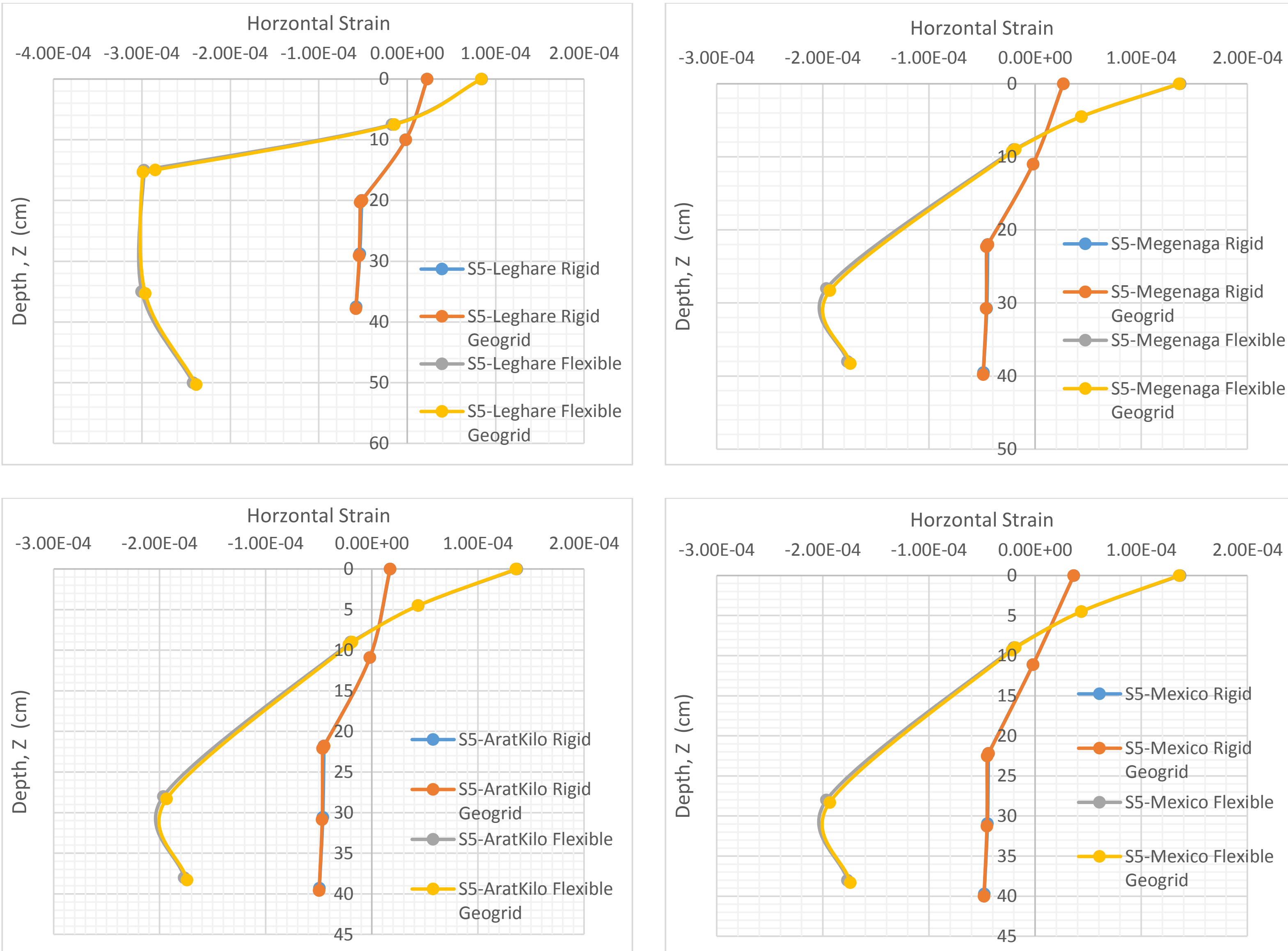


Figure 39: horizontal principal strain against changes in vertical coordinate for S5

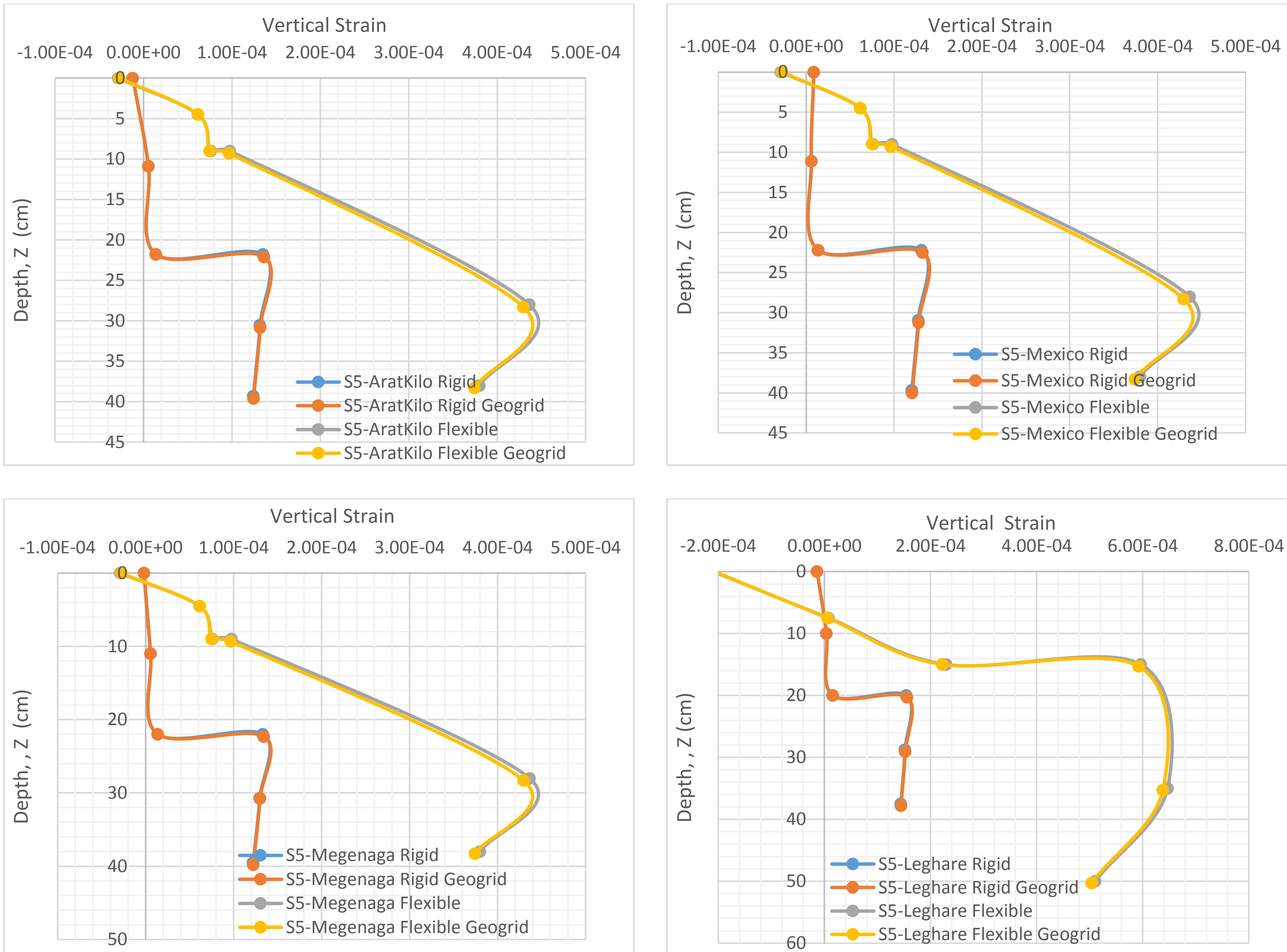


Figure 40: vertical strain against changes in vertical coordinate for S5

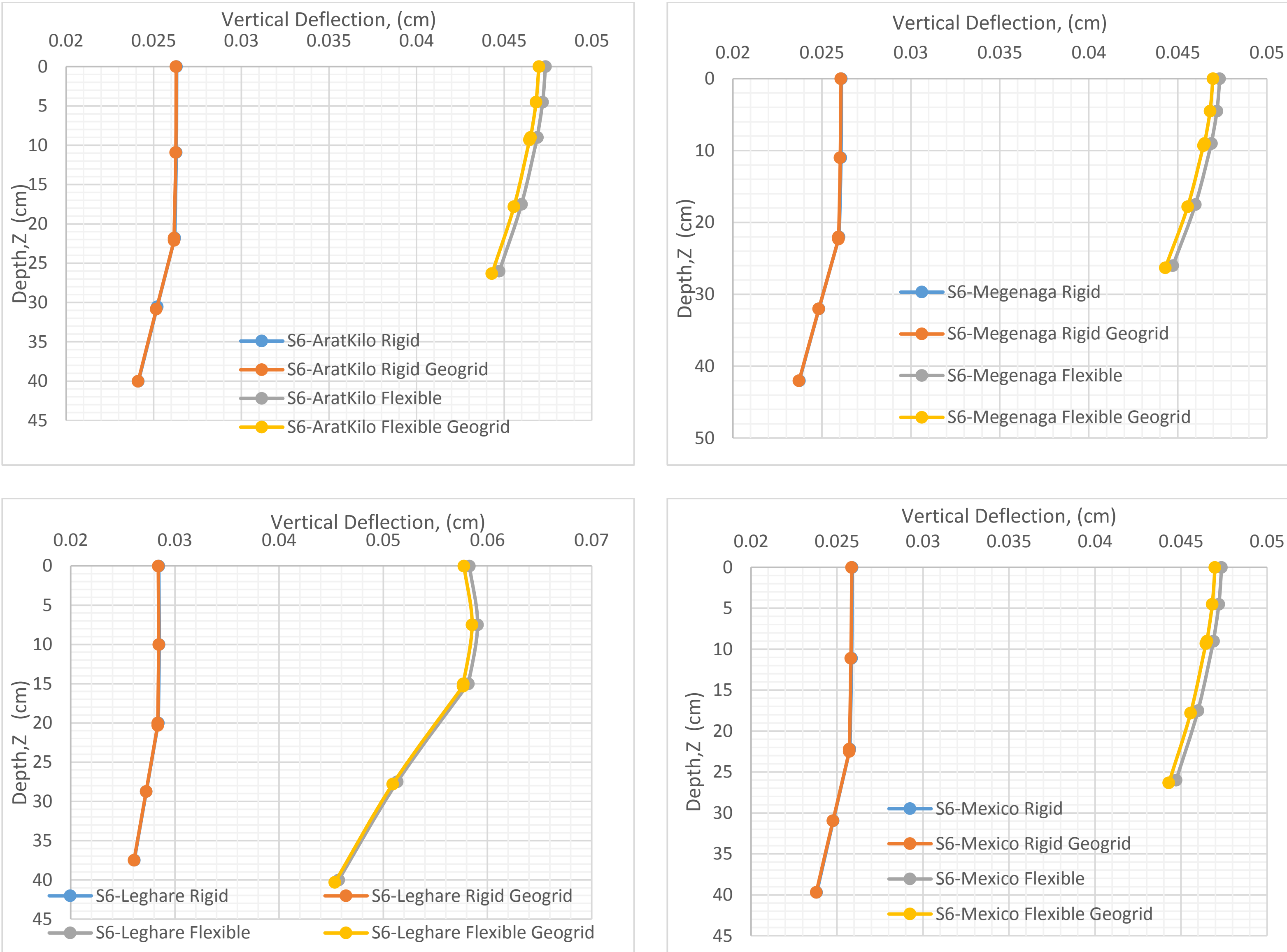


Figure 41: Variation of the vertical displacement against changes in vertical coordinate for S6

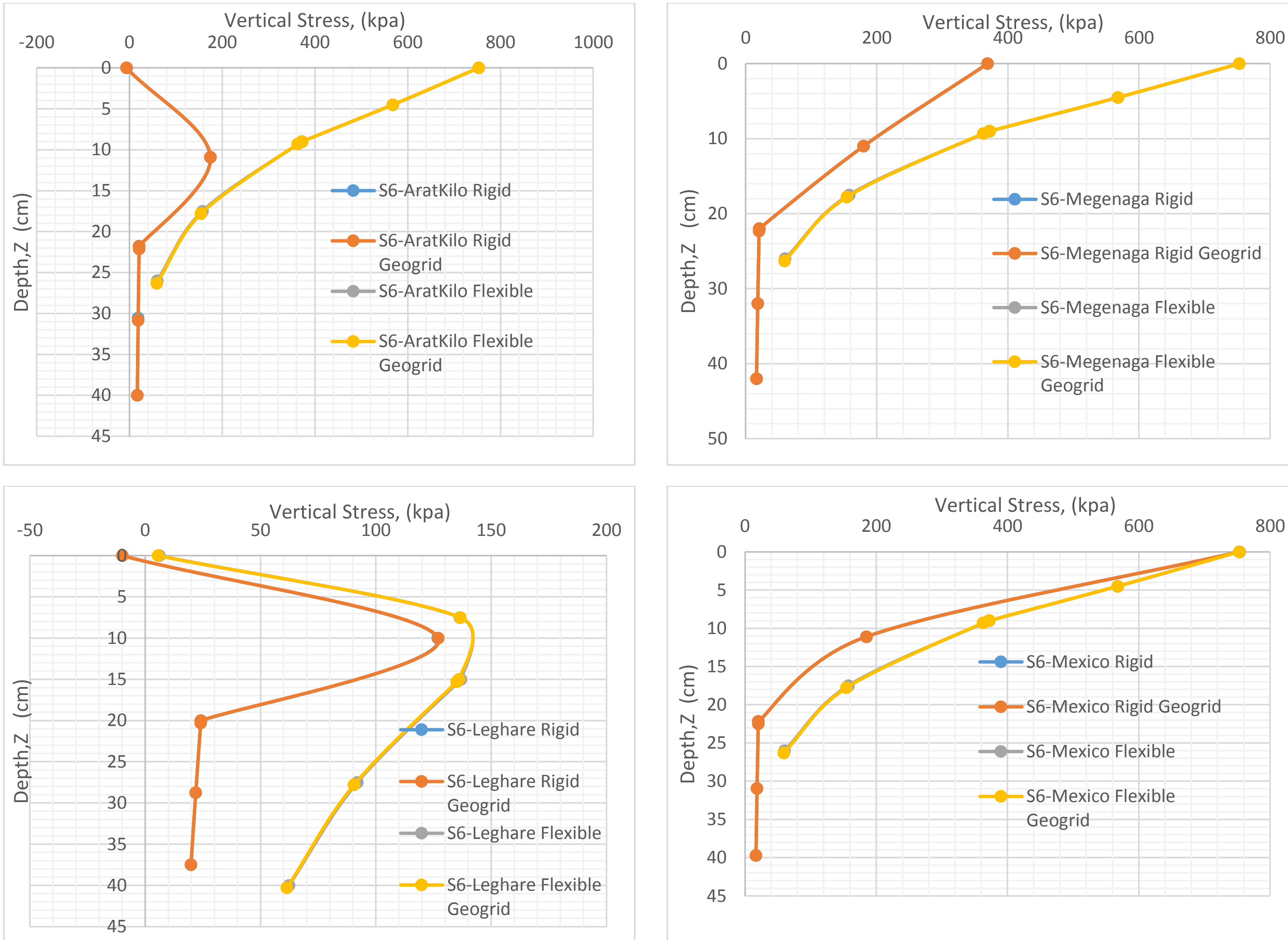


Figure 42: vertical stress against changes in vertical coordinate for S6

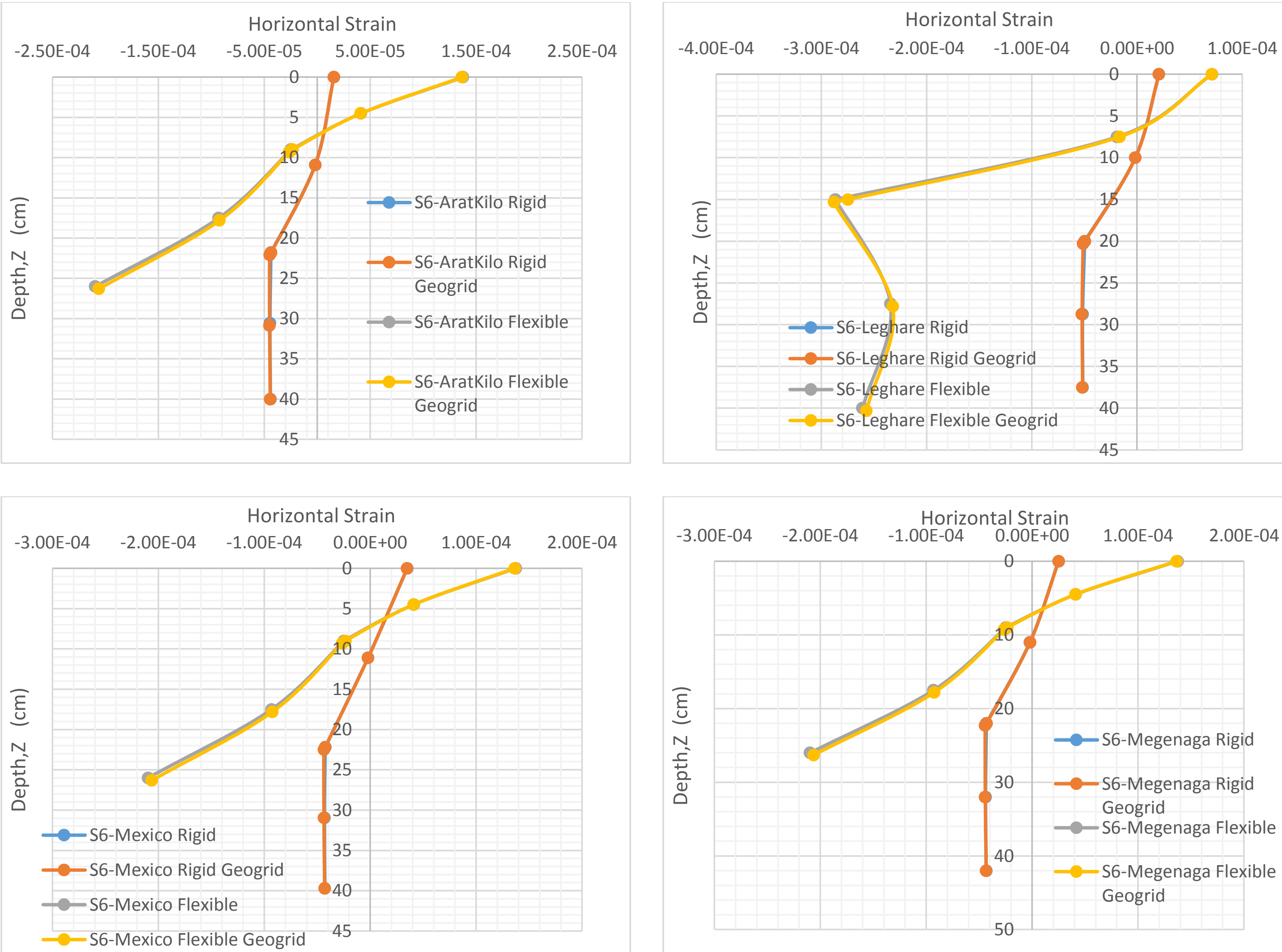


Figure 43: horizontal principal strain against changes in vertical coordinate for S6

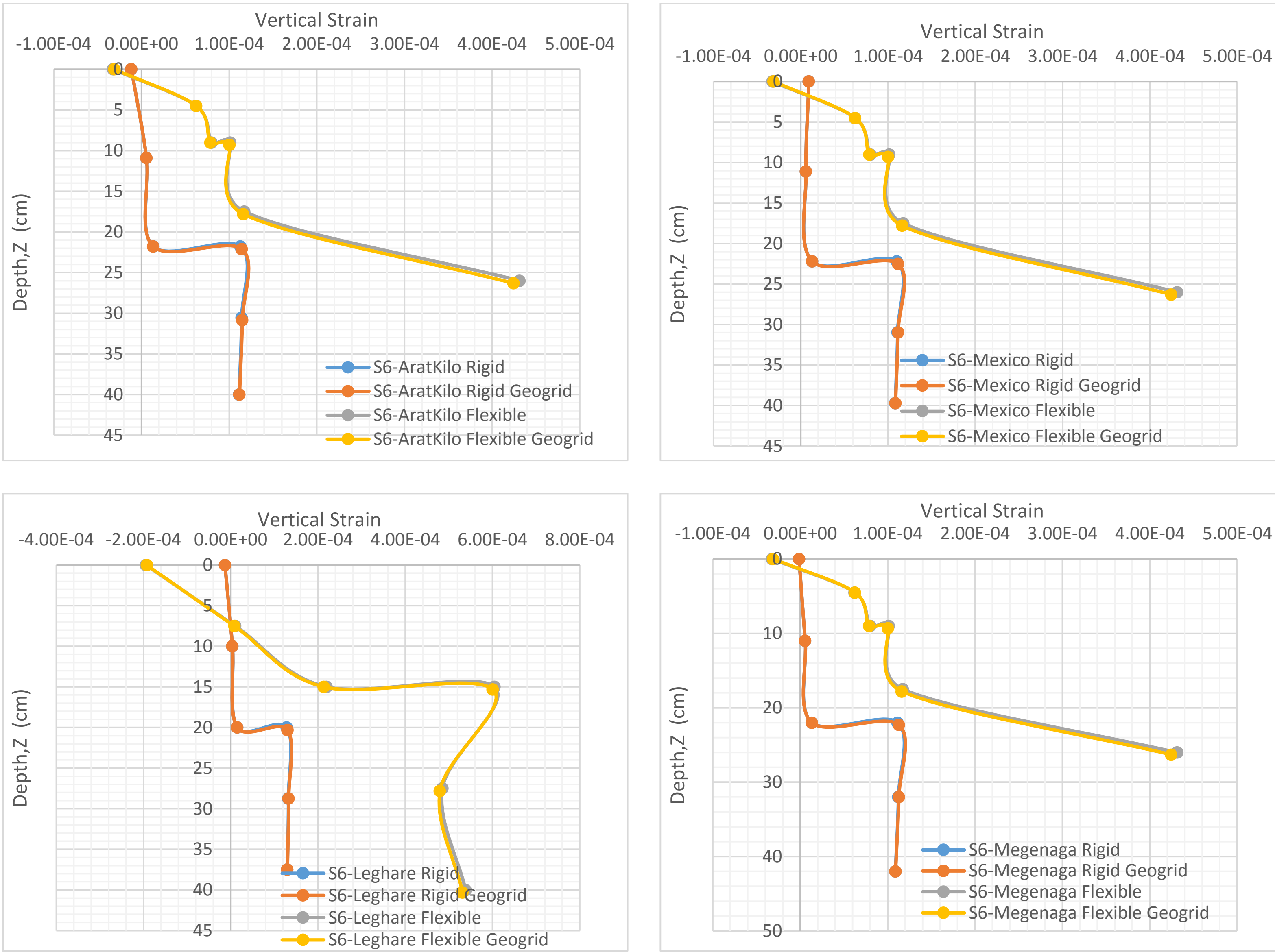


Figure 44: vertical strain against changes in vertical coordinate for S6

4.8 Life Cycle Cost Analysis, LCCA

4.8.1 Analysis Period

The analysis period is the period of time during which the initial and any future costs for the project pavement alternatives will be evaluated. It does not have to be equal to the design or service life and in most cases it is not. The main criterion is that it be long enough to reflect the cost differences between the alternative pavement types. LCCA assumes that the pavement will be properly maintained and rehabilitated to carry the projected traffic over the specified analysis period. Typical values are 30-40 years for highways, 20-30 years for streets, and 30 years for airports. In general, costs that are incurred 25-30 years or beyond play a minimal role in the life cycle cost analysis. [5] For this research paper the length of analysis period 30 years were selected.

4.8.2 Salvage Value

It represents value of an investment alternative at the end of the analysis period. The two fundamental components associated with salvage value are residual value and serviceable life. [14]

Residual Value: refers to the net value from recycling the pavement. The differential residual value between pavement design strategies is generally not very large, and, when discounted over 30 years, tends to have little effect on LCCA results.

Serviceable Life: represents the more significant salvage value component and is the remaining life in a pavement alternative at the end of the analysis period. It is primarily used to account for differences in remaining pavement life between alternative pavement design strategies at the end of the analysis period.

4.8.3 Initial Construction Cost

The initial costs have a major impact on the total cost analysis. The initial costs are determined at year zero of the analysis period. Initial costs may be divided into pavement and non-pavement costs associated with the original development of the project. Pavement costs include subgrade preparation, subbase, base, and surface materials; labor; equipment; drainage, etc. The non-pavement costs are costs that affect the overall cost of the project, but are not necessarily part of the pavement structure. These include extra fill or cut due to different grade elevations between the pavement types, traffic control, median, fill slopes, utilities, guardrail and sign adjustments, lighting requirements, overhead structures and at-grade structures, culvert extensions etc. Unless a non-pavement cost item varies between alternates, it can be disregarded, as it will have no impact on the outcome. [5]

For the analysis, 100m length of bus stop with 3.65 width was used and Initial cost of the pavement determined using unit rates that found from AACRA for flexible pavement and cost break downs are done and unit rates determined for C-40 concrete. The cost break down of C-40 concrete are attached in Appendix D. Initial costs are computed based on the unit rates for the designed pavement alternatives and the detail analysis shown in Appendix E. The computed results are shown from Figure 45 – Figure 47 below for the road sections. As we can see from the figure the initial cost of rigid pavement is higher than that of flexible pavement.

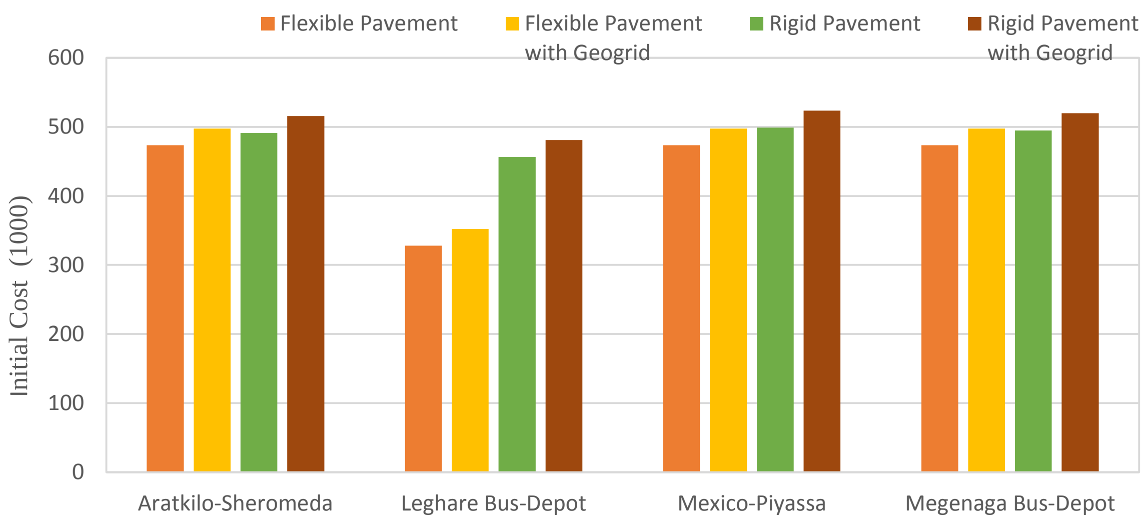


Figure 45: Total initial cost for the road section, S3

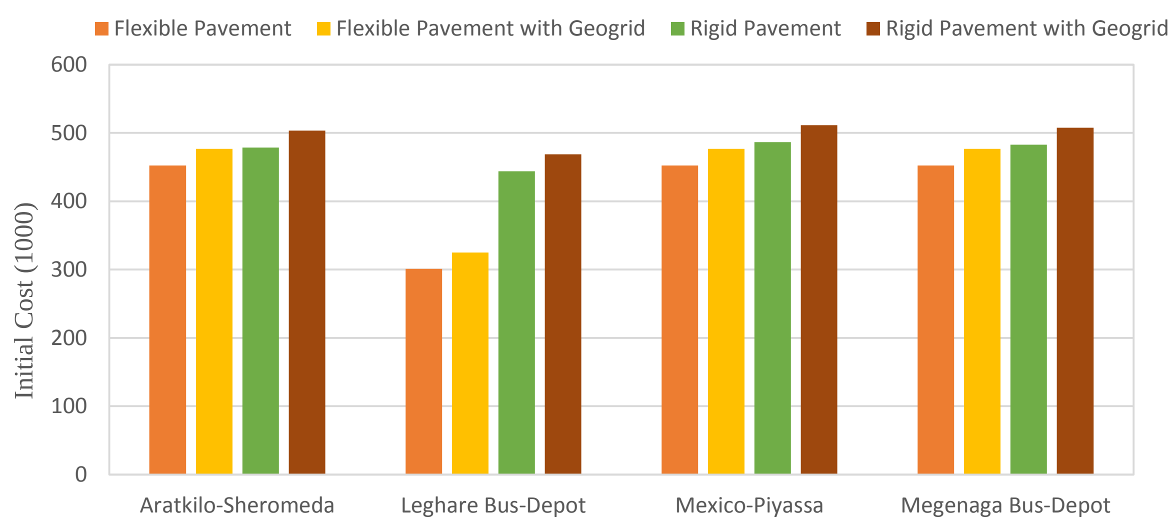


Figure 46: Total initial cost for the road section, S5

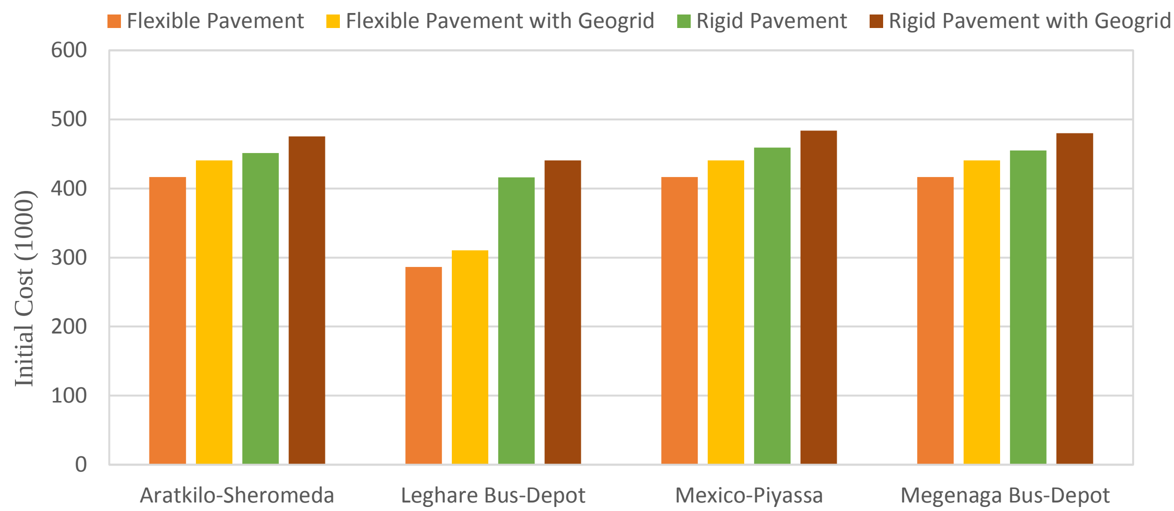


Figure 47: Total initial cost for the road section, S6

4.8.4 Maintenance and Rehabilitation Cost

a) Flexible Pavement

Road maintenance is a fundamental necessity, as important as the original road provision. The maintenance of the roadway asset must, additionally, be planned, designed and carried out in the knowledge that the road is there to provide a high level of service to users who, rightly, expect their needs to be met even when activities are being carried out on the network.

Maintenance costs include costs for routine, preventive, and corrective maintenance, such as joint and crack sealing, Bituminous surface treatment, BST (chip seal, seal coat), patching spall repair, individual slab replacements, thin HMA overlay, etc., whose purpose is to preserve the service life of a pavement.

Maintenance costs are frequently difficult to define because of either a lack of record keeping or accounting that does not appropriately discriminate between different types of maintenance activities. Maintenance costs in a life-cycle cost analysis usually have minimal impact when compared to the initial and rehabilitation costs. If maintenance costs are used within an LCCA procedure, then historical documentation of actual pavement activities and expenditures should be used. But the highway agencies doesn’t have historical documentation of the actual pavement activities and expenditures. So the maintenance period and type found on this research paper depend on the distress found in the study area. The type of maintenance used was preventive maintenance treatments because it is cost effective, preserves the pavement system, retards future deterioration, and maintains or improves the functional condition of the system. The maximum time between preventive maintenance treatments should be based on time, rather than the amount of traffic on a roadway section. Bituminous Surface Treatments (BST), thin overlays, slurry, micro surfacing, crack sealing, and patching are among preventive maintenance. The major maintenance activity are shown in the diagram below for each road sections.

Timing of Rehabilitation Activities for Flexible Pavement

Due to of the effects of discounting, the time at which rehabilitation activities are placed into the analysis must be chosen as realistically as possible. If not chosen carefully, a change of one year in rehabilitation timing, in either direction, for either pavement alternate can alter the LCCA results. This is most important with the early rehabilitation activities since they are discounted less and have a greater impact on LCCA results than later activities.

If no information is available to estimate the life of pavement and rehabilitation activities, one way to estimate the timing for rehabilitation activities is to use traffic counts. That is, estimate the life of the original pavement and determine how many vehicles are carried over that time. Next, assume that each major rehabilitation will carry that same amount of traffic and determine the life of each rehabilitation by matching the amount of traffic. [5]

The traffic volume analysis of each section attached in Appendix C also have timing of rehabilitation activities for each section. The cash flow diagram (below) shows timing of rehabilitation and maintenance activity. The maintenance and rehabilitation activity costs applied at different years of the analysis period are discounted in to Present Worth/Value using Eqn. 11.

$$NPV_n = \sum_{k=1}^{n} Maintenace\ Cost[\frac{1}{(1+i)^n}] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(Eqn. 11)$$

Where: NPV_n = the Net Present Value of maintenance cost for activity on year n

i = discount rate,

n = analysis Period,

k = year of activity

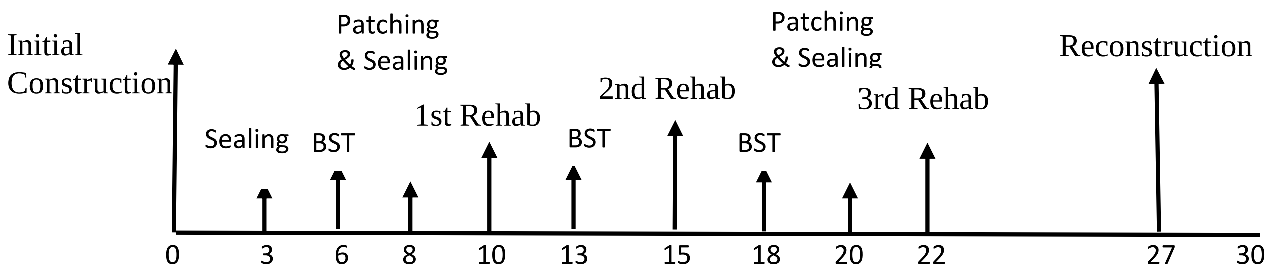


Figure 48: Timing of maintenance and rehabilitation for Flexible pavement without Geogrid

According to AACRA the extent of distress severity will be a decision factor to choose between 3cm overlay and 5cm overlay. In the table below shows the maintenance type, thickness of rehabilitation and unit cost for each activity.

*Table 26: **Maintenance** and Rehabilitation cost for flexible pavement for the three road sections*

Maintenance for flexible pavement-AratKilo-Sheromeda, Mexico-Piyassa & Megenaga Bus-Depot							
Year	Maintenance Activity	Unit	Unit Rate	Total Quantity	Total Cost	$1/(1+i)^n$	NPV_n
3	Crack Sealing, 15% of area	Lm	13.562	54.75	742.5195	0.731191381	542.93
6	BST or thin overlay	m^2	117.1	365	42741.5	0.534640836	22851.35
8	Patching & Sealing, 35% of area	m^2	434	127.75	55443.5	0.433926496	24058.41
10	Overlay of 3cm	m^2	162	365	59130	0.352184479	20824.67
13	BST or thin overlay	m^2	117.1	365	42741.5	0.257514256	11006.55
15	Mill and Overlay of 10cm Ac	m^2	567.4	365	207101	0.209004347	43285.01
18	BST or thin overlay	m^2	117.1	365	42741.5	0.152822177	6531.85
20	Patching & Sealing, 35% of area	m^2	434	127.75	55443.5	0.124033907	6876.88
22	Overlay of 3cm	m^2	162	365	59130	0.100668701	5952.54
27	Average Reconstruction cost				447,339.01	0.059741975	26724.92
30	Residual Life Value (12 years)				357,871.21	0.043682817	-15632.83
						Total	**153,022.26**

*Table 27: **Maintenance** and Rehabilitation cost for flexible pavement for the Leghare Bus-Depot*

Maintenance for flexible pavement-Leghare Bus-Depot							
Year	Maintenance Activity	Unit	Unit Rate	Total Quantity	Total Cost	$1/(1+i)^n$	NPV_n
3	Crack Sealing, 15% of area	Lm	13.562	54.75	742.5195	0.731191381	542.93
6	BST or thin overlay	m^2	117.1	365	42741.5	0.534640836	22851.35
8	Patching & Sealing, 35% of area	m^2	434	127.75	55443.5	0.433926496	24058.41
10	Overlay of 3cm	m^2	162	365	59130	0.352184479	20824.67
13	BST or thin overlay	m^2	117.1	365	42741.5	0.257514256	11006.55
15	Mill and Overlay of 10cm Ac	m^2	448.5	365	163702.5	0.209004347	43285.01
18	BST or thin overlay	m^2	117.1	365	42741.5	0.152822177	6531.85

20	Patching & Sealing, 35% of area	m^2	434	127.75	55443.5	0.124033907	6876.88
22	Overlay of 3cm	m^2	162	365	59130	0.100668701	5952.54
27	Average Reconstruction cost				305,065.48	0.059741975	18225.21
30	Residual Life Value (12 years)				244,052.38	0.043682817	-10660.89
						Total	**140,424.01**

b) Flexible Pavement with Geogrid

When reinforcement done to the pavement layer with geogrid materials there will be advantages for the pavement system, like extension of rehabilitation intervals, extension of service life, reduction of maintenance costs, very economical solution for rehabilitation of traffic areas and up to 4 times better retardation of reflective cracks. This implies that the maintenance time schedule will be changed from the flexible pavement. The diagram below shows the timing of rehabilitation and maintenance activity for flexible pavement with geogrid for all road sections.

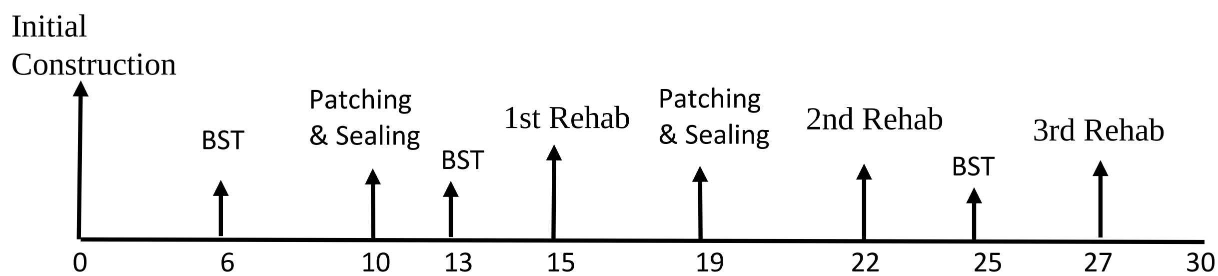


Figure 49: Timing of maintenance and rehabilitation for flexible pavement with Geogrid

In the table below shows the type of maintenance, thickness of rehabilitation and its' unit cost of flexible pavement with geogrid material for all road sections.

Table 28: Maintenance and Rehabilitation cost for Flexible Pavement with Geogrid

Maintenance for flexible pavement with Geogrid-For all Road Sections							
Year	Maintenance Activity	Unit	Unit Rate	Total Quantity	Total Cost	$1/(1 + i)^n$	NPV_n
6	BST or thin overlay	m^2	117.1	365	42741.5	0.5346408	22851.35
10	Patching & Sealing, 35% of area	m^2	343.6	127.75	43894.9	0.3521845	15459.10
13	BST or thin overlay	m^2	117.1	365	42741.5	0.2575143	11006.55
15	Overlay of 3cm	m^2	162	365	59130	0.2090043	12358.43
19	Patching & Sealing, 35% of area	m^2	343.6	127.75	43894.9	0.1376776	6043.35
22	Overlay of 5cm	m^2	257.8	365	94097	0.1006687	9472.62
25	BST or thin overlay	m^2	117.1	365	42741.5	0.0736081	3146.12
27	Overlay of 3cm	m^2	162	365	167,770.74	0.059742	10022.96
						Total	**90,360.47**

c) Rigid Pavement, CRCP

Well-built concrete pavements generally require less maintenance than asphalt pavements under similar traffic and environmental conditions. CRCP has the potential to provide a long-term, "zero-maintenance," service life under heavy traffic loadings and challenging environmental conditions, provided proper design and quality construction practices are utilized. [15] Different agencies may define different repair techniques as either maintenance or rehabilitation, based on the circumstances and on agency practices. But in our country the use of rigid pavements as alternate pavement structure are not used for long time. So the maintenance and rehabilitation of concrete pavements activities not done yet, here the most common types of activities are used. The maintenance and rehabilitation types generally called concrete pavement restoration (CPR) operations. This encompasses: resealing joints and cracks, to restore pavement surface friction by diamond grinding, partial or full depth repair/replacement of slab. [25] The recommended maintenance and rehabilitation plans are outlined in the diagram below.

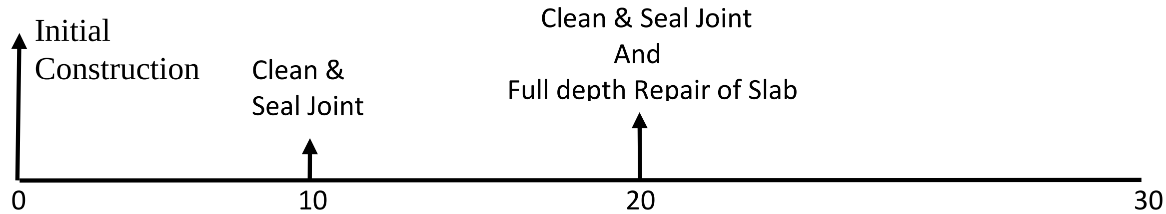


Figure 50: Timing of Maintenance for CRCP without Geogrid

In the table below shows the time & type of maintenance of each activity and its' unit cost for CRCP without geogrid material for all road sections.

Table 29: Maintenance cost for CRCP without Geogrid for the three Road Sections

Maintenance for Rigid pavement-For all Road Section							
Year	Maintenance Activity	Unit	Unit Rate	Total Quantity	Total Cost	$1/(1 + i)^n$	NPV_n
10	Clean & Seal Joint-100%	m	100	107.3	10730	0.3521845	3778.94
20	Clean & Seal Joint-100%	m	100	107.3	10730	0.1240339	1330.88
20	Full depth Repair of Slab-10%	m^3	3925.5	8.103	31808.33	0.1240339	3945.31
20	Full depth Repair of Slab-10%	Kg	27	459.98	12419.46	0.1240339	1540.43
						Total	**10,595.57**

d) Rigid Pavement with Geogrid, CRCP

As indicated above about the property of CRCP, i.e. it has the potential to provide a long-term, "zero-maintenance," service life under heavy traffic loadings and challenging environmental conditions. In addition to this When reinforcement done to the pavement layer with geogrid materials there will be additional strength and advantages for the pavement system. This indirectly indicate that the maintenance period will be different compared to that of CRCP without geogrid material. The diagram below shows the timing and type of maintenance activity for CRCP pavement with geogrid for all road sections.

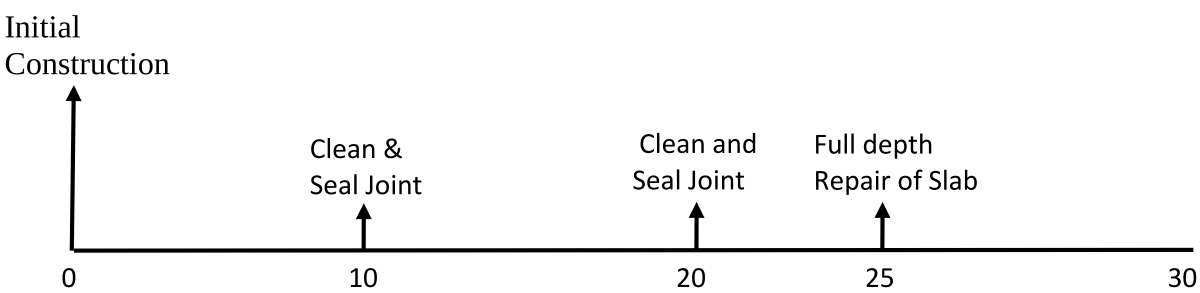


Figure 51: Timing of Maintenance for CRCP with Geogrid

The time & type of maintenance of each activity and its' unit cost for CRCP with geogrid material for all road sections presented in the table below.

Table 30: Maintenance cost for CRCP with Geogrid

Maintenance for Rigid pavement with Geogrid material-For all Road Section							
Year	Maintenance Activity	Unit	Unit Rate	Total Quantity	Total Cost	$1/(1 + i)^n$	NPV_n
10	Clean & Seal Joint-100%	m	100	107.3	10730	0.3521845	3778.94
20	Clean & Seal Joint-100%	m	100	107.3	10730	0.1240339	1330.89
25	Full depth Repair of Slab-10%	m^2	3925.5	8.103	31808.327	0.0736081	2341.35
25	Full depth Repair of Slab-10%	Kg	27	459.98	12419.46	0.0736081	914.17
						Total	**8,365.35**

4.8.5 Life Cycle Costs of the Design Pavement Alternatives

The choice of the appropriate economically advantageous pavement type, flexible or rigid, made by carrying out LCCA which takes into account the initial investment cost and also the maintenance/rehabilitation cost over the design life of the pavement structure. Life cycle cost analysis can be defined as a procedure by which a pavement design alternative will be selected, which will provide a satisfactory level of service at the lowest cost over design life. The details of economic analysis done based on net present worth method using Eqn. 12, i.e. net present value of total construction cost, maintenance and rehabilitation cost over the analysis period by applying of the discount rate of 11%.

$$NPV = Initial\ Cost + \sum_{k=1}^{n} Rehab\ Cost[\frac{1}{(1+i)^n}] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(Eqn. 12)$$

Where: NPV = the Net Present Value

i = discount rate

n = analysis Period

k = year of activity

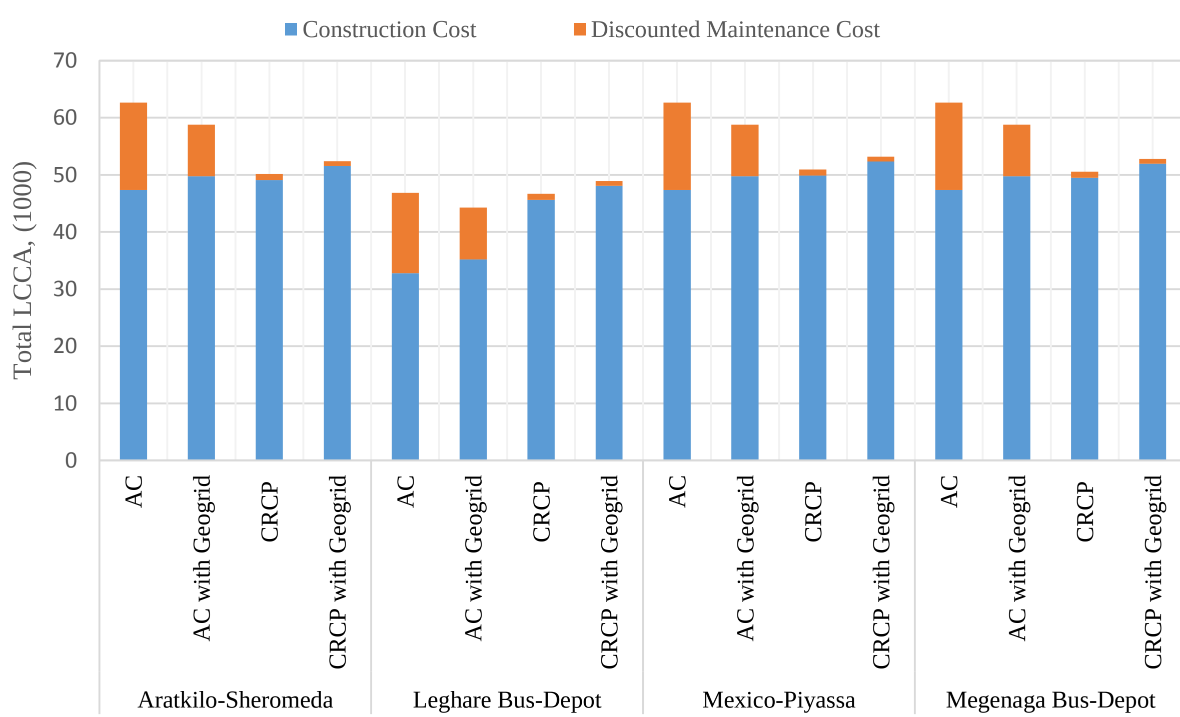


Figure 52: LCCA of Pavement Alternatives for S3

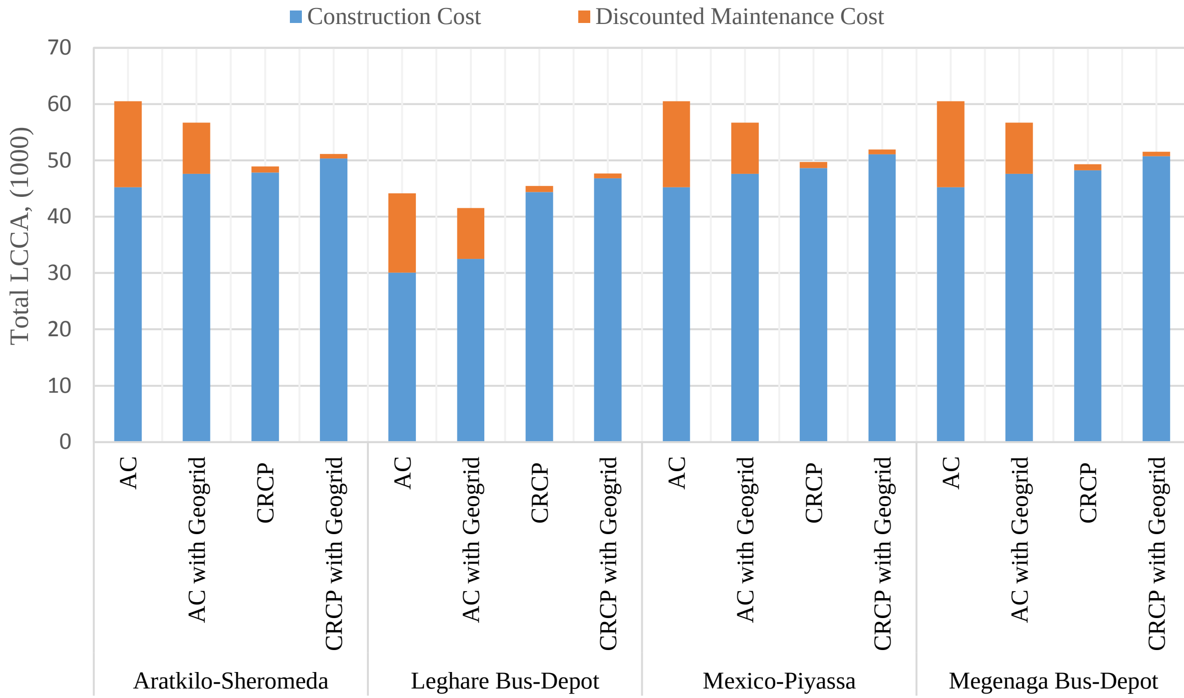


Figure 53: LCCA of Pavement Alternatives for S5

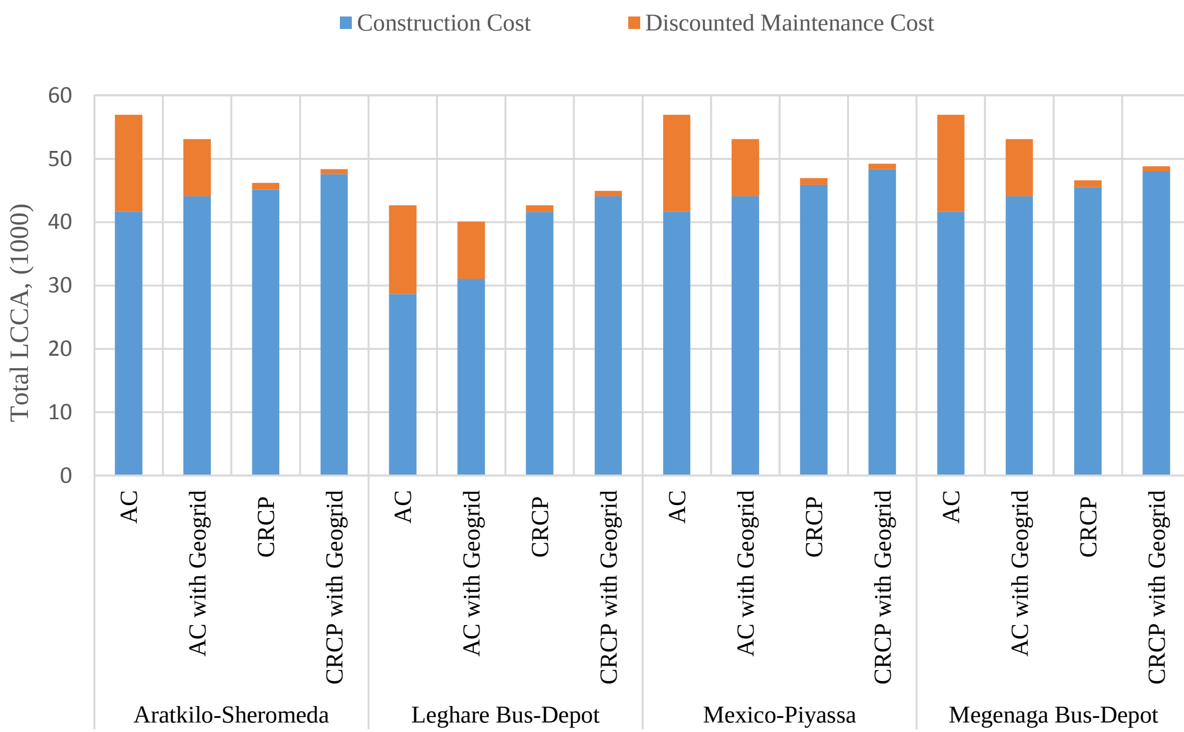


Figure 54: LCCA of Pavement Alternatives for S6

From the computed results of life cycle costs indicated in the figure above, For the three road sections, i.e. AratKilo-Sheromeda, Mexico-Piyassa & Megenaga bus-depot, cement concrete pavements by (> 22%), cement concrete pavements with Geogrid material by (> 15%) and also asphalt concrete with Geogrid material by (> 6%) have far better cost saving advantages as compared to the asphalt concrete options. For the Leghare bus-depot, only asphalt concrete pavement with Geogrid material have better cost saving compared to the asphalt concrete options by (> 5%) while Cement concrete pavement alternative has the same life cycle cost. But Cement concrete pavement with Geogrid material alternative has higher life cost than the asphalt concrete options.

4.8.6 Sensitivity Analysis

As with any kind of analysis or research, it is important to understand which parameters make the biggest contribution to the final results. For example: the pavement subgrade strength and traffic loading have the major impact on the design outcome in the pavement design procedure. For LCCA, many variables can affect the final NPV for a pavement alternative. For instance, the unit price of a material is very important and can cause an alternative to go from the lowest NPV to the highest. Therefore, it is very important to perform a sensitivity analysis. Other factors that can greatly influence the LCCA results are the discount rate, analysis period and timing of activities.

Here for sensitivity analysis, the impact of asphalt and concrete unit prices on total cost changes results was examined. The asphalt and concrete unit price variations were adjusted to get the worst scenario such that the unit price of one material is increase, the other material decrease by the same amount or vice versa. For the analysis 10% unit price increase or decrease taken on the effects of changes on the total LCCA.

The Sensitivity analysis results on LCCA (Figure 55 - Figure 57) when cost of Cement increased by 10% and cost of Bitumen decreased by 10% still shows the three pavement alternative has better advantage than the asphalt concrete pavement. To show the advantages in number, for the three road sections, i.e. AratKilo-Sheromeda, Mexico-Piyassa & Megenaga bus-depot, cement concrete pavements by (> 5%), cement concrete pavements with Geogrid material by (> 1.4% except Mexico-Piyassa route for S6 it's lower to 0.62) and asphalt concrete with Geogrid material by (> 6.7%). For the Leghare bus-depot the alternative's pavements except for asphalt concrete pavements with Geogrid material, have higher life cycle cost compared to the asphalt concrete options. In case of asphalt concrete with Geogrid material by (> 5.86%) have far better cost saving advantages.

The Sensitivity analysis results on LCCA (Figure 58 - Figure 60) when cost of Cement decreased by 10% and cost of Bitumen increased by 10% shows the three pavement alternative has much better advantage than the asphalt concrete pavement. To show the advantages in number, For the three road sections, i.e. AratKilo-Sheromeda, Mexico-Piyassa & Megenaga bus-depot, cement concrete pavements by (> 40 %), Cement concrete pavements with Geogrid material by (> 33%) and asphalt concrete with Geogrid material by (> 6.34%). In this case for the Leghare bus-depot all the three pavement alternative has better advantage. The cement concrete pavements by (> 9.81%), cement concrete pavements with Geogrid material by (> 4.17%) and also asphalt concrete with Geogrid material by (> 5.78%).

From Sensitivity analysis for LCCA over all I can say that, bitumen price fluctuations have significant effect on the initial cost of flexible pavements than cement price fluctuations on concrete pavement. Hence, bitumen is more sensitive and risky than cement as an alternative pavement construction material. Therefore, rigid pavements are more feasible, less responsive for price changes on cement as compared to the competing flexible pavement which is more sensitive to price changes on bitumen.

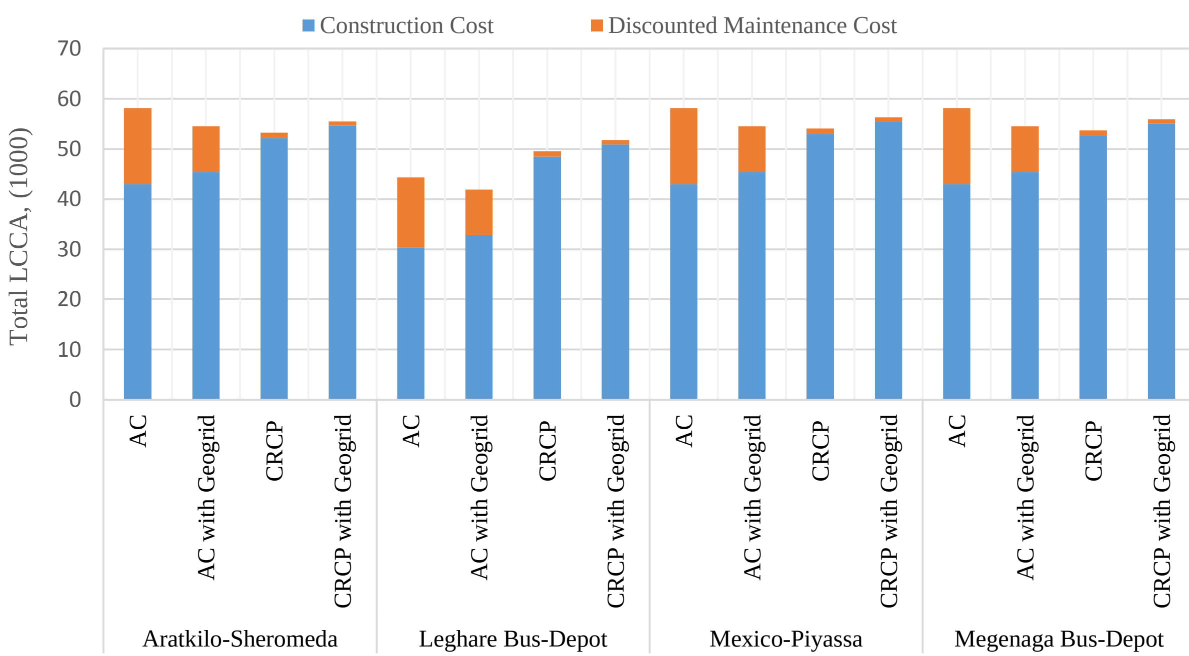


Figure 55: LCCA, When cost of Cement increased by 10% and cost of Bitumen decreased by 10% for S3

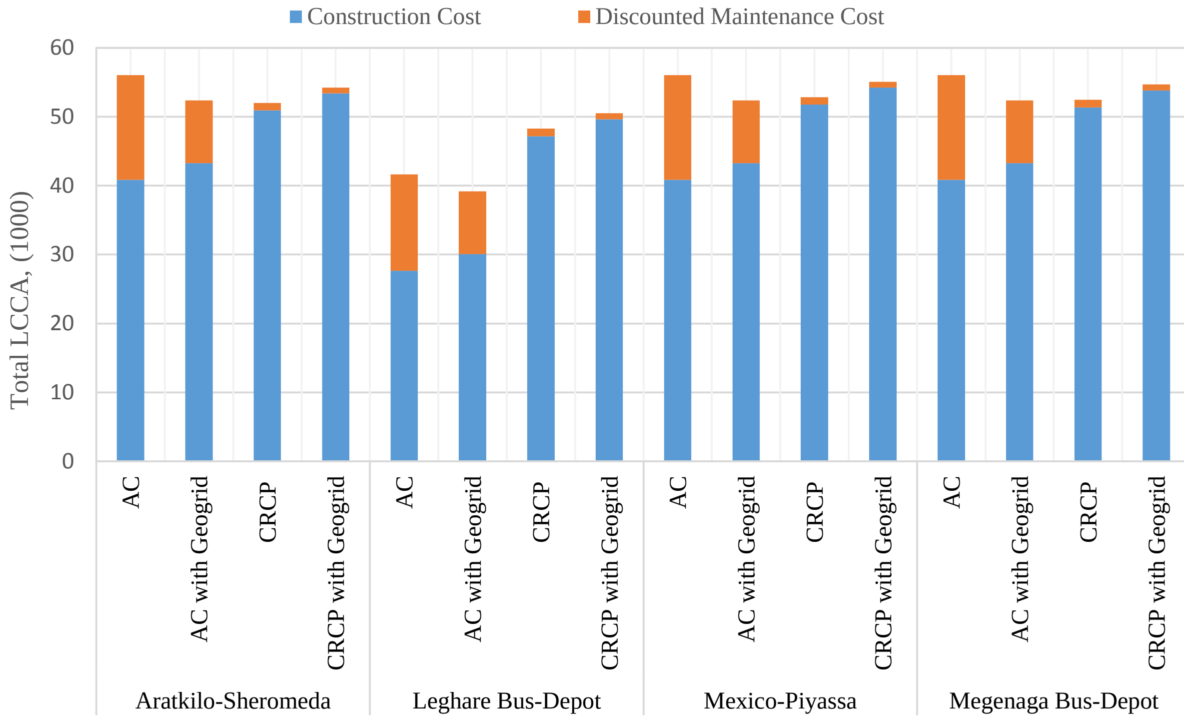


Figure 56: LCCA, When cost of Cement increased by 10% and cost of Bitumen decreased by 10% for S5

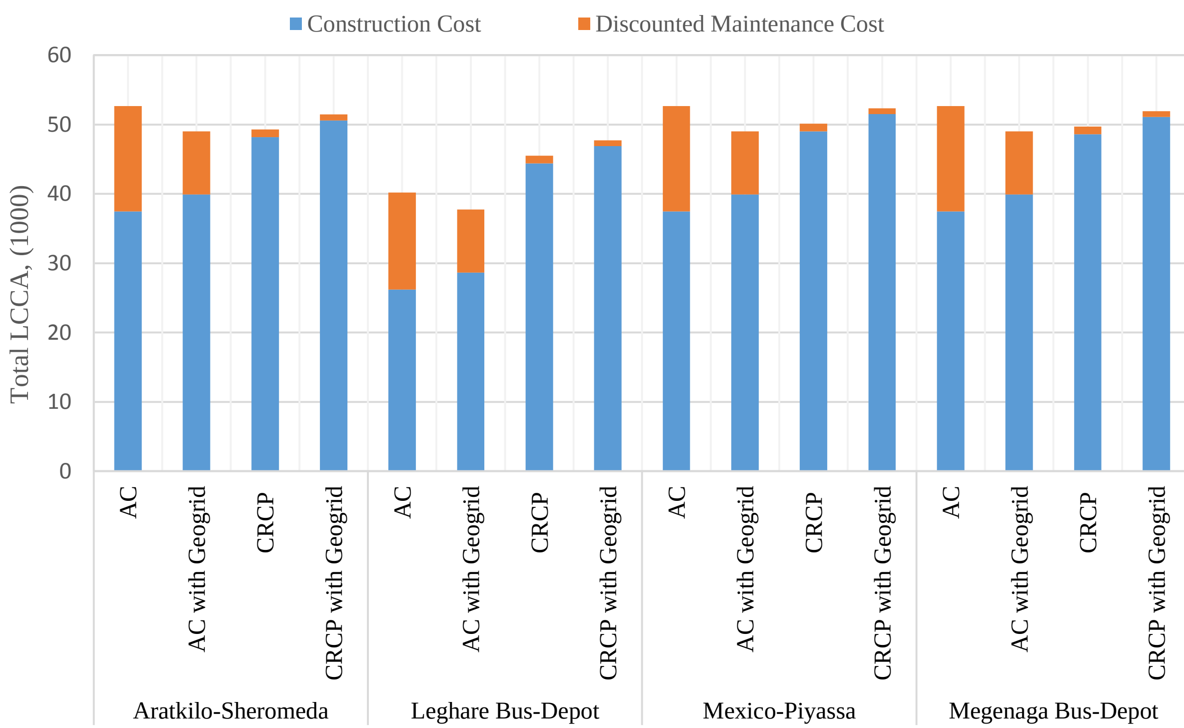


Figure 57: LCCA, When cost of Cement increased by 10% and cost of Bitumen decreased by 10% for S6

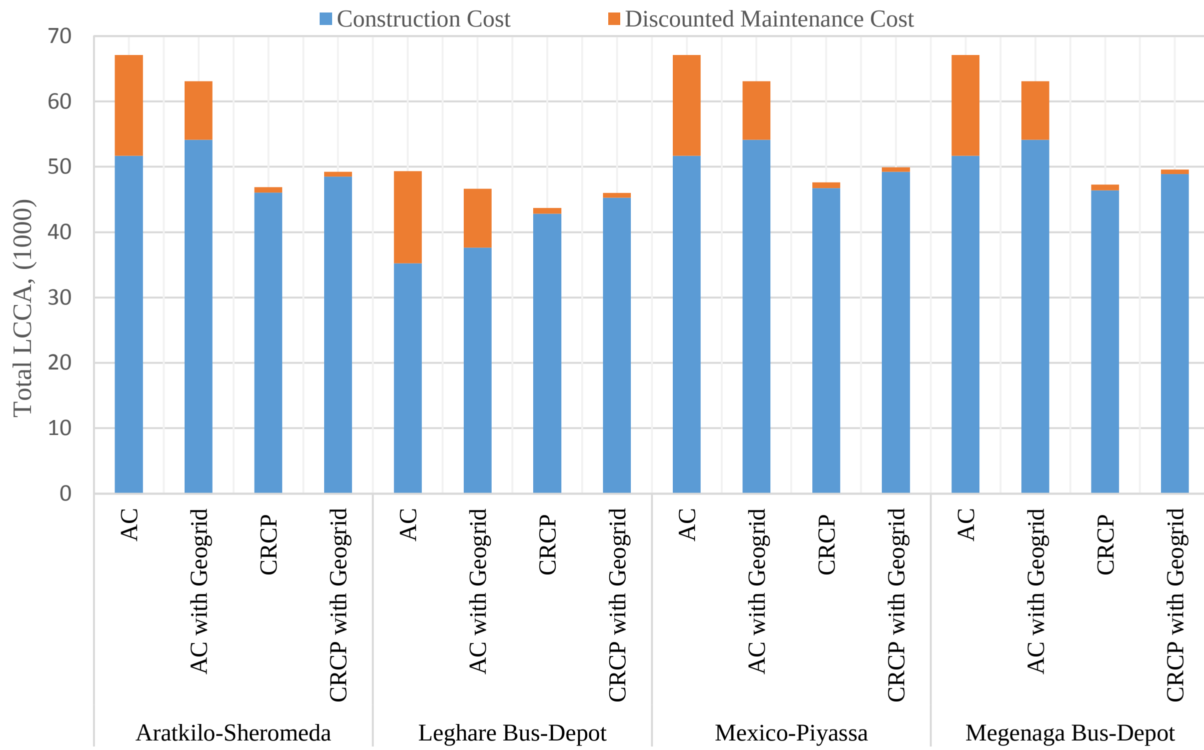


Figure 58: LCCA, When cost of Cement decreased by 10% and cost of Bitumen increased by 10% for S3

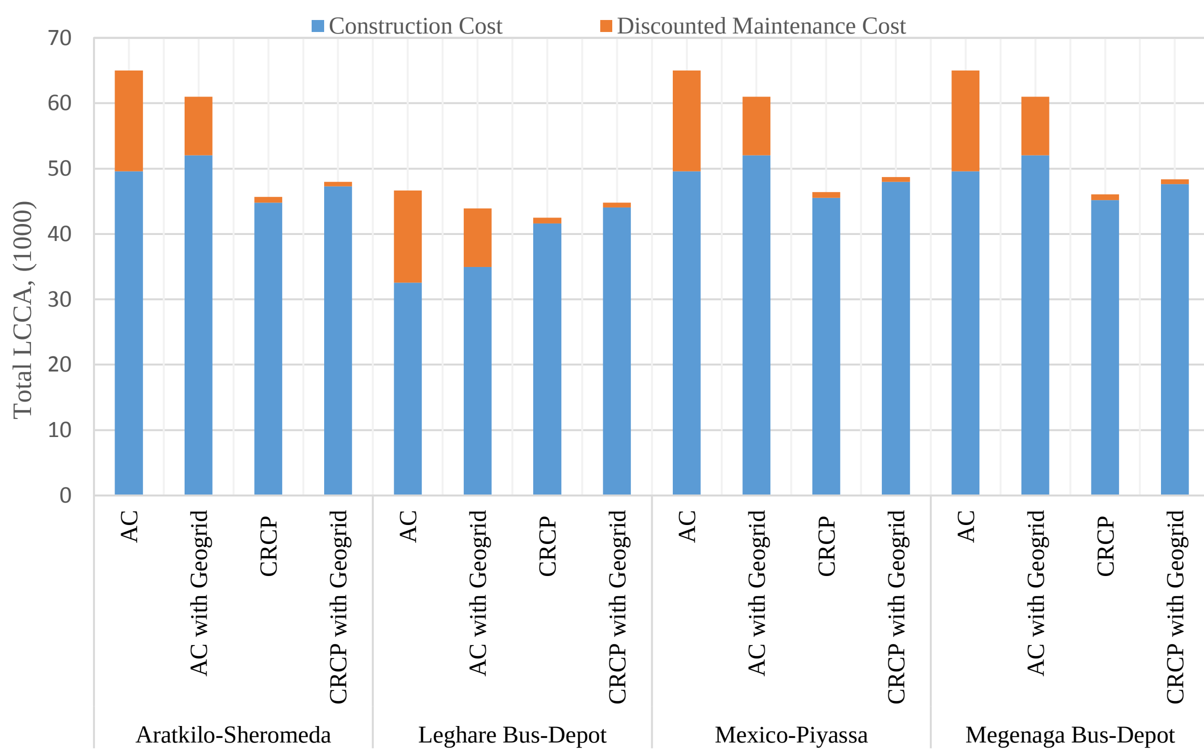


Figure 59: LCCA, When cost of Cement decreased by 10% and cost of Bitumen increased by 10% for S5

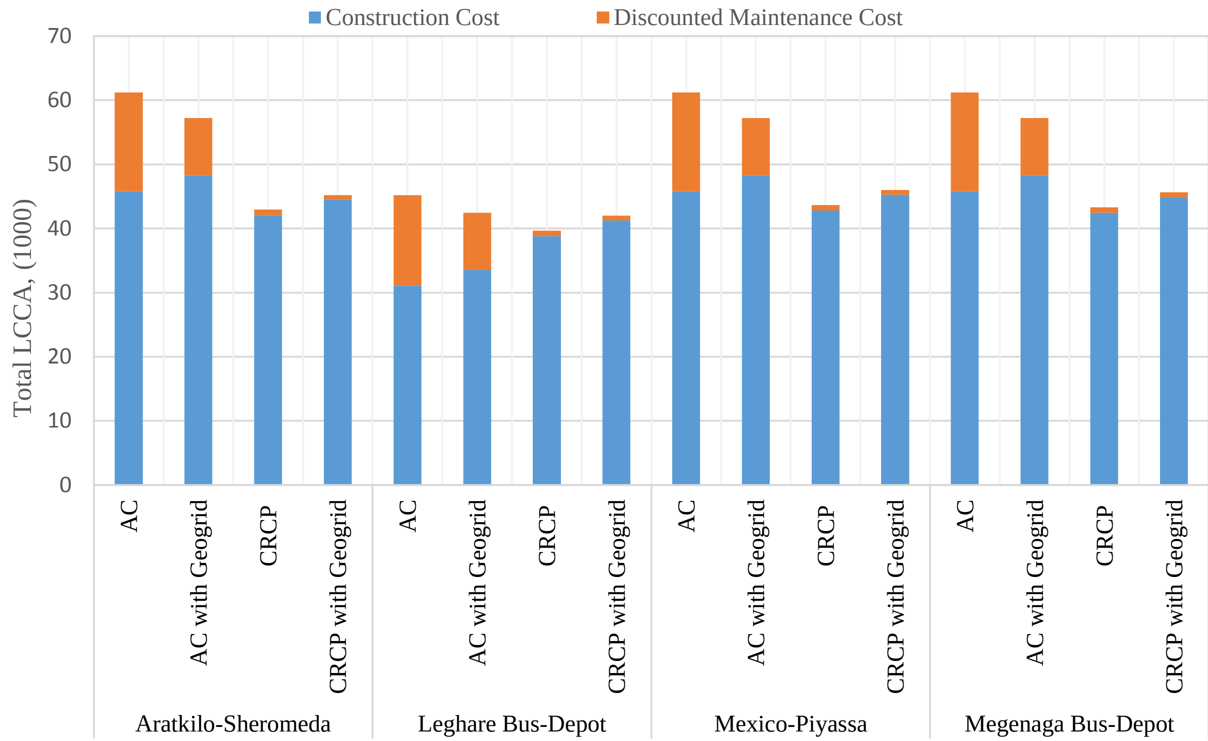


Figure 60: LCCA, When cost of Cement decreased by 10% and cost of Bitumen increased by 10% for S6

Chapter Five

Conclusions and Recommendations

5.1 Conclusions

This study tried to investigate and show the effect of bus on flexible pavement by determining surface distresses on selected studying area. To overcome this distresses and to minimize the overall cost, different pavement alternatives designed and LCCA comparison was done. It was found that in terms of lifecycle cost, use of Cement concrete pavement is cheaper. Further, pavement analysis done and showed that Cement concrete pavement is better in performance. Therefore, it is possible to conclude that rigid pavement option should be adopted on bus stops areas.

In summary it can therefore be concluded that:-

- Collection of accurate data for determining dominant distresses in a road network, identifying primary causes of distress by performing detail material test of the existing pavement structure, and developing functional relationship among different pavement evaluation variables to the material test data would only be good on experimental test sections which are carefully designated in such a way to reasonably model the road sections under study. To this effect one can understand that the analysis and findings of this research could only be considered as a preliminary assessment that may serve as a spring board to further carry out detailed assessment within the Addis Ababa bus stop and stations depots. Hence, it is advisable to develop a continuous system of data collection for distresses, classified traffic counts, pavement evaluation results, and maintenance and construction records on representative test sections for a longer period of time. Such strategic data collection and analysis could certainly enable to develop clear functional relationship among different pavement alternatives for different pavement sections.
- The traffic condition observed at bus stops was heavily loaded. The values of loads are several time higher comparing with common traffic loads because time of loading is longer. Moreover, loads of these areas are Static, accelerating and braking loads and this loads affect pavement. The repeated action of this scenario leads to develop distresses on the pavement.

- ❖ The results of the selected road that are evaluated using distresses survey showed that the mean PCI of 44% at Aratkilo – Sheromeda route, 52% at Mexico – Piyassa, for both cases the pavement surface rated as poor. For Leghare and Megenaga bus-depot the PCI value is 0 and this value suggests the pavement is failed. This shows that the pavements at bus stop areas were at poor level of function.
- ❖ According to the pavement evaluation from the condition survey finding indicates that most of the deterioration in the study sections, caused by excessive traffic loading.
- ❖ In terms of LCCA the uses of concrete pavement is cheaper as compared with Asphalt concrete. And also, addition of Geogrid material for concrete pavement is by far economical and advantages in performance than Asphalt concrete.
- ❖ The use of Geogrid material as a reinforcement in a bituminous pavement is advantages in cost saving and performance than that of flexible pavement without Geogrid.
- ❖ The length of service of Concrete pavements and its less maintenance requirement make it sustainable pavement material than asphalt concrete, as it requires frequent reconstruction and rehabilitation activities that consume high road agencies budget, increase user cost in traffic congestion and the most important one is consuming nonrenewable raw materials like; fuel, road base material, sub-base material, aggregates for asphalt concrete, etc.
- ❖ When we increase the strength of the soil, i.e. CBR values, the initial construction costs and the total lifecycle cost decreases. The cost of Asphalt concrete pavement alternative for subgrade class S5 relative to S3 decrease averagely by 5.41%, 5.12% for Asphalt concrete pavement with Geogrid and for cement concrete pavement by 2.54%, 2.43% when we apply Geogrid material. For subgrade class S6 relative to S3, 12.19% and 11.53% reduction for Asphalt concrete with and without Geogrid material respectively. And also for cement concrete pavement with or without Geogrid material by 8.12% and 7.84% reduction.
- ❖ Using Kenpave pavement software analysis, the Pavement performance of flexible as compared with rigid pavement is less which indicates the early failure of the pavement. It is possible to conclude that rigid pavement is the best alternatives than flexible one.
- ❖ In general, a Cement concrete pavement is preferable to a flexible pavement in terms of durability, performance and costs savings in bus stop and Stations areas.

5.2 Recommendations

- This research is undertaken in assumption of the cumulative AADT of all vehicle counted are using the bus stop at all routes. However if the area of bus stop is restricted only for public buses, the preference of pavement type of the bus stop will be decided based on the respective traffic volume and hence further study will be expected in this area.
- For the damaged road section, if reconstruction is to be undertaken, then cement concrete pavement should be adopted.
- Based on lifecycle cost, cement concrete pavement is cheaper than flexible pavement on sections of bus stops areas, there is need for alternate bidding in procuring of construction services, in order to get durable as well as safer roadway system.
- The Governments may not be able to provide necessary yearly funds for maintenance for bituminous roads due to inadequate funds available for maintenance of roads due to paucity of funds, which will result in loss of assets to the nation. But Cement Concrete roads once constructed properly will prove an asset to the nation. Thereafter cement concrete road will be a bonus (free from maintenance) to the road agencies and for State Government.
- Road agencies should embrace the high initial investment costs for cement concrete pavement as its life cycle cost is cheaper and also they should include cement concrete pavement alternatives in their feasibility studies as well as in their tendering stages for different roads.
- To increase the performance of the roads in Ethiopia, implementing Authorities, ERA and AACRA should adopt the use of different reinforcing material like Geogrid as a pavement layer.
- It is possible to conduct further researches on :-
  - ✓ As to which limit in the design traffic, flexible pavement is economical than rigid pavement for roads in Ethiopia.
  - ✓ Reinforcement of pavement layers with Geogrid material and their performance on pavements.

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APPENDIX A

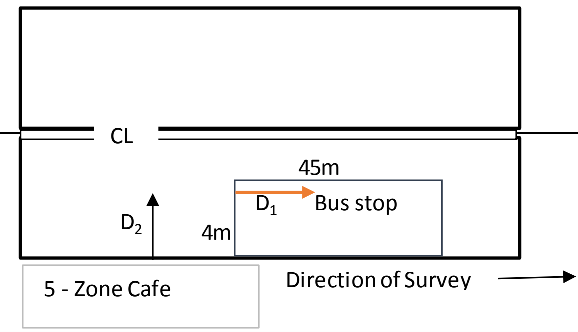
DISTRESS SURVEY DATA AND CALCULATION OF PCI FOR EACH STUDY AREA

Table A. Pavement condition survey data sheets and PCI calculation for AratKilo to Sheromeda route

Table A.1 Pavement condition survey data for Bus stop 3

Distress survey for pavements with
Asphalt concrete surfaces data sheet

Bus-Stop: 3 Photo, Video or Both with survey (P, V, B): P
Surveyours: Groups Date of Distress survey (Month / Day / Year): 08/ 29 /2016



Distress Types

1.Fatigue cracking	6. Transverse cracking	11. Bleeding	16. Other**
2. Block cracking	7. Patch/patch Deterioration	12. Polished Aggregate	
3. Edge cracking	8. Potholes	13. Raveling	
4. Longitudinal cracking	9.Rutting	14. Lane-to-Shoulder Dropoff	
5. Reflection cracking	10. Shoving	15. Water Bleeding and Pumping	

Distress Types	Severity Level			Measurement for calculating quantity of distress						Measurement for distress Map		NOTE
	Low	Moderate	High	Length, m	Width, m	height, mm	Crack width, mm	Number	Area, m^2	D_1, m	D_2, m	
8	-	-	H	1.85	2.3	130	-	-	4.255	0	0.95	
10	-	M	-	1.95	1.6	-	-	1	3.12	1.85	1.52	
10	-	M	-	1.9	0.3	-	-	1	0.57	3.8	0.7	
10	-	M	-	1.2	0.4	-	-	1	0.48	5	0.6	
10	-	M	-	0.6	0.5	-	-	1	0.3	6.2	0.45	
8	-	M	-	1.6	0.8	30	-	-	1.28	7	2.3	
10	-	-	H	1.8	0.3	-	-	4	2.16	8	0.35	
10	-	M	-	1.6	1.4	-	-	2	4.48	14.2	0.6	
10	-	M	-	1	0.5	-	-	15	7.5	20	2	
3	-	M	-	2.75		-	40	-	-	15	0	
10	-	M	-	1	0.3	-	-	10	3	25	0.2	
1	-	M	-	1.1	0.45	-	-	-	0.495	16	3	

Table A.2 Calculation of Deduct Value for Bus stop 3

Distress Types					
	1.Fatigue cracking 2. Block cracking 3. Edge cracking 4. Longitudinal cracking 5. Reflection cracking	6.Transverse cracking 7.Patch/patch Deterioration 8.Potholes 9.Rutting 10.Shoving	11. Bleeding 12. Polished Aggregate 13. Raveling 14. Lane-to-Shoulder Dropoff 15. Water Bleeding and Pumping	16. Other**	
Distress Severity	Quantity	Total	sample Area	Density	Deduct Value
10 H	2.16	2.16	180	1.2	20
10 M	19.45	19.45	180	10.80555556	26
8 H	4.255	4.255	180	2.363888889	69
8 M	1.28	1.28	180	0.711111111	25
3 M	2.75	2.75	180	1.527777778	7
1 M	0.495	0.495	180	0.275	11

M=1+(9/98) * (100 - 69)

M= 3.9 ...... Correction needed for the lowest deduct value.

Use highest 3 deducts and the corrected value will be:-

(3.9 - 3) * 7 = 6.3

Table A.3 Calculation of Pavement Condition Index and Pavement Condition Rate for Bus stop

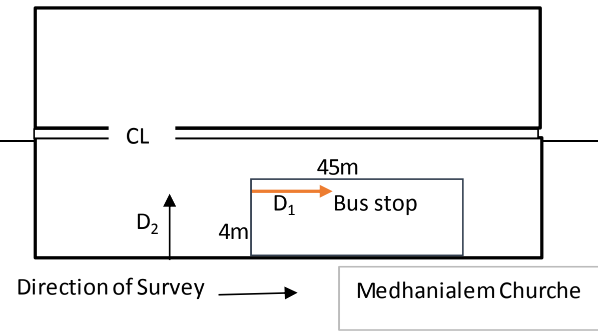
#	Deduct values In Descending Order									TDV	q	CDV	PCI	PCR
1	69	26	25	20	11	6.3				157.3	6	76	19	Serious
2	69	26	25	20	11	2				153	5	78		
3	69	26	25	20	2	2				144	4	80		
4	69	26	25	2	2	2				126	3	76		
5	69	26	2	2	2	2				103	2	72		
6	69	2	2	2	2	2				79	1	81		

PCI=100 - Max CDV
PCI = 100 - 81
PCI = 19
Pavemnt rating condition ,PCR= Serious

Table A.1 Pavement condition survey data for Bus stop 8

Distress survey for pavements with
Asphalt concrete surfaces data sheet

Bus-Stop: 8 Photo, Video or Both with survey (P, V, B): P
Surveyours: Groups Date of Distress survey (Month / Day / Year): 08/ 29 /2016



Distress Types

1.Fatigue cracking
2. Block cracking
3. Edge cracking
4. Longitudinal cracking
5. Reflection cracking
6. Transverse cracking
7. Patch/patch Deterioration
8. Potholes
9.Rutting
10. Shoving
11. Bleeding
12. Polished Aggregate
13. Raveling
14. Lane-to-Shoulder Dropoff
15. Water Bleeding and Pumping
16. Other**

Distress Types	Severity Level			Measurement for calculating quantity of distress						Measurement for distress Map		NOTE
	Low	Moderate	High	Length, m	Width, m	height, mm	Crack width, mm	Number	Area, m^2	D_1, m	D_2, m	
1	-	-	H	2.3	1.9	-	-	-	4.37	0	1.4	
1	-	-	H	1.6	2.3	-	-	-	3.68	3.2	1.4	
8	-	-	H	0.9	0.55	110	-	-	0.495	5	1.2	
8	-	M	-	1.5	0.7	40	-	-	1.05	5.9	1.2	
8	-	-	H	1.8	0.9	160	-	-	1.62	7.4	0.8	
1	-	-	H	2.1	0.95	-	-	-	1.995	9.2	1	
2	-	-	H	4.3	0.6	-	20	-	2.58	11.3	1	
1	-	-	H	2.5	1.1	-	-	-	2.75	15.6	0.46	
4	-	-	H	1.1		-	30	-		18.1	1.35	
1	-	-	H	4.6	0.85	-	-	-	3.91	19.2	0.6	
8	-	-	H	0.9	1.3	50	-	-	1.17	23.8	0.3	
7	-	-	H	1.9	1.8	-	-	-	3.42	24.7	0	
1	-	M	-	1.8	0.55	-	-	-	0.99	33.2	1	
10	-	M	-	2	1.4	-	-	2	5.6	30	2.85	
13	-	M	-	15	2.5	-	-	-	37.5	0	1	

Table A.2 Calculation of Deduct Value for Bus stop 8

Distress Types	1.Fatigue cracking 2. Block cracking 3. Edge cracking 4. Longitudinal cracking 5. Reflection cracking	6.Transverse cracking 7.Patch/patch Deterioration 8.Potholes 9.Rutting 10.Shoving	11. Bleeding 12. Polished Aggregate 13. Raveling 14. Lane-to-Shoulder Dropoff 15. Water Bleeding and Pumping	16. Other**	
Distress Severity	Quantity	Total	sample Area	Density	Deduct Value
1 H	16.705	16.705	180	9.280555556	61
1 M	0.99	0.99	180	0.55	17
8 H	3.285	3.285	180	1.825	65
8 M	1.05	1.05	180	0.583333333	23
2 H	2.58	2.58	180	1.433333333	8
4 H	1.1	1.1	180	0.611111111	5
7 H	3.42	3.42	180	1.9	26
10 M	5.6	5.6	180	3.111111111	19
13 M	37.5	37.5	180	20.83333333	22

M=1+(9/98) * (100 - 65)

M= 4.2...... Correction needed for the lowest deduct value.

Use highest 4 deducts and and the corrected value will be:-

(4.2 - 4) * 5 = 1

Table A.3 Calculation of Pavement Condition Index and Pavement Condition Rate for Bus stop 8

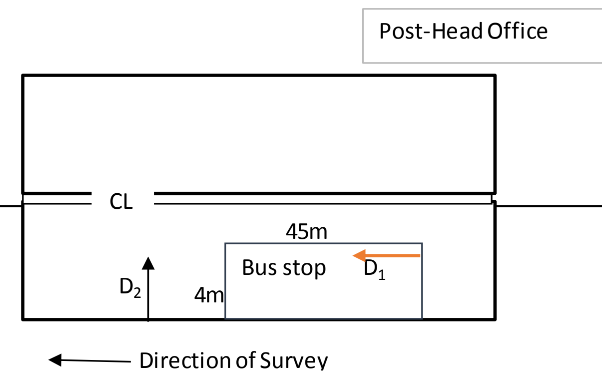
#	Deduct values In Descending Order									TDV	q	CDV	PCI	PCR
1	65	61	26	23	22	19	17	8	1	242	8	100	0	Failed
2	65	61	26	23	22	19	17	2	1	236	7	100		
3	65	61	26	23	22	19	2	2	1	221	6	100		
4	65	61	26	23	22	2	2	2	1	204	5	100		
5	65	61	26	23	2	2	2	2	2	185	4	91		
6	65	61	26	2	2	2	2	2	2	164	3	94		
7	65	61	2	2	2	2	2	2	2	140	2	90		
8	65	2	2	2	2	2	2	2	2	81	1	81		

Table B. Pavement condition survey data sheets and PCI calculation for Mexico-Piyassa route

Table B.1 Pavement condition survey data for Bus stop 6

Distress survey for pavements with
Asphalt concrete surfaces data sheet

Bus-Stop: 6 Photo, Video or Both with survey (P, V, B): P
Surveyours: Groups Date of Distress survey (Month / Day / Year): 08/ 28 /2016



Distress Types:

1.Fatigue cracking
2. Block cracking
3. Edge cracking
4. Longitudinal cracking
5. Reflection cracking
6. Transverse cracking
7. Patch/patch Deterioration
8. Potholes
9.Rutting
10. Shoving
11. Bleeding
12. Polished Aggregate
13. Raveling
14. Lane-to-Shoulder Dropoff
15. Water Bleeding and Pumping
16. Other**

Distress Types	Severity Level			Measurement for calculating quantity of distress						Measurement for distress Map		NOTE
	Low	Moderate	High	Length, m	Width, m	height, mm	Crack width, mm	Number	Area, m^2	$D_{1,}$ m	$D_{2,}$ m	
6	-	M	-	2	-	-	16	-	-	2	0.9	
6	-	-	H	1.2	-	-	20	-	-	6.7	1.25	
6	-	M	-	1.8	-	-	10	-	-	12.3	1.1	
6	-	-	H	4.6	-	-	30	-	-	10.4	2.7	
6	-	M	-	1.9	-	-	10	-	-	14.2	0.2	
4	-	-	H	1.3	-	-	30	-	-	9.1	3.7	
4	-	-	H	26	-	-	70	-	-	9.6	3.8	
3	-	-	H	10.9	-	-	100	-	-	23.75	0.2	
6	-	M	-	5	-	-	10	-	-	30.5	0.1	
6	-	-	H	3.9	-	-	70	-	-	44.5	0.1	
2	-	M	-	2.5	0.5	-	20	-	1.25	42.5	0	
8	-	-	H	1.1	0.7	130		-	0.77	43.9	0.7	
6	-	-	H	1.75	-	-	20	-	-	44	1.5	

Table B.2 Calculation of Deduct Value for Bus stop 6

Distress Severity	Quantity	Total	sample Area	Density	Deduct Value
6 M	10.7	10.7	180	5.944444444	12
6 H	11.45	11.45	180	6.361111111	28
4 H	27.3	27.3	180	15.16666667	13
3 H	1O.9	1O.9	180	6.05555556	18
2 M	1.25	1.25	180	0.694444444	1
8 H	0.77	0.77	180	0.427777778	37

M=1+(9/98) * (100-37)
M=6.8.....So no need of correction to be done

Table B.3 Calculation of Pavement Condition Index and Pavement Condition Rate for Bus stop 6

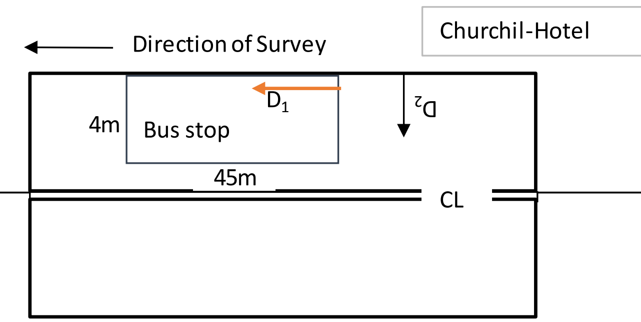
#	Deduct values In Descending Order									TDV	q	CDV	PCI	PCR
1	37	28	18	13	12	1				109	5	58	42	Poor
2	37	28	18	13	2	1				99	4	57		
3	37	28	18	2	2	1				88	3	56		
4	37	28	2	2	2	1				72	2	52		
5	37	2	2	2	2	1				46	1	46		

PCI=100 - Max CDV
PCI = 100 - 58
PCI = 42

Pavemnt rating condition ,PCR= PooR

Table B.1 Pavement condition survey data for Bus stop 8

Distress survey for pavements with
Asphalt concrete surfaces data sheet



Route: Mexico-Piyassa
Bus-Stop: 8 Photo, Video or Both with survey (P, V, B): P
Surveyours: Groups Date of Distress survey (Month / Day / Year): 08/ 28 /2016

Distress Types

1. Fatigue cracking
2. Block cracking
3. Edge cracking
4. Longitudinal cracking
5. Reflection cracking
6. Transverse cracking
7. Patch/patch Deterioration
8. Potholes
9. Rutting
10. Shoving
11. Bleeding
12. Polished Aggregate
13. Raveling
14. Lane-to-Shoulder Dropoff
15. Water Bleeding and Pumping
16. Other**

Distress Types	Severity Level			Measurement for calculating quantity of distress						Measurement for distress Map		NOTE
	Low	Moderate	High	Length, m	Width, m	height, mm	Crack width, mm	Number	Area, m^2	D_1, m	D_2, m	
4	-	M	-	3.31	-	-	10	-	-	0	1.9	
4	-	M	-	2.6	-	-	10	-	-	27.9	2.9	
10	-	M	-	1.55	0.6	-		2	1.86	15	0.6	
10	-	M	-	1.1	1.05	-	-	3	3.465	18.1	0.3	
10	-	M	-	1.15	0.4	-	-	4	1.84	21.2	0.55	
1	-	-	H	0.7	0.7	-	-	-	0.49	18.1	0.6	
1	-	-	H	1.7	0.5	-		-	0.85	19.1	0.3	
2	-	M	-	0.4	0.8	-	15	-	0.32	27.9	1.75	
10	-	M	-	1.35	0.6	-	-	1	0.81	33.6	0	

Table B.2 Calculation of Deduct Value for Bus stop 8

Distress Severity	Quantity	Total	sample Area	Density	Deduct Value
4 M	5.91	5.91	180	3.283333333	8
10 M	7.975	7.975	180	4.430555556	24
1 H	1.34	1.34	180	0.744444444	6
2 M	0.32	0.32	180	0.177777778	0

M=1+(9/98) * (100-24)
M=7.97.....So no need of correction to be done

Table B.3 Calculation of Pavement Condition Index and Pavement Condition Rate for Bus stop 8

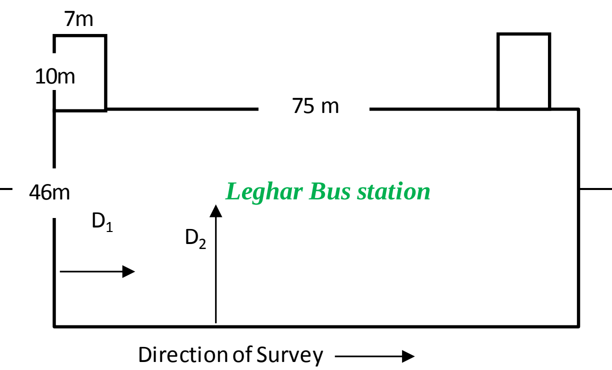
#	Deduct values In Descending Order									TDV	q	CDV	PCI	PCR
1	24	8	6	0						38	3	22	72	Satisfactory
2	24	8	2	0						34	2	25		
3	24	2	2	0						28	1	28		

Table C. Pavement condition survey data sheets and PCI calculation for Leghar station

Table C.1 Pavement condition survey data

Distress survey for pavements with
Asphalt concrete surfaces data sheet

Station: Leghar station Photo, Video or Both with survey (P, V, B): P
Surveyours: Groups Date of Distress survey (Month / Day / Year): 08/ 30 /2016



Distress Types

1.Fatigue cracking	6. Transverse cracking	11. Bleeding	16. Other**
2. Block cracking	7. Patch/patch Deterioration	12. Polished Aggregate	
3. Edge cracking	8. Potholes	13. Raveling	
4. Longitudinal cracking	9.Rutting	14. Lane-to-Shoulder Dropoff	
5. Reflection cracking	10. Shoving	15. Water Bleeding and Pumping	

Distress Types	Severity Level			Measurement for calculating quantity of distress						Measurement for distress Map		NOTE
	Low	Moderate	High	Length, m	Width, m	height, mm	Crack width, mm	Number	Area, m^2	D_1, m	D_2, m	
8	-	-	H	2.1	2.6	60	-	-	5.46	0.7	1.4	
8	-	-	H	2.5	2.3	60	-	-	5.75	22.5	5	
8	-	M	-	0.8	0.8	45	-	-	0.64	30	10	
10	-	-	H	2.2	2	-	-	1	4.4	30	8	
8	-	M	-	1.4	1.2	50	-	-	1.68	31.4	7.3	
8	-	M	-	1.1	1	30	-	-	1.1	33	7.3	
8	-	-	H	2.2	1.3	70	-	-	2.86	35	7	
8	-	-	H	1.8	1	120	-	-	1.8	37.6	6.9	
8	L	-	-	1	0.5	20	-	-	0.5	40	7.4	
8	-	-	H	1	1.3	80	-	-	1.3	41.5	9	
8	-	-	H	0.8	0.85	83	-	-	0.68	50	5.5	
8	-	M	-	1.5	1.2	40	-	-	1.8	49.3	12.9	
8	L	-	-	1.1	0.9	10	-	-	1.32	49.7	13.35	
8	-	-	H	2.3	1.7	70	-	-	2.07	48.5	16.5	
8	-	-	H	1.1	1.1	80	-	-	1.87	58.8	23.8	

8	-	-	H	1.3	1.1	100	-	-	1.43	58.8	24	
8	-	M	-	0.7	1.25	50	-	-	0.875	49.5	35	
8	-	M	-	0.6	1.1	40	-	-	0.66	50.1	35.4	
8	-	-	H	1.6	3.6	100	-	-	5.76	50.8	37.2	
10	-	-	H	4	3.5	---	-	1	14	45.8	40	
8	-	M	-	3.9	2.8	30	-	-	10.92	44.8	40	
8	-	-	H	3.5	5	60	-	-	17.5	48.3	47	
8	-	-	H	3.4	2.8	80	-	-	9.52	48	48	
8	-	-	H	2	2.1	110	-	-	4.2	47.1	35	
8	-	-	H	1.2	1.1	130	-	-	1.32	34.8	43.4	
8	-	-	H	1.6	1.6	200	-	-	2.56	32.6	43.4	
8	-	-	H	1.6	1.5	130	-	-	2.4	23	45.5	
8	-	-	H	3.2	2.6	300	-	-	8.32	17.2	40.3	
8	-	-	H	1.1	1.3	70	-	-	1.43	17.7	42.9	
8	-	-	H	90	1.3	80	-	-	117	17.2	43.1	
8	-	M	-	5	4.2	30	-	-	21	7	45	
10	-	-	H	1.7	2.3	-	-	1	3.91	12	45	
8	-	-	H	1.5	1.3	60	-	-	1.95	4	18.6	
8	-	-	H	1.85	2	70	-	-	3.7	4	18.9	
13	-	-	H	68	43.15	-	-	-	2934.2	0	0	
16	-	M	-	2.6	2.2	40	-	-	5.72	2.5	3.4	Depression
16	-	M	-	3	6	50	-	-	18	0	13	

Table C.2 Calculation of Deduct Value

Distress Severity	Quantity	Total	sample Area	Density	Deduct Value
8 H	198.88	198.88	3590	5.539832869	90
8 M	38.675	38.675	3590	1.07729805	31
8 L	1.82	1.82	3590	0.050696379	2
10 H	22.31	22.31	3590	0.621448468	13
13 H	2934.2	2934.2	3590	81.73259053	77
16 M	23.72	23.72	3590	0.660724234	8

M=1+(9/98) * (100 - 90)
M= 1.9...... Correction needed for the lowest deduct value, Use highest 1 deducts and the corrected value will be:-
(1.92 - 1) * 2 = 1.8

Table C.3 Calculation of Pavement Condition Index and Pavement Condition Rate

#	Deduct values In Descending Order									TDV	q	CDV	PCI	PCR
1	90	77	31	13	8	1.8				220.8	5	100	0	Failed
2	90	77	31	13	2	1.8				214.8	4	100		
3	90	77	31	2	2	1.8				203.8	3	100		
4	90	77	2	2	2	1.8				174.8	2	100		
5	90	2	2	2	2	1.8				99.8	1	99.8		

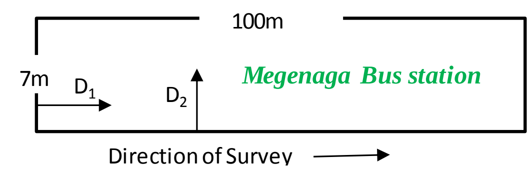
PCI=100 - Max CDV
PCI = 100 - 100
PCI = 0

Pavemnt rating condition ,PCR= Failed

Table D. Pavement condition survey data sheets and PCI calculation for Megenaga station

Table D.1 Pavement condition survey data

Distress survey for pavements with
Asphalt concrete surfaces data sheet



Station: Megenaga station Photo, Video or Both with survey (P, V, B): P
Surveyours: Groups Date of Distress survey (Month / Day / Year): 08/ 31 /2016

Distress Types

1.Fatigue cracking	6. Transverse cracking	11. Bleeding	16. Other**
2. Block cracking	7. Patch/patch Deterioration	12. Polished Aggregate	
3. Edge cracking	8. Potholes	13. Raveling	
4. Longitudinal cracking	9.Rutting	14. Lane-to-Shoulder Dropoff	
5. Reflection cracking	10. Shoving	15. Water Bleeding and Pumping	

Distress Types	Severity Level			Measurement for calculating quantity of distress						Measurement for distress Map		NOTE
	Low	Moderate	High	Length, m	Width, m	height, mm	Crack width, mm	Number	Area, m^2	D_1, m	D_2, m	
10	-	M	H	1.1	2.7	-	-	2	5.94	2.8	1.6	
10	-	M	H	0.4	1.05	-	-	3	1.26	6.45	1.1	
13	-	-	H	18	3.2	-	-	-	57.6	10	0	
13	-	-	H	9.7	3.2	-	-	-	31.04	25	0	
7	-	-	H	1.5	1.3	-	-	-	1.95	34.7	0.7	
8	-	M	-	2.9	0.6	50	-	-	1.74	36.2	1.4	
8	-	M	-	1.7	0.9	40	-	-	1.53	40	0	
8	-	-	H	3.4	1.6	60	-	-	5.44	40.4	1	
7	-	-	H	7.7	3.3	-	-	-	25.41	40	0	
7	-	-	H	14	6.8	-	-	-	95.2	48.3	0	
8	-	-	H	4.9	3.3	160	-	-	16.17	48.3	0	
13	-	-	H	8.5	5		-	-	42.5	64.3	0	
8	-	-	H	8.6	3.2	100	-	-	27.52	72.9	0	
10	-	M	H	0.8	1.6		-	10	12.8	80.3	0.6	
8	-	-	H	1.8	0.8	90	-	-	1.44	84.3	0.25	
16**	-	M	-	1.85	1.3	20	-	-	2.405	7.15	3.9	Depression

Table D.2 Calculation of Deduct Value

Distress Severity	Quantity	Total	sample Area	Density	Deduct Value
1O M	20	20	700	2.857142857	18
13 H	131.14	131.14	700	18.73428571	54
7 H	122.56	122.56	700	17.50857143	64
8 M	3.27	3.27	700	0.467142857	20
8 H	50.57	50.57	700	7.224285714	96
16 M	2.405	2.405	700	0.343571429	8

M=1+(9/98) * (100 - 96)
M= 1.4 ...... Correction needed for the lowest deduct value, Use highest 1 deducts and the corrected value will be:-
(1.4 - 1) * 8 = 3.2

Table D.3 Calculation of Pavement Condition Index and Pavement Condition Rate

#	Deduct values In Descending Order									TDV	q	CDV	PCI	PCR
1	96	64	54	20	18	3.2				255.2	6	100	0	Failed
2	96	64	54	20	18	2				254	5	100		
3	96	64	54	20	2	2				238	4	100		
4	96	64	54	2	2	2				220	3	100		
5	96	64	2	2	2	2				168	2	100		
6	96	2	2	2	2	2				106	1	100		

PCI=100 - Max CDV
PCI = 100 - 100
PCI = 0

Pavemnt rating condition ,PCR= Failed

Total Distress Density in all Test Section

Distress No.	Distress Type	Distress Density in Test Section				Total Distress Density Combined	%age Distress
		Megenaga	Leghare	King Gorge St.	Mexico-Piyassa		
1	Fatigue cracking	0.00	0.00	31.55	7.97	39.52	7.24
2	Block cracking	0.00	0.00	3.27	0.87	4.14	0.76
3	Edge cracking	0.00	0.00	1.53	6.06	7.58	1.39
4	Longitudinal cracking	0.00	0.00	5.11	48.12	53.23	9.75
6	Transverse cracking	0.00	0.00	0.00	18.19	18.19	3.33
7	Patch/patch Deterioration	17.51	0.00	14.73	35.55	67.79	12.42
8	Potholes	7.69	6.67	11.69	74.18	100.24	18.36
9	Rutting	0.00	0.00	25.00	0.00	25.00	4.58
10	Shoving	2.86	0.62	62.89	25.93	92.30	16.90
13	Raveling	18.73	81.73	20.83	3.89	125.19	22.93
16	Other**[Depression]	0.34	0.66	3.17	8.70	12.87	2.36
	Total	47.14	89.68	179.77	229.45	546.05	100.00

Summary of PCI values for each Bus stop and Bus-Hub in the study sections

AratKilo to Sheromeda		
Bus Stop No.	PCI	PCR
1	51	Poor
2	0	Failed
3	19	Serious
4	28	Very Poor
5	100	Good
6	51	Poor
7	12	Serious
8	0	Failed
9	58	Fair
10	20	Serious
11	100	Good
12	52	Poor
13	78	Satisfactory
Total average	43.769	Poor

Mexico to Piyassa		
Bus Stop No.	PCI	PCR
1	40	Very Poor
2	20	Serious
3	26	Very Poor
4	46	Poor
5	57	Fair
6	42	Poor
7	35	Very Poor
8	72	Satisfactory
9	41	Poor
10	91	Good
11	100	Good
Total average	51.818	Poor

Leghare Bus station	
PCI	PCR
0	Failed

Megenaga Bus station	
PCI	PCR
0	Failed

APPENDIX B

DEDUCT VALUE CURVES FOR ASPHALT

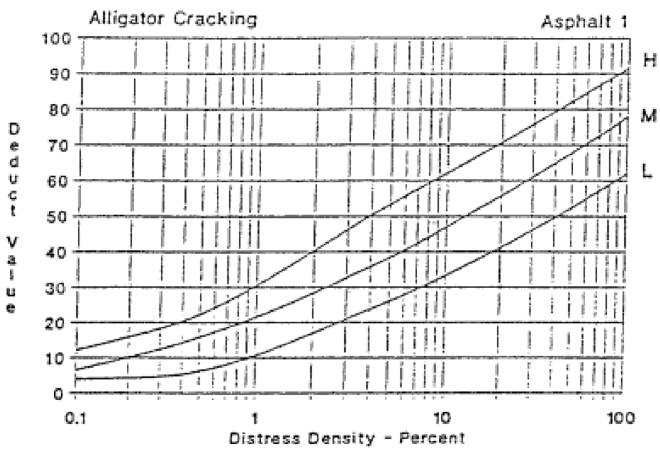


FIG. X3.1 Alligator Cracking

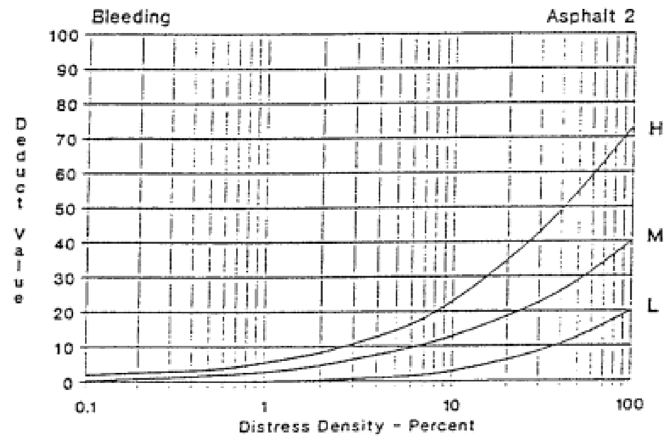


FIG. X3.2 Bleeding

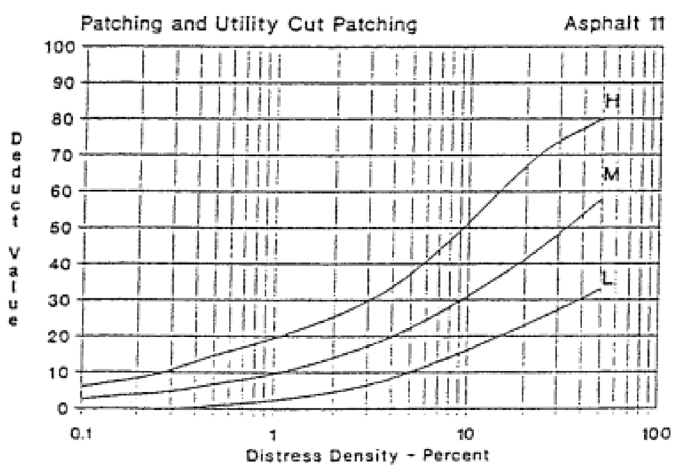


FIG. X3.16 Patching and Utility Cut Patching

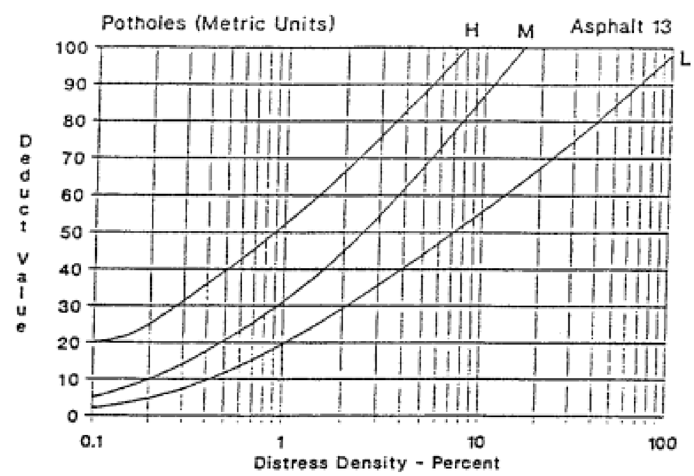


FIG. X3.19 Potholes (metric units)

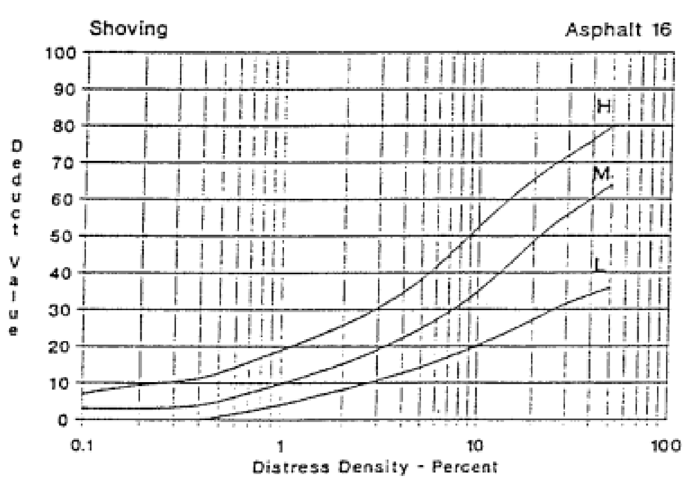


FIG. X3.22 Shoving

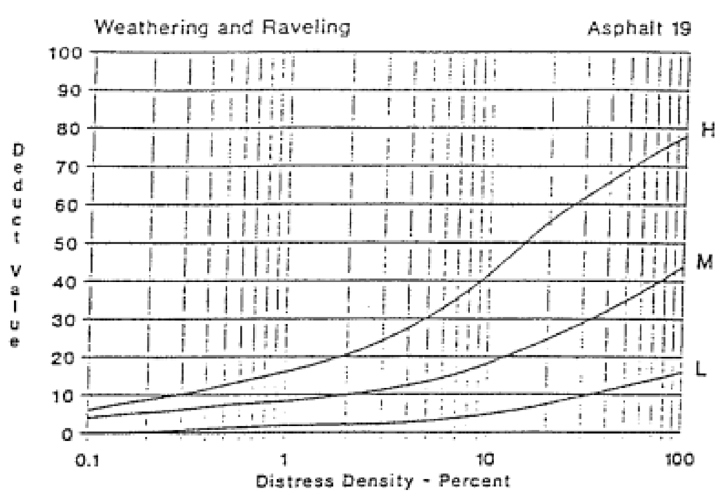


FIG. X3.25 Weathering and Raveling

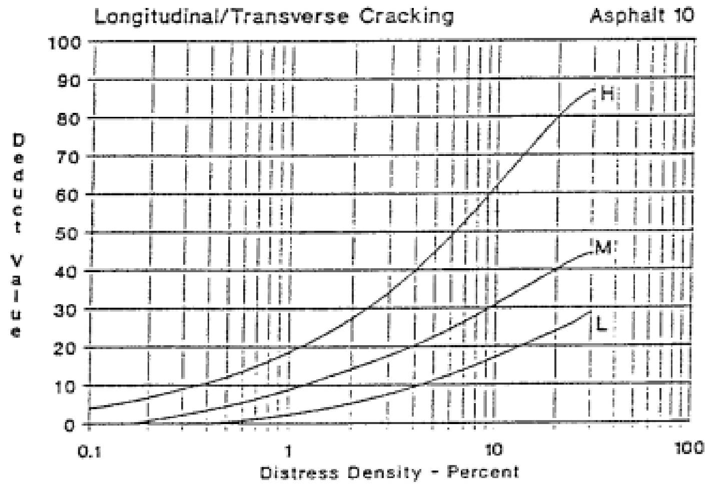


FIG. X3.14 Longitudinal/Transverse Cracking

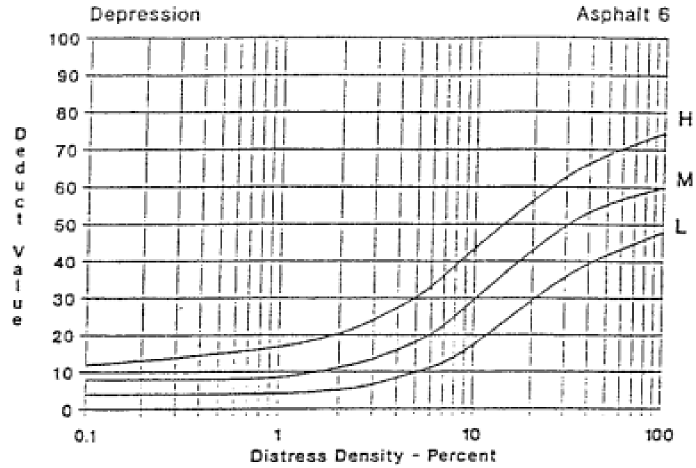


FIG. X3.7 Depression

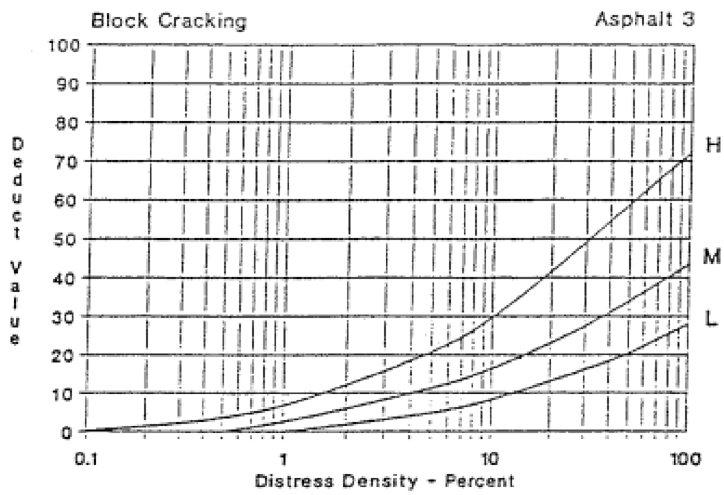


FIG. X3.3 Block Cracking

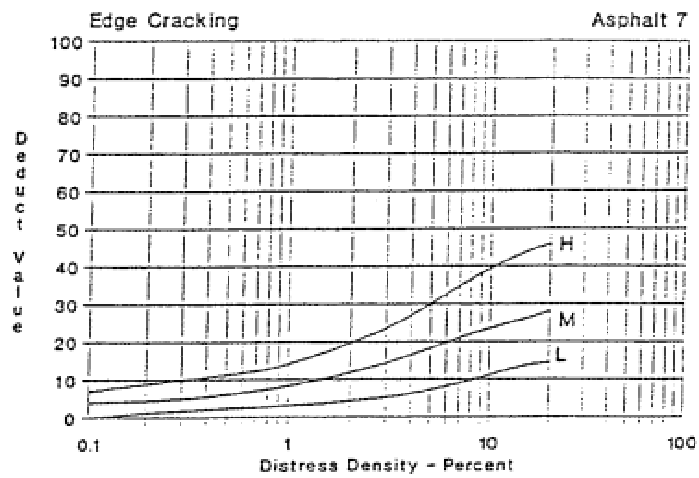


FIG. X3.8 Edge Cracking

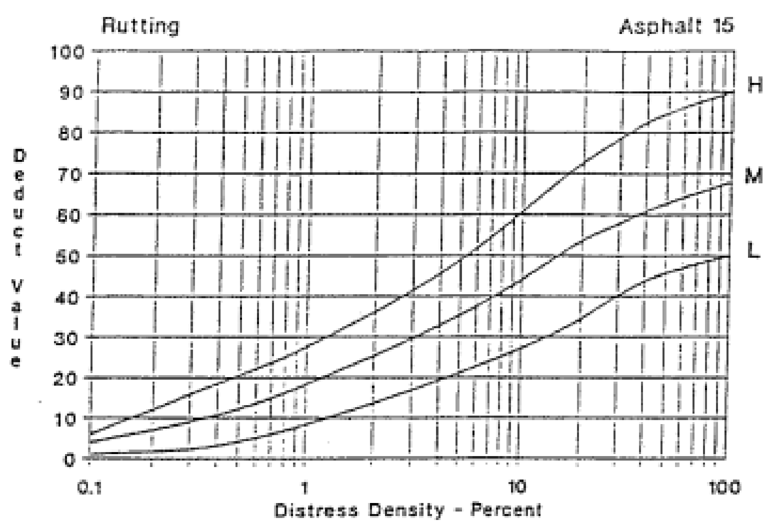


FIG. X3.21 Rutting

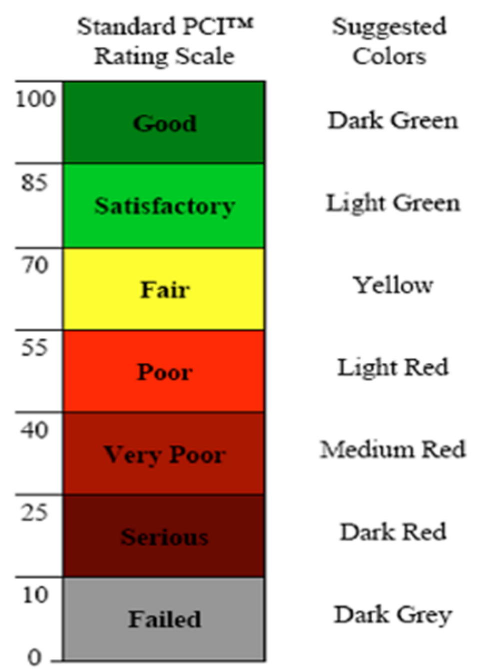
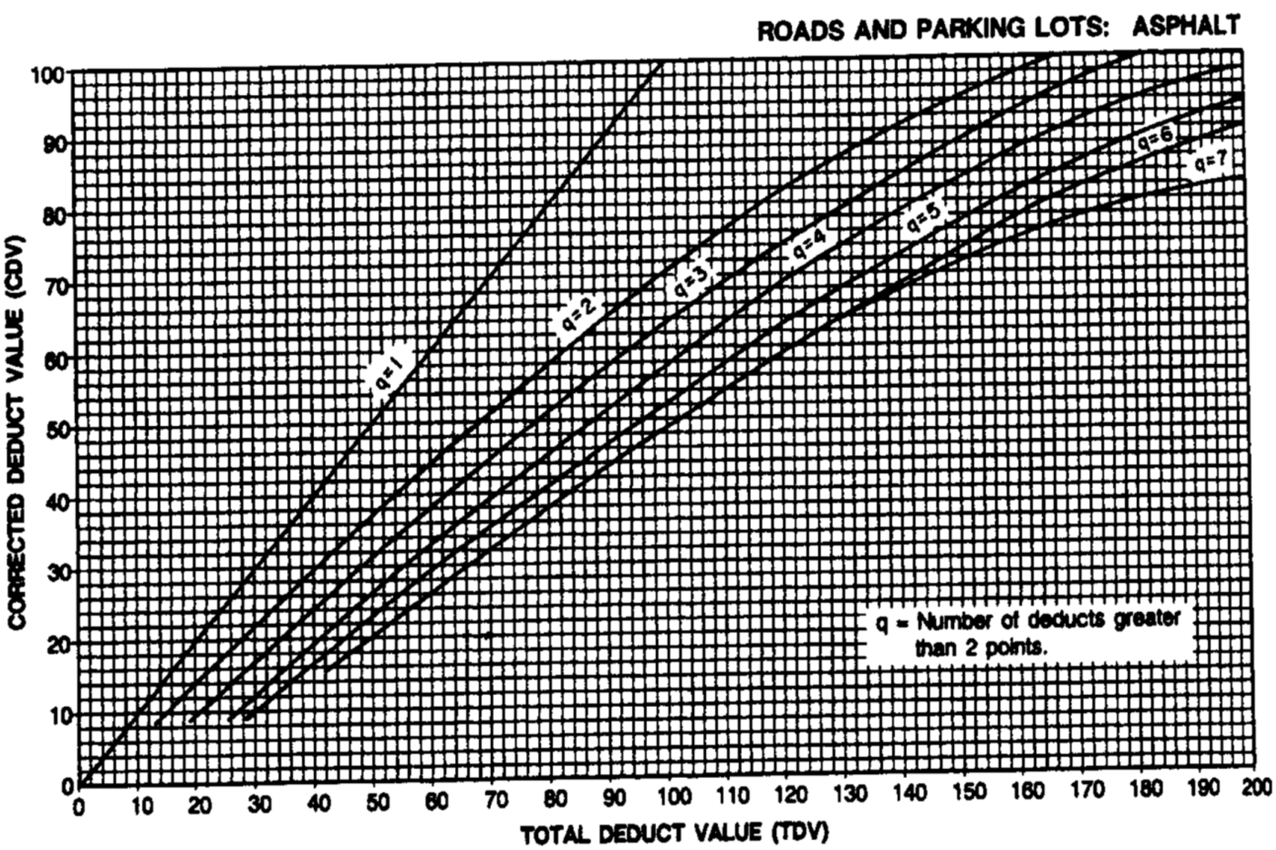


FIG. 1 Pavement Condition Index (PCI), Rating Scale, and Suggested Colors



APPENDIX C

TRAFFIC COUNT DATA, ANNUAL AVERAGE DAILY TRAFFIC, TRAFFIC VOLUME ANALYSIS and PAVEMENT DESIGN CHARTS

TRAFFIC COUNT DATA

Table C1: The traffic count data of AratKilo - Sheromeda

Date of Survey August 22/2016 - August 28/2016									
Name of the Road: AratKilo - Sheromeda									
Day	Cars			Light		Medium		Heavy	Articulated
	Standard Car	wagon & pickup	minibus & van	Large Bus	Single rear axle truck	Double Bus	Dual rear axle truck	4 Axle truck	Large Truck
Aug. 22	7479	4352	5299	823	338	135	36	5	0
Aug. 23	7451	4495	4975	821	365	129	50	0	0
Aug. 24	8111	4467	5123	724	398	149	33	0	0
Aug. 25, Day	7465	4423	4669	639	376	122	49	2	0
Aug. 25, Night	1761	598	1054	136	51	8	7	0	0
Aug. 26	7355	4510	4601	601	344	134	35	1	0
Aug. 27, Day	7855	3676	4996	418	373	151	26	1	0
Aug. 27, Night	1101	464	913	96	28	14	2	2	0
Aug. 28	4073	1898	3055	337	112	127	14	1	0
Total each	52651	28883	34685	4595	2385	969	252	12	0
Total	116219			6980		1221		12	0

Table C2: The traffic count data of Leghare Bus Depot

Date of Survey August 15/2016 - August 21/2016									
Name of the Road: Leghare Bus Depot									
Day	Cars			Light		Medium		Heavy	Articulated
	Standard Car	wagon & pickup	minibus & van	Large Bus	Single rear axle truck	Double Bus	Dual rear axle truck	4 Axle truck	Large Truck
Aug. 15	0	0	0	305	0	165	0	0	0
Aug. 16	0	0	0	289	0	125	0	0	0
Aug. 17	0	0	0	284	0	134	0	0	0
Aug. 18	0	0	0	268	0	144	0	0	0
Aug. 19	0	0	0	297	0	171	0	0	0
Aug. 20	0	0	0	183	0	153	0	0	0
Aug. 21	0	0	0	154	0	94	0	0	0
Total each	0	0	0	1780	0	986	0	0	0
Total	0			1780		986		0	0

Table C3: The traffic count data of Mexico - Piyassa

Date of Survey Jan 2/2017 - Jan 8/2017									
Name of the Road: Mexico - Piyassa									
Day	Cars			Light		Medium		Heavy	Articulated
	Standard Car	wagon & pickup	minibus & van	Large Bus	Single rear axle truck	Double Bus	Dual rear axle truck	4 Axle truck	Large Truck
Jan. 2	15137	8394	6570	699	438	215	62	0	1
Jan. 3	15080	8668	6168	688	423	200	54	6	3
Jan. 4, Day	17580	8856	7076	856	372	196	85	4	4
Jan. 4, Night	4215	1285	3623	101	132	28	3	0	1
Jan. 5	15652	7820	6988	777	524	188	72	3	0
Jan. 6	15421	7973	6886	622	563	225	52	5	2
Jan. 7, Day	12342	5863	5065	478	385	165	30	1	1
Jan. 7, Night	3729	2745	3925	115	98	35	7	0	0
Jan. 8	5536	4606	4604	394	349	101	15	0	0
Total each	104692	56210	50905	4730	3284	1353	380	19	12
Total	211807			8014		1733		19	12

Table C4: The traffic count data of Megenaga Bus Depot

Date of Survey Jan 2/2017 - Jan 8/2017									
Name of the Road: Megenaga Bus Depot									
Day	Cars			Light		Medium		Heavy	Articulated
	Standard Car	wagon & pickup	minibus & van	Large Bus	Single rear axle truck	Double Bus	Dual rear axle truck	4 Axle truck	Large Truck
Jan. 9	0	0	0	567	670	300	0	0	0
Jan. 10	0	0	0	569	611	265	0	0	0
Jan. 11, Day	0	0	0	665	768	204	0	0	0
Jan. 11, Night	0	0	0	52	53	26	0	0	0
Jan. 12	0	0	0	713	726	176	0	0	0
Jan. 13	0	0	0	666	664	197	0	0	0
Jan. 14, Day	0	0	0	386	443	132	0	0	0
Jan. 14, Night	0	0	0	33	33	40	0	0	0
Jan. 15	0	0	0	189	292	86	0	0	0
Total each	0	0	0	3840	4260	1426	0	0	0
Total	0			8100		1426		0	0

ANNUAL AVERAGE DAILY TRAFFIC

Table C5: AADT of AratKilo – Sheromeda

Date of Survey August 22/2016 - August 28/2016									
Name of the Road: 4kg-sheromeda									
Day	Cars			Light		Medium		Heavy	Articulated
	Standard Car	wagon & pickup	minibus & van	Large Bus	Single rear axle truck	Double Bus	Dual rear axle truck	4 Axle truck	Large Truck
Aug. 22	9243	4940	6495	998	384	144	41	5	0
Aug. 23	9209	5103	6098	996	415	137	57	0	0
Aug. 24	10024	5071	6279	878	452	159	38	0	0
Aug. 25	9226	5021	5723	775	427	130	56	2	0
Aug. 26	9090	5120	5640	729	391	143	40	1	0
Aug. 27	8956	4140	5909	514	401	165	28	3	0
Aug. 28	4644	2138	3613	414	120	139	15	3	0
Total each	60392	31532	39758	5304	2589	1017	275	14	0
Total	131682			7894		1292		14	0

Table C6: AADT of Mexico – Piyassa

Date of Survey Jan 2/2017 - Jan 8/2017									
Name of the Road: Mexico - Piyassa									
Day	Cars			Light		Medium		Heavy	Articulated
	Standard Car	wagon & pickup	minibus & van	Large Bus	Single rear axle truck	Double Bus	Dual rear axle truck	4 Axle truck	Large Truck
Jan. 2	18766	9612	9934	781	593	246	64	0	1
Jan. 3	18696	9926	9326	769	573	229	56	6	4
Jan. 4	21795	10141	10699	957	504	224	88	4	5
Jan. 5	19405	8955	10566	869	710	215	75	3	0
Jan. 6	19118	9130	10412	695	763	257	54	5	3
Jan. 7	16071	8608	8990	593	483	200	37	1	1
Jan. 8	7209	6762	8172	489	438	122	19	0	0
Total each	121060	63134	68098	5154	4064	1493	392	19	14
Total	252292			9218		1885		19	14

Table C7: AADT of Megenaga Bus-Depot

Date of Survey January 9/2016 - January 15/2016									
Name of the Bus-Depot : - Megenaga									
Day	Cars			Light		Medium		Heavy	Articulated
	Standard Car	wagon & pickup	minibus & van	Large Bus	Single rear axle truck	Double Bus	Dual rear axle truck	4 Axle truck	Large Truck
Jan. 9	0	0	0	611	716	338	0	0	0
Jan. 10	0	0	0	613	653	299	0	0	0
Jan. 11	0	0	0	717	821	230	0	0	0
Jan. 12	0	0	0	769	776	198	0	0	0
Jan. 13	0	0	0	718	710	222	0	0	0
Jan. 14	0	0	0	419	476	172	0	0	0
Jan. 15	0	0	0	205	314	112	0	0	0
Total each				4053	4466	1572	0	0	0
Total	0			8519		1572		0	0

Table C8: AADT of Leghare Bus-Depot

Date of Survey August 15/2016 - August 21/2016									
Name of the Bus-Depot : - Leghare									
Day	Cars			Light		Medium		Heavy	Articulated
	Standard Car	wagon & pickup	minibus & van	Large Bus	Single rear axle truck	Double Bus	Dual rear axle truck	4 Axle truck	Large Truck
Aug. 15	0	0	0	305	0	165	0	0	0
Aug. 16	0	0	0	289	0	125	0	0	0
Aug. 17	0	0	0	284	0	134	0	0	0
Aug. 18	0	0	0	268	0	144	0	0	0
Aug. 19	0	0	0	297	0	171	0	0	0
Aug. 20	0	0	0	183	0	153	0	0	0
Aug. 21	0	0	0	154	0	94	0	0	0
Total each	0	0	0	1780	0	986	0	0	0
Total	0			1780		986		0	0

Table C9: Cumulative projected AADT for 15years design period, in 10^4

Location	*Car*	*Light*	*Medium*	*Heavy*	*Articulated*	*Total AADT ∑15years*
AratKilo-Sheromeda	*346.63*	*22.72*	*4.07*	*0.04*	*0*	*373.46*
Leghare Bus-Depot	*0*	*5.48*	*3.24*	*0*	*0*	*8.73*
Mexico-Piyassa	*664.11*	*25.89*	*5.94*	*0.06*	*0.0403*	*696.04*
Megenaga Bus-Depot	*0*	*26.24*	*5.17*	*0*	*0*	*31.41*

Table C10: Cumulative projected AADT for 30 years design period, in 10^5

Location	*Car*	*Light*	*Medium*	*Heavy*	*Articulated*	*Total AADT ∑30years*
AratKilo-Sheromeda	*136.19*	*8.40*	*1.60*	*0.02*	*0*	*146.21*
Leghare Bus-Depot	*0*	*2.03*	*1.27*	*0*	*0*	*3.30*
Mexico-Piyassa	*260.94*	*9.57*	*2.34*	*0.026*	*0.018*	*272.88*
Megenaga Bus-Depot	*0*	*9.70*	*2.03*	*0*	*0*	*11.73*

TRAFFIC VOLUME ANALYSIS

a) Aratkilo-Sheromeda

Cumulative Equivalent standard Axle (CESA) for Aratkilo-Sheromeda

AADT	Car	ESA	Light	ESA	Medium	ESA	Heavy	ESA	Articulated	ESA	CESA	Comulative Traffic	Traffic Carried by Pavt. Rehab	Activities
2017	114195.0472	0	7892.128	979737.19	1340.588464	77152.7094	12.2976	7126.42	0	0	1064016.323	1064016.323		
2018	123787.4312	0	8499.822	1055177	1453.197895	83633.537	13.50276	7824.809	0	0	1146635.304	2210651.627		
2019	134185.5754	0	9154.308	1136425.6	1575.266518	90658.7541	14.82604	8591.64	0	0	1235675.978	3446327.605		
2020	145457.1638	0	9859.19	1223930.4	1707.588906	98274.0895	16.27899	9433.621	0	0	1331638.064	4777965.669		
2021	157675.5655	0	10618.35	1318173	1851.026374	106529.113	17.87433	10358.12	0	0	1435060.22	6213025.889		
2022	170920.313	0	11435.96	1419672.3	2006.51259	115477.558	19.62601	11373.21	0	0	1546523.081	7759548.97		
2023	185277.6193	0	12316.53	1528987.1	2175.059647	125177.673	21.54936	12487.79	0	0	1666652.538	9426201.508		
2024	200840.9393	0	13264.9	1646719.1	2357.764657	135692.598	23.6612	13711.59	0	0	1796123.271	11222324.78		
2025	217711.5782	0	14286.3	1773516.5	2555.816889	147090.776	25.98	15055.33	0	0	1935662.555	13157987.33		
2026	235999.3508	0	15386.35	1910077.2	2770.505507	159446.401	28.52604	16530.75	0	0	2086054.368	15244041.7		
2027	255823.2963	0	16571.09	2057153.2	3003.22797	172839.899	31.32159	18150.76	0	0	2248143.825	17492185.53		
2028	260887.7203	0	16956.52	2105000.7	3062.681586	176261.536	32.05477	18575.64	0	0	2299837.822	19792023.35		
2029	281236.9625	0	18177.39	2256560.7	3301.570749	190009.936	34.97175	20266.02	0	0	2466836.652	22258860		
2030	303173.4456	0	19486.16	2419033.1	3559.093268	204830.711	38.15418	22110.23	0	0	2645974.005	24904834.01		
2031	326820.9743	0	20889.17	2593203.4	3836.702543	220807.507	41.62621	24122.26	0	0	2838133.211	27742967.22		
2032	352313.0103	0	22393.19	2779914.1	4135.965341	238030.492	45.4142	26317.38	0	0	3044261.971	30787229.19		
∑15years		0		28203280		2341913.29		242035.5		0	**30,787,229.19**			
													30,787,229.19	**1st Rehab**
2033	379793.4251	0	24005.5	2980067.9	4458.570638	256596.871	49.54689	28712.26	0	0	3265377.046	34052606.23	3,265,377.04	
2034	409417.3123	0	25733.89	3194632.8	4806.339147	276611.427	54.05565	31325.08	0	0	3502569.307	37555175.54	6,767,946.35	
2035	441351.8626	0	27586.73	3424646.4	5181.233601	298187.118	58.97472	34175.66	0	0	3757009.142	41312184.68	10,524,955.49	
2036	475777.3079	0	29572.98	3671220.9	5585.369822	321445.713	64.34142	37285.65	0	0	4029952.261	45342136.94	14,554,907.75	
2037	512887.938	0	31702.23	3935548.8	6021.028668	346518.479	70.19649	40678.64	0	0	4322745.925	49664882.87	18,877,653.68	
2038	552893.1971	0	33984.79	4218908.3	6490.668904	373546.92	76.58437	44380.4	0	0	4636835.637	54,301,718.51	23,514,489.32	
2039	596018.8665	0	36431.7	4522669.7	6996.941078	402683.58	83.55354	48419.01	0	0	4973772.312	**59,275,490.82**	**28,488,261.63**	**2nd Rehab**
2040	642508.3381	0	39054.78	4848301.9	7542.702482	434092.899	91.15692	52825.14	0	0	5335219.981	64610710.8	5,335,219.98	
2041	692623.9884	0	41866.72	5197379.7	8131.033276	467952.145	99.4522	57632.23	0	0	5722964.055	70333674.85	11,058,184.03	
2042	746648.6595	0	44881.13	5571591	8765.253872	504452.413	108.5023	62876.76	0	0	6138920.192	76472595.04	17,197,104.22	
2043	804887.255	0	48112.57	5972745.6	9448.943673	543799.701	118.3761	68598.55	0	0	6585143.819	83057738.86	23,782,248.04	
2044	867668.4609	0	51576.68	6402783.2	10185.96128	586216.077	129.1483	74841.02	0	0	7063840.344	**90,121,579.21**	**30,846,088.39**	**3nd Rehab**
2045	935346.6008	0	55290.2	6863783.6	10980.46626	631940.931	140.9008	81651.55	0	0	7577376.125	97698955.33	7,577,376.12	
2046	1008303.636	0	59271.09	7357976.1	11836.94263	681232.324	153.7227	89081.84	0	0	8128290.231	105827245.6	15,705,666.35	
2047	1086951.319	0	63538.61	7887750.3	12760.22415	734368.445	167.7115	97188.29	0	0	8719307.076	114546552.6	24,424,973.43	
∑30years		0		104253287		9201558.34		1091708		0	**114,546,552.64**			

b) Leghare Bus-Hub

Cumulative Equivalent standard Axle (CESA) for Leghare Bus-Hub

AADT	Car	ESA	Light	ESA	Medium	ESA	Heavy	ESA	Articulated	ESA	CESA	Comulative Traffic	Traffic Carried by Pavt. Rehab	Activities
2017	0	0	1904.6	472878.14	1068.824	123024.582	0	0	0	0	595902.7169	595902.7169		
2018	0	0	2051.254	509289.75	1158.605216	133358.647	0	0	0	0	642648.3982	1238551.115		
2019	0	0	2209.201	548505.06	1255.928054	144560.773	0	0	0	0	693065.8354	1931616.951		
2020	0	0	2379.309	590739.95	1361.426011	156703.878	0	0	0	0	747443.8301	2679060.781		
2021	0	0	2562.516	636226.93	1475.785796	169867.003	0	0	0	0	806093.9322	3485154.713		
2022	0	0	2759.83	685216.4	1599.751802	184135.832	0	0	0	0	869352.234	4354506.947		
2023	0	0	2972.337	737978.07	1734.130954	199603.242	0	0	0	0	937581.3069	5292088.254		
2024	0	0	3201.207	794802.38	1879.797954	216369.914	0	0	0	0	1011172.29	6303260.544		
2025	0	0	3447.7	856002.16	2037.700982	234544.987	0	0	0	0	1090547.146	7393807.69		
2026	0	0	3713.172	921914.33	2208.867865	254246.766	0	0	0	0	1176161.091	8569968.781		
2027	0	0	3999.087	992901.73	2394.412765	275603.494	0	0	0	0	1268505.222	9838474.003		
2028	0	0	4092.102	1015995.7	2441.813927	281059.498	0	0	0	0	1297055.205	11135529.21		
2029	0	0	4386.733	1089147.4	2632.275414	302982.139	0	0	0	0	1392129.536	12527658.74		
2030	0	0	4702.578	1167566	2837.592896	326614.746	0	0	0	0	1494180.756	14021839.5		
2031	0	0	5041.163	1251630.8	3058.925142	352090.696	0	0	0	0	1603721.459	15625560.96		
2032	0	0	5404.127	1341748.2	3297.521303	379553.77	0	0	0	0	1721301.948	17346862.91		
∑15years		0		13612543		3734319.96		0		0	**17,346,862.91**			
													17,346,862.91	**1st Rehab**
2033	0	0	5793.224	1438354	3554.727965	409158.964	0	0	0	0	1847513.011	19194375.92	1,847,513.01	
2034	0	0	6210.336	1541915.5	3831.996746	441073.363	0	0	0	0	1982988.901	21177364.82	3,830,501.91	
2035	0	0	6657.481	1652933.5	4130.892492	475477.086	0	0	0	0	2128410.542	23305775.36	5,958,912.45	
2036	0	0	7136.819	1771944.7	4453.102106	512564.298	0	0	0	0	2284508.964	25590284.32	8,243,421.41	
2037	0	0	7650.67	1899524.7	4800.444071	552544.314	0	0	0	0	2452068.995	28042353.32	10,695,490.41	
2038	0	0	8201.519	2036290.5	5174.878708	595642.77	0	0	0	0	2631933.229	30,674,286.55	13,327,423.64	
2039	0	0	8792.028	2182903.4	5578.519248	642102.906	0	0	0	0	2825006.278	**33,499,292.83**	**16,152,429.92**	**2nd Rehab**
2040	0	0	9425.054	2340072.4	6013.643749	692186.933	0	0	0	0	3032259.347	36531552.17	3,032,259.34	
2041	0	0	10103.66	2508557.6	6482.707961	746177.514	0	0	0	0	3254735.142	39786287.32	6,286,994.49	
2042	0	0	10831.12	2689173.8	6988.359182	804379.36	0	0	0	0	3493553.137	43279840.45	9,780,547.62	
2043	0	0	11610.96	2882794.3	7533.451198	867120.95	0	0	0	0	3749915.239	47029755.69	13,530,462.86	
2044	0	0	12446.95	3090355.5	8121.060392	934756.384	0	0	0	0	4025111.862	**51,054,867.55**	**17,555,574.72**	**3rd Rehab**
2045	0	0	13343.13	3312861.1	8754.503102	1007667.38	0	0	0	0	4320528.454	55375396.01	4,320,528.46	
2046	0	0	14303.84	3551387.1	9437.354344	1086265.44	0	0	0	0	4637652.507	60013048.51	8,958,180.96	
2047	0	0	15333.71	3807086.9	10173.46798	1170994.14	0	0	0	0	4978081.081	64991129.6	13,936,262.05	
∑30years		0		50318698		14672431.8		0		0	**64,991,129.60**			

c) Mexico – Piyassa Route

Cumulative Equivalent standard Axle (CESA) for Mexico – Piyassa Route

AADT	Car	ESA	Light	ESA	Medium	ESA	Heavy	ESA	Articulated	ESA	CESA	Comulative Traffic	Traffic Carried by Pavt. Rehab	Activities
2017	218787.4122	0	8993.096	1116412.5	1958.014487	112686.426	16.6896	9671.57	11.8584	12401.1664	1251171.639	1251171.639		
2018	237165.5548	0	9685.564	1202376.2	2122.487704	122152.086	18.32518	10619.38	13.020523	13616.4807	1348764.187	2599935.826		
2019	257087.4614	0	10431.35	1294959.2	2300.776671	132412.861	20.12105	11660.08	14.296534	14950.8958	1453983.047	4053918.873		
2020	278682.8082	0	11234.57	1394671.1	2494.041912	143535.541	22.09291	12802.77	15.697595	16416.0836	1567425.463	5621344.336		
2021	302092.1641	0	12099.63	1502060.7	2703.541432	155592.527	24.25802	14057.44	17.235959	18024.8598	1689735.568	7311079.904		
2022	327467.9058	0	13031.3	1617719.4	2930.638913	168662.299	26.6353	15435.07	18.925083	19791.296	1821608.083	9132687.987		
2023	354975.2099	0	14034.71	1742283.8	3176.812581	182829.932	29.24556	16947.71	20.779741	21730.843	1963792.295	11096480.28		
2024	384793.1276	0	15115.38	1876439.7	3443.664838	198187.646	32.11163	18608.59	22.816156	23860.4657	2117096.361	13213576.64		
2025	417115.7503	0	16279.27	2020925.5	3732.932684	214835.409	35.25857	20432.23	25.052139	26198.7913	2282391.944	15495968.59		
2026	452153.4733	0	17532.77	2176536.8	4046.49903	232881.583	38.71391	22434.59	27.507249	28766.2728	2460619.223	17956587.81		
2027	490134.3651	0	18882.79	2344130.1	4386.404948	252443.636	42.50787	24633.17	30.202959	31585.3676	2652792.293	20609380.1		
2028	499837.3448	0	19321.99	2398652.4	4473.240725	257441.154	43.5029	25209.79	30.909954	32324.7214	2713628.084	23323008.19		
2029	538824.6577	0	20713.17	2571355.4	4822.153502	277521.564	47.46166	27503.88	33.722759	35266.2711	2911647.109	26234655.3		
2030	580852.981	0	22204.52	2756493	5198.281475	299168.247	51.78067	30006.73	36.79153	38475.5017	3124143.463	29358798.76		
2031	626159.5135	0	23803.25	2954960.5	5603.74743	322503.37	56.49271	32737.35	40.13956	41976.7724	3352177.965	32710976.72		
2032	674999.9556	0	25517.08	3167717.6	6040.83973	347658.633	61.63355	35716.45	43.79226	45796.6587	3596889.367	36307866.09		
∑15years		0		32137694		3420512.91		328476.8		421182.448	**36,307,866.09**			
													36,307,866.09	**1st Rehab**
2033	727649.9521	0	27354.31	3395793.3	6512.025228	374776.006	67.2422	38966.64	47.777355	49964.1546	3859500.102	40167366.19	3,859,500.10	
2034	784406.6484	0	29323.82	3640290.4	7019.963196	404008.534	73.36124	42512.61	52.125095	54510.8927	4141322.45	44308688.64	8,000,822.55	
2035	845590.367	0	31435.14	3902391.3	7567.520326	435521.2	80.03712	46381.25	56.868478	59471.3839	4443765.164	48752453.81	12,444,587.72	
2036	911546.4156	0	33698.47	4183363.5	8157.786911	469491.854	87.3205	50601.95	62.04351	64883.2799	4768340.583	53520794.39	17,212,928.30	
2037	982647.036	0	36124.76	4484565.7	8794.09429	506112.218	95.26666	55206.73	67.689469	70787.6583	5116672.276	58637466.67	22,329,600.58	
2038	1059293.505	0	38725.74	4807454.4	9480.033645	545588.971	103.9359	60230.54	73.849211	77229.3352	5490503.246	64,127,969.91	27,820,103.82	
2039	1141918.398	0	41513.99	5153591.1	10219.47627	588144.911	113.3941	65711.52	80.569489	84257.2047	5891704.752	**70,019,674.66**	**33,711,808.57**	**2nd Rehab**
2040	1230988.033	0	44503	5524649.7	11016.59542	634020.214	123.713	71691.26	87.901312	91924.6104	6322285.769	76341960.43	6,322,285.77	
2041	1327005.1	0	47707.22	5922424.5	11875.88986	683473.791	134.9708	78215.17	95.900332	100289.75	6784403.167	83126363.6	13,106,688.94	
2042	1430511.498	0	51142.14	6348839	12802.20927	736784.747	147.2532	85332.75	104.62726	109416.117	7280372.631	90406736.23	20,387,061.57	
2043	1542091.394	0	54824.37	6805955.4	13800.78159	794253.957	160.6532	93098.03	114.14834	119372.984	7812680.398	98219416.63	28,199,741.97	
2044	1662374.523	0	58771.72	7295984.2	14877.24256	856205.765	175.2727	101570	124.53584	130235.925	8383995.859	**106,603,412.49**	**36,583,737.83**	**3rd Rehab**
2045	1792039.736	0	63003.29	7821295.1	16037.66748	922989.815	191.2225	110812.8	135.8686	142087.395	8997185.108	115600597.6	**8,997,185.11**	
2046	1931818.835	0	67539.52	8384428.3	17288.60554	994983.021	208.6237	120896.8	148.23265	155017.347	9655325.478	125255923.1	**18,652,510.58**	
2047	2082500.705	0	72402.37	8988107.2	18637.11677	1072591.7	227.6085	131898.4	161.72182	169123.926	10361721.18	135617644.3	**29,014,231.76**	
∑30years		0		118796827		13439459.6		1481603		1899754.41	**135,617,644.25**			

d) Megenaga Bus-Hub

Cumulative Equivalent standard Axle (CESA) for Megenaga Bus-Hub

AADT	Car	ESA	Light	ESA	Medium	ESA	Heavy	ESA	Articulated	ESA	CESA	Comulative Traffic	Traffic Carried by Pavt. Rehab	Activities
2017	0	0	9115.221	1131573.2	1703.624834	98045.9517	0	0	0	0	1229619.181	1229619.181		
2018	0	0	9817.093	1218704.4	1846.72932	106281.812	0	0	0	0	1324986.179	2554605.36		
2019	0	0	10573.01	1312544.6	2001.854583	115209.484	0	0	0	0	1427754.088	3982359.448		
2020	0	0	11387.13	1413610.5	2170.010368	124887.08	0	0	0	0	1538497.619	5520857.068		
2021	0	0	12263.94	1522458.6	2352.291239	135377.595	0	0	0	0	1657836.145	7178693.213		
2022	0	0	13208.26	1639687.9	2549.883703	146749.313	0	0	0	0	1786437.172	8965130.385		
2023	0	0	14225.3	1765943.8	2764.073934	159076.256	0	0	0	0	1925020.079	10890150.46		
2024	0	0	15320.65	1901921.5	2996.256145	172438.661	0	0	0	0	2074360.159	12964510.62		
2025	0	0	16500.34	2048369.5	3247.941661	186923.509	0	0	0	0	2235292.962	15199803.58		
2026	0	0	17770.86	2206093.9	3520.76876	202625.083	0	0	0	0	2408718.985	17608522.57		
2027	0	0	19139.22	2375963.1	3816.513336	219645.59	0	0	0	0	2595608.722	20204131.29		
2028	0	0	19584.38	2431225.8	3892.067213	223993.82	0	0	0	0	2655219.662	22859350.95		
2029	0	0	20994.46	2606274.1	4195.648456	241465.338	0	0	0	0	2847739.44	25707090.39		
2030	0	0	22506.06	2793925.8	4522.909036	260299.634	0	0	0	0	3054225.472	28761315.86		
2031	0	0	24126.49	2995088.5	4875.69594	280603.005	0	0	0	0	3275691.504	32037007.37		
2032	0	0	25863.6	3210734.9	5256.000224	302490.04	0	0	0	0	3513224.91	35550232.28		
∑15years		0		32574120		2976112.17		0		0	**35,550,232.28**			
													35,550,232.28	**1st Rehab**
2033	0	0	27725.78	3441907.8	5665.968241	326084.263	0	0	0	0	3767992.044	39318224.32	3,767,992.04	
2034	0	0	29722.04	3689725.1	6107.913764	351518.836	0	0	0	0	4041243.976	43359468.3	7,809,236.02	
2035	0	0	31862.02	3955385.4	6584.331038	378937.305	0	0	0	0	4334322.656	47693790.95	12,143,558.67	
2036	0	0	34156.09	4240173.1	7097.908859	408494.414	0	0	0	0	4648667.511	52342458.46	16,792,226.18	
2037	0	0	36615.33	4545465.6	7651.54575	440356.979	0	0	0	0	4985822.538	57328281.00	21,778,048.72	
2038	0	0	39251.63	4872739.1	8248.366318	474704.823	0	0	0	0	5347443.903	62,675,724.91	27,125,492.63	
2039	0	0	42077.75	5223576.3	8891.738891	511731.799	0	0	0	0	5735308.093	**68,411,033.00**	**32,860,800.72**	**2nd Rehab**
2040	0	0	45107.35	5599673.8	9585.294524	551646.88	0	0	0	0	6151320.666	74562353.66	6,151,320.66	
2041	0	0	48355.07	6002850.3	10332.9475	594675.336	0	0	0	0	6597525.635	81159879.3	12,748,846.30	
2042	0	0	51836.64	6435055.5	11138.9174	641060.012	0	0	0	0	7076115.533	88235994.83	19,824,961.83	
2043	0	0	55568.88	6898379.5	12007.75296	691062.693	0	0	0	0	7589442.211	95825437.04	27,414,404.04	
2044	0	0	59569.84	7395062.8	12944.35769	744965.584	0	0	0	0	8140028.427	**103,965,465.47**	**35,554,432.47**	**3rd Rehab**
2045	0	0	63858.87	7927507.4	13954.01759	803072.899	0	0	0	0	8730580.267	112696045.7	8,730,580.27	
2046	0	0	68456.7	8498287.9	15042.43096	865712.585	0	0	0	0	9364000.484	122060046.2	18,094,580.75	
2047	0	0	73385.59	9110164.6	16215.74058	933238.167	0	0	0	0	10043402.79	132103449	28,137,983.55	
∑30years		0		120410074		11693374.7		0		0	**132,103,449.02**			

Total CESA of each Vehicle Category for 15years design period for Flexible Pavement Design

Type	Car	Light	Medium	Heavy	Articulated	Total CESA ∑15years	Traffic Class
AratKilo-Sheromeda	0	28,203,280.35	2,341,913.29	242,035.54	0	30,787,229.19	T9
Leghare Bus-Hub	0	13,612,542.94	3734319.965	0	0	17,346,862.91	T8
Mexico-Piyassa	0	32,137,693.92	3,420,512.91	328,476.81	421,182.45	36,307,866.09	T9
Megenaga Bus-Hub	0	32,574,120.11	2,976,112.17	0	0	35,550,232.28	T9

Total CESA of each Vehicle Category for 30years design period for Rigid Pavement Design

Type	Car	Light	Medium	Heavy	Articulated	Total CESA ∑30years
AratKilo-Sheromeda	0	104,253,286.68	9,201,558.34	1,091,707.62	0	114,546,552.64
Leghare Bus-Hub	0	50,318,697.83	14672431.77	0	0	64,991,129.60
Mexico-Piyassa	0	118,796,827.03	13,439,459.61	1,481,603.20	1,899,754.41	135,617,644.25
Megenaga Bus-Hub	0	120,410,074.27	11,693,374.75	0	0	132,103,449.02

Pavement Design Charts, ERA Pavement Design Manual Volume I & II

a) For Flexible Pavement

CHART C1: HMA SURFACE, UNBOUND GRANULAR ROADBASE

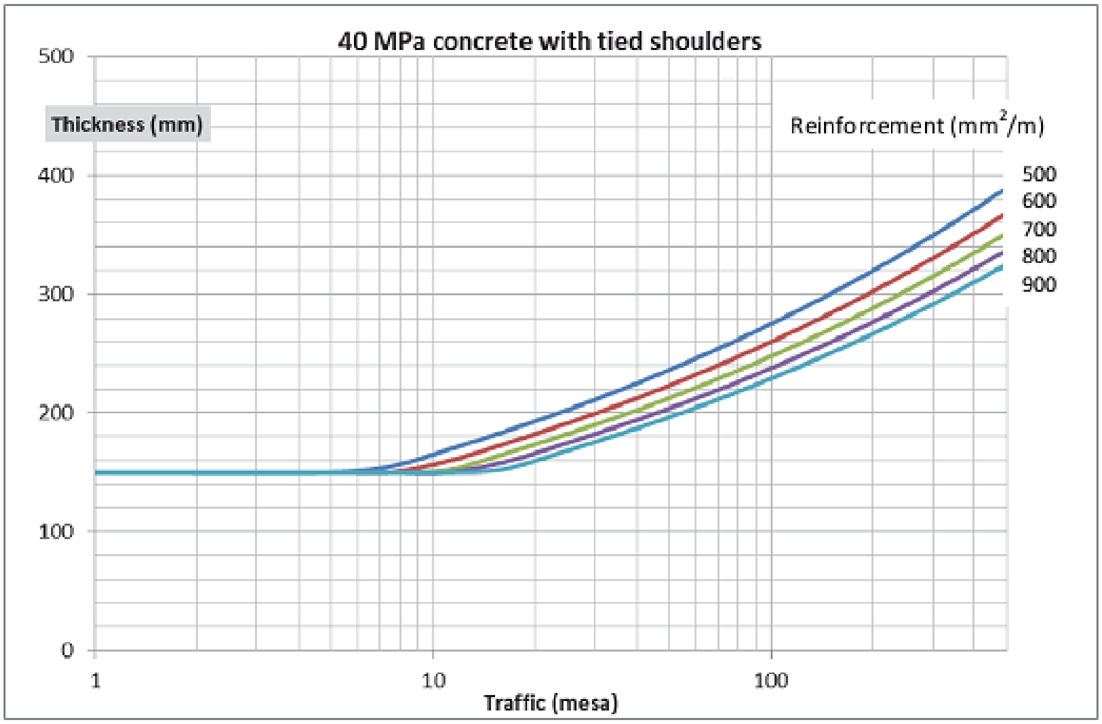
Subgrade class	T6 6 – 10	T7 10 – 17	T8 17 - 30
S1	100 200 225 350	125 200 250 350	150 200 300 350
S2	100 200 225 200	125 200 250 200	150 200 300 200
S3	100 200 250	125 200 275	150 200 325
S4	100 200 175	125 200 200	150 200 225
S5	100 150 150	125 175 150	150 200 150
S6	100 200	125 225	150 250

CHART D1: HMA SURFACE, BITUMEN-BOUND ROADBASE

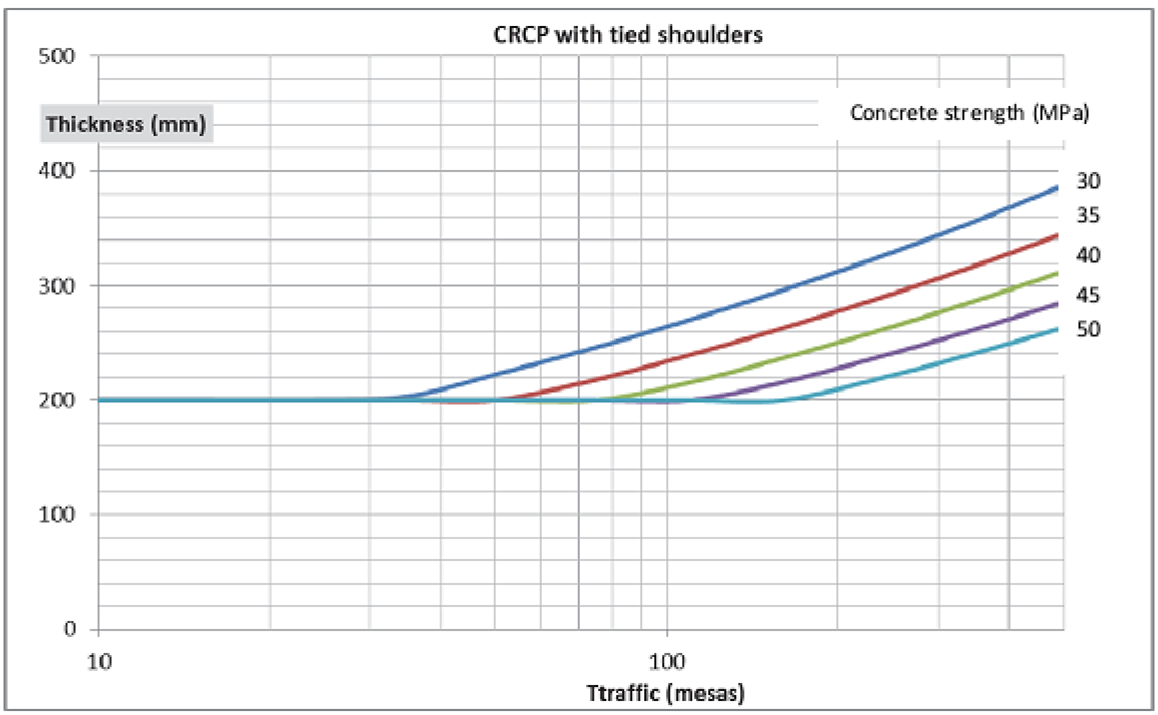
Subgrade class	T6 6 – 10	T7 10 – 17	T8 17 - 30	T9 30 - 50	T10 50 - 80
S1	90 130 200 300	90 150 225 300	90 170 250 300	90 190 250 300	90 220 250 300
S2	90 130 200 200	90 150 200 200	90 170 200 200	90 190 225 200	90 220 225 200
S3	90 130 150 150	90 150 150 150	90 170 175 150	90 190 175 150	90 220 175 150
S4	90 130 150	90 150 150	90 170 175	90 190 175	90 220 175
S5	90 130 100	90 150 100	90 170 100	90 190 100	90 220 100
S6	90 110	90 130	90 150	90 170	90 190

B) For Rigid Pavement

Design Thicknesses for JRCP (40 MPa concrete and tied shoulders)



Design Thickness for CRCP with tied shoulders



APPENDIX D

COST BREAK DOWN FOR C-40 CONCRETE

ANALYSIS OF COST BREDOWN FOR C-40 CONCRETE

										Date					
										Page No.					
	(i) Concrete C-40									Monthly Output					
										Labor:					
										Equipment:					
										Resultant Taken:	10.00		m^3/d		
											1.43		m^3/h		
No.	**D) Material Type**	**Qty. Per Measure**	**Unit Price**	**Cost Per Measure**	**E) Labor by Skills**	**No.**	**U.F.**	**Indexed Hourly Rate**	**Hourly Cost**	**F) Equipment Type**	**No.**	**U.F.**	**Hourly Rental Rate**	**Hourly Cost**	
	Cement	4.50	263.80	1187.10	Construction Forman	1	1.00	26.79	26.79	Concrete Mixer	1	1.00	216.83	216.83	
	Aggregate(20mm)	0.79	517.39	408.74	Mason & Carpentor	4	1.00	20.00	80.00	Concrete Vibrator	2	1.00	76.94	153.88	
	Sand	0.52	520.00	270.40	Bar bender	1	1.00	18.75	18.75	Water Tanker	1	1.00	5.00	5.00	
	formwork	1.50	215.00	322.50	light vehicle	1	0.25	16.46	4.12	Dump Truck	2	0.25	588.36	294.18	
					Laborers	15	1.00	7.13	106.88	Water Truck	1	0.50	387.21	193.61	
					Heavy Truck Driver	1	0.25	48.08	12.02	Hand Tools	15	1.00	0.35	5.25	
										light vehicle	1	0.25	278.66	69.67	
		Sub Total (A)	=	2188.74			Sub Total (B)	=	248.55			Sub Total (C)	=	938.41	
Purchase+Fabic's+Transport+Waste+Store															
(D)	Material			(E)	Manpower					(F) Equipment					
	Unit Price=Sub Total (A) =		2188.74		Unit Cost =	Sub Total(B) = / Hourly output		248.55 / 1.43	173.99	Unit Cost =	Sub Total(C) = / Hourly output		938.41 / 1.43	656.89	
	Direct Cost =	D+E+F =	3,019.61	Birr/M3											
	Remarks:			Considering O.H. and Profit margin =		1.3	x	3,019.61	=	**3,925.49**					
	UF - Utilization Factor			H.D.E - Heavy Duty Equipment											

APPENDIX E

INITIAL COST ANALYSIS and COST COMPARISON BETWEEN ALTERNATIVE PAVEMENT STRUCTURES

INITIAL COST ANALYSIS

Table E 1: Initial costs for AratKilo-Sheromeda, Mexico-Piyassa & Megenaga Bus-Depot for S3

Description	*Pavement Layers*	*Amount*	*Unit*	*Quantity per 100m*	*Unit Rate (ETB)*	*Cost(ETB)*
Surface	*AC, WC*	*40mm*	*m^2*	*365*	*286*	*104390*
	AC, BC	*50mm*	*m^2*	*365*	*344.5*	*125742.5*
Tack Coat	*Rc-70*	*0.2 l/m^2*	*Liter*	*73*	*35*	*2555*
Prime coat	*MC-30*	*1 l/m^2*	*liter*	*365*	*30*	*10950*
Base layer	*BRB*	*190mm*	*m^3*	*69.35*	*2785.13*	*193148.7655*
Sub-Base	*GS*	*175mm*	*m^3*	*63.875*	*422.5*	*26987.1875*
Capping	*GC*	*150mm*	*m^3*	*54.75*	*175*	*9581.25*
					Total Initial Cost	*473,354.70*

Table E 2: Initial costs for AratKilo-Sheromeda, Mexico-Piyassa & Megenaga Bus-Depot for S3 with Geogrid

Description	*Pavement Layers*	*Amount*	*Unit*	*Quantity per 100m*	*Unit Rate (ETB)*	*Cost(ETB)*
Surface	*AC, WC*	*40mm*	*m^2*	*365*	*286*	*104390*
	AC, BC	*50mm*	*m^2*	*365*	*344.5*	*125742.5*
Geosynthetic	*Geogrid*		*m^2*	*365*	*66.6*	*24309*
Tack Coat	*Rc-70*	*0.2L/m^2*	*liter*	*73*	*35*	*2555*
Prime coat	*MC-30*	*1L/m^2*	*liter*	*365*	*30*	*10950*
Base layer	*BRB*	*190mm*	*m^3*	*69.35*	*2785.13*	*193148.7655*
Sub-Base	*GS*	*175mm*	*m^3*	*63.875*	*422.5*	*26987.1875*
Capping	*GC*	*150mm*	*m^3*	*54.75*	*175*	*9581.25*
Total Initial Cost						*497,663.70*

Table E 3: Initial costs for AratKilo-Sheromeda, Rigid Pavement for S3

Description	*Pavement Layers*	*Amount*	*Unit*	*Quantity per 100m*	*Unit Rate (ETB)*	*Cost(ETB)*
Surface	*Concrete*	*218mm*	*m^3*	*79.57*	*3925.5*	*312352.035*
	Reinforcement		*Kg*	*4491.7*	*27*	*121275.9*
Prime coat	*MC-30*	*1L/m^2*	*liter*	*365*	*30*	*10950*
Sub-Base	*GS*	*150mm*	*m^3*	*54.75*	*422.5*	*23131.875*
Capping	*GC*	*250mm*	*m^3*	*91.25*	*175*	*15968.75*
Material for Joints, and Curing Work (1.5 % of pavement Costs)						*7255.1784*
					Total Initial Cost	*490,933.74*

Table E 4: Initial costs for AratKilo-Sheromeda, Rigid Pavement for S3 with Geogrid

Description	*Pavement Layers*	*Amount*	*Unit*	*Quantity per 100m*	*Unit Rate (ETB)*	*Cost(ETB)*
Surface	*Concrete*	*218mm*	*m^3*	*79.57*	*3925.5*	*312352.035*
	Reinforcement		*Kg*	*4491.7*	*27*	*121275.9*
Geosynthetic	*Geogrid*		*m^2*	*365*	*66.6*	*24309*
Prime coat	*MC-30*	*$1L/m^2$*	*Liter*	*365*	*30*	*10950*
Sub-Base	*GS*	*150mm*	*m^3*	*54.75*	*422.5*	*23131.875*
Capping	*GC*	*250mm*	*m^3*	*91.25*	*175*	*15968.75*
Material for Joints, and Curing Work (1.5 % of pavement Costs)						*7619.8134*
Total Initial Cost						*515,607.37*

Table E 5: Total initial cost for the road section, S3

Road Section	*Total Initial Cost for S3*			
	Flexible Pavement	*Flexible Pavement with Geogrid*	*Rigid Pavement*	*Rigid Pavement with Geogrid*
Aratkilo-Sheromeda	*473,354.70*	*497,663.70*	*490,933.74*	*515,607.37*
Leghare Bus-Depot	*327,920.56*	*352,229.56*	*456,279.98*	*480,953.61*
Mexico-Piyassa	*473,354.70*	*497,663.70*	*498,740.54*	*523,414.17*
Megenaga Bus-Depot	*473,354.70*	*497,663.70*	*494,965.94*	*519,639.58*

Table E 6: Total initial cost for the road section, S5

Road Section	*Total Initial Cost for S5*			
	Flexible Pavement	*Flexible Pavement with Geogrid*	*Rigid Pavement*	*Rigid Pavement with Geogrid*
Aratkilo-Sheromeda	*452,207.52*	*476,516.52*	*478,638.60*	*503,312.23*
Leghare Bus-Depot	*300,933.38*	*325,023.38*	*443,984.84*	*468,436.19*
Mexico-Piyassa	*452,207.52*	*476,516.52*	*486,445.40*	*511,119.04*
Megenaga Bus-Depot	*452,207.52*	*476,516.52*	*482,670.80*	*507,344.44*

Table E 7: Total initial cost for the road section, S6

Road Section	*Total Initial Cost for S6*			
	Flexible Pavement	*Flexible Pavement with Geogrid*	*Rigid Pavement*	*Rigid Pavement with Geogrid*
Aratkilo-Sheromeda	*416,454.82*	*440,763.82*	*451,246.60*	*475,424.21*
Leghare Bus-Depot	*286,342.50*	*310,651.50*	*416,050.23*	*440,723.86*
Mexico-Piyassa	*416,454.82*	*440,763.82*	*459,053.41*	*483,727.04*
Megenaga Bus-Depot	*416,454.82*	*440,763.82*	*455,278.81*	*479,952.44*

Cost Comparison between Alternative Pavement Structures

A) Flexible Pavement

Cost comparison was conducted to select economical pavement structure for Leghare Bus-Hub. Latest unit rates shown in the following table, were utilized for comparison of the structures.

Table E8: Unit Price for Construction Materials

Material	Unit	Unit Rate
WC	M^3	5200
BC	M^3	5300
BRB	M^3	2785.13
GRB	M^3	468
GS	M^3	422.5
GC	M^3	175

The Price Comparison of the pavement structure per cubic meter for subgrade class S3 from chart C1 & D1 given in the table E9 (a), for S5 in the table E9 (b) and S6 in the table E9 (c).

Table E9 : (a) Price Comparison between Alternative Pavement Structures for S3

Material Type	Unit Rate	Chart C1		Chart D1	
		Quantity	Cost	Quantity	Cost
AC, Wearing Course	5200	0.07	364	0.04	208
AC, Binder Course	5300	0.08	424	0.05	265
Bituminous Road Base, BRB	2785.13	0	0	0.17	473.4721
Granular Road Base, GRB	468	0.2	93.6	0	0
Granular Sub Base, GS	422.5	0.325	137.3125	0.175	73.9375
Granular capping layer, GC	175	0	0	0.15	26.25
Total			1018.913		1046.66

Table E9: (b) Price Comparison between Alternative Pavement Structures for S5

Material Type	Unit Rate	Chart C1		Chart D1	
		Quantity	Cost	Quantity	Cost
AC, Wearing Course	5200	0.07	364	0.04	208
AC, Binder Course	5300	0.08	424	0.05	265
Bituminous Road Base, BRB	2785.13	0	0	0.17	473.4721
Granular Road Base, GRB	468	0.2	93.6	0	0
Granular Sub Base, GS	422.5	0.15	63.375	0.1	42.25
Granular capping layer, GC	175	0	0	0	0
Total			944.975		988.7221

Table E9: (c) Price Comparison between Alternative Pavement Structures for S6

Material Type	Unit Rate	Chart C1		Chart D1	
		Quantity	Cost	Quantity	Cost
AC,Wearing Course	5200	0.07	364	0.04	208
AC, Binder Course	5300	0.08	424	0.05	265
Bituminous Road Base, BRB	2785.13	0	0	0.17	473.4721
Granular Road Base, GRB	468	0.25	117	0	0
Granular Sub Base, GS	422.5	0	0	0	0
Granular capping layer, GC	175	0	0	0	0
Total			905		946.4721

The cost comparison indicated that the pavement structure that selected from Chart C1 is more economical than the other pavement structure. Therefore, the recommended pavement structure is shown below in the table for each subgrade layer.

Table E10: Recommended Pavement Structure

Traffic Class	Subgrade Class	Asphalt Pavement thickness (mm)			CHART
		AC	GRB	GS	
T8	S3	150	200	325	C1
	S5	150	200	150	
	S6	150	250		

B) Rigid Pavement

Table E11: Unit Price for Construction Materials

Material	Unit	Unit Rate
Concrete	M^3	3925.5
Sub Base	M^3	422.5
Capping Layer	M^3	175
Reinforcement Bar	Kg	27

The Price Comparison of the pavement structure per cubic meter for subgrade class S3 given in the table E12 (a-d), for S5 in the table E13 (a-d) and S6 in the table E14 (a-d) between JRCP and CRCP.

Table E12: (a) Price Comparison between Alternative Pavement Structures for S3 in AratKilo-Sheromeda

Material Type	Unit Rate	JRCP		CRCP	
		Quantity	Cost	Quantity	Cost
Concrete	3925.5	104.025	408350.138	79.57	312352.035
Sub Base	422.5	0.15	63.375	0.15	63.375
Capping Layer	175	0.25	43.75	0.25	43.75
Reinforcement Bar	27	2893.1	78113.39846	4491.7	121276.168
Total			486,570.66		433,735.33

Table E12: (b) Price Comparison between Alternative Pavement Structures for S3 in Leghare Bus-Hub

Material Type	Unit Rate	JRCP		CRCP	
		Quantity	Cost	Quantity	Cost
Concrete	3925.5	90.885	356769.068	73	286561.5
Sub Base	422.5	0.15	63.375	0.15	63.375
Capping Layer	175	0.25	43.75	0.25	43.75
Reinforcement Bar	27	2893.1	78113.39846	4182.4	112925.392
Total			434,989.59		399,594.017

Table E12: (c) Price Comparison between Alternative Pavement Structures for S3 in Mexico-Piyassa

Material Type	Unit Rate	JRCP		CRCP	
		Quantity	Cost	Quantity	Cost
Concrete	3925.5	105.85	415514.175	81.03	318083.265
Sub Base	422.5	0.15	63.375	0.15	63.375
Capping Layer	175	0.25	43.75	0.25	43.75
Reinforcement Bar	27	2893.1	78113.39846	4564.3	123236.044
Total			493,734.70		441,426.43

Table E12: (d) Price Comparison between Alternative Pavement Structures for S3 in Megenaga Bus-Hub

Material Type	Unit Rate	JRCP		CRCP	
		Quantity	Cost	Quantity	Cost
Concrete	3925.5	105.485	414081.368	80.3	315217.65
SubBase	422.5	0.15	63.375	0.15	63.375
Capping Layer	175	0.25	43.75	0.25	43.75
Reinforcement Bar	27	2893.1	78113.39846	4532.7	122383.924
Total			492,301.89		437,708.7

Table E13: (a) Price Comparison between Alternative Pavement Structures for S5 in AratKilo-Sheromeda

Material Type	Unit Rate	JRCP		CRCP	
		Quantity	Cost	Quantity	Cost
Concrete	3925.5	98.55	386858.025	79.57	312352.035
Sub Base	422.5	0.175	73.9375	0.175	73.9375
Capping Layer	175	0	0	0	0
Reinforcement Bar	27	2893.1	78113.3985	4491.7	121276.168
Total			465,045.361		433,702.141

Table E13: (b) Price Comparison between Alternative Pavement Structures for S5 in Leghare Bus-Hub

Material Type	Unit Rate	JRCP		CRCP	
		Quantity	Cost	Quantity	Cost
Concrete	3925.5	85.41	335276.955	73	286561.5
Sub Base	422.5	0.175	73.9375	0.175	73.9375
Capping Layer	175	0	0	0	0
Reinforcement Bar	27	2836.7	76592.0843	4182.4	112925.392
Total			411,942.98		399,560.83

Table E13: (c) Price Comparison between Alternative Pavement Structures for S5 in Mexico-Piyassa

Material Type	Unit Rate	JRCP		CRCP	
		Quantity	Cost	Quantity	Cost
Concrete	3925.5	100.375	394022.063	81.03	318083.265
Sub Base	422.5	0.175	73.9375	0.218	92.105
Capping Layer	175	0	0	0	0
Reinforcement Bar	27	2893.1	78113.3985	4564.3	123236.044
Total			472,209.398		441,411.414

Table E13: (d) Price Comparison between Alternative Pavement Structures for S5 in Megenaga Bus-Hub

Material Type	Unit Rate	JRCP		CRCP	
		Quantity	Cost	Quantity	Cost
Concrete	3925.5	100.01	392589.255	80.3	315217.65
Sub Base	422.5	0.175	73.9375	0.175	73.9375
Capping Layer	175	0	0	0	0
Reinforcement Bar	27	2893.1	78113.3985	4532.7	122383.924
Total			470,776.591		437,675.512

Table E14: (a) Price Comparison between Alternative Pavement Structures for S6 in AratKilo-Sheromeda

Material Type	Unit Rate	JRCP		CRCP	
		Quantity	Cost	Quantity	Cost
Concrete	3925.5	98.55	386858.025	79.57	312352.035
Sub Base	422.5	0	0	0	0
Capping Layer	175	0	0	0	0
Reinforcement Bar	27	2893.1	78113.39846	4491.7	121276.1682
Total			464,971.42		433,628.203

Table E14: (b) Price Comparison between Alternative Pavement Structures for S6 in Leghare Bus-Hub

Material Type	Unit Rate	JRCP		CRCP	
		Quantity	Cost	Quantity	Cost
Concrete	3925.5	85.41	335276.955	73	286561.5
Sub Base	422.5	0	0	0	0
Capping Layer	175	0	0	0	0
Reinforcement Bar	27	2836.7	76592.08433	4182.4	112925.3922
Total			411,869.039		399,486.89

Table E14: (c) Price Comparison between Alternative Pavement Structures for S6 in Mexico-Piyassa

Material Type	Unit Rate	JRCP		CRCP	
		Quantity	Cost	Quantity	Cost
Concrete	3925.5	100.375	394022.063	81.03	318083.265
SubBase	422.5	0	0	0.218	92.105
Capping Layer	175	0	0	0	0
Reinforcement Bar	27	2893.1	78113.39846	4564.3	123236.0442
Total			472135.461		441,411.414

Table E14: (d) Price Comparison between Alternative Pavement Structures for S6 in Megenaga Bus-Hub

Material Type	Unit Rate	JRCP		CRCP	
		Quantity	Cost	Quantity	Cost
Concrete	3925.5	100.01	392589.255	80.3	315217.65
Sub Base	422.5	0	0	0	0
Capping Layer	175	0	0	0	0
Reinforcement Bar	27	2893.1	78113.39846	4532.7	122383.9242
Total			470,702.65		437,601.57

The cost comparison indicated that for all road section CRCP pavement alternative is more economical.

APPENDIX F

CONCRETE PAVEMENT TRANSITION

Transitions between CRC Pavement and AC Pavement

The transition between a PCC pavement and an AC pavement is a very common, as well as problematic transition. Unless there are provisions made to gradually transition the expansion and contraction of the PCC to the AC pavement, there is a distinct possibility of developing a bump on the AC side of the transition joint. The transition for the expansion and contraction joint is made by incorporating one or two doweled expansion joints at the end of the PCC pavement. The details below for the transition taken from best practices of Texas Department of Transportation (TxDOT). Figure below shows a detail that has been used for transition from AC to CRC pavement (sleeper slab).

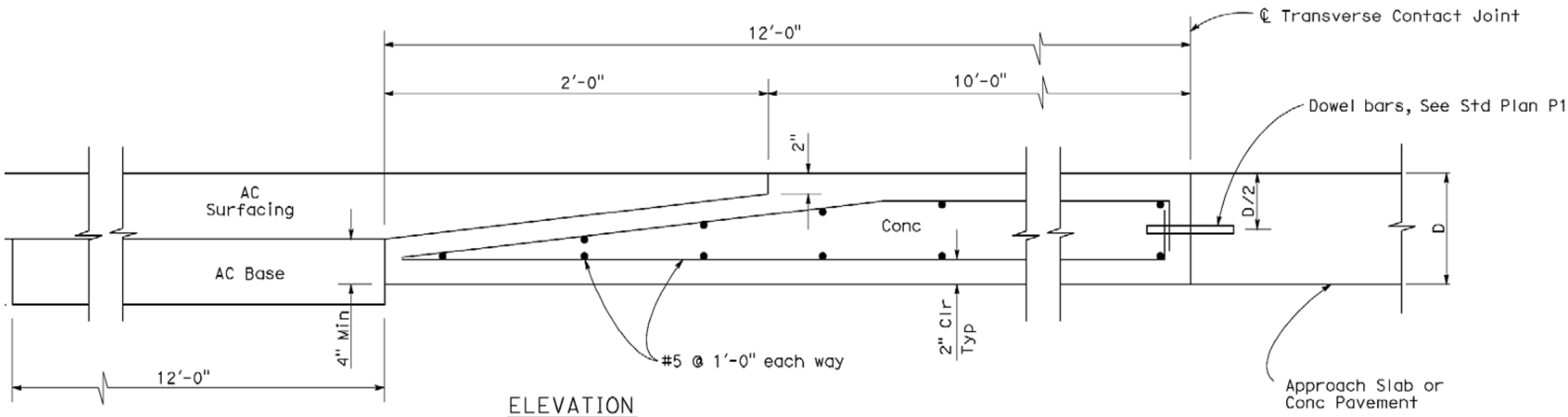


Figure: Shows detail about the sleeper slab reinforcement

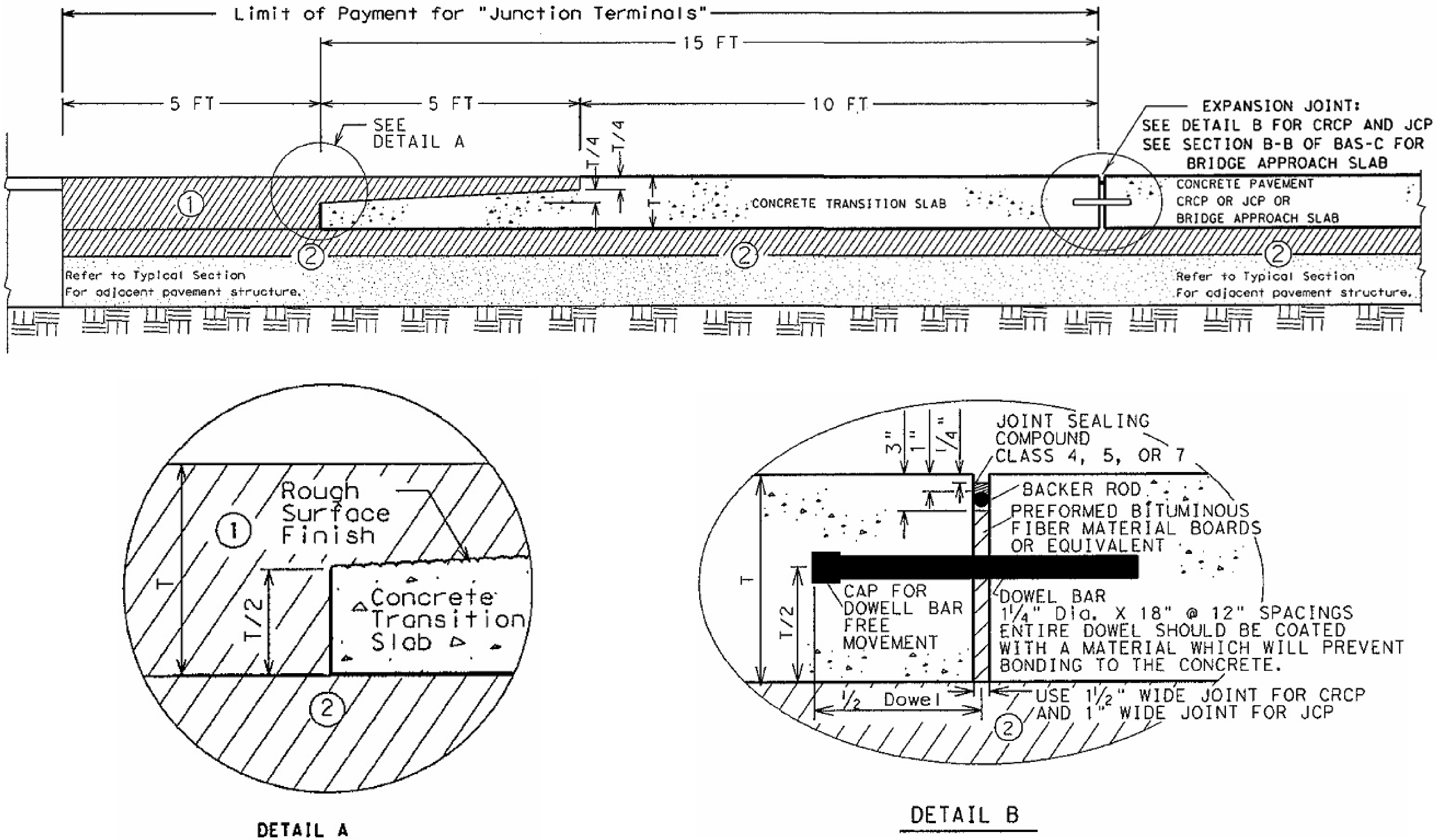


Figure: Shows detail about the connection of Ac & sleeper slab, sleeper slab and dowel (CRCP)