Jimma University
School of Graduate Studies
Jimma Institute of Technology
Civil Engineering Department
Construction and Engineering Management

COST AND BENEFIT ANALYSIS OF RIGID AND FLEXIBLE PAVEMENT: CASE STUDY IN CHANCHO –DERBA-BECHO ROAD PROJECT

A thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfilment of the requirements for the Degree of Master of Science in Civil Engineering (Construction and Engineering Management Stream).

By

Yonas Ketema Hailegebriel

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November 2015

Jimma, Ethiopia

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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This thesis has been submitted for examination with my approval as university supervisor.

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ABSTRACT

Road construction projects have been implemented all over Ethiopia as part of the national development plans. Roads are one of the country's basic infrastructural facilities where high amount of budget allocated during every fiscal year planning period.

To execute such a very crucial project large amount of money will be allocated to the pavement surfacing component of a road section. It is known that pavements are an important part of road projects. Since they cost large portion of investment, a careful evaluation of the alternatives is necessary to make the right choice for a particular project on a cost effective basis, which may be comparatively more economical to our country, Ethiopia.

In history of Ethiopia road development program, almost all of road pavements are flexible type and they demand high foreign currency for asphalt material importing from abroad. In addition flexible pavement needs to be maintained and rehabilitated within few years after initial construction.

In view of the emerging cement factories and the availability of cement in within Ethiopia it becomes practical to consider rigid pavement a far better alternative.

In this regard, this research was conducted with the main objective of identifying the cost and benefit of rigid and flexible pavement at Chancho-Derba-Becho road project, in Oromia North showa Zone. In addition, the research work was conducted with specific objectives to determine and compare life cycle cost of rigid and flexible pavement and to investigate all other qualitative merit of rigid pavement over flexible pavement.

To achieve these objectives, review of related literatures, design and specification, observation and investigation of actual pavement construction project, evaluation of life cycle costs and present worth calculation was made for an analysis period of 40 years.

The data for this study was gathered through investigation on actual rigid and flexible pavement project, examination of specifications, drawings and pavement design, Ethiopian Road Authority manuals, rehabilitation and maintenance documents.

This research limited to cost and benefit analysis of rigid pavement by comparing with flexible pavement in Ethiopian context specific to study area. Here, the cost parameters investigated were initial, maintenance, rehabilitation, user and salvages value in addition to other qualitative and quantitative data.

In the main outcome of the research indicates that the initial cost of rigid pavement is almost twice of that of flexible however the cost of flexible pavement is 7.9 million more than rigid due to the incurring cost of maintenance through its design life.

Key words: *Flexible and Rigid Pavement, Life Cycle Cost, Cost and Benefit*

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ABBREVIATION AND ACRONYMS

ERA Ethiopian Roads Authority

RSDP Road Sector Development Program

LCCA Life cycle cost analysis

LCC Life cycle cost

RP Rigid pavement

FP Flexible pavement

ERCC Ethiopian Road construction Corporation

AADT Average Annual Daily Traffic

ESA Equivalent Standard Axles

HMA Hot Mix Asphalt

BOQ Bill of Quantity

LLP Long Life Pavement

HDM High way Development Management

MAT Monthly Average Temperature

CHAPTER ONE

INTRODUCTION

1.1 Background

In many nations with developed road networks, new road construction typically accounts for around 50% of the road budget. Much of the remainder of national road budgets is spent on maintenance and rehabilitation of existing roads. Current road construction methods and materials contribute to this outcome, as they lead to recurrent maintenance requirements that can only be met at a relatively high cost. Long-life Pavements (LLP) project is approved if the costs of future maintenance, rehabilitation and the resulting road user delays costs are economically justified. For this to be the case, the reduced maintenance and other associated costs (e.g. user costs) would at least need to compensate for higher costs of construction [1].

A Long-Life Pavement is defined as a pavement where no significant deterioration will develop in the foundations or the road base layers provided that correct surface maintenance is carried out during the life of the pavement .A Long-Life Pavements (LLP) concept has been developed to build more cost-effective pavements in meeting the present socio-economic requirements. In practice the LLP-concept significantly extends the current pavement design life by restricting distress in the pavement surface to achieve low life-cycle costs [2].

The performance and economy of highway pavements is a matter of critical importance to governmental agencies, highway engineers, paving contractors and others involved in the highway industry. So it is beneficial to know the economic value over the design life of pavements, generally called the "life-cycle costs" of pavements.

There has historically been a difference of opinion as to whether hot mix asphalt (flexible) pavements were more economical or less economical over time than Portland cement concrete (rigid) pavements. Each industry claims that its product is more economical or longer lasting, or both. Even experienced state highway agencies and highway engineers disagree on the subject [3].

Roads with Concrete pavement were probably first constructed in the USA in the beginning of the twentieth century, and spread to Europe in the twenties. Concrete pavements use significantly less aggregate in total than flexible pavements. This conserves our non-renewable resources and results in less truck traffic and congestion. Less soil needs to be excavated for a concrete road (when compared to the flexible alternatives) due to the rigid nature of concrete pavement allowing for thinner base cross-sections. This is a huge advantage with the increased difficulty in finding areas to dump any contaminated soils [4].

Equally important is that longer lasting concrete helps reduce traffic congestion and vehicle emissions because there are simply fewer construction zones slowing traffic flow during the life of the pavement. Some other advantages of concrete pavements are that they save fuel and reflect light and heat rather than absorbing it. Studies from National Research Council (Canada) show substantial savings on diesel fuel with heavy trucks, and new studies are available from Sweden and United States showing gasoline savings on cars and light vehicles. These savings result in lower vehicle operating costs and greatly reduced CO_2 emissions. Concrete pavement's ability to reflect light can lead to a 20 to 30% reduction in the cost to purchase and operate light standards, and because concrete pavements reflect heat, they also contribute to cool communities and reduce the Urban Heat Island Effect [5].

Ethiopian has been undertaking massive development programs to eradicate the country's poverty problems and to bring up the country to the level of middle income countries in 2025 G.C. Aware of the road infrastructure development as the back bone and blood artery for all economic, social progress, due emphasis has been given to the implementation of Road Sector Development program (RSDP) since 1997 and subsequently dramatic success have so far been registered and construction industry booming in the country in general and the road construction in particular.

To execute such a very crucial project large amount of many will be allocated to the pavement, surfacing component of a road section. It is known that pavements are an important part of road projects, since they require large portion of the budget to be investment, a careful evaluation of the alternatives is necessary to make the right choice before implementation, which may be comparatively more economical to our country, Ethiopia.

Flexible Pavements have been the preferred choice because of low initial cost as compared to the Rigid Pavements. In view of availability of cement in plenty within the country and scarcity and prices fluctuation of bitumen (as crude oil prices in the International market are fluctuating and bulk of crude oil has to be imported from other countries), it has become practical to consider rigid pavement, a far better alternative to flexible pavement. The superiority of rigid pavements over flexible pavements were well recognized in the world over and many developed countries have already constructed long stretches of concrete roads to meet the increasing passenger and freight traffic on high traffic corridors. However in Ethiopia very few and short kilometre length road projects are with rigid pavement viz; in Oromia (Chancho-Derba-Bocho and Beseka road), Addis Ababa (Rehabilitation projects) and Tigray (Michew –Adigudem) of which Beseka and Addis Ababa rehabilitation projects were completed [6].

Table 1. 1 Rigid Pavement Projects in Ethiopia

S/no	Road Project name	Location	Length(km)	Remark
1	Beseka Road	Methara	1	Completed in 2014
2	Kality Square to Hana mariam	Addis Ababa	0.3	Completed in 2014
3	Michew –Adigudem	Alagae mountain(Tigray)	1	Completed in 2014
4	Chacho- Derba –Becho	North Shewa – Oromiya	10	Completed in July 2015
5	Dichito-Gaielfi junction-Beleho	North –East Ethiopia-Afar	83	Feasibility stage

This research was limited to cost and benefit analysis of rigid pavement by comparing with flexible pavement at Chancho_ Derba –Becho road project. Here, the parameters that will be investigated were initial, maintenance, rehabilitation, user and salvages value in addition to other qualitative and quantitative data.

The project is located in North Shewa Oromia zone start at chancho, 38km from Addis Ababa and 31 kilometers long through Derba to Becho. It is ongoing and includes flexible pavement for 21kilimeters and rigid pavements for the rest of 10 kilometers, where the concrete pavement section was completed in July 2015.

1.2 Statement of the problem

The condition survey results indicate that the existing chancho Derba gravel wearing course was affected by pavement distresses like potholes, rutting, corrugation, and loss of camber and oversize materials. The pavement distresses were pronounced in the first 18kms and on the junction to Derba village and these sections have poor riding quality. In addition ,due to rapid economic growth of our country, there is a high demand for cement and the existing Chancho – Derba – Becho road is a potential corridor for cement production and hence there are existing cement factories which are under operation and also new cement factories which are under construction and more will be expected. Among the new cement factories Derba Midorc Cement Plc the biggest cement factory in

Ethiopia, which produce 7000ton cement per day. Apart from cement factories there are other ongoing development projects like flower farming and related development projects. These and other socio economic developments in the project generate too much traffic and the existing gravel road was not able to accommodate the current and future transport smoothly and satisfactorily. In order to satisfy the demand of the economy for bulk transport of cement and other production by heavy trucks and truck Trailer it was required to upgrade the existing gravel wearing course road to higher standard, DS3 paved road[28].

Even though there are newly emerging cement and reinforcement production factories in Ethiopia that avoid foreign currency to buy flexible pavement materials, only few and small scale concrete pavement projects has been undertaken in the country. Among these projects, Beseka Road, a one kilometer length, was the first cement concrete pavement in the history of Ethiopian road construction project. Since then, only small and vary short kilometer stretch rigid pavement road projects have been implemented in Ethiopia. In the last seventeen years (1997-2014 G.C) total length of rigid pavement constructed is only 2.3 kilometers while about 99.9% or 12,640 kilometers are flexible pavement [6].

Moreover, flexible pavement demands high foreign currency for asphalt material importing form abroad and requires large scale maintenance and rehabilitation within few years after initial construction. Over the past 17 years, 41.2% of the total RSDP expenditure was on rehabilitation and upgrading roads, 28.8% was on construction of link roads, 5.7% on maintenance of federal roads, 8% on regional road and 11.7% on Woreda roads and 2.8% was on institutional support projects and other activities at the federal level. During the last four years (2010-2014 G.C) RSDP accomplishment expenditure show that 4.3 billon for rehabilitation, 4.8 billion for periodic and 0.7 billion for routine maintenance was utilized to federal and regional flexible pavement roads [7].

In history of Ethiopia road development program, almost all of road pavement is flexible type and it demands high foreign currency for asphalt material importing form abroad. In addition flexible pavement needs to be maintained and rehabilitated within few years after initial construction.

In view of the emerging cement factories, the availability of cement and all other construction materials in within Ethiopia it becomes practical to consider rigid pavement a far better alternative. And it is important to evaluate and investigate the cost and benefits of concrete and asphalt pavement in Ethiopian context in general and project area in particular.

1.3 Research questions

1. Is the Life cycle cost of rigid pavement greater than flexible?
2. What are the advantages and disadvantages of rigid and flexible pavement?
3. Which type of pavement is easy to maintain and repair?
4. Which pavement type has longer design life?

1.4 Objective of the study

1.4.1 General objective

The general objective of this research was to analyze the cost and benefit of rigid and flexible pavement in Chancho –Derba-Becho road project containing of 21 km flexible and 10 km rigid.

1.4.2 Specific objectives

1. To determine and compare life cycle cost of rigid and flexible pavement.
2. To list the advantages and disadvantages of rigid and flexible pavement.
3. To identify the possible maintenance and repairing types for both pavements.
4. To compare the design life of flexible and rigid pavement.

1.5 Significance of the study

The findings of this research will help in deciding which pavement alternatives are economical and applicable according to the location in particular and in country level in general. The parameters considered will also be applied during selection, decision making and prioritization of road surfacing materials during design of road projects. It also one of the cement and reinforcing bar demanding project for the concerned factories in Ethiopia since one kilometer jointly reinforced concrete pavement needs about 9,500 quintal Ordinary Portland cement and 64,000 kilogram reinforcement bar .

1.6 Scope of the study

This research was limited to cost and benefit analysis of rigid pavement comparing with flexible pavement in the context of Ethiopia in general and in Chancho-Derba-Becho road in particular. Here initial construction cost of both pavements compared from the particular project, future maintenance, rehabilitation, fuel cost, time savings and salvages value was evaluated from secondary data, literatures ,manuals ,related projects and ERA road sector feasibility study documents.

1.7 Limitation of the study

During the research secondary data were not available enough especially rehabilitation activities and schedule for both pavements and maintenance activity for concrete rigid pavement at Ethiopian context. And the research also did not include road maintenance like cleaning of drainage systems, vegetation and flood controls.

Concerning the inflation rate it was difficult to predict future inflation rate at the time of occurrence of maintenance, rehabilitation and salvage value of pavement alternatives.

In addition economic cost determination for user cost especially for vehicle operation cost required a model software like High way Development Management (HDM) which is very costly and difficult to get at individual and company level too.

1.8 Structure of the research

This research organized in to six chapters and their contents are outlined and discussed as follows:-

The first chapter introduces the study with general introduction, statement of the problem, objective of the study, basic research questions, significance of the study, scope of the study, limitation of the study.

The second chapter discussed about the review of related literatures regarding deals with the literature review about rigid and flexible pavement initial construction, maintenance, rehabilitation and user costs. The advantages and disadvantages of the two pavement types were also discussed here.

The third chapter encompasses description the study area location, temperature, rain fall and the materials and methods, the methodology by which the research was conducted.

The fourth chapter deals with the result and discussion, along with major calculation results were discussed with respect to the pavement types and research parameters stated in the objectives and questions.

The fifth chapter presents the conclusions and recommendations and directions for further research.

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CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Road Construction projects have been implemented all over Ethiopia as part of the national development plan. Road construction project is one of the country's basic infrastructural facilities where high amount of budget are allocated during each countries fiscal year planning period [7].

It is known that pavements are important part of road projects, since they cost large portion of investment, a careful evaluation of the alternatives is necessary to make the right choice on a rational basis, which may be comparatively more beneficial to the nation. There are two most common types of pavements, flexible and rigid.

Flexible Pavement: Consisting of various layers of granular materials and provided with a layer of bituminous materials on top.

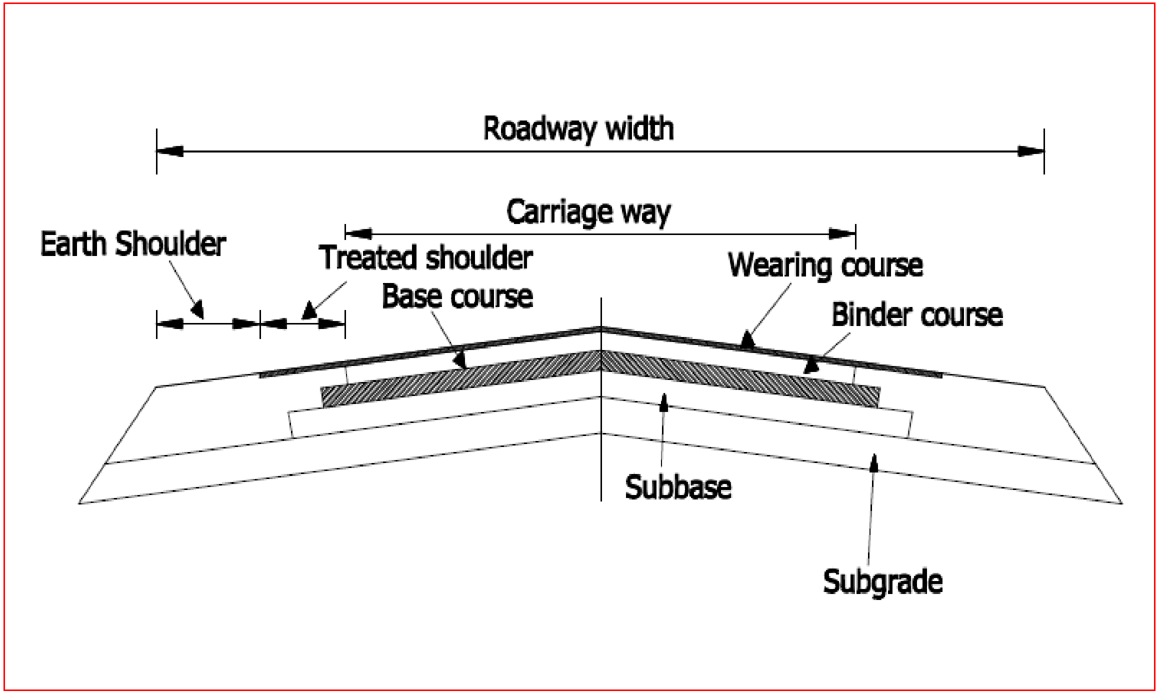


Figure 2. 1 Cross section of a typical flexible pavement [8]

Rigid Pavement: Consisting of a cement concrete pavement laid on a well prepared granular sub-base.

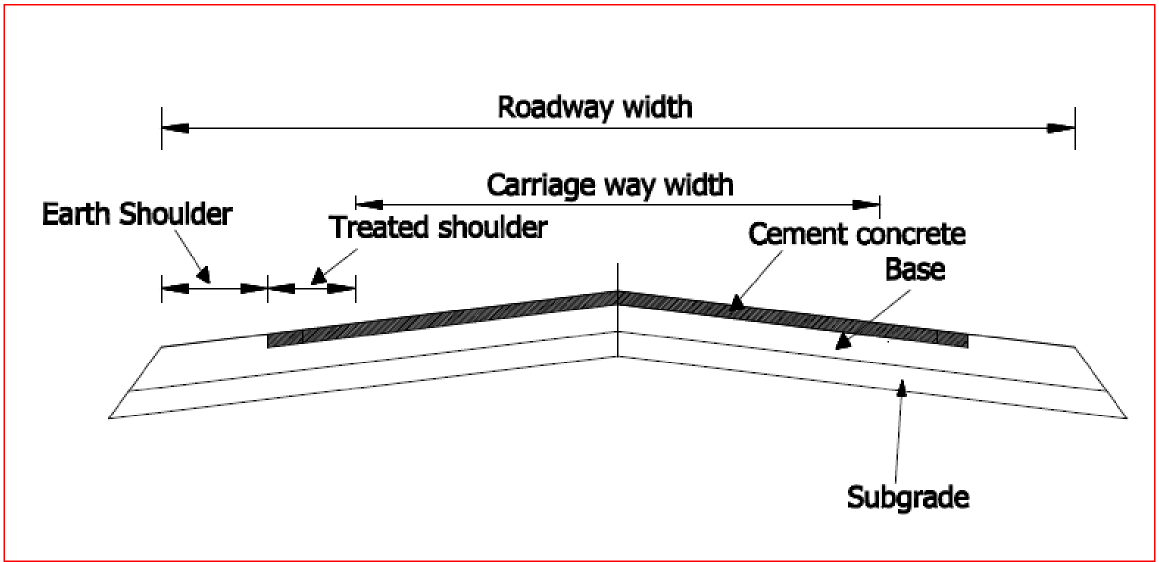


Figure 2. 2 Cross section of a typical rigid pavement [8]

Rigid pavements are mostly found in major highways and airports. They also serve as heavy-duty industrial floor slabs, port and harbor yard pavements, and heavy-vehicle park or terminal pavements. Rigid highway pavements, like flexible pavements, are designed as all-weather, long-lasting structures to serve modern day high-speed traffic. They offer high quality riding surfaces for safe vehicular travel, and function as structural layers to distribute vehicular wheel loads in such a manner that the induced stresses transmitted to the sub grade soil are of acceptable magnitudes.

The most common type of material used for rigid pavement slab construction is Portland cement concrete, mainly because of economic reasons and its easy availability. The concrete slab must be designed to withstand repeated traffic loadings. Fatigue failure of pavement due to repeated loadings caused by daily traffic is a major design consideration of rigid pavements. Fatigue failure occurs when a load, though smaller than the failure load of the concrete slab, is repeatedly applied on the pavement a sufficiently number of times. This form of failure is common for highway pavements because a typical highway will receive millions of wheel passes during its service life. While the design life of a flexible pavement may be in the range of 15 to 20 years, it is common for a concrete pavement to be designed with a service life of 30 to 40 years [8].

The following table shows difference between Flexible Pavements and Rigid Pavements:

Table 2. 1 Differences between Flexible Pavements and Rigid Pavements [9, 10]

Item	Flexible Pavement	Rigid Pavement
1	Deformation in the sub grade is transferred to the upper layers	Deformation in the sub grade is not transferred to subsequent layers
2	Design is based on load distributing characteristics of the component layers	Design is based on flexural strength or slab action
3	Have low flexural strength	Have high flexural strength
4	Load is transferred by grain to grain contact	No such phenomenon of grain to grain load transfer exists
5	Have low completion cost but repairing cost is high	Have low repairing cost but completion cost is high
6	Have low life span	Life span is more as compare to flexible
7	Surfacing cannot be laid directly on the sub grade but a sub base is needed	Surfacing can be directly laid on the sub grade
8	No thermal stresses are induced as the pavement have the ability to contract and expand freely	Thermal stresses are more vulnerable to be induced as the ability to contract and expand is very less in concrete
9	That’s why expansion joints are not needed	That’s why expansion joints are needed
10	Strength of the road is highly dependent on the strength of the sub grade	Strength of the road is less dependent on the strength of the sub grade
11	Rolling of the surfacing is needed	Rolling of the surfacing in not needed
12	Road can be used for traffic within 24 hours	Road cannot be used until 14 days of curing
13	Force of friction is less	Force of friction is high
14	Deformation in the sub grade is not transferred to the upper layers.	

Table 3:- Differences between Flexible Pavements and Rigid Pavements [10]

S/No	Parameter	Flexible Pavement	Rigid Pavement
1	Smoothness	Reduces tire bounce, load impact and vehicle fatigue	Reduces pavement deflection
2	Safety	Good road Traction	Good night time pavement visibility
		Reduces stopping distance	Reduces stopping distance
		Road Markings have higher contrast	
3	Durability	lasts 20-40 years	lasts 30-50 years
		softens in high temperatures	weather resistant
			cracks in cold weather
4	Sustainability and recyclability	100% recyclable	Not reusable or recyclable for pavement use
		can be reused as reclaimed asphalt pavements(RAPs)	
5	Noise Reduction	Excellent noise reduction	Good noise reduction on high quality PCCP
6	Effects on fuel consumption	1.8-2.9% reduction for passenger vehicles	0.8-2% reduction for passengers vehicles
		4.5% reduction for trucks	4.1% reduction for trucks
7	Construction and maintenance	3days to build(average)	2 weeks to 1 month to build
		maintenance work is done every 3 to 5 years	maintenance work is done every 8 to 12 years

In 2014, Addis Ababa City Roads Authority (ACRA) announced that it has built the first concrete road of its kind in the country. The Authority's executive officer, Engineer Fekade Haile,said that the concrete road is capable of giving service without any repair for up to thirty years. The concrete road is built on the 300 meters road that stretches from Kaliti square to Hana Mariam which was previously been known for its repeated repair. It is said that the concrete road's construction is 30 % more costly than the asphalt road. But due to its durability, the Authority has decided to build concrete roads at selected locations in Addis next year to cut cost of repeated repair [6].

Rigid pavements (also called concrete pavements), as the name implies, are rigid and very strong in compression. The strength of the pavement is contributed mainly by a concrete slab, unlike flexible pavements where successive layers of the pavement contribute cumulatively. The surface required for an adequate resistance to skidding in wet conditions can be provided by dragging stiff brooms transversely across the newly-laid concrete or by cutting shallow randomly spaced grooves in the surface of the hardened concrete slab. The main advantages of rigid pavement are, it is feasible to design for longer design lives, up to 60 years, little maintenance is generally required, do not deform under traffic and a relatively thin pavement slab distributes the load over a wide area due to its high rigidity. Localized low strength sub grade materials can be overcome due to this wider distribution area. It is very resistant to abrasion making the anti-skidding surface texture last longer. And in the absence of deleterious materials (either in the in the aggregate or entering the concrete in solution from an external source), unlike flexible pavement, rigid pavement does not suffer deterioration from weathering. Neither its strength nor its stiffness is materially affected by temperature changes [11].

The main disadvantages compared to flexible pavements are, the initial investment is often more costly and if badly designed or not properly constructed, they tend to be more troublesome and reconstruction or repair is more difficult [11].

Until now, concrete pavements have not been extensively used in most tropical countries and in Ethiopia in particular, mainly due to a lack of tradition and experience in their design and construction. One characteristic of concrete pavements is that either they prove to be extremely durable, lasting for many years with little attention and maintenance, or they give troubles from the start, sometimes because of faults in design, but more often because of mistakes in construction [11].

2.2 Types of Rigid Pavements

There are three basic types of rigid pavement:

1. Jointed Unreinforced Concrete Pavements (JUCP)
2. Jointed Reinforced Concrete Pavements (JRCP)
3. Continuously Reinforced Concrete Pavements (CRCP)

2.2.1 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)

2.2.2 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.

2.2.3 Continuously Reinforced Concrete Pavement

Continuously Reinforced Concrete Pavements (CRCP) is 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.

2.3 Pavement Structure

Rigid pavements usually consist of a sub-base and a concrete slab but a capping layer is also used if required (Figure 2.2). When the sub grade is weak, the required thickness of material of sub-base quality required to protect the sub grade and to provide sufficient support for the concrete slab is substantial and it is usually more economical to provide a capping layer to perform part of the task, as shown in the Figure. Any erosion of the sub-base layer under the concrete slab caused by the pumping action as traffic uses the road reduces the support to the concrete slab. This increases the tensile strains in the concrete itself and therefore the risk of cracking. In circumstances where this is likely it is recommended that the sub-base material is stabilized with cement or lime to provide support that is strongly resistant to erosion. The sub-base is also required to provide a stable working platform on which to construct the concrete slab [11].

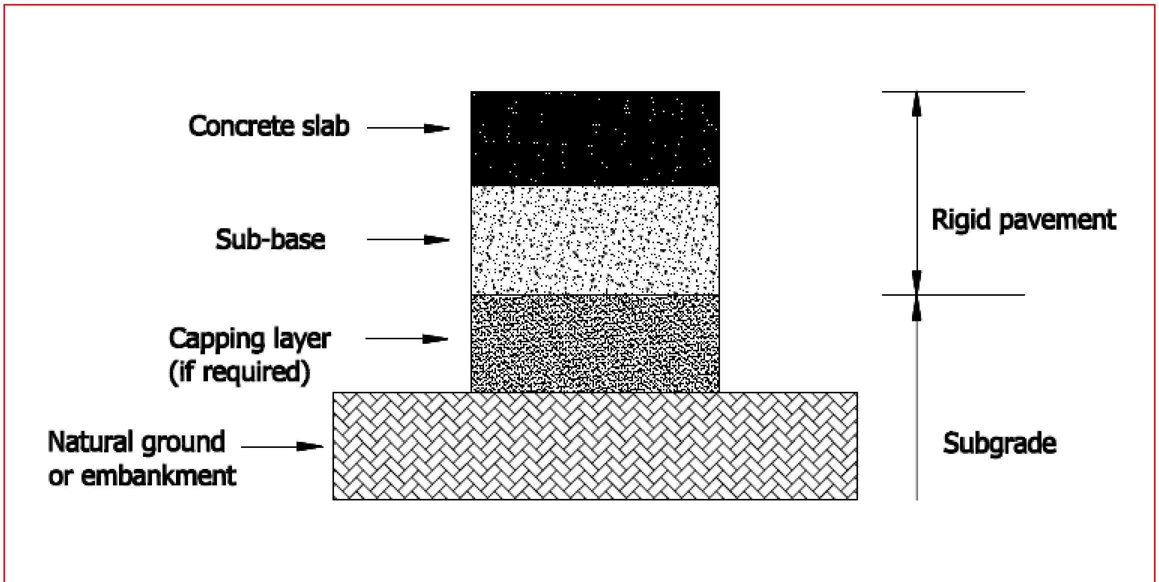


Figure 2. 3 Rigid pavement structure [12]

Flexible pavement has low initial construction cost, less traffic noise and ease of construction and maintenance technology compared to rigid pavement. However it is prone to damage, has short life span , there is much interruptive of traffic flow during maintenance and has high heat absorption rate .On the other hand, concrete is safer than asphalt roads because it increases visibility, especially at night, reflect heat energy better than asphalt, which will be beneficial to the passage of vehicles in hot climates. And has less energy for the propulsion and fuel savings between 10-20% than asphalt. Whereas, concrete pavements has high initial cost, traffic noise, requires advanced technology in both construction and maintenance [12].

Advancements in concrete technology have reduced the cost of concrete paving while improving performance greatly; advancements in asphalt technology (so-called "SuperPave" mixtures) have increased paving costs significantly (even before considering skyrocketing oil prices) with only modest increases in performance [13].

The superiority of rigid pavements over flexible pavements was well recognized in the world and many developed countries have already constructed long stretches of concrete roads to meet the increasing passenger and freight traffic on high traffic corridors.

Even though there are newly emerging cement and reinforcement production factories in Ethiopia that avoid foreign currency to buy flexible pavement materials, only few and small scale concrete pavement projects has been undertaken in the country. Beseka Road is the first cement concrete pavement in the history of Ethiopian road construction project [14].

2.4 Life cycle Cost Analysis

Life cycle cost analysis (LCCA) is a tool used to compare the total user and agency costs of competing project implementation alternatives, specifically HMA and PCCP pavements. LCCA is a subset of Benefit-Cost Analysis (BCA), an economic analysis tool that compares benefits as well as costs in selecting optimal projects or implementation alternatives. Because the distinction between LCCA and BCA can be confusing in day-to-day practice, the differences between LCCA and BCA, and their appropriate applications, are discussed below. The agency that uses LCCA has already decided to undertake a project or improvement and is seeking to determine the most cost-effective means to accomplish the project’s objectives. LCCA is appropriately applied only to compare project implementation alternatives that would yield the same level of service and benefits to the project user at any specific volume of traffic. [15]

2.5 Discount Rate

Discount rate is the interest rate by which future costs will be converted to present value. In other words, it is the percentage by which the cost of future benefits will be reduced to present value (as if the future benefit takes place in the present day). Real discount rates (as opposed to nominal discount rates) reflect only the true time value of money without including the general rate of inflation.[16]

It also defined as the interest rate charged to commercial banks and other depository institutions on loans they receive from their regional Federal Reserve Bank's lending facility—the discount window. The Federal Reserve Banks offer three discount window programs to depository institutions: primary credit, secondary credit, and seasonal credit, each with its own interest rate. All discount window loans are fully secured. Under the primary credit program, loans are extended for a very short term (usually overnight) to depository institutions in generally sound financial condition. Depository institutions that are not eligible for primary credit may apply for secondary credit to meet short-term liquidity needs or to resolve severe financial difficulties. Seasonal credit is extended to relatively small depository institutions that have recurring intra-year fluctuations in funding needs, such as banks in agricultural or seasonal resort communities.

The discount rate charged for primary credit (the primary credit rate) is set above the usual level of short-term market interest rates. (Because primary credit is the Federal Reserve's main discount window program, the Federal Reserve at times uses the term "discount rate" to mean the primary credit rate.) The discount rate on secondary credit is above the rate on primary credit.

The discount rate for seasonal credit is an average of selected market rates. Discount rates are established by each Reserve Bank's board of directors, subject to the review and determination of the Board of Governors of the Federal Reserve System. The discount rates for the three lending programs are the same across all Reserve Banks.

The discount rate used in roadway LCCA is a function of both the interest rate and the inflation rate. In general, the interest rate (often referred to as the market interest rate) is associated with the cost of borrowing money and represents the earning power of money. Low interest rates favor those alternatives that combine large capital investments with low maintenance or user costs, whereas high interest rates favor reverse combinations. The inflation rate is the rate of increase in the prices of goods and services (construction and upkeep of highways) and represents changes in the purchasing power of money. The discount rate used in roadway LCCA is approximately the difference of the interest rate minus inflation rates. Discount rate represents the real value of money over time.

As per the National Bank of Ethiopia Proclamation no.591/2010 article 5, the minimum interest rate on savings is 5% [17].

In the feasibility study of road projects in Ethiopia, example in Jimma –Mizan up grading project Economic analysis , discount rate of 10% is used [18] and 10.23% for that of Adama- Awash express way [19] .

The inflation rate in Ethiopia was recorded at 11.60 percent in August of 2015. Inflation Rate in Ethiopia averaged 18.13 percent from 2006 until 2015, reaching an all-time high of 64.20 percent in July of 2008 and a record low of -4.10 percent in September of 2009. Inflation Rate in Ethiopia is reported by the Central Statistical Agency of Ethiopia.

As per the National Bank of Ethiopia Proclamation no.591/2010 article 5, the minimum interest rate on savings is 5% [14].

Table 2. 2 Ethiopian Inflation Rate [13]

Month	Value (%)	Month	Value (%)
14-Sep-14	5.6	15-Apr-15	8.5
14-Oct-14	5.4	15-May-15	9.3
14-Nov-14	5.9	15-Jun-15	9.4
14-Dec-14	7.1	15-Jul-15	10.4
15-Jan-15	7.7	15-Aug-15	11.9
15-Feb-15	8.2	15-Sep-15	11.6
15-Mar-15	8.2		

2.6 Pavement costs

The major initial and recurring costs of pavement that should be considered in LCCA techniques include agency and user costs. The major agency costs are initial construction, future construction or rehabilitation costs (overlays, seal coats, reconstruction, etc.), maintenance costs, recurring throughout the design period, salvage return or residual value at the end of the design period (which may be a "negative" cost), engineering and administration costs and traffic control costs .On the other hand the user cost include travel time, vehicle operation and maintenance, accidents, discomfort (driving discomfort), and time delay and extra vehicle operating costs during resurfacing or major maintenance. For a simplified analysis, the costs are usually considered for life cycle analysis are initial construction costs, future costs of reconstruction or rehabilitation, maintenance costs and salvage value. When designing roads, every engineer asks the basic questions: what is the initial cost, how much does it cost to operate and how long is it going to last. Life-cycle costing brings all those elements together into a true cost of pavement. The influence of these six cost components is shown in table below [20].

Table 2. 3 Life cycle cost and their influence

S/No	The six major Life -cycle cost components	Influence on Life-Cycle costs
1	Initial Construction costs	moderate to high
2	Maintenance costs	moderate
3	Rehabilitation Costs	moderate
4	User costs	low to moderate
5	Residual Value(remaining service life of the road after analysis period)	low
6	Salvage Value(reusable components at the end of the analysis period)	low

2.6.1 Rehabilitation and Maintenance

All roads deteriorate with time as a result of traffic and environmental effects. The deterioration may be relatively easy to correct or may require major works, depending on the causes and extent of deterioration. The works processes for keeping roads in good condition are often subdivided into the following categories:-[21]

2.6.1.1Road Maintenance

The maintenance of a road section, immediately subsequent to the completion of the civil construction works, is required to keep road ways and sides to its original shape and allow for smooth and uninterrupted flow of traffic for which it is primarily designed. The work may broadly be classified into three: routine, periodic and emergency works.

A) **Routine Maintenance Works**: The major activity in routine type of intervention is surface maintenance. In case of asphalt pavement, it consists of asphalt patching, crack resealing, and certain base corrections. For gravel surfaced roads, the major activities are surface grading, spot re-gravelling, ditch clearing and shaping, control of evading vegetation, improvement of sight distance, etc. normally, routine maintenance is carried out throughout the year.

B) **Periodic Maintenance Works**: Apart from regular surface patching, shoulder conservation on paved roads and the shaping of gravel roads, all weather type of roads require the restoration of road way surfaces at a certain interval of years. Factors initiating periodic maintenance intervention are traffic level and composition, the type of pavement (surface) etc. Accordingly, while gravel roads generally have to be intervened at frequency of 3-5 years, asphalt roads require to be maintained at a frequency of 7-8 years intervals.

Resealing surface dressing (resealing) is needed on extensively worn out pavements and on areas where the paved surface (asphaltic) has become permeable, allowing water to penetrate the base and cause deterioration. Before proceeding with resealing works, it is essential to carry out pothole repairs, correction of ruts and depressions. And then, the surface dressing includes the application of either one layer of bituminous binder with one layer of chippings (single surface dressing) or two layers of bituminous binder with two layers of chippings (double surface dressing), depending on the extent and level of pavement damage. The surface resealing is generally applied over the whole width of pavement or part of the carriageway.

The operation also involves the re gravelling (shaping) of the shoulders on each side of the roadway, by placing adequate surface materials.

C) **Emergency Maintenance Works:** This type of intervention is needed in emergency cases, like the occurrence of slides, floods etc. Hence, the work involves the removal of slides, the monitoring and execution of corrective works on unstable slopes, both along the road way and on the road sides. On occasions, with the prevalence of floods, the emergency work required is the re channeling of the flood water, removal of derbis, etc. to facilitate the quick movement of traffic.

2.6.1.2 Road rehabilitation and Upgrading

A) Up grading

This is a change of design standards of the existing road, including horizontal and vertical geometry, and the pavement. Generally, it involves reduction of gradients and curves, change of alignments, improvement of the thickness of base course and the subsequent pavement (say from gravel to asphalt, from regional roads to major link road etc.) and hence enable increased mobility and accessibility of regions. Such an intervention measure, when justified on the basis of economic and engineering parameters, brings about a good riding surface, reduced vehicle operating costs (VOC) and increased traffic safety by reducing accidents.

B) Rehabilitation

This is a major intervention work requiring extensive civil works. Rehabilitation is carried out on road sections where the geometric features and structures along the road way have almost failed. Roads to be rehabilitated may not be restored to an original shape even with periodic maintenance intervention, because of the magnitude of the damage done. Major civil works required under the rehabilitation scheme consists of corrective measures on base course and on pavements, normally involving the scarification of existing road surfaces and, occasionally, the reconstruction of major and minor structures. Changes of alignment, reduction of gradient and curves may also be required during the rehabilitation program. In general, rehabilitation works are close to reconstruction of the facility.

C) Reconstruction

Renewing the road structure, generally using existing earthworks and road alignment, to remedy the consequences of prolonged neglect or where rehabilitation is no longer possible. [22]

2.7 Salvage Value

The salvage value of a pavement structure is the reusable component at the end of the analysis period. If at the end of this analysis period, it is expected that the facility will be abandoned, the salvage value is any value that the materials may have if removed and reused. In general, it is practical to assume that the salvage value is zero unless specific data are available to calculate otherwise. However, the facility may possess useful life after the analysis period, and if so, the salvage value should be included in the life-cycle cost analysis. The residual value of the last rehabilitation action based on its anticipated remaining life appears to be the best method for determining salvage value. Use of this simplified approach in estimating salvage value is justified by the fact that there are several uncertainties associated with the service lives and costs for the different pavement component layers, and the relatively small impact that salvage value actually has on life cycle comparisons.[23]

If an alternative has reached its full life cycle at the end of the analysis period, it is generally considered to have no remaining salvage value. If it has not completed a life cycle, it is given a salvage value, which is usually determined by multiplying the last construction or rehabilitation cost, by the ratio of the remaining expected life cycle to the total expected life.

$$SalvageValue = LC\left[\frac{ERL}{TEL}\right]$$ -----------------------------------Eq [24]

Where,

LC = Last construction or rehabilitation project costs

ERL = Expected remaining life of the last construction or rehabilitation project

TEL = Total expected life of the last construction or rehabilitation project

2.8 Flexible pavement Rehabilitation and Maintenance plans

According to the technical specification for road maintenance works in Ethiopian the activities of maintenance are asphalt patching, crack sealing ,pothole repair as routine and sand seal coat, single bituminous surface treatment ,double bituminous surface treatment ,asphaltic concrete over lay, prime coat, tack coat and pavement reconstruction as periodic maintenance [25].

2.9 Rigid pavement Maintenance and Rehabilitation Plans

Concrete pavements are often constructed for their long service life and the reduced level of maintenance expected due to their slower rate of deterioration.

For the maintenance and rehabilitation of concrete pavements, the most common activities include improving joint performance through resealing, partial depth repairs, and slab replacements with full depth repairs. On higher volume roadways, the smoothness of the roadway has more significance and some surface texturization is recommended to ensure an acceptable performance.

These plans were developed to provide a consistent level of service in a cost effective manner. The maintenance and rehabilitation quantities provided are for a 1km length of roadway and need to be adjusted for different section lengths.

Table 2. 4 Major Rigid pavement Maintenance and Rehabilitation Plans [26]

Expected years	Activity Description	Quantity (per 1 km)	Quantity (m)
12	Reseal joints	25%	250
12	Partial depth PCC repair	2%	20
25	Partial depth PCC repair	5%	50
25	Full depth PCC repair	10%	100
25	Reseal joints	50%	500
25	Texturizing	25%	250
40	Partial depth PCC repair	5%	50
40	Full depth PCC repair	15%	150
40	Reseal joints	50%	500
40	Texturizing	50%	500

Table 2. 5 Rehabilitation Scenarios of FP and RP

Year	Flexible Pavement	Rigid Pavement
0	Construction	Construction
15	HMA over lay	
30	HMA over lay	
40	Salvage Value	Full depth repair

2.9 Safety issues

Maintenance and rehabilitation activities increase accident risk on the road, as normal traffic flow is disturbed. Even with good road markings and information signs, traffic accident risk increases compared with the usual traffic flow situation [27].

2.10 Lane closure

For the purpose of temporary traffic safety one or more of the lane will be closed during routine and periodic maintenance. The task involves setting up, operating and subsequently removing traffic safety measures for the duration of maintenance works within the highway which involve the closure of one or more traffic lanes. [25]

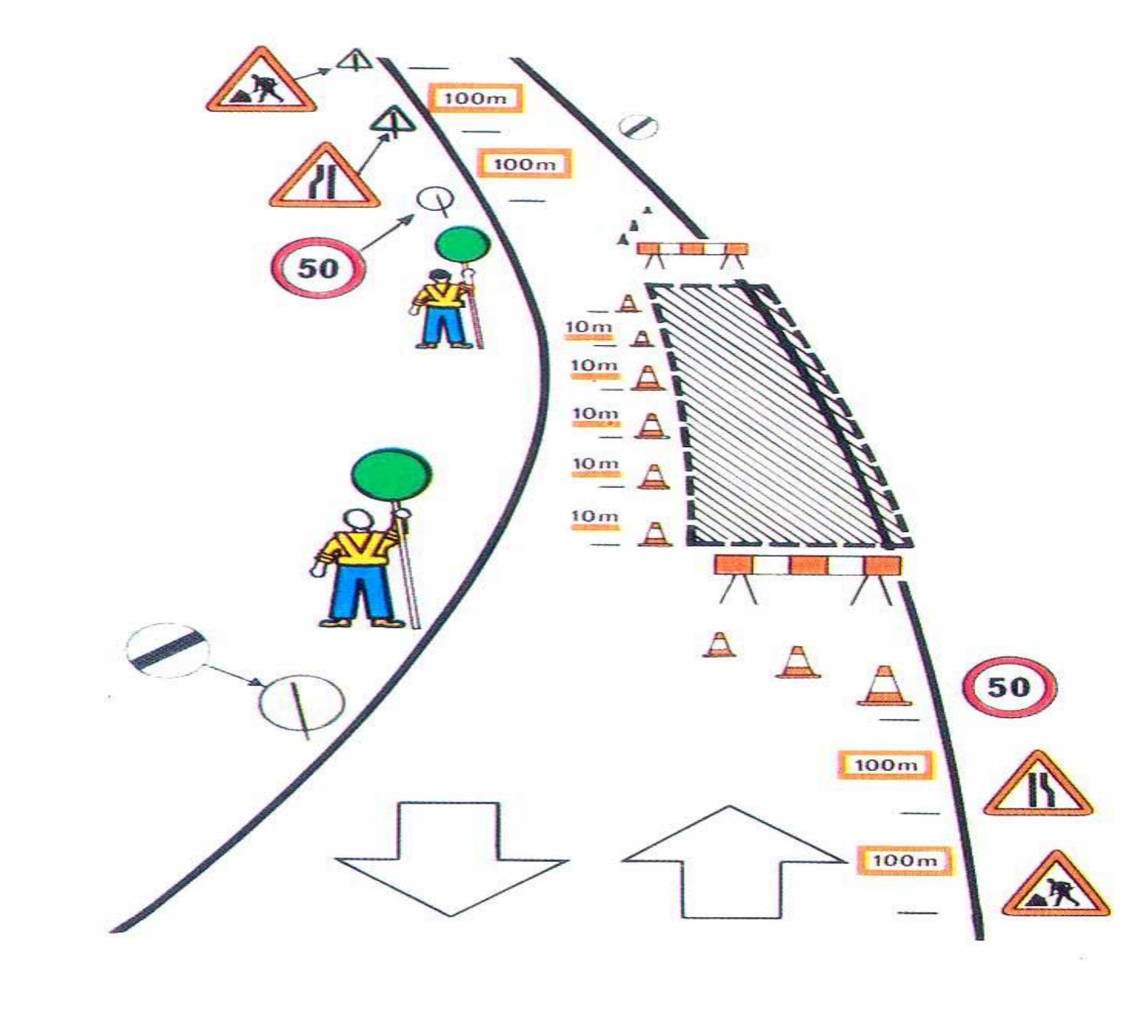


Figure 2. 4 Lane closure for routine and periodic maintenance [25]

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Study area

The study area is located in Oromia Regional State north showa zone where the start of the project Chancho with coordinates of 472639E, 1028068N and 2608 Elevation located at approximately 38 km from Addis Ababa and the project road branches to the left from main trunk road (Addis Ababa – Gohatsion) at the entrance of Chancho town. The project road is existing gravel road standard which starts from Chancho and terminates at Becho near Derba cement factory area with additional 2.3km spur road from Derba junction to Muger Cement passing through Derba village. The elevation of the road is around 2608m above sea level at Chancho, 2384m above sea level at Derba, 2370m above sea level at Factory Site and around 1498m above sea level around the mining area.

Due to rapid economic growth of our country, there is a high demand for cement and the existing Chancho – Derba – Becho road is a potential corridor for cement production and hence there are existing cement factories which are under operation and also new cement factories which are under construction and more will be expected. Among the new cement factories under construction is Derba Midorc Cement Plc the biggest cement factory in Ethiopia, which is expected to produce 7000ton cement per day. Apart from cement factories there are other ongoing development projects like flower farming and related development projects. These and other socio economic developments in the project will generate too much traffic and the existing road will not be able to accommodate the current and future transport smoothly and satisfactorily. In order to satisfy the demand of the economy for bulk transport of cement and other production it is required to upgrade the existing road to higher standard.

Table 3. 1 Large freight vehicle list

Major Vehicle	Capacity
Small Truck	Up to 3.5 tons load.
Medium Truck	3.5 up to 7.5 tons load.
Heavy Truck	Over 7.5 tons load.
Truck and Trailer	Over 12 tons load.

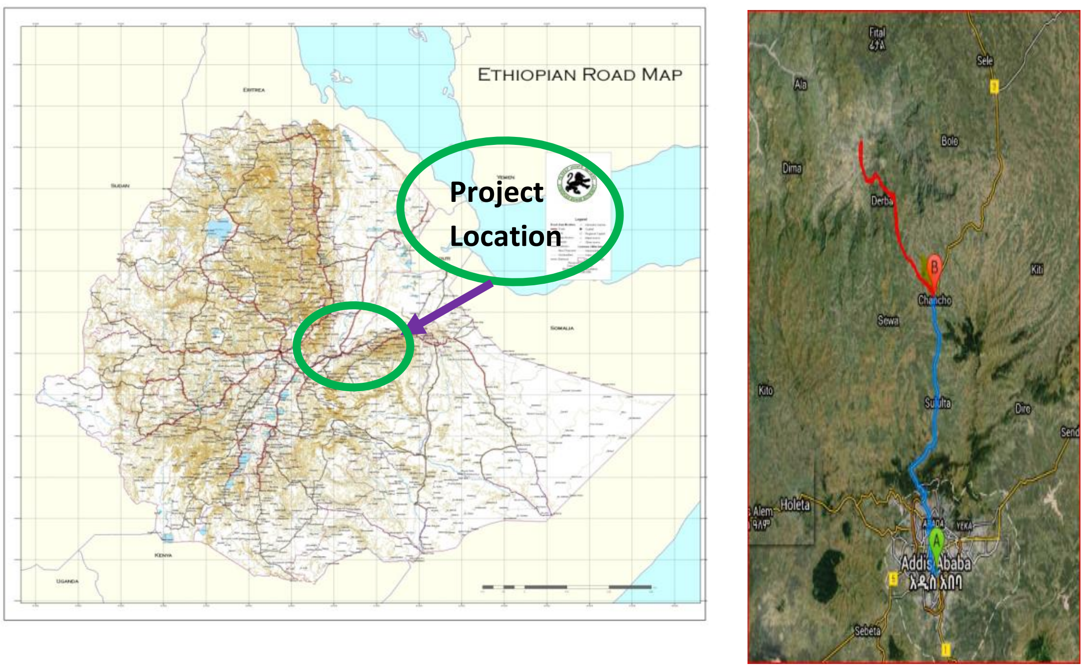


Figure 3. 1 Project area map

Table 3. 2 Town/Villages traversed by the route corridor

No.	Easting	Northing	Description	Remark
1	472681	1028051	Chancho	
2	466482	1031610	Rob Gebeya	
3	461686	1042510	Derba town	Debra cement Factory
4	462704	1045442	Becho	

3.1.1 Climate

The area through which the project road traverses can be classified as “Weina Dega” with the altitude ranging from 2300 to 2600m amsl. The project area has mean annual temperature between 5 and 20 ^{0}C and mean annual rainfall between 10 and 400mm.

3.1.2Temperature

The mean monthly minimum and maximum temperature of the project area is assessed by referring to the Meteorological Map of Ethiopia. Accordingly, the mean monthly minimum and maximum temperatures are 5 & 200C, respectively.

The mean monthly maximum and minimum temperatures for the project area are summarized and presented in the table below.

Table 3. 3 Mean Monthly Maximum and Minimum Temperature (^{0}C)

	Jan	Feb	Mar	Apr	May	Jun	Jul
Max.	20	20	20	20	20	20	20
Min.	5	5	10	10	10	10	10

	Aug	Sep	Oct	Nov	Dec	MAT
Max.	15	15	20	20	20	20
Min.	10	10	5	5	5	8

3.1.3 Rainfall

Rainfall data of the project area has been obtained, similar to the temperature data, from the Meteorological Map of Ethiopia. Accordingly, the monthly rainfall varies from 25mm December to 400mm in July and August and the annual rainfall is 1335mm.

The mean monthly and annual rainfall of the project area is presented in the table below.

Table 3. 4 Mean Monthly and Annual Rainfall (mm)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul
Rainfall (mm)	25	25	50	50	50	100	400

Month	Aug	Sep	Oct	Nov	Dec	Annual
Rainfall (mm)	400	150	50	25	10	1335

3.2 Existing pavement condition

The condition survey results indicate that the existing gravel wearing course is affected by pavement distresses like potholes, rutting, corrugation, and loss of camber and oversize materials. The pavement distresses are pronounced in the first 18kms and on the spur to Derba village and hence these sections have poor riding quality. Whereas the section of the road from Derba junction to the factory site has fair riding quality. The pavement condition and possible cause of the distresses is discussed below [28].

3.2.1 Corrugation

This distress is a series of ridges perpendicular to the centreline of the road and usually extends along the whole width of the carriageway. The wave length is usually between 50 and 100 cm. Corrugation crest lengths are measured as the distance between the troughs using steel tape or wedges by placing a straight edge longitudinally along the wheel paths spanning the corrugation crest. The severity of corrugation is the measured distance between crests and the extent of the distress is the length of the road section affected by the distress as a %-age.

In the project route, corrugations are extensive on the first 18km of the route and on the 2.3km spur. It could be observed that these sections are relatively flat sections on which vehicles travel faster with vibration.

The probable cause of this distress is one or combination of the following:

Traffic: displacement of less cohesive soils by moving traffic is one of the reasons for the formation of corrugations. The frequency of vibration of the suspended mass of vehicles combined with their speed determines the spacing of the ridges. The damage is occasioned by and continues to develop through existing irregularities in the surface.

Climate: During rainy season the ridge will also develop in the gravel wearing course. The loss of coarse material from the valley will create weak spots leading to other damages. The damage develops during rainy seasons when the material has little cohesion. The dryness and wind provide favorable conditions for the loss of fines.

3.2.2 Potholes:

These are bowl shaped localized holes on the pavement surface caused by the loss of surfacing materials. The extent of potholes is recorded as their number per the sub section considered while the severity of this distress is the maximum depth of the potholes in the subsection. Potholes are encountered on the majority of the project route.

The probable cause of potholes is one or combination of the following:

Traffic: potholes develop on areas where the sub grade is uneven or results from other damages (corrugation, rutting, erosion gullies, weak spots, removal of oversized cobbles, etc). The traffic will accelerate the development of potholes.

Climate: potholes start to develop in wet seasons; water remains in them and soak the surface material making it vulnerable to further damage. Once developed, potholes will grow deeper and wider.

Materials: clayey soils prevent proper drainage of surface water and permit weak spots to develop in to potholes. Moreover wearing gravels having oversized gravels and cobbles are prone to the formation of potholes, i.e. when these materials are removed, pot holes develop.

Workmanship problem: if the subgrade is not compacted properly, weak spots will form small depressions that will progress to formation of potholes.

Removal of Oversized materials: When oversized materials are removed from the surface by different reasons, the holes form small ponds during rainy seasons that may lead to formation of potholes.

Other defects: potholes may arise from other defects like corrugations, rutting or drainages related problems. Corrugations and rutting may lead to development of series of potholes.

3.2.3 Rutting

This distress is a load associated deformation and will appear as a longitudinal depression in the wheel paths. It is the result of non-recoverable vertical strain in the pavement layers and in the underlying sub grade. Rut depth is measured by placing a 2m straight edge across the road. The deepest part of the rut is measured and recorded as the rut depth showing the severity of the distress while the percentage of the sub section length is recorded as extent of the distress.

For the project road, the occurrence of ruts is limited on specific locations. The probable cause of rut is one or a combination of the following:

***Traffic**:* rut may result from wheel loads. It is strongly influenced by the traffic intensity, speed and loading. The development of rut is accelerated by the heavy traffic and channelized traffic. On the project route the most rutted section is Becho bound lane as a result of heavy vehicles transporting various equipment to the factory site.

***Climate**:* Ruts are aggravated during the driest season of the year as there is lateral displacement of non-cohesive materials. It is also facilitated on rainy seasons by liquefaction of surfacing materials or loss of stability of the road embankment or underlying subgrade materials. The project area has rainy seasons that may cause ruts.

3.2.4 Oversized selected materials

Segregation of fines and exposure of oversized materials has occurred because coarser gravels are used as wearing gravel without selective screening. Besides, washing away of cohesive fines by water and traffic induced displacement of these fines leads to disintegration and hence exposure of the oversize.

The defect affects the riddablity of the road badly and leads to increased vehicle operation costs.

3.2.5 Loss of camber

Loss of camber is distortion of the road cross section from the original transverse slope. The entire section of the project road is affected by loss of camber. The absence of camber leads to accumulation of water on the wearing gravel and latter it becomes the cause for most of the other pavement defects.

The probable cause of loss of camber is one or a combination of the following:

Wear by traffic: the traction forces of vehicles usually tend to cause the wear and tear of the gravel surfacing and result in the loss of camber.

Movement of materials: the central part of the road receives repeated wheel loads leading to the disintegration of the materials around the crown resulting in the loss of camber.

Channelized traffic flow: when one of the lanes of the road is defective, vehicles on both lanes of the road will follow a channelized traffic and this leads to loss of camber.

The existing pavement condition is summarized and presented in the table and figure below.

Table 3. 5 Summary of existing gravel pavement condition

Road section	Observed distresses	Pavement rating	Recommended remedial measures
0+000 – 7+000	Oversized materials, potholes, and loss of camber	Poor	Scarify, reshape and re-compact
7+000 – 18+700, *18+700 - *21+000	Oversized materials, potholes, corrugation, rutting and loss of camber	Poor to very poor	Scarify, reshape and re-compact
18+700 – 28+830	Oversized materials, potholes, and loss of camber	Fair to Poor	Scarify the top 15 – 20 cm, reshape and re-compact

3.3 Research design

The research was a case study type and conducted on the selected road project after review of the different literatures, journals, books, manuals, standards, pre-researches and related websites. The methodologies that were applied to achieve the objective of the research are:-

1. Literature review
2. A case study on Chancho-Derba-Becho road project through site investigation, field observation, data collection and review of drawing and design documents ,
3. Evaluating initial construction cost for one kilometre of both flexible and rigid pavement,
4. Estimating of future maintenance, rehabilitation ,fuel cost and time saving costs from secondary datas,
5. Life cycle cost analysis (LCCA) for both pavements by present worth method for 40 years analysis period.

3.3.1 Step in the determination of Life cycle cost

1. Determine the initial construction cost

- Asphalt versus concrete pavement(both pavement segments has been undertaken in the project)
- Quantity Take off prepared, Cost break down done, and Initial cost was estimated for 1km 2 lane road for both pavement types as per the typical road section of the project(chancho-Derba-Becho)

2. Determining schedule (frequency) of activities

- Analysis period
- Maintenance schedule and frequency in years
- Rehabilitation schedule and frequency in years

3. Estimate agency costs and user costs

- Exclude elements that are same for all alternatives ,like taxes, overhead and profit costs, contingency and drainage cleaning ,vegetation and flood control costs
- Agency costs – construction costs
- User costs –vehicle time savings and fuel costs

4. Compute life-cycle costs (Present Worth) Present worth of Costs

- Formula Computation
- Discounts all future costs (and benefits) to the present

5. Analyze the results

Table 3. 6 Parameters considered for the LCCA

S/No	LCCA elements considered		
	Parameters	Description	Remark
1	Construction Cost	Included	For pavements, sub base, base course and capping layer
2	Maintenance cost	Included	
3	Rehabilitation cost	Included	
4	User Cost(fuel and Time saving)	Included	
5	Salvage Value	Included	
6	Traffic Direction	2	Two lane- Two way
7	Analysis Period (Years)	40	
8	Beginning of Analysis Period	2015 GC	End of 2015
9	Discount Rate (%)	10.23	
10	Inflation rate	11.6	August 2015 Data
11	Interest rate (%)	5	CBE data
12	Number of Alternatives	2	Concrete(JRCP) and Asphalt
13	VAT, Tax ,contingency& miscellaneous	Not included	Common for two alternatives

Table 3. 7 Pavement maintenance and rehabilitation schedule

Description	Flexible pavement					Rigid pavement				
	Twice a year	Every three year	15th year	30th year	40th year	Every Eight year	Every Twelve year	Every Eight year	30th year	40th year
Routine maintenance	√					√				
Periodic Maintenance		√					√			
Rehabilitation			√	√						√
Salvage					√					√

3.3 Target population

The research targeted Ethiopian road projects that have both flexible and rigid along the stretch in general to have optimum comparison to meet the intended objectives. The selected road project, particularly, was in Oromia zone, chancho-Derba-Bocho road project.

3.4 Study Variables

i. Dependent study variable
   - Cost and benefit of Rigid and Flexible pavement

ii. Independent Variable:
   - Initial construction costs
   - Maintenance cost
   - Rehabilitation cost
   - Vehicle fuel costs
   - Vehicle time Saving
   - Salvage value

3.5 Sampling

During research, study, data collection, review and investigation was made on road projects having both flexible and rigid pavements in Ethiopia in general and Chancho Berba- Becho in particular. And informal interview of client representatives, contractors and consultants who have been involving in the construction and design of road projects was contacted.

3. 6 Instruments and tools

Data collection, site investigation and observations was the instruments used in this thesis.

3.7 Data source and collection

During data collection, data was collected from the following sources to accomplish the research work:

1. Road maintenance & rehabilitation data from ERA, ERCC and ERA manuals.
2. Field inspection of Chancho-Dreba-Bocho road project and design and specifications.
3. Informal Interviews to road project consultants and contractors.
4. Primary and secondary data were also collected from literatures, pre road feasibility studies, internets and websites.

Table 3. 8 Data description and data sources

S/no	Data Description	Data type		**Data Source**
		Primary	Secondary	
1	Design parameters		√	(chancho -Derba) site
2	Construction Materials list	√	√	(chancho -Derba) site
3	Construction Equipment list	√	√	(chancho -Derba) site
4	Construction Manpower list		√	(chancho -Derba) site
5	Pictures	√		(chancho -Derba) site
6	Actual road segments	√		(chancho -Derba) site
7	Direct cost	√	√	ERCC and ERA
8	Maintenance and Rehabilitation		√	Literatures, ERCC and ERA
10	Salvage value		√	Literatures
11	Discount rate		√	Literatures and prefeasibility study data in ERA projects
12	User costs		√	Literatures and prefeasibility study data in ERA projects

3.8 Data processing and analysis

After cost determination of pavement initial, maintenance, rehabilitation, salvage value and user costs for one kilometre then calculation of the present worth of rigid and flexible pavements was done. In addition to this qualitative comparison of the benefits was done by analysing data collected during from the site observation, investigations and literature review.

The net present worth formula used was the following:-

$$NPW = Ic + \left[\sum_{n}^{N} Mc\right]\left[\frac{1}{(1+dr)^{n}}\right] + \left[\sum_{n}^{N} Rc\right]\left[\frac{1}{(1+dr)^{n}}\right] + \left[\sum_{n}^{N} Uc\right]\left[\frac{1}{(1+dr)^{n}}\right] - Sv\left[\frac{1}{(1+dr)^{n}}\right] \text{........Eq[27]}$$

Where

Where Ic = initial construction cost; Mc =maintenance

Rc=Rehabilitation cost Uc = User cost [Fuel and time savings]

S = salvage value n = number of years.

N= analysis period in years [40] dr = discount rate[10.23%]

Since all the costs other than initial construction will occur in the future analysis years, future value of money should be determined for maintenance, rehabilitation, user and salvage values by considering the inflation rate. Inflation Rate, the rate of increase in the general price levels, caused usually by an increase in the volume of money and credit relative to available goods. The inflation rate is also reflective of the rate of decline in the general purchasing power of a currency.

$$Fc = PV[1 + if]^{n} \text{........................Eq(27)}$$

Where

Fc=Future cost at time of n years PV= Present Value of Money in birr
if= inflation adjusted interest rate

CHAPTER FOUR

RESULTS AND DISCUSION

4.1 Analysis Period

The LCCA analysis period should be sufficiently long to reflect long-term cost differences associated with reasonable design strategies. The analysis period should generally always be longer than the pavement design period, except in the case of extremely long-lived pavements. As a rule of thumb, the analysis period should be long enough to incorporate at least one rehabilitation activity. The FHWA's September 1996 Final LCCA Policy statement recommends an analysis period of at least 35 years for all pavement projects, including new or total reconstruction projects as well as rehabilitation, restoration, and resurfacing projects [29].

As per the above recommendation period of 40 years was considered for the analysis as shown in the following table to include one rehabilitation activity for the rigid pavement (JRCPCCP). The design period, 40 and 15 years for the respective pavements was taken from was taken from chancho-Derba-Becho road project design document.

Table 4. 1 Life Cycle Cost analysis periods

S/No	Pavement Type	Design period	Analysis period	Segment of road considered	Remark
1	Rigid (JRPCCP) pavement	40 years	40 years	1km length and 7m width	To consider at least one Rehabilitation of rigid pavement
2	Flexible pavement	15 years	40 years		

Table 4. 2 Activity Parameters and cost schedule

Type	Descriptions	Frequency	cost Base line	Projection
	Initial Construction Cost	in 2015 G.C	Cost of 2015	
Rigid (JRCP) Pavement	Routine Maintenance Cost	Every 8th years		Projected with Time value of money consideration to the coming years,
	Periodic Maintenance	Every 12th year		
	Rehabilitation Cost	At 40 th year(2055 G.C)		
	User time savings and fuel costs	In the analysis period		
	Salvage value	At 40th year(2055 G.C)		
Flexible Pavement	Initial Construction Cost	In 2015 G.C		
	Routine Maintenance Cost	two times a year		Projected with Time value of money consideration to the coming years
	Periodic Maintenance	once every three year		
	Rehabilitation Cost	Every 15th years of 40 year(2030 and 2055 G.C)		
	User time and fuel costs	During maintenance and rehabilitation		
	Salvage value	At 40th year(2055 G.C)		

4.2 Determination of agency Costs

4.2.1 Initial construction Cost of pavements

The cost was calculated after determining the quantity and cost break down for 1km and 7meter road width base on the typical road section of both pavement types particular to Chancho-Derba- Becho Road project. The break down calculation include direct and indirect costs but other like overhead, contingency and value added taxes are ignored since they have the same effect on comparison of the pavement costs.

Table 4. 3 Initial cost Summary for flexible pavement (from Annex B table)

Item No	DESCRIPTION	TOTAL ETB
1	Sub base and Base course	959,630.00
2	Bituminous Concrete Surface	5,342,008.47
	TOTAL	6,301,638.47
	Cost per km	6,301,638.47

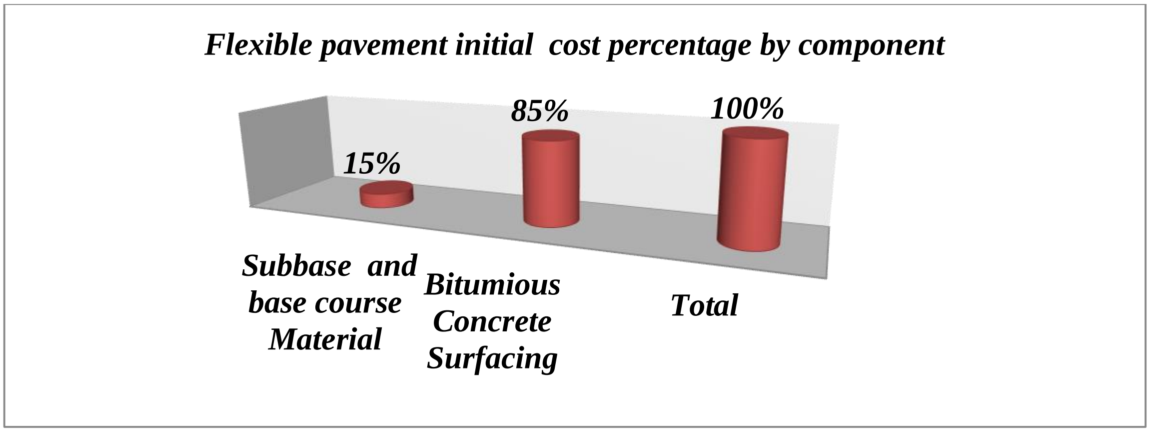


Figure 4. 1 Flexible pavement initial cost percentage by component

Table 4. 4 Initial cost Summary for rigid pavement (from Annex B table)

S/no	DESCRIPTION	TOTAL ETB
1	Sub base materials	842,590.00
2	Concrete Pavement	10,066,914.20
3	Texturing and Curing	510,400.00
4	Joints	35,165.52
5	Reinforcing steel Bars	3,332,671.15
6	Separation Membrane(Impermeable plastic sheet)	350,787.50
	TOTAL	15,138,607.72
	Cost for 1km per KM	**15,138,607.72**

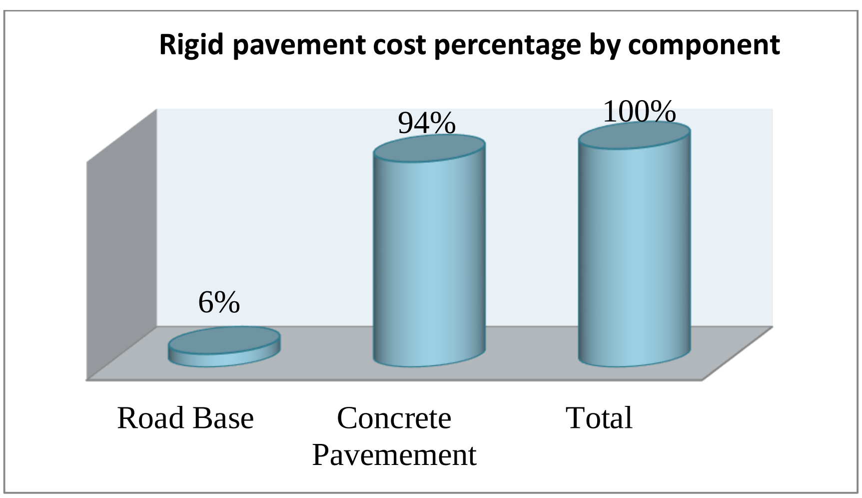


Figure 4. 2 Rigid pavement cost percentage by component

Table 4. 5 Initial Cost comparison of the two pavements

Pavement Type	Length(km)	No of lane	width per lane(m)	Cost per km (Birr)
Flexible pavement	1	2	3.5	6,301,638.47
Rigid (JRCCP) pavement	1	2	3.5	15,138,528.37

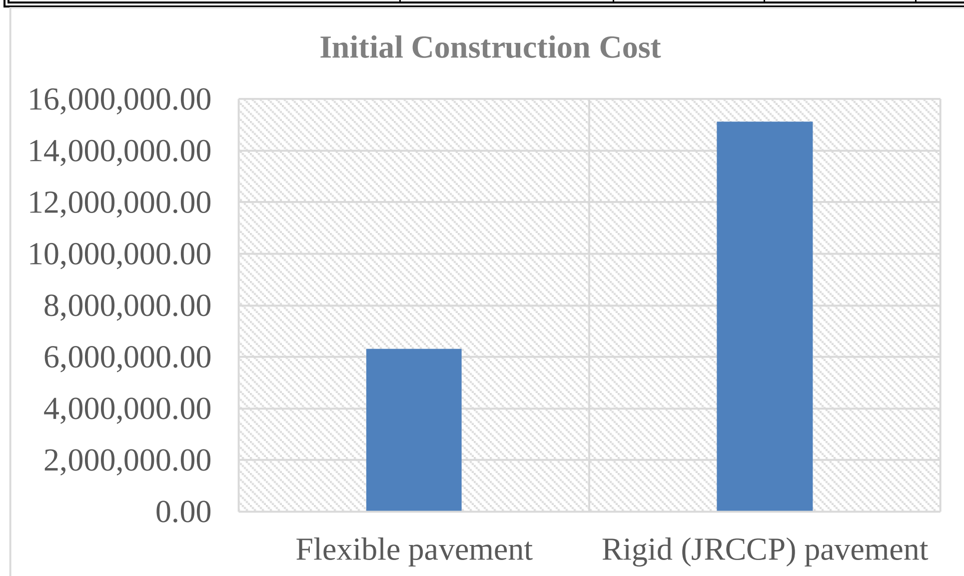


Figure 4. 3 Initial Construction cost of flexible and rigid pavement

4.3 Maintenance cost of pavements

4.3.1 Routine maintenance of flexible pavement

Based on the monthly rain fall data of the study area June, July, August and September has high intensity [28]. Hence, it is practical for this project area to consider and carry out the routine maintenance before and after these wet seasons.

Table 4. 6 Flexible pavement routine maintenance schedule

Frequency in a year	Month of Year	Routine Maintenance activities	Remark
1st	March	Seal coat, Single surface treatment, Double surface treatment, crack sealing and Pothole repair[25]	Twice a year before and after the wet season
	April		
	May		
2nd	October		
	November		
	December		

4.3.2 Periodic maintenance for flexible pavement

The Periodic maintenance is to be conducted once a year before the rain comes as per the experience of ERCC and ERA.

Table 4. 7 Flexible pavement periodic maintenance schedule

Frequency in a year	Month of a Year	Periodic Maintenance activities	Remark
Once a year	March	Sand seal coat, Single and double Surface treatment Cold mix overlay, Asphalt Concrete Overlay ,Prime and Tack coat, Base course reconstruction [19]	Once every three years before the wet season
	April		
	May		

Table 4. 8 Summary of maintenance for flexible pavement

Maintenance Type	Frequency	Cost per occurrence	Total Cost/km/year
Routine	Twice a year	336,588.13	673,176.26
Periodic	Once every three years	681,856.38	681,856.38

4.3.3 Rehabilitation of flexible pavement

Considering two times rehabilitation of the flexible pavement in 40 years of analysis period the cost was calculated for full replacement asphalt bitumen after scarifying it and the aggregate sub base course [26].

Table 4. 9 Rehabilitation Schedule of Flexible pavement

Year	**GC**	**Activities**	**Remark**
0	2015	Construction	Twice Hot mix overlay for the analysis period
15	2030	HMA over lay	
30	2045	HMA over lay	
40	2055	Salvage Value	

The total cost of rehabilitation for 15th and 30th years became 2,558,500.84 per kilometer of the road .this cost was 35% of the initial construction cost in the respective year (value taken from summery of cost under annex A).

4.3.4 Salvage Value

$$SalvageValue = LC\left[\frac{ERL}{TEL}\right]$$ --------------EQ-[24]

Where,

LC = Last rehabilitation costs of pavement

ERL = Expected remaining life of the last rehabilitation of pavements

TEL = Total expected life of the last rehabilitation pavements

$$SalvageValue = 2{,}558{,}500.84\left[\frac{10}{15}\right] = 1{,}705{,}667.23$$

Table 4. 10 Agency of Flexible pavement

S/No	Activity	Cost (ETB)	Remark
1	Construction Cost	7,246,884.24	
2	Routine Maintenance Cost	673,176.26	Twice every years
3	Periodic Maintenance Cost	681,856.38	Once every three years
4	Rehabilitation Cost	2,558,500.84	At 15^{th} and 30^{th} years
5	Salvage Value	1,705,667.23	After 40^{th} years

4.4 Maintenance and rehabilitation of rigid pavement

The major routine maintenance activities were scheduled to be conducted at every 8 years and periodic activities at 12 years before wet season. At 40 years after construction rehabilitation was scheduled for the particular project.

Table 4. 11 Schedule of Maintenance and rehabilitation of rigid pavement [26]

Maintenance Type	Activity	Frequency
Routine Maintenance	Joint Sealing	Every 8 years
	Crack Sealing	
Periodic maintenance	Partial Depth repair	every 12 years
Rehabilitation	Full depth repair	at 40 years

4.5 Salvage Value of rigid pavement

$$SalvageValue = 1{,}191{,}000.00\left[\frac{8}{12}\right] = 794{,}000.00$$

Table 4. 12 Agency cost of rigid pavement

S/No	Activity	Cost (ETB)	Remark
1	Construction Cost	13,398,607.72	
2	Routine Maintenance Cost	300,000.00	Every 8 years
3	Periodic Maintenance Cost	119,000.00	Every 12years
4	Rehabilitation Cost	1,191,000.00	At 40 years
5	Salvage Value	794,0000.00	After 40 Years

4.7 Determination User Costs

The Cost- Benefit analysis of the road project measures the capital cost in monetary terms on the one hand, and the benefits that accrue in the form of travel time and the vehicle operating cost savings on the other.

The major considerations in the measurement of costs and benefits for the economic appraisal of this road project are: the travelling that incurs costs to road users such as the time spent travelling; costs arising from direct costs of fuel, maintenance and depreciation. The rehabilitation and maintenance of a road would be expected to reduce these costs. The travel time used to make journey may be reduced due to the improvement of the road.

4.8 Vehicle time savings

This is the benefit of the pavements gained after the construction when the condition of the pavement improved. The existing unpaved road was DS5 standard having average design speed of 54km /hr was improved DS3 standard to 73km/hr after construction of this particular chancho-Derba- Becho pavements and the time saving became 0.29 minute and valued to one birr per one minute saving.

Table 4. 13 Design speed of paved and unpaved road [30]

Surface Type	Design Standard	Design Speed (km/hr)				
		Flat	Rolling	Mountainous	Escarpment	Urban/ Peri-Urban
Paved	DS3	100	85	70	60	50
Unpaved	DS5	70	60	50	40	50

Table 4. 14 Time saving value of paved road

Surface Type	Average Speed	Time required to cover 1km		Time saved
Paved	73km/hr	0.14hr	0.82min	
Unpaved	54km/hr	0.185hr	1.11mim	1.11-0.82=**0.29mim**

Table 4. 15 Time saved by each vehicle type

Vehicle Group	AADT (2014-2028)	Composition	No of Vehicles	Time savings	Total time savings/day
Small Bus(SB)	429	37%	158	0.29min	45.82
Medium Bus(MB)	429	2%	9	0.29min	2.61
Large Bus	429	1%	4	0.29min	1.16
Medium Truck(MT)	429	25%	109	0.29min	31.61
Heavy Truck(HT)	429	24%	101	0.29min	29.29
Truck Trailer(TT)	429	11%	48	0.29min	13.92
Total time saved by all vehicle type in minute /per day					**124.41**

Since maintenance and rehabilitation requirement of flexible and rigid pavement occurred at different years through the analysis period, the years of time savings were different. Time savings were not expected during maintenance and rehabilitation times due to activities the road and partial lane closure. Therefore, for flexible pavement 6 months per year for routine maintenance that became a sub total of 120 months (10 years) and 3 months for every 3 years of periodic maintenance that became sub total of 24 months (2years) and two time s rehabilitation for 2 years that totally result 14years has no time savings . For rigid pavement for a total of 2.5 years, 18 months for routine and periodic maintenance that became a sub total of 1.5 years and 1 year’s rehabilitation, time savings was not expected.

Table 4. 16 Annual Time Saving considerations

Flexible pavement		Rigid pavement	
40 years analysis period		40 years analysis period	
Time saving years	Maintenance years	Time saving years	Maintenance years
26 total years	14 Total years	37.5 total years	2.5 Total years

Total annual saved time = [124.41minutes/day]*365days = 90,885.00.minutes.Total annual benefit from time savings in birr becomes=90,885.00 minutes*1 birr/minutes=90,885.00 birr.

For rigid pavement the annual saved time is benefit for a period of 37.5 years (40 years - 2.5 years) after deducting the years of maintenance (at 8,12,16,24,32 and 36 years) and rehabilitation(at 40 years) ,where the saving time become dis- benefit, delay due to maintenance and rehabilitation activities and closures for the remaining 2.5years .

For flexible pavement the annual saved time is benefit for a period of 26 years (40 years - 14 years) after deducting the years of maintenance and rehabilitation ,where the saving time become dis- benefit, delay due to maintenance and rehabilitation activities and lane closures for the remaining 14 years .

4.9 Vehicle Fuel Cost

The types of fuel used by the vehicles are gasoline and diesel. Ethiopia's consumption of fuel is largely attributed to transport industry than any other economic sector. The economic prices of fuels and lubricants oils used in the study are as shown in Table 5.5 below.

Table 4. 17 Economic prices of Fuel and Lubricant oil [19]

Type of Fuel & Lubricant oil	Economic Price (Birr/liter)
1. Fuel	
Diesel	16.82
Gasoline	19.68
2. Lubricant Oil	45.5

Assuming that vehicles consume 0.33 liters per kilometer the annual fuel consumption becomes:-

Cost of fuel per day =0.33lt/1km*1km*429*16.82birr/lit=2,381.21 birr/day

The annual cost of fuel=2,381.21 birr/day *365 days=869,140.70 birr/km/year

Rigid pavement reduce 0.8% fuel consumption for a period of 37.5 years (40 years -2.5years) after deducting the years of maintenance and rehabilitation ,where such reduction is not considered due to maintenance and rehabilitation activities and lane closures for the remaining 2.5years [9,10] .

Flexible pavement reduce 1.8% fuel consumption for a period of 26 years (40 years -14 years) after deducting the years of maintenance and rehabilitation ,where such reduction is not considered due to maintenance and rehabilitation activities and lane closures for the remaining 14years[9,10] .

Table 4. 18 Cost of fuel and time savings in the analysis period

Pavement type	**Time Savings (birr/km)**	**Fuel Cost (birr/km)**	**Remark**
Rigid	3,180,975.00	34,765,628.00	For 40 years
Flexible	1,090,620.00	34,350,384.40	
Rigid	79,524.38	869,140.70	Per each year
Flexible	27,265.50	858,759.61	

4.9 Future Value of Costs

Since all the costs other than initial construction will occur in the future analysis years, future value of money should be determined for maintenance, rehabilitation, user and salvage values by considering the inflation rate. Inflation Rate, the rate of increase in the general price levels, caused usually by an increase in the volume of money and credit relative to available goods. The inflation rate is also reflective of the rate of decline in the general purchasing power of a currency.

$$Fc = PV[1 + if]^n \text{........................Eq (2)}$$

Where

Fc=Future cost at time of n years

PV= Present Value of Money in birr

if= inflation adjusted interest rate

n= number of years

4.10 Present worth Calculations

The net present worth formula used was the following:-

$$NPW = Ic + \left[\sum_{n}^{N} Mc\right]\left[\frac{1}{(1+dr)^{n}}\right] + \left[\sum_{n}^{N} Rc\right]\left[\frac{1}{\left((1+dr)^{n}\right)}\right] + \left[\sum_{n}^{N} Uc\right]\left[\frac{1}{(1+dr)^{n}}\right] - Sv\left[\frac{1}{(1+dr)^{n}}\right]$$

The initial construction cost for the flexible pavement was 6,159,851.60 Birr/Km and for rigid pavement was 13,398,607.72 Birr/Km at the end of 2015 and the discount rate used was 10.23%. Here the future value of all costs except the initial construction of pavements was calculated with the corresponding occurrence years to account inflation and then brought to the present value as of 2015.

Table 4. 19 Present worth of pavements with the corresponding cost

Alternatives	**Description**	**PW (Birr/km)**
Flexible pavement	Construction	6,159,851.60
	Routine Maintenance	4,751,072.46
	Periodic Maintenance	2,095,019.25
	Rehabilitation	806,517.58
	Salvage Value	-43,688.51
	Fuel Cost	8,721,417.57
	Time Savings(benefit)	-276,903.81
Net PW for FP	-	***22,213,286.14***
Rigid pavement	Construction	13,398,607.72
	Routine Maintenance	262,688.40
	Periodic Maintenance	56,849.86
	Rehabilitation	30,505.96
	Salvage Value	-20,337.31
	Fuel Cost	9,384,726.90
	Time Savings(benefit)	-8,826,941.34
Net PW RP		***14,286,100.19***

Table 4. 20 Cost Comparison for 40 years of analysis

Description	Flexible pavement	Rigid pavement
Construction cost		2 times of flexible
Routine Maintenance cost	18 time rigid	
Periodic Maintenance cost	37 times rigid	
Rehabilitation cost	26 time rigid	
Salvage Value(benefit)	2 time rigid	
Fuel Cost		almost equal to flexible
Time Savings(benefit)		32 times flexible
Total Life Cycle cost	7.9 million birr higher	

4.11 Time and Material requirement

4.11.1 Time requirement

To execute the initial construction of one kilometer pavement stretch major time required for critical activities was determined based on the performance output of standard crew deployed at the project and the quantity determined based on typical road section of Chancho –Derba- Becho road project. As per the table below flexible pavement requires 5 days and 42 days are required to execute rigid pavement.

Table 4. 21 Critical activities of initial construction pavement

S/No	Flexible Pavements Critical activities	Rigid Pavements Critical activities
1	construction of Dense Bitumen Macadam	Reinforcing steel bars
2	Asphalt surfacing	Casting of C-35 concrete
3		Curing of concrete

Table 4. 22 Time required for the initial construction of one kilometer flexible pavement

S/no	Major and critical Activities	unit	Quantity /km	Required Working Days	Performance
1	Dense Bitumen Macadam	M3	1015	3	345M3/day
2	Asphalt surfacing	M3	350	2	173m3/day
Total working days				5	

Table 4. 23 Time required for the initial construction of one kilometer rigid pavement

S/no	Major and critical Activities	unit	Quantity /km	Required Working Days	Performance
1	Placing of Rebar	kg	6677.44	7	1179kg /day
2	Casting of C-35 Concrete	M3	2400	21	119m3/day
3	Curing of concrete(14 minimum curing days)	m2	7000	14	700m2/day
Total working days				42	

4.11.2 Material requirement

To execute one kilometer pavement stretch major material required for critical activities was determined based on the performance output of standard crew and actual Chancho – Derba- Becho road project. The aggregate requirement for flexible pavement is more than twice that of rigid pavement. It also requires more material for sub base and base course than rigid pavement.

Table 4. 24 Material required for the initial construction of one kilometer flexible pavement

S/no	Description	unit	Qty	Remark
1	Bitumen 80/100(for Asphalt and Macadam)	kg	175,490	156kg/m3+117kg/m3
2	Aggregate (gravel)for Asphalt	M^3	805	2.3/m3
3	Aggregate for Base course	M^3	1,750	
4	Sub base Material	M^3	1,400	

Table 4. 25 Material required for the initial construction of one kilometer rigid pavement

S/no	Description	unit	Qty	Remark
1	Portland Cement	Qnt	9,596	4qnt/m3
2	Aggregate(gravel) for C-35 concrete	M^3	360	0.15/m3
3	River sand for c-35 concrete	M^3	960	0.40/m3
4	Sub base Material	M^3	3,045	

4.12 Accident

Maintenance and rehabilitation activities increase accident risk on the road, as normal traffic flow is disturbed. Even with good road markings and information signs, traffic accident risk increases compared with the usual traffic flow situation.

Table 4. 26 Expected Accident in 40 years of analysis period

Flexible pavement		Rigid pavement	
40 years analysis period		40 years analysis period	
Years of expected accident	Years of disturbance to normal traffic flow	Years of expected accident	Years of disturbance to normal traffic flow
14 total years	14 Total years	2.5 Total years	2.5 Total years
35% of 40 year	35% of 40 year	6% of 40 year	6% of 40 year

4.13 Foreign currency saved

After the material requirement per kilometre stretch of each pavement type was multiplied by the corresponding cost and converted to USD .A total of 105,526.13 currency per kilometre will be saved if the roads use rigid pavement alternative.

Table 4. 27 foreign currency saved by rigid pavement

Description	unit	Qnt	Unit Price	Total Amount
Total Bitumen /km FP	Kg	175,490.00	25	4,387,250.00
Total Cement/km RP	Qnt	9,596.00	225	2,159,100.00
Total difference in Birr				2,228,150.00
Total difference in USD (saved Currency/km)				105.526.13

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the analysis, results and discussion about study area as well as literatures review in the previous chapters the following conclusion are drawn particularly for life cycle cost, advantages and disadvantages of flexible and rigid pavement ,maintenance activities and design life.

5.1.1 Life Cycle Cost

The life cycle cost of rigid pavement is lower than flexible pavement. For one kilometer stretch it has 7.8 million birr lower than flexible pavement for 40 years analysis period. Routine and periodic maintenance costs for the period of 40 years are 1.1 times greater than the initial construction cost of the same one kilometer stretch for flexible pavement. Flexible pavement requires 7.3 million birr higher for maintenance and rehabilitation compared to rigid pavement.

5.1.2 Merit and demerit of pavement alternatives

In the history of road construction in Ethiopia rigid pavement is only about 0.10% of the total pavement road due to the lack of construction technology and tradition to use this pavement for highway projects in spite of its advantage [6].

Rigid pavement fully constructed with local material, cement and reinforcement without the requirement of importing construction material from abroad ,whereas flexible needs importing of bitumen material as of major pavement material.

Rigid pavement has good night visibility compared to flexible and reduce the occurrence of accidents at night. Materials of flexible pavement, asphalt can be reused easily than rigid pavement concrete.

5.1.3 Maintenance of pavements

Maintenance and repairing flexible pavements is an easy activity compared to that of rigid pavement. Table below show the major maintenance activities of flexible pavement as per the practice of ERA, ERCC and literatures for rigid pavement.

Table 5. 1 Maintenance and Rehabilitation Activities for pavements

Type	Maintenance activities		Rehabilitation
	Routine	Periodic	
Flexible Pavement	Seal coat	Sand seal coat	Asphalt concrete overlay
	Single surface treatment	Single Surface treatment	Bitumen tack coat
	Double surface treatment	Double Surface treatment	Base course reconstruction
	Crack sealing	Mix-in Place(clod mix) overlay	
	Pothole repair	Asphalt Concrete Overlay &Prime and Tack coat	
		Base course reconstruction	
Rigid Pavement	Joint Sealing	Partial Depth repair	Full depth repair
	Crack Sealing		

5.1.4 Design life of pavements

For longer design life of paved roads rigid pavement is the best alternative than flexible. In the study area design life of rigid pavement was 40 years and 15 years for flexible pavement.

5.2 Recommendations

It is crucial and economical to use rigid(Portland cement concrete pavement) in Ethiopia especially for high traffic volume roads and weak sub grade(low CBR)value stretches since all the materials required are found locally in the country and the majority of axle loads are carried by the pavement because of its rigidity .

It is important to think and incorporate rigid pavement as one of the best alternative during design and selection of pavements as road surfacing materials.

In addition, to have better knowledge regarding rigid pavement in particular it is important to evaluate the performance of the newly constructed rigid pavement projects like chancho –Derba Becho by recording the challenges, construction methodologies, and maintenance and rehabilitation activities in the futures years to improve the construction, maintenance and rehabilitation strategy in the country.

Moreover it is important to plan, schedule maintenance and rehabilitation strategies and activities for pavements and to include as project activity during the design life of roads and consider the life-cycle cost of a project rather than the initial construction as a target project only.

5.3 **Recommendations** for further research

To increase the pavement life in general and reduce the maintenance and rehabilitation costs, pavement alternatives should be selected considering the whole life cycle costs and along with better maintenance and rehabilitation strategy. The Life cycle cost analysis and pavement selection alternatives particularly for rigid and flexible type in the study area particular and in Ethiopia in general should be evaluated using models like HDM4 and other performance evaluation software.

CHAPTER SIX

REFERENCES

[1]. Developement, O.F.E.C.-o. (2005) *Economic Evaluation of Long -Life pavements-Phase I*.

[2]. Association, E.A.P., *Long-Life Asphalt Pavements – version for 'bankers'*. June 2007. p. 3.

[3]. ENGINEER, J.N.V.C., *Pavement Life-Cycle Cost Studies Using Actual Cost Data*. 2005. p. 4.

[4]. Williams, R.I.T., *Cement -Treated Pavements: Material,Desinand Construction.* 1986, Elsevier Applied Science Publisher Ltd: New York,NY,USA.

[5]. Ontario, R.M.C.A.o., *Concrete Pavement Specifiers Guidelines* August 2009.

[6]. Openion, E. *www.ethiopianopenion.com*. 2014 [cited 2014].

[7]. Authority, E.R., *17 Years Performance Assessement* 2014, Ethiopian Road Authority,Road sector Development, Addis Ababa ,Ethiopia. p. 3-32.

[8]. Tayler and Francis Group, L.F.F., *The hand book of Hihway Engineering*.2006.

[9]. www.http://theconstructor.org/transportation/.*Types-of-pavement-flexible-and-rigid-pavement*. [internate] 2015 [cited 2015 8/20/2015].

[10]. Antonio, M., *Concrete vs Asphalt.A posiotion paper*, in *Presentation from shell specialist*. July ,2014: Philipines ,Makati City.

[11]. Authority, E.R., *Pavement Design Manual Volume II-* in *Rigid Pavement* 2013, Ethiopian Road Authority: Addis Ababa,Ethiopia.

[12]. KIBUKWO, K.F., *cost comparion of concrete versus flexible pavment designs for steep to rolling sections along A104 road (NAKURU – ELDORET)*, in *Department of Civil and Construction Engineering*. 2013, University of Nirobi, p. 39.

[13]. MINNESOTA, C.P.A.O. *www.concreteisbetter.com*. 2015 july,2015].

[14]. Reporter, E., *concrete road in Ethiopia*, in *Reporter*. 2014.

[15]. (AASHTO), A.A.o.S.H.a.T.O., *User Benefit Analysis for Highways*. 2003.

[16]. Design, S.o.C.D.o.T.P.S.T.a.D.o., *Life -Cycle Cost Analysis Procedures Manual*. 2010. p. 14.

[17]. Ethiopia, N.B.o., *Interest Rate* in *Directive No.NBE/INT/11/2010*. 2010, National Back of Ethiopia: Addis Ababa.

[18]. Fund, A.d., *Jimma-Mizan Road Upgrading Project-Aprasial Report*, in *Economic Analysis Summry*. 2006: Addis Ababa -Ethiopia.

[19]. Beijing Expressway Supervision Co., L.I.J.w.B.C.E., *Fesibility Study of Adama-Awash Express way Project*. 2014. p. 28.

[20]. *Limited., J.E.G.E., Asphalt pavement life-cycle costing. May 1998, Ontario Hot Mix Producers Association*: *OHMPA*.

[21]. Authority, E.R., *Pavement Rehabilitation and Ashpalt Overlay Design Manual*. 2003, Ethiopian Road Authority: Addis Ababa-Ethiopia. p. 10.

[22]. Authority, E.R., *Road Sector Developement Program (1997-2007) report*. 2007, Ethiopian Road Authority: Addis Ababa,Ethiopia. p. 65-66.

[23]. *Pavement Recycling Guidelines for State and Local Governments U.S. Department of Transportation, Washington, DC 1987*. Vol. Reference Manual, Report No. FHWA-TS-87-230, FHA,.

[24]. Transportation, W.S.D.o., *WSDOT pavement Policy*2011, Environmental and Engineering Division State materials Laboratory Pavement s Division Olympia,WA p. 45.

[25]. Authority, E.R., *Technical Specification for Road Maintenance works,2nd Edition*. 2003, Ethiopian Road Authority: Addis Ababa. p. III-1-III-2, V1-V22.

[26]. Anne Holt, P.E., I. Applied Research Associates, and S. 5401 Eglinton Avenue West, Toronto, ON, Canada, M9C 5K6, *Life Cycle Cost Analysis of Municipal Pavements in Southern and Eastern Ontario* September 2011: Edmonton, Alberta p. 10.

[27]. Scheving, A.G., *Life Cycle Cost Analysis of Asphalt and Concrete Pavements*. 2011, Reykjavík University: Iceland.

[28]. PLC, C.C.E., *Engineering Desing Report Chancho-Derba*. 2012, ERA: Addis Ababa, Ethiopia.

[29]. Smith, J.W.I.a.M.R., *Life-Cycle Cost Analysis in Pavement Design* 1998. p. 9.

[30]. Erhiopian Road Authority, E., *ERA Design Manual*, in *Geometeric Design Manual* 2002, ERA: Addis Ababa Ethiopia.

APPENDIX A:-Major data collected

A-1:- Pavement data

S/No	Description of parameters	Rigid Pavement	Flexible pavement	Remark
1	Road Design Standard	DS3	DS3	
2	Design Life	40 years	15 Years	25 years difference
3	Design Traffic	114.97 Million ESA	92 Million ESA	
4	OPC Cement concrete(RC)	340mm thick		
5	Asphalt Concrete		50mm thick	
6	Dense Bitumen Macadam		145/130mm thick	21km(chancho Derba)/18km(derba Becho)
7	Gravel Base Course layer		250mm	
8	Granular sub- base layer	185 mm thick	230/200mm thick	21km(chancho Derba)/18km(derba Becho)
9	Capping layer	250mm thick		
10	Shoulder	Double Surface treatment	Double Surface treatment	MC-3000 Bitumen
11	Carriage Way width	7m	7m	Except town section

A-2:- Rigid Pavement data

S/No	Description of parameters		Remark
1	Pavement Type	Jointly Reinforced concrete Pavement(JRCP)	
2	Design life	40 years	
3	Design Traffic	114.97 million ESA	
4	Replacement of Unsuitable sub grade Materials	600 mm thick below capping layer	
5	Capping Layer thickness	250mm	
6	Sub Base Layer Thickness	185mm	
7	Concrete slab Thickness	340mm	
8	Concrete Class	C-35	
9	Spacing of Transversal Joint	at every 25meters	
10	Transversal Reinforcement	Ø12mm c/c 600mm,L=3300mm	
11	Longitudinal Reinforcement	Ø14mm c/c 250mm, L=24400mm	
12	Dowels bar for Transversal Joints	Ø25 mm c/c 300mm,L=400m	Plain bars
13	Tie bars for longitudinal Joints	Ø12mm c/c 600mm,L=1000m	
14	RC Concrete Anchore Key @ 39 meters	300x300mm, for 7m width	
15	Separation Membrane	B/n Sub base and RC pavement	MC-30 or Plastic sheet

A- 3:-Flexible Pavement data

S/No	Description of parameters		Remark
1	Pavement Type	Asphalt Concrete with Penetration Grade 80/100	
2	Design life	15 years	
3	Design Traffic	92 Million ESA	
4	Replacement of Unsuitable sub grade Materials	600 mm thick below sub base	
5	Sub Base layer thickness	330mm/200mm	Chancho - Derba/Derba -Becho
6	Base course Layer thickness	250mm	
7	Dense Bitumen Macadam(DBM)	145mm/130mm	Chancho - Derba/Derba -Becho
8	Asphalt Concrete thickness	50mm	
9	Bituminous Prime coat	MC-30, Cutback bitumen	
10	Bituminous Tack coat	MC-70, Cutback bitumen	

A-4:-Flexible pavement maintenance activities in Ethiopian context [25]

Type	Code	Name of Activity	Unit
Routine Maintenance	210	Asphalt Patching (Seal Coat)	m^2
	211	Asphalt Patching (Single Surface Treatment)	m^2
	212	Asphalt Patching (Double Surface Treatment)	m^2
	213	Asphalt Patching (Cold Mix)	m^3
	214	Asphalt Patching (Hot-Mini-Mix)	m^3
	215	Crack Sealing (Individual Cracks)	Lm
	218	Pothole Reinstatement (Hot-Mini-Mix)	m^3
	219	Pothole (Base Failure Repair)	m^3
Periodic Maintenance	309	Sand seal coat	m^2
	310	Single Bituminous Surface Treatment (SBST)	m^2
	311	Double Bituminous Surface Treatment (DBST)	m^2
	312	Mix-In-Place Overlay (Cold Mix)	m^3
	313	Asphaltic Concrete Overlay	m^3
	314	Bitumen Prime Coat	Lt
	315	Bitumen Tack Coat	Lt
	316	Pavement Reconstruction (Aggregate Road base)	m^3

A-5 :-Vehicle group and classification

Vehicle classification	Description
1. Passenger vehicles	
1.1. Cars	Small automobiles
1.2. Land Rovers	4WD and utility vehicles
1.3. Small Bus	Buses up to 25 passenger seats
1.4. Medium Bus	Buses with 25 up to 45 passenger seats
1.5. Large Bus	Buses with over 45 passenger seats.
2. Freight vehicles	
2.1. Small Truck	Trucks of capacity up to 3.5 tons load.
2.2. Medium Truck	Trucks of capacity 3.5 up to 7.5 tons load.
2.3. Heavy Truck	Trucks of capacity over 7.5 tons load.
2.4. Truck and Trailer	Articulated Trucks and tanker trailers of capacity over 12 tons load.

A.6: -Vehicle Fleet Characteristics and Costs

Vehicle Type	**S/Bus**	**M/Bus**	**L/Bus**	**M/Truck**	**H/Truck**	**T/Trailer**
Physical Characteristics						
Operating Weight (kg)	5,200	7,100	9,000	13,000	22,000	28,000
Axles per Vehicle(no.)	2	2	2	2	3	5
Tires per vehicle (no.)	4	5	6	6	10	18
Passenger Occupancy (no.)	20	33	45	2	2	2
Utilization						
Annual Run (km)	50,000	55,000	60,000	60,000	65,000	65,000
Annual Hours	1,800	1,900	2,000	1,800	2,100	2,100
Average Service Life (yrs)	15	15	15	15	20	20
Unit Costs (Economic)						
New Vehicle Price (Birr)	997,826	1,435,861	2,204,583	1,741,388	2,671,891	3,756,607
Tyre Price (Birr)	255	1,828	3,400	5,950	7,225	8,500
Fuel (per liter)	16.82	17	16.82	16.82	16.82	16.82
Lubricant oil (per liter)	45.5	46	45.5	45.5	45.5	45.5
Crew Wages (Birr/hr)	14.38	13	11.81	12.7	12.7	21.68
Annual Overhead (Birr)	60,000	70,000	80,000	30,000	50,000	60,000
Maintenance Labour (ETB/hr)	22.9	23	22.9	22.9	22.9	22.9
Discount Rate (%)	10.23	10	10.23	10.23	10.23	10.23
Passenger Working time (per hour)	1.47	1.47	1.47	2.26	2.26	2.26
Passenger Non-working time (per hour)	0.52	0.52	0.52	0.79	0.79	0.79
Cargo Costs (per hour)				0.3	0.36	0.77

APPENDIX B: - Calculations

B-1:- Flexible pavement cost schedule in the 40 years analysis period (2015-2055)

Year		Construction	Maintenance		Rehabilitation	Salvage Value	Vehicle time savings	Fuel Cost
			Routine	Periodic				
0	2015	√						
1	2016		√				√	√
2	2017		√				√	√
3	2018			√			√	√
4	2019		√				√	√
5	2020		√				√	√
6	2021			√			√	√
7	2022		√				√	√
8	2023		√				√	√
9	2024			√			√	√
10	2025		√				√	√
11	2026		√				√	√
12	2027			√			√	√
13	2028		√				√	√
14	2029		√				√	√
15	2030		√		√		√	√
16	2031		√				√	√
17	2032		√				√	√
18	2033			√			√	√
19	2034		√				√	√
20	2035		√				√	√
21	2036			√			√	√
22	2037		√				√	√
23	2038		√				√	√
24	2039			√			√	√
25	2040		√				√	√
26	2041		√				√	√
27	2042			√			√	√
28	2043		√				√	√
29	2044		√				√	√
30	2045				√		√	√
31	2046		√				√	√
32	2047		√				√	√
33	2048			√			√	√
34	2049		√				√	√
35	2050		√				√	√
36	2051			√			√	√
37	2052		√				√	√
38	2053		√				√	√
39	2054			√			√	√
40	2055					√	√	√

B-2:- Rigid pavement cost schedule in the 40 years analysis period (2015-2055)

Year		Construction	Maintenance		Rehabilitation	Salvage Value	Vehicle time savings	Fuel Cost
			Routine	Periodic				
0	2015	√						
1	2016						√	√
2	2017						√	√
3	2018						√	√
4	2019						√	√
5	2020						√	√
6	2021						√	√
7	2022						√	√
8	2023		√				√	√
9	2024						√	√
10	2025						√	√
11	2026						√	√
12	2027			√			√	√
13	2028						√	√
14	2029						√	√
15	2030						√	√
16	2031		√				√	√
17	2032						√	√
18	2033						√	√
19	2034						√	√
20	2035						√	√
21	2036						√	√
22	2037						√	√
23	2038						√	√
24	2039		√	√			√	√
25	2040						√	√
26	2041						√	√
27	2042						√	√
28	2043						√	√
29	2044						√	√
30	2045						√	√
31	2046						√	√
32	2047		√				√	√
33	2048						√	√
34	2049						√	√
35	2050						√	√
36	2051			√			√	√
37	2052						√	√
38	2053						√	√
39	2054						√	√
40	2055				√	√	√	√

B-3:-:-Quantity Take off for Flexible pavement for 1km and 2 lanes (as per the typical road section)

T	D	R	Description
			1. 0 Sub-base, Road Base and Gravel Wearing Course
			Sub-base Material
			1.1 Sub Base
			1.1.1 Gravel Sub base layer,97% MDD,AASHTO T-180
1	1,000.00		*for 200mm thick and 1000m length*
	0.20		
	7.00		
		1,400.00	*m3*
			1.2 Base course material
			1.2.1 Crushed stone base compacted to 100% of modified AASHTO density, layer thickness max. 200mm
1	1,000.00		*for 250mm thick and 1000m length*
	0.250		
	7.00		
		1,750.00	*m3*
			2.0 Bituminous Prime Coat
			2.1 Bituminous Prime cat
			2.1.1 MC-30 cut back bitumen applied at 1 liters per sq. m
1	1,000.00		
	7.00		
		7,000.00	*lit*
			2.2 Tack Coat
			2.2.1 RC-70 cut back bitumen applied at 1 liters per sq. m
1	1,000.00		
	7.00		
		7,000.00	*lit*
			3. Asphaltic Surfacing
	1,000.00		3.1 50mm Asphaltic surfacing with penetration grade 80/100 bitumen
	7.00		
		7,000.00	*m2*
			3.2 Dense Bitumen Macadam (145 mm)
	1,000.00		
	7.00		
	0.145	1,015.00	*m3*

B-4:-BOQ for Flexible pavement for 1km and 2 lanes (as per the typical road section)

Item No	Description	unit	Quantity	Rate	Amount
1	**Sub base, Road Base and Gravel Wearing Course**				
1.1	**Sub-base Material**				
1.1.1	Gravel Sub base layer,97% MDD,AASHTO T-180	m3	1,400.00	184.10	257,740.00
1.2	**Base Course Material**				
1.2.1	Crushed stone base compacted to 100% of modified AASHTO density, layer thickness max. 200mm	m3	1,750.00	401.08	701,890.00
	Carried to Summery				**959,630.00**
2	**Bituminous Surfacing**				
2.1	**Bituminous Prime Coat**				
2.1.1	MC-30 cut back bitumen applied at 1 liters per sq. m	lit	7,000.00	40.09	280,639.82
2.2	**Tack Coat**				
2.2.1	RC-70 cut back bitumen applied at 1 liters per sq. m	lit	7,000.00	38.19	267,311.14
	Carried to Summery				**547,950.96**
3	**Asphaltic Surfacing**				
3.1	50mm Asphaltic surfacing with penetration grade 80/100 bitumen	m2	7,000.00	213.01	1,491,076.05
3.2	Dense Bitumen Macadam (145 mm)	m3	1,015.00	3,254.17	3,302,981.46
	Carried to Summery				**4,794,057.51**

B-5:- Reinforcing steel bar quantity Take off for rigid pavement for 1km and 2 lanes (as per the typical road section)

Description	Position of Bar	ø	Length	No of Member	NO of Bar(No)	Diam. ø12	ø14	ø25
Dowel Bars	Transversal joint	25	0.4	40	23			373.33
Tie Bars	Longitudinal Joint	12	1	1	1,667	1,666.67		
End caps at anchor key	every 39 meters	12	0.35	26	24	218.38		
		12	6.6	26	125	21,369.25		
Longitudinal bar	top main bar	14	24.89	40	29		28,872.40	
Transversal bar	top bar	12	6.6	40	29	7,656.00		
			Total Length			30,910.29	28,872.40	373.33
			Wt/Lm (Kg/m)			0.888	1.21	3.854
			Total Weight (Kg)			**27,448.34**	**34,935.60**	**1,438.83**

Total bars	
	Dowel Bars
1,438.83	kg
	Tie Bars
1,480.00	kg
	End caps at anchor
19,169.81	kg
	Longitudinal bar
34,935.60	kg
	Transversal bar
6,798.53	kg

B-6:-: Quantity Take off for rigid pavement for 1km and 2 lanes (as per the typical road section)

T	D	R	Description
			1 Capping and sub base
			1.1 Capping Layer compacted to 95% of MDD ,AASHTO T-180
1	**1,000.00**		***for 250mm thick and 1000m length***
	0.25		
	7	**1,750.00**	***m3***
			1.2 Gravel Sub Base Layer compacted to 97% MDD, AASHTO T-180
	1,000.00		***for 185mm thick and 1000m length***
	0.185		
	7	**1,295.00**	***m3***
			2.Concrete(rigid) pavement
			Concrete pavement 340mm thick(C-35) concrete
1	**1,000.00**		
	7	**7,000.00**	***m2***
			concrete anchor Keys at every 39 meters (considering grade of greater than 5% for all 1km)
26	**0.3**		
	7	**54.6**	***m2***
			-
		7,054.60	**M2 Total for this item**
			Texturing and Curing the Concrete pavement
			Burlap dragged and/or grooved texture
	1,000.00		
	7		
		7,000.00	***m2***
			Curing
	1,000.00		
	7	**7,000.00**	***m2***
2	**1,000.00**		
	0.34	**680**	***m2***
		7,680.00	**M2 Total for this item**
			Joints
2	**7**		Expansion Joint complete (Except Dowels and end caps)
		14	***m (Assuming 2 crossing structures)***
			Longitudinal Joints complete (Except Tie bars) for 1km
	1,000.00		
		1,000.00	***m***
40	**7**		Sealed Transverse Contraction joints as per drawings except dowels at every 25meters in 1km
		280	***m***
			Separation Membrane
			MC-30 Prime coat material ,1.25lit/m2
	1,000.00		
	7		
	1.25	**8,750.00**	***lit***

B-7:- BOQ for Rigid pavement for 1km and 2 lanes at end of 2015

Item No	Description	unit	Quantity	Rate	Amount
1	**Road base preparation**				
1.1	**Capping and sub base**				
1.1.1	**Capping Layer** compacted to 95% of MDD ,AASHTO T-180	m3	1,750.00	184.00	322,000.00
1.2	**Sub-base Material**				
1.2.1	**Gravel Sub Base Layer** compacted to 97% MDD, AASHTO T-180	m3	1,295.00	402.00	520,590.00
	Carried to Summery				**842,590.00**
2	**Rigid Pavement**				
2.1	**Concrete pavement**				
2.1.1	Concrete pavement 340mm thick(C-35) concrete with flexural strength of 3.5mpa at 28 days for the concrete slabs ,and concrete anchor Keys at every 39 meters locations and end details shown in the drawings	m^2	7,054.60	1,427.00	10,066,914.20
	Carried to Summery				**10,066,914.20**
3	**Texturing and Curing the Concrete pavement**				
3.1	Burlap dragged and/or grooved texture	m^2	7,000.00	10.00	70,000.00
3.2	Curing	m^2	7,340.00	60.00	440,400.00
	Carried to Summery				**510,400.00**
4	**Joints**				
4.1	Expansion Joint complete (Except Dowels and end caps)	m	14.00	284.28	3,979.92
4.2	Longitudinal Joints complete (Except Tie bars)	m	1,000.00	23.69	23,690.00

Item No	Description	unit	Quantity	Rate	Amount
4.3	Sealed Transverse Contraction joints as per drawings except dowels	m	280	26.77	7,495.60
	Carried to Summery				**35,165.52**
5	**Reinforcement Bar**				
5.1	Dowels Bars(Mild steel plain bars, epoxy coated) Ø25mm and 400mm long @300mm spacing	Kg	1,326.08	52.31	69,36 7.24
5.2	Tie Bars(Ø12mm high strength deformed bars) and 1000mm long @600mm spacing, with 15cm long protective coating as per the drawing)	Kg	1,480.00	52.31	77,41 8.80
5.3	End Caps(**Anchor Key**) (Ø12mm high strength deformed bars) and 300mm long @300mm spacing vertical and 3Ø12 ,6900mm long transversal bars @ 170mm spacing as per the drawing)	Kg	19,169.81	52.31	1,002 ,772.76
5.4	High Tensile strength steel bars (Ø14mm) diameter longitudinal bar for main concrete pavement top reinforcement	Kg	34,935.60	52.31	1,827 ,481.24
5.5	Ditto but (Ø12mm) diameter transversal bar for main concrete pavement top reinforcement	Kg	6,798.53	52.31	355,6 31.10
	Carried to Summery				**3,332,671.15**
6	**Separation Membrane**	M2			
6.1	Or **MC-30** Prime coat material to be used in the absence of impermeable plastic sheeting ,application rate of 1.25lit/m2	lit	8,750.00	40.09	350,787.50
	Carried to Summery				**350,787.50**

B-8:-Routine maintenance cost of Flexible pavement at end of 2015

Code	Name of Activity	Unit	Unit Rate	Quantity in % per Km	Quantity for 2 lane	Amount (ETB Birr)
210	Asphalt Patching (Seal Coat)	m^2	52.98	5%	350.00	18,542.41
211	Asphalt Patching (Single Surface Treatment)	m^2	66.48	2%	140.00	9,307.65
212	Asphalt Patching (Double Surface Treatment)	m^2	122.26	2%	140.00	17,116.15
214	Asphalt Patching (Hot-Mini-Mix)	m^3	4,272.10	5%	35.00	149,523.38
215	Crack Sealing (Individual Cracks)(>3mm)	Lm	40.31	5%	50.00	2,015.31
218	Pothole Reinstatement (Hot-Mini-Mix) 150mm avg. thickness	m^3	6,199.68	2%	21.00	130,193.38
219	Pothole (Base Failure Repair) for **100mm avg. thickness**	m^3	706.42	2%	14.00	9,889.85
Total Cost						**336,588.13**

B-9:-Periodic Maintenance cost of Flexible pavement at end of 2015

Code	Name of Activity	Unit	Unit Rate (Birr/unit)	Quantity in % per Km	Quantity for 2 lane	Amount (Birr)
309	Sand seal coat	m^2	48.20	10%	700.00	33,738.66
310	Single Bituminous Surface Treatment (SBST)	m^2	50.45	10%	700.00	35,313.94
311	Double Bituminous Surface Treatment (DBST)	m^2	104.34	10%	700.00	73,037.18
312	Mix-In-Place Overlay (Cold Mix) for 50mm thickness	m^3	3,882.89	10%	35.00	135,901.06
313	Asphaltic Concrete Overlay for 40mm thickness	m^3	4,335.42	15%	42.00	182,087.79
314	Bitumen Prime Coat (0.3lt/m2)	Lt	37.65	60%	1,260.00	47,438.58
315	Bitumen Tack Coat (0.5lt/m2)	Lt	41.85	60%	2,100.00	87,885.88
316	Pavement Reconstruction (Aggregate Road base)	m^3	823.36	10%	105.00	86,453.29
Total Cost						**681,856.38**

B-10:-Rehabilitation cost of flexible pavement at end of 2015

Name of Activity	Unit	Unit Rate (Birr/unit)	Quantity in % per Km	Quantity for 2 lane	Amount (Birr)
Asphaltic Concrete Overlay for 50mm thickness	m^3	4,335.42	100%	350.00	1,517,398.25
Bitumen Tack Coat (0.5lt/m2)	Lt	50.45	100%	3,500.00	176,569.69
Pavement Reconstruction (Aggregate Road base)	m^3	823.36	100%	1,050.00	864,532.90
					2,558,500.84

B-11:- Maintenance and rehabilitation cost for of rigid pavement at end of 2015

Maintenance Type	**Activity Description**	**Unit**	**Quantity (per km)**	**Quantity (m2) for 2 lane**	Unit Rate	Amount (ETB birr)
Routine	Joint Sealing	ml	50%	500	300	150,000.00
	Crack Sealing	ml	50%	500	300	150,000.00
Periodic	Partial depth PCC repair	m3	20%	34	3500	119,000.00
Rehabilitation	Full depth PCC repair	m3	70%	238	4500	1,071,000.00
	Texturizing	m2	80%	800	150	120,000.00

B.12:-Road standard [ERA Manual]

Surface Type	Design Standard	Design Speed (km/hr)				
		Flat	Rolling	Mountainous	Escarpment	Urban/ Peri-Urban
Paved	DS3	100	85	70	60	50
Unpaved	DS5	70	60	50	40	50

B13:- Time saving value of paved road

Surface Type	Average Speed	Time required to cover 1km		Time saved
Paved	73km/hr	0.14hr	0.82min	
Unpaved	54km/hr	0.185hr	1.11min	1.11-0.82=**0.29mim**

B14:-Time saved by each vehicle type

Vehicle Group	AADT (2014-2028)	Composition	No of Vehicles	Time savings	Total time savings/day
Small Bus(SB)	429	37%	158	0.29min	45.82
Medium Bus(MB)	429	2%	9	0.29min	2.61
Large Bus	429	1%	4	0.29min	1.16
Medium Truck(MT)	429	25%	109	0.29min	31.61
Heavy Truck(HT)	429	24%	101	0.29min	29.29
Truck Trailer(TT)	429	11%	48	0.29min	13.92
Total time saved by all vehicle type in minute /per day					**124.41**

Since maintenance and rehabilitation requirement of flexible and rigid pavement occurred at different years through the analysis period, the years of time savings were different. Time savings were not expected during maintenance and rehabilitation times due to activities the road and partial lane closure. Therefore, for flexible pavement 6 months per year for routine maintenance that became a sub total of 120 months (10 years) and 3 months for every 3 years of periodic maintenance that became sub total of 24 months (2years) and two time s rehabilitation for 2 years that totally result 14years has no time savings . For rigid pavement for a total of 2.5 years, 18 months for routine and periodic maintenance that became a sub total of 1.5 years and 1 year's rehabilitation, time savings was not expected.

B15:- Annual Time saving considerations

Flexible pavement		Rigid pavement	
40 years analysis period		40 years analysis period	
Time saving years	Maintenance years	Time saving years	Maintenance years
26 total years	14 Total years	37.5 total years	2.5 Total years

Total annual saved time = [124.41minutes/day]*365days = 90,885.00.minutes.Total annual benefit from time savings in birr becomes=90,885.00 minutes*1 birr/minutes=90,885.00 birr.

For rigid pavement the annual saved time is benefit for a period of 37.5 years (40 years - 2.5 years) after deducting the years of maintenance (at 8,12,16,24,32 and 36 years) and rehabilitation(at 40 years) ,where the saving time become dis- benefit, delay due to maintenance and rehabilitation activities and closures for the remaining 2.5years .

- Total value of birr for time savings during analysis period of 40 years becomes $90{,}885.00 birr/year * 37.5 years = 3{,}408{,}187.50 birr/km$.
- Total value of birr for time delay(cost) during analysis period of 40 years becomes $90{,}885.00 birr/year * 2.5 years = 227{,}212.50 birr/km$
- Total benefit=3,408,187.50-227,212.50 =**3,180,975.00 birr/km**

For flexible pavement the annual saved time is benefit for a period of 26 years (40 years - 14 years) after deducting the years of maintenance and rehabilitation ,where the saving time become dis- benefit, delay due to maintenance and rehabilitation activities and lane closures for the remaining 14 years .

- Total value of birr for time savings during analysis period of 40 years becomes $90{,}885.00 birr/year * 26 years = 2{,}363{,}010.00 birr/km$.
- Total value of birr for time delay(cost) during analysis period of 40 years becomes $90{,}885.00 birr/year * 14 years = 1{,}272{,}390.00 birr/km$

- Total benefit=2,363,010.00-1,272,390.00=**1,090,620.00 birr/km**

B.16:- Cost of fuel

Assuming that vehicles consume 0.33 liters per kilometer the annual fuel consumption becomes:-Cost of fuel per day =0.33lt/1km*1km*429*16.82birr/lit=2,381.21 birr/day

The annual cost of fuel=2,381.21 birr/day *365 days=869,140.70 birr/km/year

Rigid pavement reduce 0.8% fuel consumption for a period of 37.5 years (40 years - 2.5years) after deducting the years of maintenance and rehabilitation ,where such reduction is not considered due to maintenance and rehabilitation activities and lane closures for the remaining 2.5years [9][10] .

- Total fuel cost during analysis period of 40 years becomes applying 0.8% reduction in consumption for 34 years,
  $869{,}140.70 birr / year * 37.5 years * (1-0.008) = 32{,}332{,}034.04 birr / km$
- Total fuel cost during maintenance and rehabilitation activities and lane closures in analysis period of 40 years becomes without applying the percentage reduction for 2.5years, $869{,}140.70 birr / year * 2.5 years = 2{,}172{,}851.75 birr / km$
- Total fuel Cost=**34,765,628.00 birr/km**

Flexible pavement reduce 1.8% fuel consumption for a period of 26 years (40 years -14 years) after deducting the years of maintenance and rehabilitation ,where such reduction is not considered due to maintenance and rehabilitation activities and lane closures for the remaining 14years[9][10] .

- Total fuel cost during analysis period of 40 years becomes applying 1.8% reduction in consumption for 27 years,
  $869{,}140.70 birr / year * 26 years * (1-0.018) = 22{,}190{,}900.35 birr / km$
- Total fuel cost during maintenance and rehabilitation activities and lane closures in analysis period of 40 years becomes without applying the percentage reduction for 13 years $869{,}140.70 birr / year * 14 years = 12{,}167{,}969.80 birr / km$
- Total fuel Cost=**34,350,384.40 birr/km**

B17: Time savings and fuel Cost

Pavement type	Time Savings (birr/km)	Fuel Cost (birr/km)	Remark
Rigid	3,180,975.00	34,765,628.00	For 40 years
Flexible	1,090,620.00	34,350,384.40	
Rigid	79,524.38	869,140.70	Per each year
Flexible	27,265.50	858,759.61	

B.18:- Future Value of costs

Since all the costs other than initial construction will occur in the future analysis years, future value of money should be determined for maintenance, rehabilitation, user and salvage values by considering the inflation rate. Inflation Rate, the rate of increase in the general price levels, caused usually by an increase in the volume of money and credit relative to available goods. The inflation rate is also reflective of the rate of decline in the general purchasing power of a currency.

$$Fc = PV[1 + if]^n \text{........................Eq(2)}$$

Where

Fc=Future cost at time of n years [rehabilitation, maintenance, salvage value, fuel and time savings]

PV= Present Value of Money in birr [Present cost of rehabilitation, maintenance, salvage value, fuel and time savings at end of 2015]

if= inflation adjusted interest rate

B19:-Flexible Pavement Future costs

Year		(1+if)	$(1+if)^n$	Maintenance cost at 2015 (PV)		Maintenance cost (Fv)=$P(1+if)^n$	
				Routine	Periodic	Routine	Periodic
0	2015						
1	2016	*1.0058*	1.006	*673,176.26*		*677,080.68*	
2	2017	*1.0058*	1.012	*673,176.26*		*681,007.75*	
3	2018	*1.0058*	1.018		*681,856.38*		*693,789.63*
4	2019	*1.0058*	1.023	*673,176.26*		*688,930.35*	
5	2020	*1.0058*	1.029	*673,176.26*		*692,926.15*	
6	2021	*1.0058*	1.035		*681,856.38*		*705,931.72*
7	2022	*1.0058*	1.041	*673,176.26*		*700,987.40*	
8	2023	*1.0058*	1.047	*673,176.26*		*705,053.13*	
9	2024	*1.0058*	1.053		*681,856.38*		*718,286.31*
10	2025	*1.0058*	1.060	*673,176.26*		*713,255.46*	
11	2026	*1.0058*	1.066	*673,176.26*		*717,392.34*	
12	2027	*1.0058*	1.072		*681,856.38*		*730,857.12*
13	2028	*1.0058*	1.078	*673,176.26*		*725,738.23*	
14	2029	*1.0058*	1.084	*673,176.26*		*729,947.51*	
15	2030	*1.0058*	1.091		*681,856.38*		*743,647.94*
16	2031	*1.0058*	1.097	*673,176.26*		*738,439.45*	
17	2032	*1.0058*	1.103	*673,176.26*		*742,722.40*	
18	2033	*1.0058*	1.110		*681,856.38*		*756,662.61*
19	2034	*1.0058*	1.116	*673,176.26*		*751,362.97*	
20	2035	*1.0058*	1.123	*673,176.26*		*755,720.87*	
21	2036	*1.0058*	1.129		*681,856.38*		*769,905.04*
22	2037	*1.0058*	1.136	*673,176.26*		*764,512.66*	
23	2038	*1.0058*	1.142	*673,176.26*		*768,946.83*	
24	2039	*1.0058*	1.149		*681,856.38*	□	*783,379.24*
25	2040	*1.0058*	1.156	*673,176.26*		*777,892.48*	
26	2041	*1.0058*	1.162	*673,176.26*		*782,404.26*	
27	2042	*1.0058*	1.169		*681,856.38*	□	*797,089.25*
28	2043	*1.0058*	1.176	*673,176.26*		*791,506.47*	
29	2044	*1.0058*	1.183	*673,176.26*		*796,097.20*	
30	2045	*1.0058*	1.189		*681,856.38*		*811,039.20*
31	2046	*1.0058*	1.196	*673,176.26*		*805,358.71*	
32	2047	*1.0058*	1.203	*673,176.26*		*810,029.79*	
33	2048	*1.0058*	1.210		*681,856.38*		*825,233.29*
34	2049	*1.0058*	1.217	*673,176.26*		*819,453.39*	
35	2050	*1.0058*	1.224	*673,176.26*		*824,206.22*	
36	2051	*1.0058*	1.231		*681,856.38*		*839,675.80*
37	2052	*1.0058*	1.239	*673,176.26*		*833,794.74*	
38	2053	*1.0058*	1.246	*673,176.26*		*838,630.75*	
39	2054	*1.0058*	1.253		*681,856.38*		*854,371.06*
40	2055	*1.0058*	1.260				
	Grand Total(Birr/km)					**19,633,398.18**	**10,029,868.21**

Year		(1+if)	$(1+if)^n$	Vehicle time savings (P v)	Fuel Cost (Pv)	Vehicle time savings(Fv)	Fuel Cost(Fv)
0	2015						
1	2016	*1.0058*	1.006	*27265.50*	858,759.61	*27,423.64*	863,740.42
2	2017	*1.0058*	1.012	*27265.50*	858,759.61	*27,582.70*	868,750.11
3	2018	*1.0058*	1.018	*27265.50*	858,759.61	*27,742.68*	873,788.86
4	2019	*1.0058*	1.023	*27265.50*	858,759.61	*27,903.58*	878,856.84
5	2020	*1.0058*	1.029	*27265.50*	858,759.61	*28,065.42*	883,954.21
6	2021	*1.0058*	1.035	*27265.50*	858,759.61	*28,228.20*	889,081.14
7	2022	*1.0058*	1.041	*27265.50*	858,759.61	*28,391.93*	894,237.81
8	2023	*1.0058*	1.047	*27265.50*	858,759.61	*28,556.60*	899,424.39
9	2024	*1.0058*	1.053	*27265.50*	858,759.61	*28,722.23*	904,641.05
10	2025	*1.0058*	1.060	*27265.50*	858,759.61	*28,888.82*	909,887.97
11	2026	*1.0058*	1.066	*27265.50*	858,759.61	*29,056.37*	915,165.32
12	2027	*1.0058*	1.072	*27265.50*	858,759.61	*29,224.90*	920,473.28
13	2028	*1.0058*	1.078	*27265.50*	858,759.61	*29,394.40*	925,812.02
14	2029	*1.0058*	1.084	*27265.50*	858,759.61	*29,564.89*	931,181.73
15	2030	*1.0058*	1.091	*27265.50*	858,759.61	*29,736.37*	936,582.59
16	2031	*1.0058*	1.097	*27265.50*	858,759.61	*29,908.84*	942,014.77
17	2032	*1.0058*	1.103	*27265.50*	858,759.61	*30,082.31*	947,478.45
18	2033	*1.0058*	1.110	*27265.50*	858,759.61	*30,256.79*	952,973.83
19	2034	*1.0058*	1.116	*27265.50*	858,759.61	*30,432.28*	958,501.08
20	2035	*1.0058*	1.123	*27265.50*	858,759.61	*30,608.79*	964,060.38
21	2036	*1.0058*	1.129	*27265.50*	858,759.61	*30,786.32*	969,651.93
22	2037	*1.0058*	1.136	*27265.50*	858,759.61	*30,964.88*	975,275.91
23	2038	*1.0058*	1.142	*27265.50*	858,759.61	*31,144.47*	980,932.51
24	2039	*1.0058*	1.149	*27265.50*	858,759.61	*31,325.11*	986,621.92
25	2040	*1.0058*	1.156	*27265.50*	858,759.61	*31,506.80*	992,344.33
26	2041	*1.0058*	1.162	*27265.50*	858,759.61	*31,689.54*	998,099.93

27	2042	*1.0058*	1.169	*27265.50*	858,759.61	*31,873.34*	1,003,888.91
28	2043	*1.0058*	1.176	*27265.50*	858,759.61	*32,058.20*	1,009,711.46
29	2044	*1.0058*	1.183	*27265.50*	858,759.61	*32,244.14*	1,015,567.79
30	2045	*1.0058*	1.189	*27265.50*	858,759.61	*32,431.15*	1,021,458.08
31	2046	*1.0058*	1.196	*27265.50*	858,759.61	*32,619.25*	1,027,382.54
32	2047	*1.0058*	1.203	*27265.50*	858,759.61	*32,808.45*	1,033,341.36
33	2048	*1.0058*	1.210	*27265.50*	858,759.61	*32,998.74*	1,039,334.74
34	2049	*1.0058*	1.217	*27265.50*	858,759.61	*33,190.13*	1,045,362.88
35	2050	*1.0058*	1.224	*27265.50*	858,759.61	*33,382.63*	1,051,425.98
36	2051	*1.0058*	1.231	*27265.50*	858,759.61	*33,576.25*	1,057,524.25
37	2052	*1.0058*	1.239	*27265.50*	858,759.61	*33,770.99*	1,063,657.89
38	2053	*1.0058*	1.246	*27265.50*	858,759.61	*33,966.86*	1,069,827.11
39	2054	*1.0058*	1.253	*27265.50*	858,759.61	*34,163.87*	1,076,032.11
40	2055	*1.0058*	1.260	*27265.50*	858,759.61	*34,362.02*	1,082,273.09
	Grand Total(Birr/km)					**1,230,634.88**	**38,760,320.96**

Year		(1+if)	$(1+if)^n$	Rehabilitation (P)	Salvage Value (P)	Rehabilitation (FV)	Salvage Value(FV)
15	2030	*1.0058*	1.091	*2558500.84*		*2,774,267.93*	
30	2045	*1.0058*	1.189	*2,558,500.84*		*3,025,679.14*	
40	2055	*1.0058*	1.260		*1,705,667.23*		*2,149,609.42*
	Grand Total(Birr/km)					**5,799,947.07**	**2,149,609.42**

B20:-Rigid Pavement Future Costs

Year		(1+if)	$(1+if)^n$	Maintenance cost at 2015(PV)		Maintenance cost (Fv)=$P(1+if)^n$	
				Routine(P)	Periodic(P)	Routine	Periodic
0	2015						
1	2016	*1.0058*	1.006			-	
2	2017	*1.0058*	1.012			-	
3	2018	*1.0058*	1.018				-
4	2019	*1.0058*	1.023			-	
5	2020	*1.0058*	1.029			-	
6	2021	*1.0058*	1.035				-
7	2022	*1.0058*	1.041			-	
8	2023	*1.0058*	1.047	*300,000.00*		*314,205.88*	
9	2024	*1.0058*	1.053				-
10	2025	*1.0058*	1.060			-	
11	2026	*1.0058*	1.066			-	
12	2027	*1.0058*	1.072		*119,000.00*		*127,551.78*
13	2028	*1.0058*	1.078			-	-
14	2029	*1.0058*	1.084			-	-
15	2030	*1.0058*	1.091				-
16	2031	*1.0058*	1.097	*300,000.00*		*329,084.45*	-
17	2032	*1.0058*	1.103			-	-
18	2033	*1.0058*	1.110				-
19	2034	*1.0058*	1.116			-	-
20	2035	*1.0058*	1.123			-	-
21	2036	*1.0058*	1.129				-
22	2037	*1.0058*	1.136			-	-
23	2038	*1.0058*	1.142			-	-
24	2039	*1.0058*	1.149	*300,000.00*	*119,000.00*	*344,667.56*	*136,718.13*
25	2040	*1.0058*	1.156			-	-
26	2041	*1.0058*	1.162			-	-
27	2042	*1.0058*	1.169				-
28	2043	*1.0058*	1.176			-	-
29	2044	*1.0058*	1.183			-	-
30	2045	*1.0058*	1.189				-
31	2046	*1.0058*	1.196			-	-
32	2047	*1.0058*	1.203	*300,000.00*		*360,988.57*	-

33	2048	*1.0058*	1.210				-
34	2049	*1.0058*	1.217			-	-
35	2050	*1.0058*	1.224			-	-
36	2051	*1.0058*	1.231				-
37	2052	*1.0058*	1.239		*119,000.00*	-	*147,393.16*
38	2053	*1.0058*	1.246			-	-
39	2054	*1.0058*	1.253				-
40	2055	*1.0058*	1.260				
Grand Total						**1,348,946.45**	**411,663.07**

Year		(1+if)	$(1+if)^n$	Vehicle time savings	Fuel Cost	Vehicle time savings(Fv)	Fuel Cost(Fv)
0	2015						
1	2016	*1.0058*	1.006	*79,524.38*	869,140.70	*79,985.62*	874,181.72
2	2017	*1.0058*	1.012	*79,525.38*	869,141.70	*80,450.55*	879,252.98
3	2018	*1.0058*	1.018	*79,526.38*	869,142.70	*80,918.18*	884,353.67
4	2019	*1.0058*	1.023	*79,527.38*	869,143.70	*81,388.53*	889,483.94
5	2020	*1.0058*	1.029	*79,528.38*	869,144.70	*81,861.61*	894,643.98
6	2021	*1.0058*	1.035	*79,529.38*	869,145.70	*82,337.44*	899,833.95
7	2022	*1.0058*	1.041	*79,530.38*	869,146.70	*82,816.04*	905,054.03
8	2023	*1.0058*	1.047	*79,531.38*	869,147.70	*83,297.42*	910,304.39
9	2024	*1.0058*	1.053	*79,532.38*	869,148.70	*83,781.60*	915,585.21
10	2025	*1.0058*	1.060	*79,533.38*	869,149.70	*84,268.59*	920,896.66
11	2026	*1.0058*	1.066	*79,534.38*	869,150.70	*84,758.42*	926,238.93
12	2027	*1.0058*	1.072	*79,535.38*	869,151.70	*85,251.09*	931,612.18
13	2028	*1.0058*	1.078	*79,536.38*	869,152.70	*85,746.62*	937,016.61
14	2029	*1.0058*	1.084	*79,537.38*	869,153.70	*86,245.04*	942,452.39
15	2030	*1.0058*	1.091	*79,538.38*	869,154.70	*86,746.35*	947,919.71
16	2031	*1.0058*	1.097	*79,539.38*	869,155.70	*87,250.58*	953,418.74
17	2032	*1.0058*	1.103	*79,540.38*	869,156.70	*87,757.73*	958,949.67
18	2033	*1.0058*	1.110	*79,541.38*	869,157.70	*88,267.84*	964,512.69

19	2034	*1.0058*	1.116	*79,542.38*	869,158.70	*88,780.91*	970,107.98
20	2035	*1.0058*	1.123	*79,543.38*	869,159.70	*89,296.96*	975,735.73
21	2036	*1.0058*	1.129	*79,544.38*	869,160.70	*89,816.01*	981,396.12
22	2037	*1.0058*	1.136	*79,545.38*	869,161.70	*90,338.08*	987,089.36
23	2038	*1.0058*	1.142	*79,546.38*	869,162.70	*90,863.18*	992,815.62
24	2039	*1.0058*	1.149	*79,547.38*	869,163.70	*91,391.34*	998,575.10
25	2040	*1.0058*	1.156	*79,548.38*	869,164.70	*91,922.56*	1,004,367.99
26	2041	*1.0058*	1.162	*79,549.38*	869,165.70	*92,456.88*	1,010,194.48
27	2042	*1.0058*	1.169	*79,550.38*	869,166.70	*92,994.29*	1,016,054.78
28	2043	*1.0058*	1.176	*79,551.38*	869,167.70	*93,534.84*	1,021,949.07
29	2044	*1.0058*	1.183	*79,552.38*	869,168.70	*94,078.52*	1,027,877.56
30	2045	*1.0058*	1.189	*79,553.38*	869,169.70	*94,625.37*	1,033,840.44
31	2046	*1.0058*	1.196	*79,554.38*	869,170.70	*95,175.39*	1,039,837.91
32	2047	*1.0058*	1.203	*79,555.38*	869,171.70	*95,728.61*	1,045,870.18
33	2048	*1.0058*	1.210	*79,556.38*	869,172.70	*96,285.05*	1,051,937.43
34	2049	*1.0058*	1.217	*79,557.38*	869,173.70	*96,844.72*	1,058,039.89
35	2050	*1.0058*	1.224	*79,558.38*	869,174.70	*97,407.64*	1,064,177.74
36	2051	*1.0058*	1.231	*79,559.38*	869,175.70	*97,973.84*	1,070,351.20
37	2052	*1.0058*	1.239	*79,560.38*	869,176.70	*98,543.32*	1,076,560.48
38	2053	*1.0058*	1.246	*79,561.38*	869,177.70	*99,116.12*	1,082,805.78
39	2054	*1.0058*	1.253	*79,562.38*	869,178.70	*99,692.25*	1,089,087.30
40	2055	*1.0058*	1.260	*79,563.38*	869,179.70	*100,271.72*	1,095,405.27
Grand Total						**3,590,266.85**	**39,229,788.84**

Year		(1+if)	$(1+if)^n$	Rehabilitation (P)	Salvage Value (P)	Rehabilitation	Salvage Value
40	2055	*1.0058*	1.260	1,191,000.00	*794,000.00*	1,500,987.28	*1,000,658.19*
Grand Total						1,500,987.28	1,000,658.19

B21:-Present Worth

The net present worth formula used was the following:-

$$NPW = Ic + \left[\sum_{n}^{N} Mc\right]\left[\frac{1}{(1+dr)^n}\right] + \left[\sum_{n}^{N} Rc\right]\left[\frac{1}{(1+dr)^n}\right] + \left[\sum_{n}^{N} Uc\right]\left[\frac{1}{(1+dr)^n}\right] - Sv\left[\frac{1}{(1+dr)^n}\right] \text{...........Eq[27]}$$

Where

Where Ic = initial construction cost;

Mc =maintenance

Rc=Rehabilitation cost

Uc = User cost [fuel&Time savings]

S = salvage value

n = number of years cost occure.

N= analysis period in years

dr = discount rate

The construction cost at the end of 2015 was 13,398,607.72 Birr/Km for rigid and 6,159,851.60 birr /km for flexible pavement and the discount rate used was 10.23%.

B22:-Flexible pavement Present value calculation

Year		(1+dr)	$(1+dr)^n$	Maintenance cost at 2015 (FV)		Maintenance cost (Pv)=Fv/$(1+dr)^n$	
				Routine(FV)	Periodic(FV)	Routine	Periodic
0	2015						
1	2016	*1.1023*	1.102	*677,080.68*		*614,243.57*	
2	2017	*1.1023*	1.215	*681,007.75*		*560,470.09*	
3	2018	*1.1023*	1.339	–	*693,789.63*	–	*517,998.35*

4	2019	*1.1023*	1.476	*688,930.35*	–	*466,633.69*	–
5	2020	*1.1023*	1.627	*692,926.15*	–	*425,782.60*	–
6	2021	*1.1023*	1.794	–	*705,931.72*	–	*393,517.32*
7	2022	*1.1023*	1.977	*700,987.40*	–	*354,496.18*	–
8	2023	*1.1023*	2.180	*705,053.13*	–	*323,462.09*	–
9	2024	*1.1023*	2.403	–	*718,286.31*	–	*298,950.53*
10	2025	*1.1023*	2.648	*713,255.46*	–	*269,306.62*	–
11	2026	*1.1023*	2.919	*717,392.34*	–	*245,730.38*	–
12	2027	*1.1023*	3.218	–	*730,857.12*	–	*227,109.24*
13	2028	*1.1023*	3.547	*725,738.23*	–	*204,589.10*	–
14	2029	*1.1023*	3.910	*729,947.51*	–	*186,678.51*	–
15	2030	*1.1023*	4.310	–	*743,647.94*	–	*172,532.24*
16	2031	*1.1023*	4.751	*738,439.45*	–	*155,423.96*	–
17	2032	*1.1023*	5.237	*742,722.40*	–	*141,817.49*	–
18	2033	*1.1023*	5.773	–	*756,662.61*	–	*131,070.74*
19	2034	*1.1023*	6.364	*751,362.97*	–	*118,073.77*	–
20	2035	*1.1023*	7.014	*755,720.87*	–	*107,737.10*	–
21	2036	*1.1023*	7.732	–	*769,905.04*	–	*99,572.91*
22	2037	*1.1023*	8.523	*764,512.66*	–	*89,699.27*	–
23	2038	*1.1023*	9.395	*768,946.83*	–	*81,846.62*	–
24	2039	*1.1023*	10.356	–	*783,379.24*	–	*75,644.38*
25	2040	*1.1023*	11.416	*777,892.48*	–	*68,143.49*	–
26	2041	*1.1023*	12.583	*782,404.26*	–	*62,177.92*	–
27	2042	*1.1023*	13.871	–	*797,089.25*	–	*57,466.16*
28	2043	*1.1023*	15.290	*791,506.47*	–	*51,767.82*	–
29	2044	*1.1023*	16.854	*796,097.20*	–	*47,235.84*	–
30	2045	*1.1023*	18.578	–	*811,039.20*	–	*43,656.37*
31	2046	*1.1023*	20.478	*805,358.71*	–	*39,327.41*	–
32	2047	*1.1023*	22.573	*810,029.79*	–	*35,884.52*	–
33	2048	*1.1023*	24.882	–	*825,233.29*	–	*33,165.24*
34	2049	*1.1023*	27.428	*819,453.39*	–	*29,876.57*	–
35	2050	*1.1023*	30.234	*824,206.22*	–	*27,261.05*	–
36	2051	*1.1023*	33.327	–	*839,675.80*	–	*25,195.24*
37	2052	*1.1023*	36.736	*833,794.74*	–	*22,696.89*	–
38	2053	*1.1023*	40.494	*838,630.75*	–	*20,709.90*	–
39	2054	*1.1023*	44.637	–	*854,371.06*	–	*19,140.53*
40	2055	*1.1023*	49.203	–	–	–	–
Grand Total birr/km						**4,751,072.46**	**2,095,019.25**

Year		(1+dr)	$(1+dr)^n$	Vehicle time savings(FV)	Fuel Cost(FV)	Vehicle time savings(PV)	Fuel Cost (PV)
0	2015						
1	2016	*1.1023*	1.102	*27423.64*	863,740.42	*24,878.56*	783,580.16
2	2017	*1.1023*	1.215	*27582.70*	868,750.11	*22,700.59*	714,982.25
3	2018	*1.1023*	1.339	*27742.68*	873,788.86	*20,713.28*	652,389.68
4	2019	*1.1023*	1.476	*27903.58*	878,856.84	*18,899.95*	595,276.73
5	2020	*1.1023*	1.627	*28065.42*	883,954.21	*17,245.37*	543,163.69
6	2021	*1.1023*	1.794	*28228.20*	889,081.14	*15,735.64*	495,612.84
7	2022	*1.1023*	1.977	*28391.93*	894,237.81	*14,358.08*	452,224.80
8	2023	*1.1023*	2.180	*28556.60*	899,424.39	*13,101.11*	412,635.13
9	2024	*1.1023*	2.403	*28722.23*	904,641.05	*11,954.18*	376,511.31
10	2025	*1.1023*	2.648	*28888.82*	909,887.97	*10,907.66*	343,549.92
11	2026	*1.1023*	2.919	*29056.37*	915,165.32	*9,952.76*	313,474.11
12	2027	*1.1023*	3.218	*29224.90*	920,473.28	*9,081.45*	286,031.26
13	2028	*1.1023*	3.547	*29394.40*	925,812.02	*8,286.42*	260,990.87
14	2029	*1.1023*	3.910	*29564.89*	931,181.73	*7,561.00*	238,142.63
15	2030	*1.1023*	4.310	*29736.37*	936,582.59	*6,899.07*	217,294.62
16	2031	*1.1023*	4.751	*29908.84*	942,014.77	*6,295.10*	198,271.73
17	2032	*1.1023*	5.237	*30082.31*	947,478.45	*5,744.00*	180,914.18
18	2033	*1.1023*	5.773	*30256.79*	952,973.83	*5,241.15*	165,076.19
19	2034	*1.1023*	6.364	*30432.28*	958,501.08	*4,782.31*	150,624.72
20	2035	*1.1023*	7.014	*30608.79*	964,060.38	*4,363.65*	137,438.40
21	2036	*1.1023*	7.732	*30786.32*	969,651.93	*3,981.64*	125,406.46
22	2037	*1.1023*	8.523	*30964.88*	975,275.91	*3,633.07*	114,427.85
23	2038	*1.1023*	9.395	*31144.47*	980,932.51	*3,315.01*	104,410.35
24	2039	*1.1023*	10.356	*31325.11*	986,621.92	*3,024.80*	95,269.83

25	2040	*1.1023*	11.416	*31506.80*	992,344.33	*2,760.00*	86,929.51
26	2041	*1.1023*	12.583	*31689.54*	998,099.93	*2,518.38*	79,319.33
27	2042	*1.1023*	13.871	*31873.34*	1,003,888.91	*2,297.91*	72,375.38
28	2043	*1.1023*	15.290	*32058.20*	1,009,711.46	*2,096.74*	66,039.33
29	2044	*1.1023*	16.854	*32244.14*	1,015,567.79	*1,913.18*	60,257.97
30	2045	*1.1023*	18.578	*32431.15*	1,021,458.08	*1,745.69*	54,982.73
31	2046	*1.1023*	20.478	*32619.25*	1,027,382.54	*1,592.87*	50,169.31
32	2047	*1.1023*	22.573	*32808.45*	1,033,341.36	*1,453.42*	45,777.28
33	2048	*1.1023*	24.882	*32998.74*	1,039,334.74	*1,326.18*	41,769.74
34	2049	*1.1023*	27.428	*33190.13*	1,045,362.88	*1,210.08*	38,113.04
35	2050	*1.1023*	30.234	*33382.63*	1,051,425.98	*1,104.15*	34,776.47
36	2051	*1.1023*	33.327	*33576.25*	1,057,524.25	*1,007.49*	31,731.99
37	2052	*1.1023*	36.736	*33770.99*	1,063,657.89	*919.29*	28,954.03
38	2053	*1.1023*	40.494	*33966.86*	1,069,827.11	*838.81*	26,419.28
39	2054	*1.1023*	44.637	*34163.87*	1,076,032.11	*765.38*	24,106.42
40	2055	*1.1023*	49.203	*34362.02*	1,082,273.09	*698.37*	21,996.04
Grand Total birr/km						**276,903.81**	**8,721,417.57**

Year		(1+dr)	$(1+dr)^n$	Rehabilitation (FV)	Salvage Value (FV)	Rehabilitation (Pv)	Salvage Value (Pv)
15	2030	*1.1023*	4.310	*2,774,267.93*		*643,652.25*	
30	2045	*1.1023*	18.578	*3,025,679.14*		*162,865.33*	
40	2055	*1.1023*	49.203		*2,149,609.42*		*43,688.51*
Grand Total birr/km						806,517.58	43,688.51

B23:- Rigid pavement Present value calculation

Year		(1+dr)	$(1+dr)^n$	Maintenance cost		Maintenance cost (PV)=FV/$(1+dr)^n$	
				Routine(FV)	Periodic(FV)	Routine	Periodic
0	2015						
8	2023	*1.1023*	2.180	*314,205.88*		144,150.40	–
12	2027	*1.1023*	3.218	–	*127,551.78*	-	*39,635.91*
16	2031	*1.1023*	4.751	*329,084.45*	–	69,264.46	–
24	2039	*1.1023*	10.356	*344,667.56*	*136,718.13*	33,281.66	*13,201.73*
32	2047	*1.1023*	22.573	*360,988.57*	–	15,991.88	–
36	2052	*1.1023*	33.33		*147,393.16*	-	*4,012.22*
Grand Total (Birr/Km)						**262,688.40**	**56,849.86**

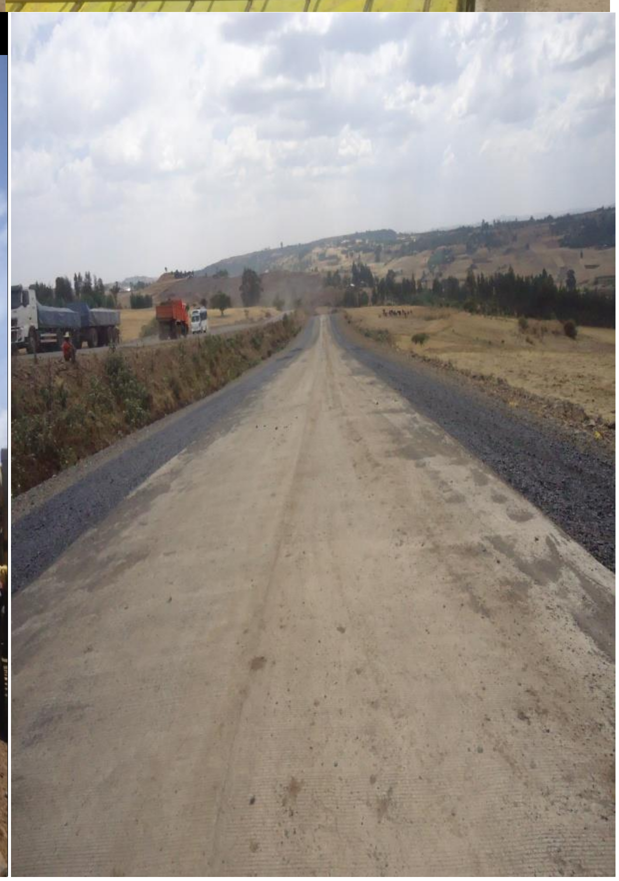
Year		(1+dr)	$(1+dr)^n$	Vehicle time savings(FV)	Fuel Cost(FV)	Vehicle time savings(PV)	Fuel Cost (PV)
0	2015	□	□				
1	2016	*1.1023*	1.102	*79,985.62*	874,181.72	*72,562.48*	793,052.45
2	2017	*1.1023*	1.215	*80,450.55*	879,252.98	*66,210.89*	723,626.12
3	2018	*1.1023*	1.339	*80,918.18*	884,353.67	*60,415.27*	660,277.59
4	2019	*1.1023*	1.476	*81,388.53*	889,483.94	*55,126.95*	602,474.79
5	2020	*1.1023*	1.627	*81,861.61*	894,643.98	*50,301.54*	549,732.24
6	2021	*1.1023*	1.794	*82,337.44*	899,833.95	*45,898.51*	501,606.93
7	2022	*1.1023*	1.977	*82,816.04*	905,054.03	*41,880.88*	457,694.67
8	2023	*1.1023*	2.180	*83,297.42*	910,304.39	*38,214.93*	417,626.62
9	2024	*1.1023*	2.403	*83,781.60*	915,585.21	*34,869.88*	381,066.26
10	2025	*1.1023*	2.648	*84,268.59*	920,896.66	*31,817.62*	347,706.51
11	2026	*1.1023*	2.919	*84,758.42*	926,238.93	*29,032.54*	317,267.18
12	2027	*1.1023*	3.218	*85,251.09*	931,612.18	*26,491.24*	289,492.60
13	2028	*1.1023*	3.547	*85,746.62*	937,016.61	*24,172.39*	264,149.50
14	2029	*1.1023*	3.910	*86,245.04*	942,452.39	*22,056.51*	241,025.01
15	2030	*1.1023*	4.310	*86,746.35*	947,919.71	*20,125.84*	219,924.92
16	2031	*1.1023*	4.751	*87,250.58*	953,418.74	*18,364.17*	200,671.99
17	2032	*1.1023*	5.237	*87,757.73*	958,949.67	*16,756.71*	183,104.53
18	2033	*1.1023*	5.773	*88,267.84*	964,512.69	*15,289.95*	167,074.98
19	2034	*1.1023*	6.364	*88,780.91*	970,107.98	*13,951.57*	152,448.70
20	2035	*1.1023*	7.014	*89,296.96*	975,735.73	*12,730.36*	139,102.86
21	2036	*1.1023*	7.732	*89,816.01*	981,396.12	*11,616.03*	126,925.35
22	2037	*1.1023*	8.523	*90,338.08*	987,089.36	*10,599.25*	115,813.91
23	2038	*1.1023*	9.395	*90,863.18*	992,815.62	*9,671.47*	105,675.19
24	2039	*1.1023*	10.356	*91,391.34*	998,575.10	*8,824.90*	96,424.05
25	2040	*1.1023*	11.416	*91,922.56*	1,004,367.99	*8,052.43*	87,982.78
26	2041	*1.1023*	12.583	*92,456.88*	1,010,194.48	*7,347.58*	80,280.49
27	2042	*1.1023*	13.871	*92,994.29*	1,016,054.78	*6,704.42*	73,252.48
28	2043	*1.1023*	15.290	*93,534.84*	1,021,949.07	*6,117.57*	66,839.72
29	2044	*1.1023*	16.854	*94,078.52*	1,027,877.56	*5,582.08*	60,988.36
30	2045	*1.1023*	18.578	*94,625.37*	1,033,840.44	*5,093.47*	55,649.25
31	2046	*1.1023*	20.478	*95,175.39*	1,039,837.91	*4,647.62*	50,777.54
32	2047	*1.1023*	22.573	*95,728.61*	1,045,870.18	*4,240.80*	46,332.31
33	2048	*1.1023*	24.882	*96,285.05*	1,051,937.43	*3,869.59*	42,276.23
34	2049	*1.1023*	27.428	*96,844.72*	1,058,039.89	*3,530.88*	38,575.24
35	2050	*1.1023*	30.234	*97,407.64*	1,064,177.74	*3,221.81*	35,198.24
36	2051	*1.1023*	33.327	*97,973.84*	1,070,351.20	*2,939.80*	32,116.87

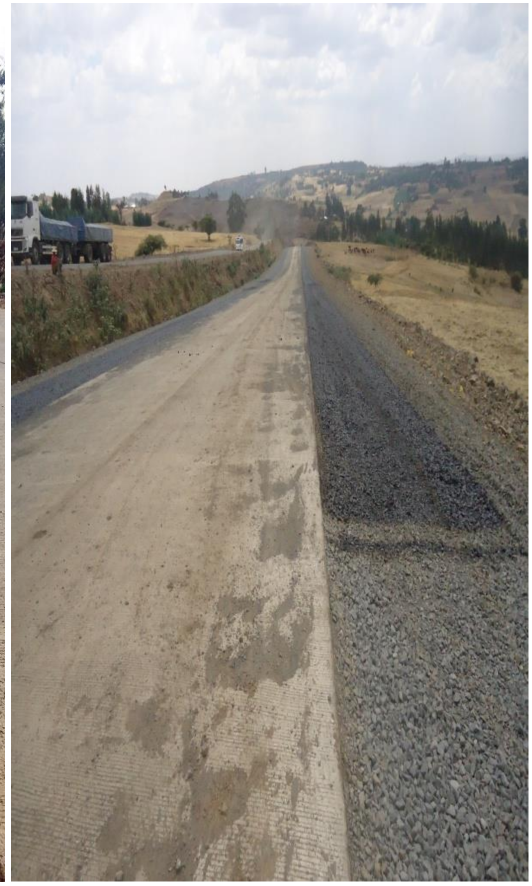
36	2052	*1.1023*	36.736	*98,543.32*	1,076,560.48	*2,682.47*	29,305.26
38	2053	*1.1023*	40.494	*99,116.12*	1,082,805.78	*2,447.66*	26,739.78
39	2054	*1.1023*	44.637	*99,692.25*	1,089,087.30	*2,233.41*	24,398.90
40	2055	*1.1023*	49.203	*100,271.72*	1,095,405.27	*2,037.92*	22,262.94
Grand Total (Birr/Km)						807,731.35	8,826,941.34

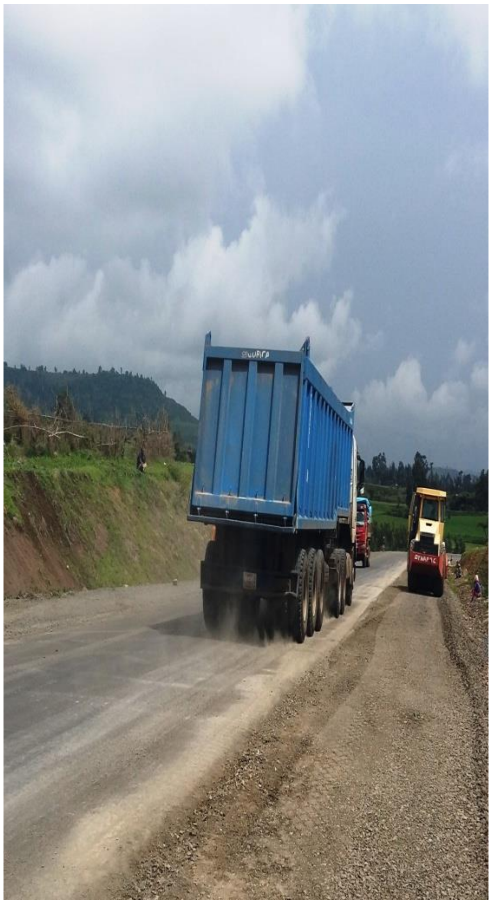
Year		(1+dr)	$(1+dr)^n$	Rehabilitation (FV)	Salvage Value (FV)	Rehabilitation	Salvage Value
40	2055	*1.1023*	49.203	1,500,987.28	*1,000,658.19*	30,505.96	*20,337.31*
Grand Total (Birr/Km)						30,505.96	20,337.31

APPENDIX C:- Project site Photograph

C.1:-Chancho Derba-Becho Site picture





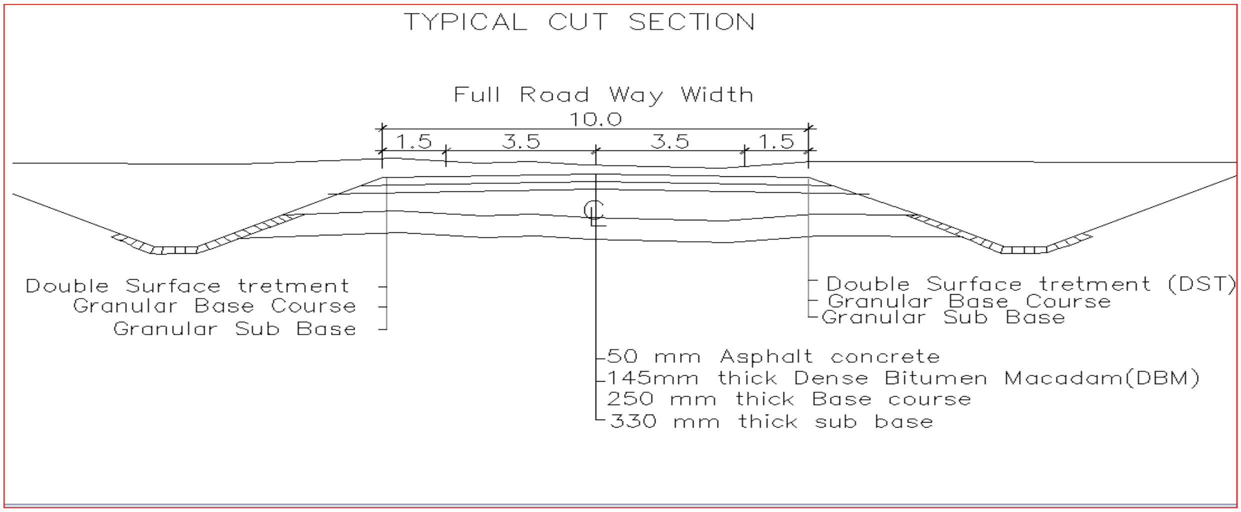

C.2:-Kality round about to Hana Mariam rigid pavement


Kality round about to Hana Mariam 300 m long concrete pavements in Addis Ababa constructed in2006 E.C

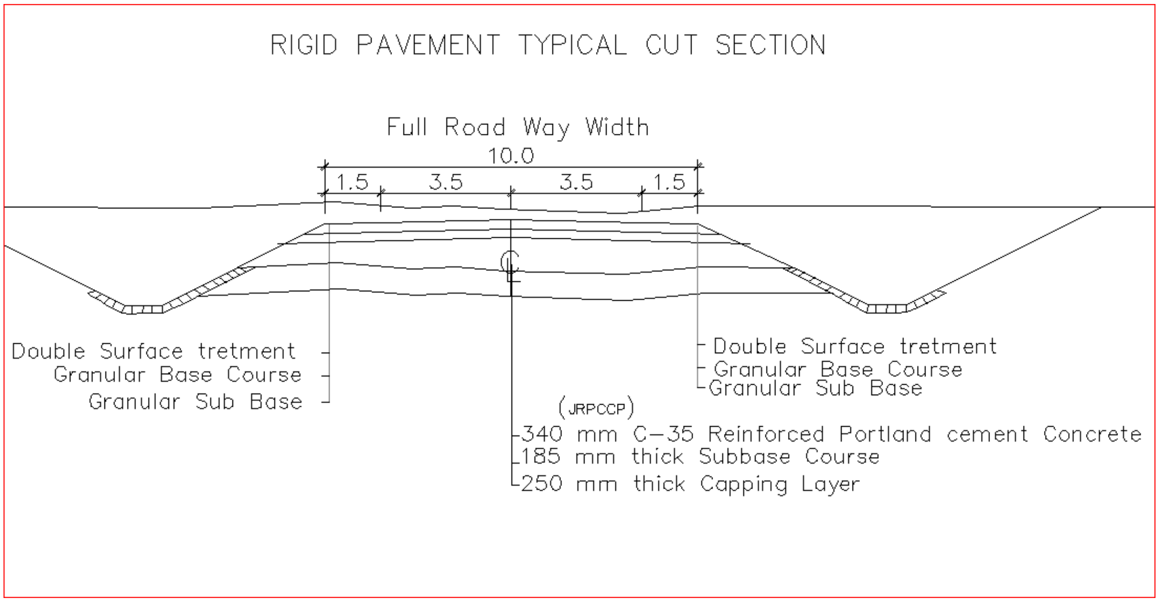



APPENDIX D: - Sample Drawings form Chancho- Derba – Becho

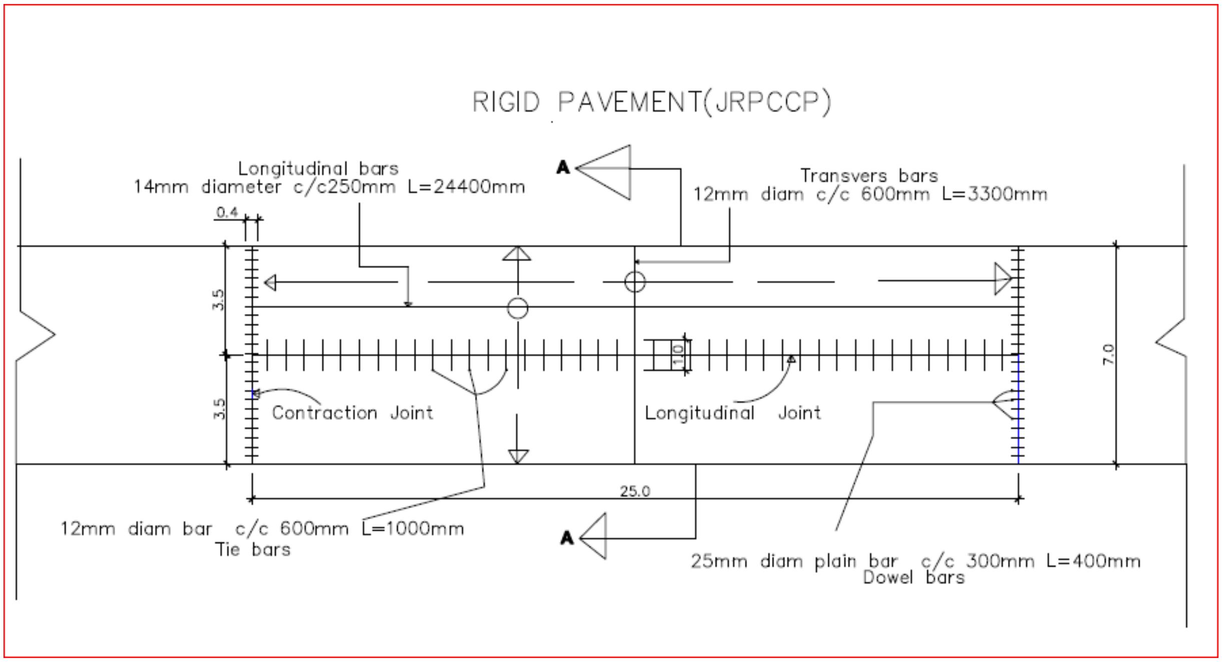
D.1 Flexible pavement section



D.2:- Rigid pavement section



D.3:- Rigid pavement lay out



D.4:- Rigid pavement detail