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(CONSTRUCTION ENGINEERING AND MANAGEMENT STREAM)

ON

THE SUSTAINABILITY OF JOINTED UNREINFORCED CONCRETE PAVEMENTS IN COMPARISON TO HOT-MIX CUT-BACK ASPHALT PAVEMENTS IN THE CONTEXT OF ETHIOPIA

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Construction Engineering and Management

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DECLARATION

I, the undersigned, declare that this thesis entitled "**The Sustainability of Jointed Unreinforced Concrete Pavements in Comparison to Hot-Mix Cut-Back Asphalt Pavements in the Context of Ethiopia**." is my original work and has not been presented for a degree in any other University. Besides that all sources of materials used for the thesis have been duly acknowledged.

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ABSTRACT

Road Construction projects in Ethiopia are often undertaken by the government and reducing the government costs by improving life cycle economy from pavement type is important to advance sustainable development. The economic impacts of road industry in Ethiopia have challenged the prospect of eco-construction and flexible road pavements are widely used despite some doubts regarding their economics under different conditions.

To assist ERA in rendering better-informed decisions for the type of pavement choices, the major research objective was to analyze the economic, environmental and social impacts of the JUCP and Hot-Mix Cut-Back Asphalt pavement alternatives from the perspective of life cycle cost analysis and life-cycle impact assessment.

The pavements were designed under different traffic conditions and considering different subgrade classes. According to the output of design parameters the layer types were determined and also the layer thicknesseswerecalculated.

This research wasanalyzed the sustainability of JUCP and Hot-Mix Cut-Back Asphalt pavements in the context of Ethiopia, on the basis of ERA Pavement Design Manual Volume 1 & II - 2013 using different methodsfor economic analysis in the perspective of life cycle cost analysis.Whereas for the social and environmental impact assessment follows life-cycle impact assessmentwithin the perspective of energy consumption, waste generation and greenhouse gases emission. These analyses play a great role on the decision-making stages in selection of pavement types.

The analysis results indicated that JUCP be the more sustainable choice than the selected HMA pavement alternative as it requires the lower life-cycle cost and has the less unfavorable impact on environment and social life when compared to the HMA flexible pavement.

Therefore, the focus of this research to bring a paradigm shift and to strengthen the three pillars of sustainability (Economy, Social & Environment) are being considered in the overall cost of the pavement structure rather than just looking at the initial investment cost during economic feasibility study of road projects under ERA custody.

Key Words*: Sustainability, Jointed Unreinforced Concrete Pavement, Hot-Mix Cut-Back Asphalt, Energy, Waste, Life cycle*

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LIST OF ABBREVIATIONS/ ACRONYMS

AADT: Annual Average Daily Traffic

AASHTO: American Association of State Highway and Transportation Officials

AC: Asphalt Concrete

ACI: American Concrete Institute

ACPA: America Concrete Pavement Association

ASTM: American Society for Testing and Materials

BS: British Standard

CRBC: Chain Road and Bridge Construction

CRCP: Continuously Reinforced Concrete Pavement

EIO-LCA: Economic Input-Output Life Cycle Assessment

ERA: Ethiopian Roads Authority

ERAPDM: Ethiopian Roads Authority Pavement Design Manuals

ERCC: Ethiopian Roads Construction Corporation

ESAL: Equivalent Single Axle Load

ETCA: Ethiopian Transport Construction Authority

FDRE: Federal Democratic Republic of Ethiopia

FHWA: Federal Highway Administration

GDP: National Gross Domestic Product

GHG: Green House Gas

GWP: Global Warming Potential

HDM: Highway Development and Management System

HMA: Hot Mix Asphalt

IRI: International Roughness Index

ISO: International Organization for Standardization

JRCP: Jointed Reinforced Concrete Pavement

JUCP: Jointed Unreinforced Concrete Pavement

LCA: Life Cycle Assessment

LCCA: Life-Cycle Cost Analysis

MEPO: MIDROC Ethiopia Project Office Contracting

MOFED: Ministry of Finance and Economic Development

NPV: Net Present Value

PCA: Portland Cement Association

PCC: Portland Cement Concrete

PCCP: Port Land Cement ConcretePavement

PDM: Pavement Design Manuals

RSDP:Road Sector Development Program

RUC: Road User Cost

UNEP: The United Nations Environment Program

WSDOT: Washington State Department of Transport

1. INTRODUCTION

1.1 Background of the Study `

From the early age of mankind, Ethiopia has a rich history for construction industry. Most of the construction activities were used for protecting the country from the external invasion and for showing the strength of the ruling dynasty. The ruined palaces of Queen Sheba at Yeha, the oblique of Axum, the rock of hewn Church of Lalibela are some examples that show the early construction stage of the country.

Transport and mobility are essential for economic and social development. For this reason, developed countries have devoted considerable resources to the development of high-quality and sustainable transport networks which need to be adequately maintained.

Roads, in Ethiopia, are significant and potential means of transporting human and material over both short and long distance in the country. Roads have also helped in developing cultural and social ties among the people by transporting them from one corner to the other corner of the country. Thus, we see that progress made by any country and well-being of a nation depends much on road facilities. Moreover, the development, civilization and efficiency of a nation can beeasily judged by the extent of its roads facilities(RSDP report, 2014).

Accordingly, ERA has adopted sustainability concerns in its vision statements,"Better roads for better Ethiopia by connecting people to better opportunities and places to enhance economic and social development", and its mission is meant to define the purpose of the organization and is read as: providing better road infrastructure by developing, leading, and managing the road sector towards supporting the socio-economic development of Ethiopia (RSDP report, 2014).

For the last two decades in Ethiopia, with the increases of populations and demands of public customers, highways have been actively and continually constructed or rehabilitated or maintained. As result, the country‘s road network has increased from 26,550 kms in 1997 to 99,522 kms in 2014 an increase of 275 percent and the total budget for the planned works during this Seventeen years of the RSDP amounted to ETB 160.3 billion or USD 11.1 billion.Since an enhanced transportation infrastructure system would sustain social and economic development. Therefore, using long-life and low-maintenance type of pavement is recommended by ERA (RSDP report, 2014).

Hence,in these days, sustainability is one of the main focuses of attention in construction industry. Sustainable construction and development implies investing in the needs of today without compromising the resources of future generations to meet their needs. The components of sustainability are economic, social and environmental.

Investment on major roads require a huge sum of capital which in severe shortage in the country. Therefore, the Government in Ethiopia is committed to ensure that there will be adequate return from investment on major roads interms of benefit to the country which in turn require adopting proper planning procedures during rehabilitation, upgrading and new construction of roads in the country.The road sector policy of the government makes planning of main roads projects compulsory. Planning of main roads projects in Ethiopia is a process which involves identifications, pre-feasibility, feasibility, design, implementation and operation cycles. Each stage consists of related but distinct technical inputs and outputs. Generally, road project cycle in Ethiopia consists of six phases which can be described as Identification, Feasibility, Design, Appraisals Funding Negotiation/Budget Allocation, Implementation, Ex-post Evaluation and Operation.

However, the economic impacts of road industry in Ethiopia have challenged the prospect of eco-construction and flexible road pavements are widely used despite some doubts regarding their economics under different conditions butthe social impacts of pavements are realized from the elimination of construction zones that result in lost time to the public caused by lane closures and vehicle operating costs and more importantly, the elimination construction zone safety hazards that may result in loss of property or life in construction zone accidents.

Therefore, selection of the appropriate pavement type has great impact to ensure the sustainability of road construction in the future generation of Ethiopia.

1.2 Statement of the Problem

Current road construction methods and approaches in ERA lead to significant maintenance and rehabilitation requirements, which can only be met at a very high life cycle cost. The continued growth in road traffic and axle loads and the pressure to restrain government spending put growing pressures on ERA to come up with new solutions. At the same time, the cost to economies due to congestion and disruption during road works on high volume roads has become unacceptably high and then there are growing pressures for long-life road infrastructures that require minimal maintenance.

Road infrastructure investment, particularly in urban area, has generally increased less in Ethiopia than road traffic. If these trends continue, the outcome will be increasing intensity of road traffic on road networks in the future. These trends support the view that there will be increasing numbers and proportions of roads which are highly trafficked and therefore candidates for more durable pavements at reasonable construction costs.

Over the past 17 years of Ethiopia, 17 % of the total RSDP expenditure was spent on maintenance and rehabilitation of existing roadswhich accounts for around ETB 27.3 billion of the national road budget.Current road construction methods and materials contribute to this outcome, as they lead to periodic and routine maintenance requirements that can only be met at a relatively high cost and congestion problems on high-traffic and urban roads during periods of road maintenance are now a major concern in Ethiopia.Besides to this roads that cover utilities (e.g. sewers, water pipes, electrical cables, telecom cables etc.), as do most city streets and suburban residential roads of Ethiopia, are subject to frequent digging, refilling and resurfacing. Hence, long-service asphalt structure wearing courses would therefore not be suited to such roads(RSDP report, 2014 A.A).

Moreover, currently asphalt pavements are becoming more expensive while their quality is declining from time to time. The expensiveness of asphalt pavements is mainly due to its main component, bitumen. Ethiopia is not oil producing country and thus bitumen is imported from foreign countries with hard currency, and the price is increasing from time to time. Consequently, for the past 20 years (from 1997-2016) Ethiopiawas spentETB 1,357,062,444.57 (USD 67,853,122.23in PV) tobitumen mixture cut-backs asphaltonly for flexible pavement construction (Ethiopia Revenues and Customs Authority).Due to this fact the search for alternative pavement construction materials is a key and fundamental factor for the sustainable growth of the road networks in the future Ethiopia. This is due to various elements such as the availability of materials, cost effectiveness, environmental & social suitability and the like.

However, in the Ethiopian context, cut-backs asphalt bitumen is used as a binding agent almost in the entirety of road projects. This is due to the consideration of only flexible pavements in the Engineering design stage despite the fact that ERA has incorporated the Rigid Pavements DesignManual since 2002. This prejudice towards asphalt pavement and the ruling out of rigid pavement from the picture might have emanated from the lack of awareness of designers, absence of skilled man power, its relatively higher initial cost, shortage of cement or a combination of them and others.

Therefore, the focus of this research to warm-up to the idea of constructing concrete pavements and will address the wrong assumption that rigid concrete road pavement is always the more expensive pavement option without even investigating life cycle cost together with user benefits, environmental benefits, social benefits, cement manufacturing industries mutual benefits and so on. Besides to these to bring a paradigm shiftand to strengthen the three pillars of sustainability (i.e. economic, social and environmental issues) are being considered in the overall cost of the structure rather than just looking at the initial investment cost during economic feasibility study of road projects under ERA custody.

1.3 Research Questions

1. Whatare the life cycle costs of a given road pavement construction project include and how they are analyzed?
2. What are the economic, social and environmental benefits of rigid and flexible asphalt pavements?
3. Are there mutual economic and social benefits between developing rigid concrete pavement and the expansion of cement manufacturing industries in Ethiopia? How?

1.4 Objectives of the Study

1.4.1 General Objective

To investigate the sustainable benefits of jointed unreinforced concrete pavements in comparison to hot-mix cut-back asphalt pavements in the context of Ethiopia.

1.4.2 Specific Objectives

Based on the general objective stated, this research is undertaken with the following specific objectives:-

1. To analyze the life cycle costs of the given rigid and flexible asphalt pavements.

2. To identify the social and environmental impacts of each pavements.
3. To compare the economic, social and environmental impacts of each pavements.
4. Finally, to forward the mutual and consequential benefits between developing rigid concrete pavement and the expansion of cement manufacturing industries in Ethiopia.

1.5 Significance of the Research

This study, generally, contributes the following major substances:

- This research will provide recommendations to ERA and other stakeholders for better-informed decision making for road construction projects that choose cement concrete pavement as alternative.
- To forward how to tackle the life cycle cost analysis of road construction projects together with user benefits, environmental benefits & social benefits.
- To minimize the maintenance and rehabilitation costs of pavement structures in country.
- To reduce the environmental and social problems related to roads construction.
- It will be an alternative means of solution in ensuring sustainable development in Ethiopia by firming the environmental and socio-economic activities in regarding to road infrastructures in the long run.

1.6 Scope of the Research

- This research is geographically limited to the country Ethiopia.
- The study wasaddressed only the sustainability JUCP rigid pavement in comparison to HMA flexible pavement.
- The study was focused only on the sustainability of the main alignment (roadway)but not includespur alignmenton trunk road project with in Ethiopia.
- In the case of environmental impact only the environmental burdens of the surface course materials will be compared from materials extraction of raw materials through the end of construction stage and does not address the entire roadway lifecycle.
- Moreover, in the case of economic impact (life cycle cost analysis) only measured initial construction costs, maintenance & rehabilitation costs, road user costs and GHG emission costs.
- To assess the environmental & social impacts considered only from the perspectives of energy emission, energy consumption, and waste generation.
- For energy emission considered only the major greenhouse gases released into the air such as CO2, SO2, NOX, CO, CH4, N2O, and VOC.

- This study addressed the social impacts related to emission costs and road user costs only in the life cycle assessment.

1.7 Research Assumptions and Limitations

Besides to all the necessaries empirical pavement design assumptions, the following were assumed:-

- For the unit rate determination of the pavements, 2016 Heavy Construction Cost Data from ERA was used for cost calculation.
- The cost data are sourced from manufacturers, dealers, distributors, consultants and contractors in Addis Ababa Ethiopia, and included10% waste. Hence, the cost breaks down were computed with the addition of 30% indirect costsbesides to material cost, labor cost and equipment cost.
- Materials such as chemicals and admixture not greater than 1% in cement and asphalt concrete are not considered as materials that have environmental impacts.
- Typical life expectancy of JUCP is 40 years and HMA is 20 years (as per ERA design manual, 2013).
- This research only considered the analysis of five major categories of impacts: economic, social, greenhouse gas emission, energy use and waste generation ofthe main roadway components.
- Due to lack of available data and difficulties in accurately quantifying, assumed that no energy is consumed for the extraction and initial transformation phase of the lifecycle for both bitumen and Portland cement.
- Net Present Value (NPV) approach is used for “discounting.”
- Besides to time and resources constraints, there is lack of adequate data on the practice of rigid pavement design and construction in Ethiopia.

2. LITERATURE REVIEW

The main purpose of this literature review is to compare jointed unreinforced concrete pavement (JUCP) and hot-mix cut-back asphalt pavement by analyzing their life cycle costsand impacts towards sustainability in the context of Ethiopia.

It was begun with discussing the overview of: The History and Organizational Background of the Ethiopian Road Sector, Sustainability and Pavements, Characteristics of Rigid Pavements, Characteristics of Flexible Pavements and Life Cycle Cost Assessment Overview.

At last, I also triedto survey the literature on the following subtopics: Noticeable Findings from Previous Studies and Current Status of Concrete Pavement construction in Ethiopia.

2.1 The History and Organizational Background of the Ethiopian Road Sector

Although there is no real data that shows how and when road development in Ethiopia had stared. Following the eviction of the Italian occupiers, the Imperial Ethiopian Government was convinced that a Road Agency solely responsible for restoring and expanding the road network throughout the country had to be established. Accordingly, the Imperial Highway Authority was established under proclamation No. 115/1951 as a semi-autonomous agency with specific duties to plan, design, construct, and maintain roads. Responsibilities for construction and maintenance of roads remained under a single autonomous authority for 26 years (1951-1977). The Ministry of Transport and Communication turned out to be the supervising authority of ERA. The Ethiopian Roads Authority has been reestablished under proclamation 133/1978 incorporating, among others, the Rural Roads Department in addition to the Highway Department.

In 1980, the Military Government Derge that took power in 1974 reformed the agency into the Ethiopian Transport Construction Authority by proclamation No. 189/1980 and became accountable to the newly formed Ministry of Construction. The proclamation enlarged responsibility of the Authority by expanding its task to incorporate the construction of Municipal Roads, Railways, Airports and Seaports.

Following the shift from a command-based economy to a market oriented one, FDRE, in1991; ERA was reestablished by proclamation No.63/1993 with a view to providing a strong administration under the leadership of a Board. As part of its reform, the government assigned administration of rural roads to the regional self-governments and main roads to ERA as part of the Federal Government’s responsibility. ERA’s role regarding rural roads was then limited to rendering support such as overall network planning, training and technical assistance as required by regional Governments.

To cope up with existing situations, ERA was again re-established by proclamation No. 80/1997 with the objective to develop and administer highways, to ensure the standard of road construction. With the establishment of the new cabinet of Ministers in October 2001, a Ministry of Infrastructure and later on Ministry of Works and Urban Development has been formed with the responsibility of developing the infrastructure of the nation. ERA, which is one of the organizations under the Ministry of Works and Urban Development and accountable to the Board, is responsible for planning and formulating long and short term plans and programs for road construction, design, maintenance of trunk and major link roads, as well as for administration of contracts.

Currently, the main responsibilities of ERA are network planning; management of contract projects and force account operations. The long-term objective is to focus on policy, planning and contract administration and to pull out gradually from direct operational works.

From its year of establishment, 1951 the organization managed to undertake various physical and policy issue works. During its establishment the total road network amounted to 6,400 km, which was mainly built during the Italian invasion. But by 1997 the road network had grown to 26,550 km, of which 3,708 km were paved. Then, as a result of investments made under RSDP during the last two decades the total length of the network has increased to 99,522 km in 2014 (an increase of 1455% percent). Also substantial improvement has been registered in the condition of the country's road network. The proportion of road network in good condition increased from 22% in 1997 to 70% in 2014(RSDP report, 2014).

Over the last two decades, overall performance was improved but still there is a big gap for improvement. The issue of addressing huge network expansion and improvement needs, as well as backlogs of maintenance needs under funding constraints, weak implementation capacity of the local construction industry& own force, few number of international contractors, high turnover of professional and managerial staffs in the organization, lengthy contract procurement processes even for small contracts under the rules and regulations set out in the public procurement and donor agencies guidelinesand slow pace of institutional change especially lack of prospective research institute toobserve &decide a better-informed alternative choices of construction materials and pavementtypesare some of the challenges for Ethiopian road sector.

2.2 Sustainability and Pavements

What is Sustainability?

Sustainability - derived from Latin sustinēre (from sus, up and tenēre, to hold) means essentially the capacity to endure. Sustainability applied very broadly to every facet of life, but increasingly in the context of human sustainability on Earth-particularly as causes of global warming and climate change are debated. So sustainability in context of roadways fundamentally focused on how we balance natural environment, societal needs and economic vitality.

A basic definition of sustainability is: - the capacity to maintain a process or state of being into perpetuity, without neither exhausting the resources upon which it depends nor degrading the environment in which it operates.

In the context of human activity, sustainability has been described as activity or development "that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Norwegian Prime Minister, 1987).

Recently, regard to transportation, the Federal Highway Administration of The United State (FHWA) defined sustainable transportation as "providing exceptional mobility and access in a manner that meets development needs without compromising the quality of life of future generations. A sustainable transportation system is safe, healthy, affordable, renewable, operates fairly, and limits emissions and the use of new and nonrenewable resources" (Harmon, 2010).

On the basis of construction, "Sustainable construction means that the principles of sustainable development are applied to the comprehensive construction cycle from the extraction and beneficiation of raw materials, through the planning, design and construction of buildings and infrastructures, until their final deconstruction and management of the resultant waste. It is a holistic process aiming to restore and maintain harmony between the natural and built environment, while creating settlements that affirm human dignity and economic equity" (UNEP, 2002).

Despite the fact that, traditional criteria held by the construction industry as project objectives are: cost, schedule, quality, and safety. But with the start of the concept of sustainability proposed three additional project criteria for the construction industry related to sustainability: resource depletion, environmental degradation, and healthy environment. Construction operations consume energy, and can create substantial noise, cause significant environmental damage, and produce large quantities of waste. Changes in construction processes may be needed to protect the environment during construction operations. Excellence in design at all levels is crucial; poor design can lead to unsustainable construction. Kibert suggests that materials should be selected for either their recyclability or their ability to be composted and returned to earth as biomass (Kibert, 1994).

Typically, three general categories (or pillars) of sustainability are recognized: economic, environmental, and social. When activities are sustainable, no pillar is ignored; instead, a workable balance among the three often-competing interests must be found. Together, the three pillars form what is commonly called the "triple bottom line" (Elkington, 1994). This concept can be expressed graphically as shown in Figure2.1, which illustrates that sustainable solutions are those that incorporate all elements of the triple bottom line.

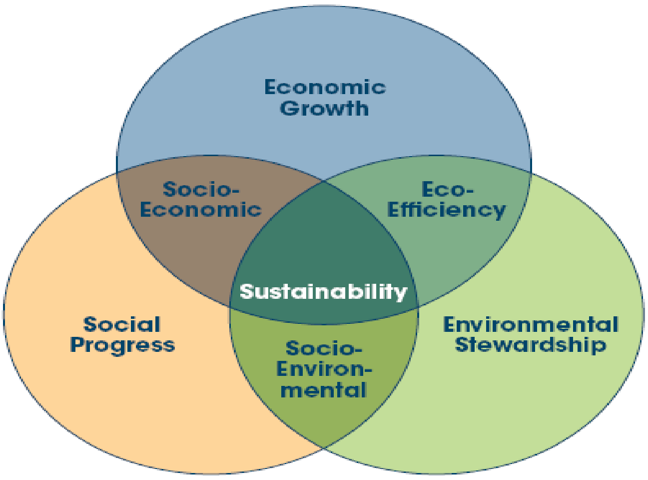


Figure 2.1: Fundamental sustainability model (CH2M Hill 2009).

Balancing economic, environmental, and societal factors for a pavement project requires identifying applicable factors in each category, collecting data for the factors to be evaluated, applying tools to quantify the impact of each factor, and assessing the combined impact of the f Conventionally, we think of pavement life as linear, moving from the "cradle" (design, material extraction and processing, and construction) through its service life and finally to the "grave" (pavement removal and reconstruction). This cradle-to-grave concept is contradicted to sustainability.

Sustainability instead requires a "cradle-to-cradle" approach in which the end of life is part of a new beginning (McDonough and Braungart 2002). For concrete and asphalt pavements, this is simply illustrated in Figure2.2, in which design, materials processing, construction, operations, preservation and rehabilitation, and reconstruction and recycling are joined in a continuous loop.

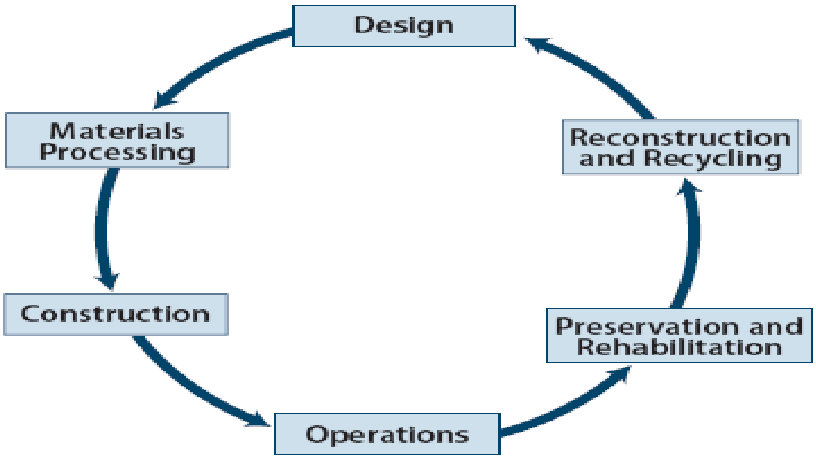


Figure 2.2: The concept pavement life cycle (Van Dam and Taylor 2009).

Although conceptually this may seem overwhelming, applying sustainability principles at a practical, implementable level using today's technologies simply means finding opportunities to minimize environmental impact while increasing economic and social benefit. Already, the value of life-cycle cost analysis (LCCA) is recognized as a way to consider current and future anticipated economic impacts over the life of the design. In addition, a number of approaches to assess sustainability are emerging and will soon be available for implementation by the concrete pavement industry, including the use of life-cycle analyses that address environmental impacts over the life of a pavement. Yet, only by stepping away from the larger issues of the economy as a whole and instead focusing on the project level can these overarching sustainability concepts be implemented into actionable and measurable activities that will be used by the pavement construction industry actors in relationship to one another.

However, sustainability is not really new; it simply raises the bar for good engineering. Good engineering has always entailed working with limited resources to achieve an objective. What has changed is the scope of the problem, along with the period of time over which a project is evaluated. Whereas in the past economic factors were paramount, now environmental and social factors must be considered equally with economic factors. Whereas in the past initial costs and other initial impacts were often paramount, now the span of time in the analysis is increased to the entire life cycle of a project, and all impacts (both positive and negative) are considered from the point of inception (mining of raw materials) to end of life (recycling). This type of analysis is often referred to as a "cradle to cradle" analysis (McDonough and Braungart, 2002).

To address these issues of sustainable pavement construction, different scholars proposes the following values for sustainable pavement construction.

Then, the following are a few general attributes of pavements that can make them a sustainable choice:

- Cost effective in life cycle and Minimal need of hard currency
- Long service life or Durability and Require little repair or maintenance
- Load bearing/ Deformation /Flexural strength
- Industrial byproduct use
- Reduced use of non-renewable resourcesand Fully recyclable
- Safety and Riding comfort: Smooth, quiet, and safe over the life cycle
- Minimal impact to the surrounding environment and Improved surface water quality
- Minimal traffic disruption during construction and preservation activities
- Minimal weathering impact
- Minimal need of construction skills and methods
- Community friendly: Aesthetically pleasing, appropriately textured, light colored surfaces reduce ambient noise, emissions, surface run-off, urban heat, and artificial lighting needs, resulting in a positive local and global impact
- Resource efficiency by using local materials and incorporating recycled products.
- Minimize energy consumption and greenhouse gas emissionsduring construction and use

  etc.

2.3 Characteristics of Rigid Pavements

Rigid pavements (also called concrete pavements) usually comprise two or three layers; a capping layer if the subgrade is weak, a sub-base layer and a strong, stiff concrete layer. The specifications for the capping layer and sub-base and methods of determining the strength of the subgrade for design purposes are essentially the same as for flexible pavements.

As the name ‘rigid’ implies, the deflections under a loaded wheel are very small compared with the deflections observed in flexible pavements and the stresses within the underlying sub-base and subgrade are also comparatively small as shown in figure2.3.

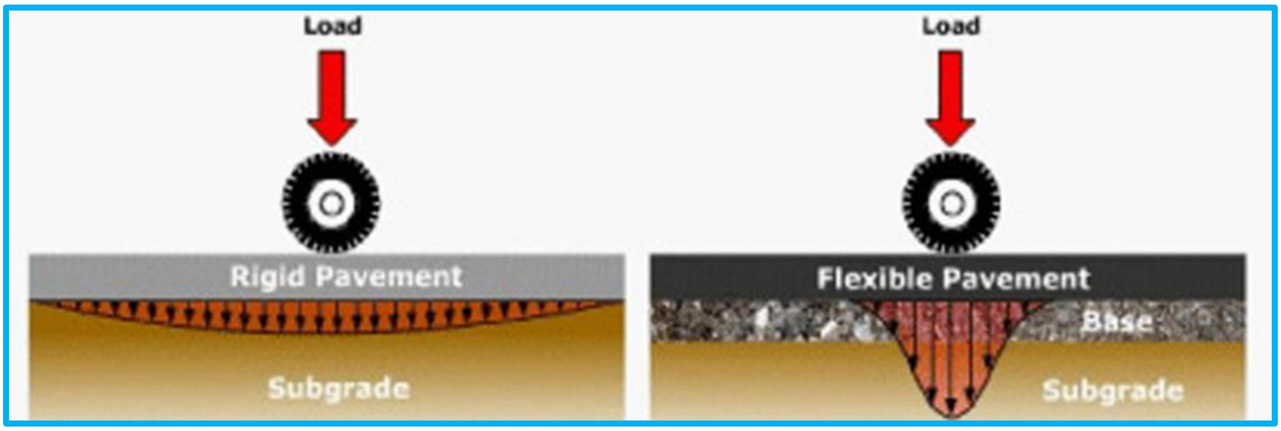


Figure 2.3:PavementDeflections under a Loaded Wheel (www.loadpavement.com)

Rigid pavements usually consist of a sub-base and a concrete slab but a capping layer is also used if required (Figure 2.4). When the subgrade is weak, the required thickness of material of sub-base quality required to protect the subgrade 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.

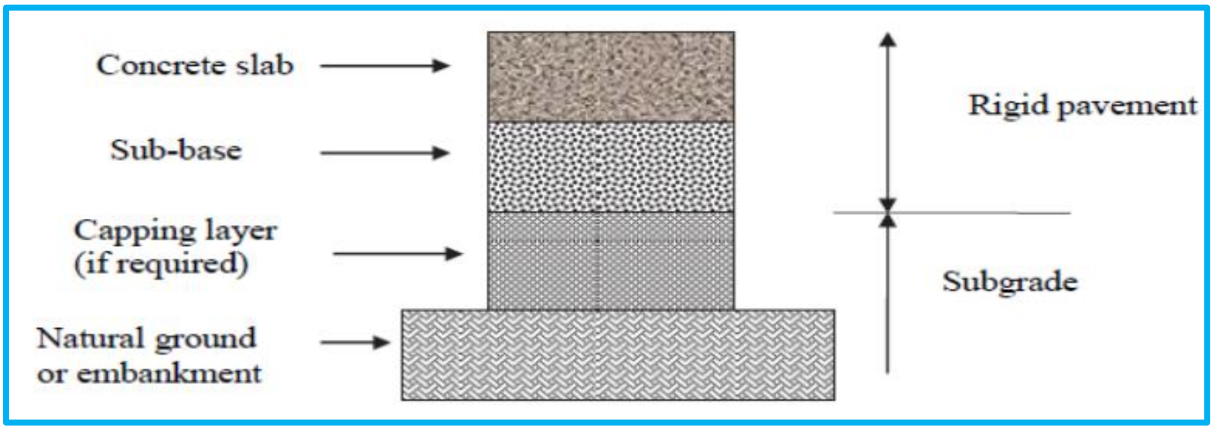


Figure 2.4: Rigid Pavement Structure (ERA Rigid Pavement DM, 2013)

The sub-base is also required to provide a stable working platform on which to construct the concrete slab. If the quality of the subgrade is acceptable, and if the design traffic is low (less than one million ESAs) a sub-base layer may not be strictly necessary between the prepared subgrade and the concrete slab. However, a sub-base layer makes it easier to achieve the required elevations within the specified tolerances and is usually recommended.

The rigid pavements can be made of plain cement concrete, reinforced or prestressed concrete. In addition, they may also be jointed or continuous.

The major factor considered in the design of rigid pavements is the structural strength of the concrete. For this reason, minor variations in subgrade strength have little influence upon the structural capacity of the pavement. The major factor considered in the design of flexible pavements is the combined strength of the layers.

Conventional pavements (JUCP, JRCP, and CRCP) make use of several types of transverse and longitudinal joints. Transverse contraction joints are used in JUCP and JRCP, usually with dowels. At the end of each daily paving operation, or for a significant delay in paving, transverse construction joints are placed, generally at the location of a planned contraction joint for JUCP or JRCP. Transverse expansion or isolation joints are placed where expansion of the pavement would damage adjacent bridges or other drainage structures. Longitudinal contraction joints are created where two or more lane widths or shoulders are paved at the same time. In contrast, longitudinal construction joints are used between lanes or shoulders paved at different times (FHWA manual, 1990a).

The performance of concrete pavements depends to a large extent upon the satisfactory performance of the joints. Most jointed concrete pavement failures can be attributed to failures at the joint, as opposed to inadequate structural capacity. Distresses that may result from joint failure include faulting, pumping, spalling, corner breaks, blowups, and mid-panel cracking. Characteristics that contribute to satisfactory joint performance, such as adequate load transfer and proper concrete consolidation have been identified through research and field experience (FHWA manual, 1990a).

The incorporation of these characteristics into the design, construction, and maintenance of concrete pavements should result in joints capable of performing satisfactorily over the life of the pavement. Regardless of the joint sealant material used, periodic resealing will be required to ensure satisfactory joint performance throughout the life of the pavement. Satisfactory joint performance also depends on appropriate pavement design standards, quality construction materials, and good construction and maintenance procedures (FHWA manual, 1990a).

2.3.1 Types of Cement Concrete Pavement

Almost all rigid pavements are made with Portland Cement Concrete (PCC). Rigid pavements are differentiated into three major categories by their means of crack control:

I. Jointed Unreinforced (i.e. Plain) Concrete Pavement (JUCP)

This is the most common type of rigid pavement. JUCP controls cracks by dividing the pavement up into individual slabs separated by contraction joints. Slabs are typically one lane wide and between 3.7 m and 6.1 m long. JUCP does not use any reinforcing steel but does use dowel bars and tie bars as shown Figure2.5&2.6.

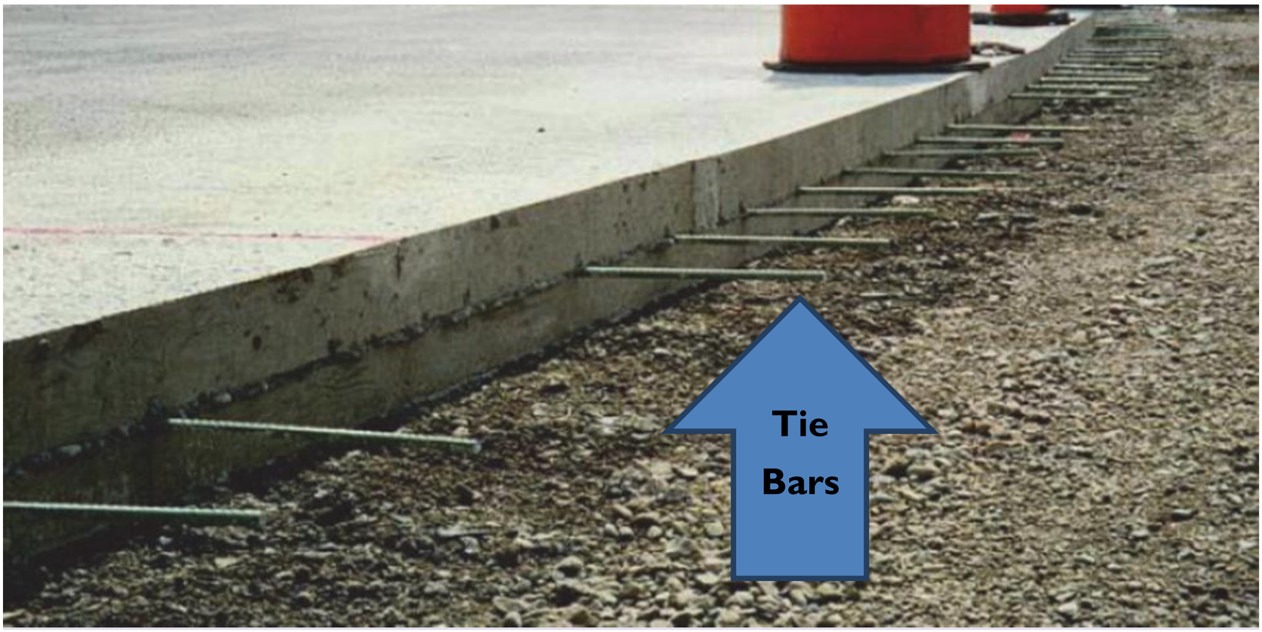


Figure 2.5: Tie bars in place to connect to parallel concrete slab (ERA PDM-2013)

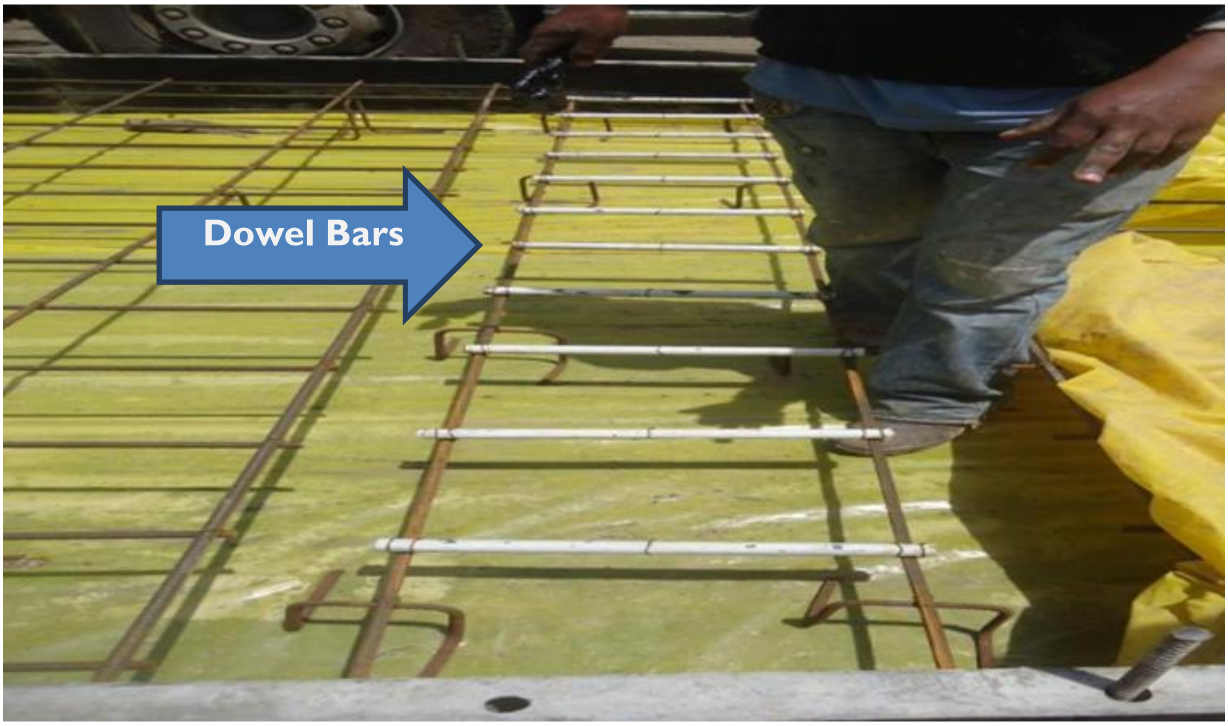


Figure 2.6:Dowel bars at joints for concrete pavement (from Chancho-Derba Project)

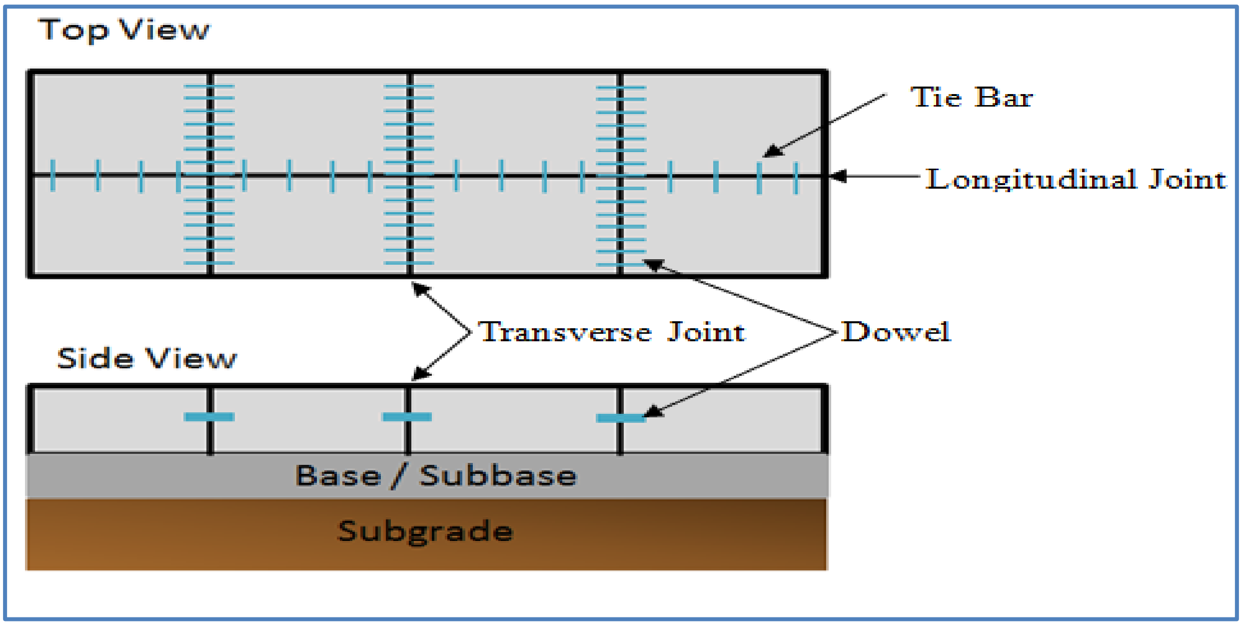


Figure 2.7:Cross-section of JUCP (WSDOT 2011)

II. Jointed Reinforced Concrete Pavement (JRCP)

As with JUCP; JRCP controls cracks by dividing the pavement into individual slabs separated by contraction joints. However, these slabs are much longer (as long as 25 m) than JPCP slabs, so JRCP uses reinforcing steel within each slab to control within-slab cracking.

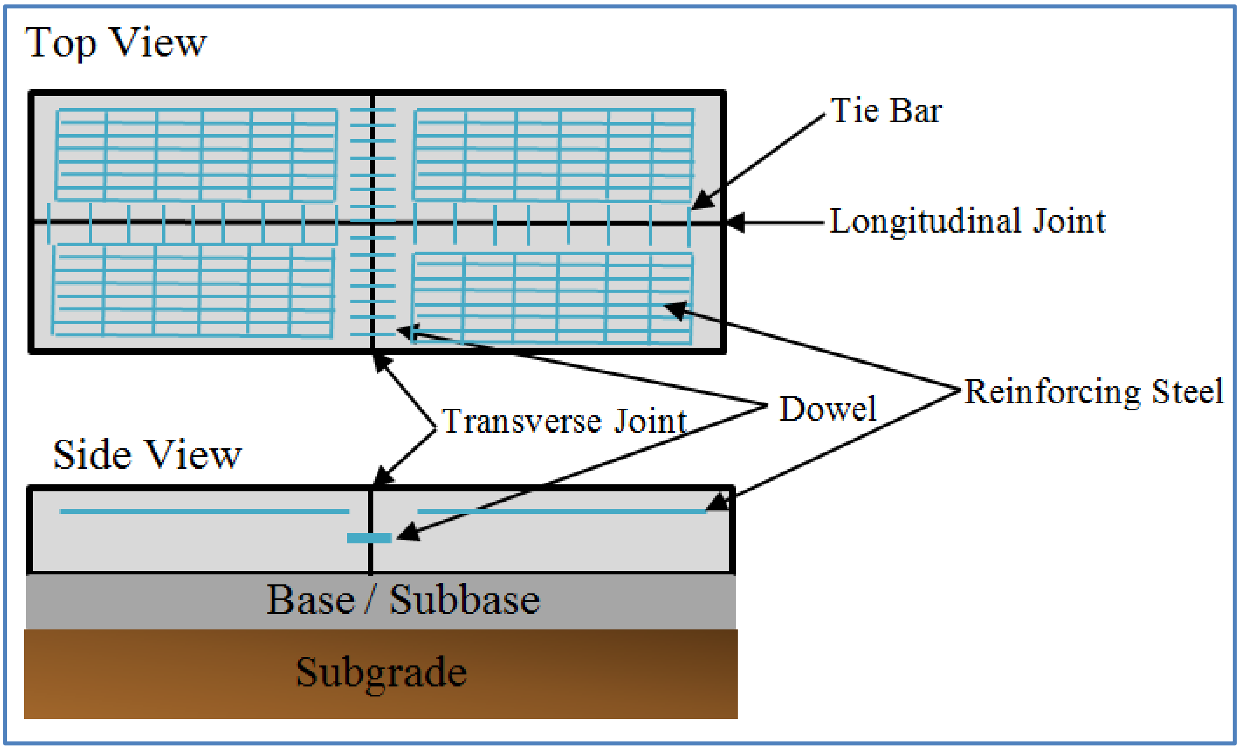


Figure 2.8:Cross-section of JRCP (WSDOT 2011)

III. **Continuously Reinforced Concrete Pavement (CRCP)**

This type of rigid pavement uses reinforcing steel rather than contraction joints for crack control. Cracks typically appear ever 1.1 – 2.4 m is held tightly together by the underlying reinforcing steel.

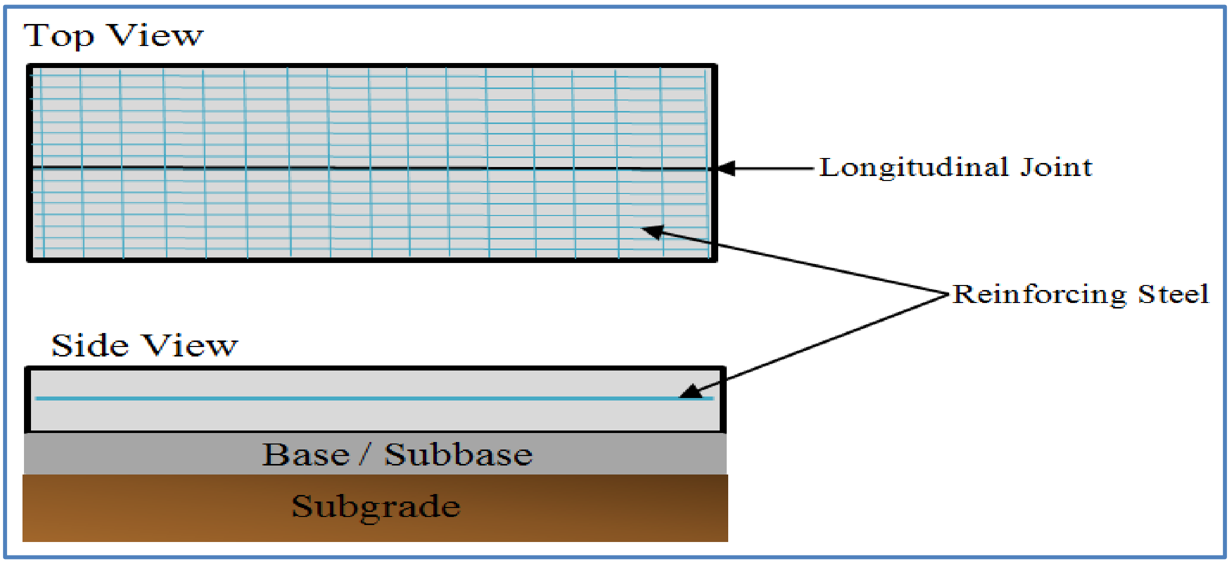


Figure 2.9:Cross-section of CRCP (WSDOT 2011)

2.3.2 Design Procedurefor Rigid Pavement

The design of concrete pavement involves capping layer, sub base, concrete slab and reinforcement design. The detail procedure are given for three types of concrete pavements ERA concrete pavement manual, 2013 however, our project is jointly reinforced concrete pavement that we are limited describing other. A general methodology for rigid pavement design is presented in Figure 2.10.

The durability of concrete is very high and therefore rigid pavements can be designed for periods of up to 60 years, but 40 years is the most common design period. If properly constructed, the pavement will last a long time with a high level of serviceability and low maintenance requirements. However, as with all pavements, the maintenance must not be neglected.

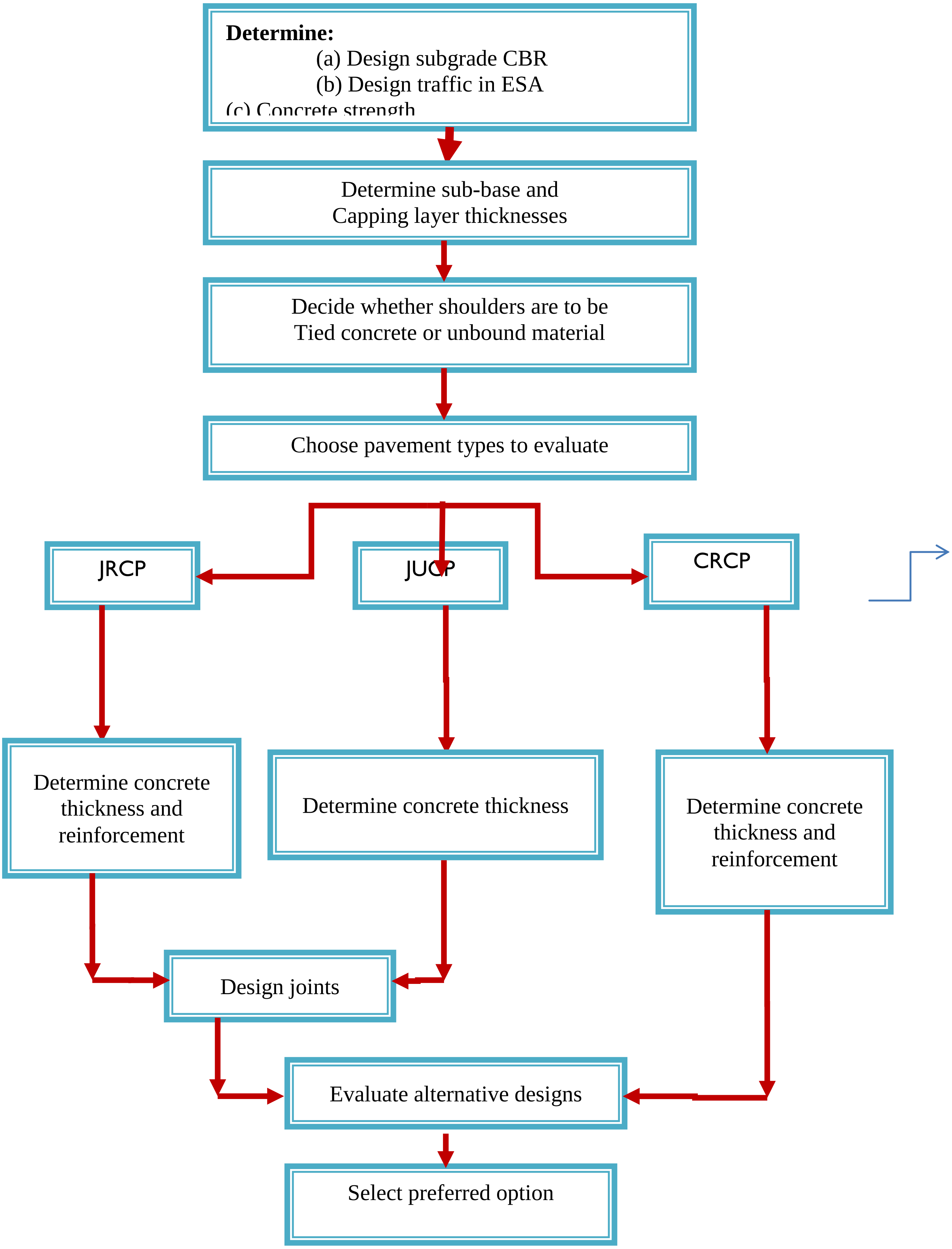


Figure2.10: Design Procedures of Concrete Pavement

The required slab thickness varies approximately linearly with the logarithm of the cumulative number of ESAs; therefore designing for longer periods requires relatively small additional slab thicknesses and reinforcement.

a) Sub base and capping layer selection

A capping layer is required if the design CBR of the subgrade is less than 15%. The required thickness of capping layer and sub-base thickness is shown in Table2-1. A sub-base layer is required whenever the subgrade material does not comply with the requirement for a sub-base (CBR is less than 30%) but it is usually provided in all cases because the sub-base and capping layers are primarily designed to provide a good working platform for construction activities. This enables construction levels to be more easily achieved within the tolerances required.

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

Table 2-1: Thickness of Sub-base and Capping Layers ERA, PDM

For good performance of ridged pavement the sub base must be resistant to erosion, to achieve that it has to be stabilized with cement lime. Therefore in case of un-stabilized sub base additional thickness is provided to compensate for erosion effect. Table2-1 show additional thicknesses required for stated effect at different traffic class.

2.3.3 Construction of Rigid Pavements

The construction of concrete pavement is similar in many ways than one to any concrete works. However it also involves peculiar procedures unique to it. The following schematic diagram summarizes the procedures involved

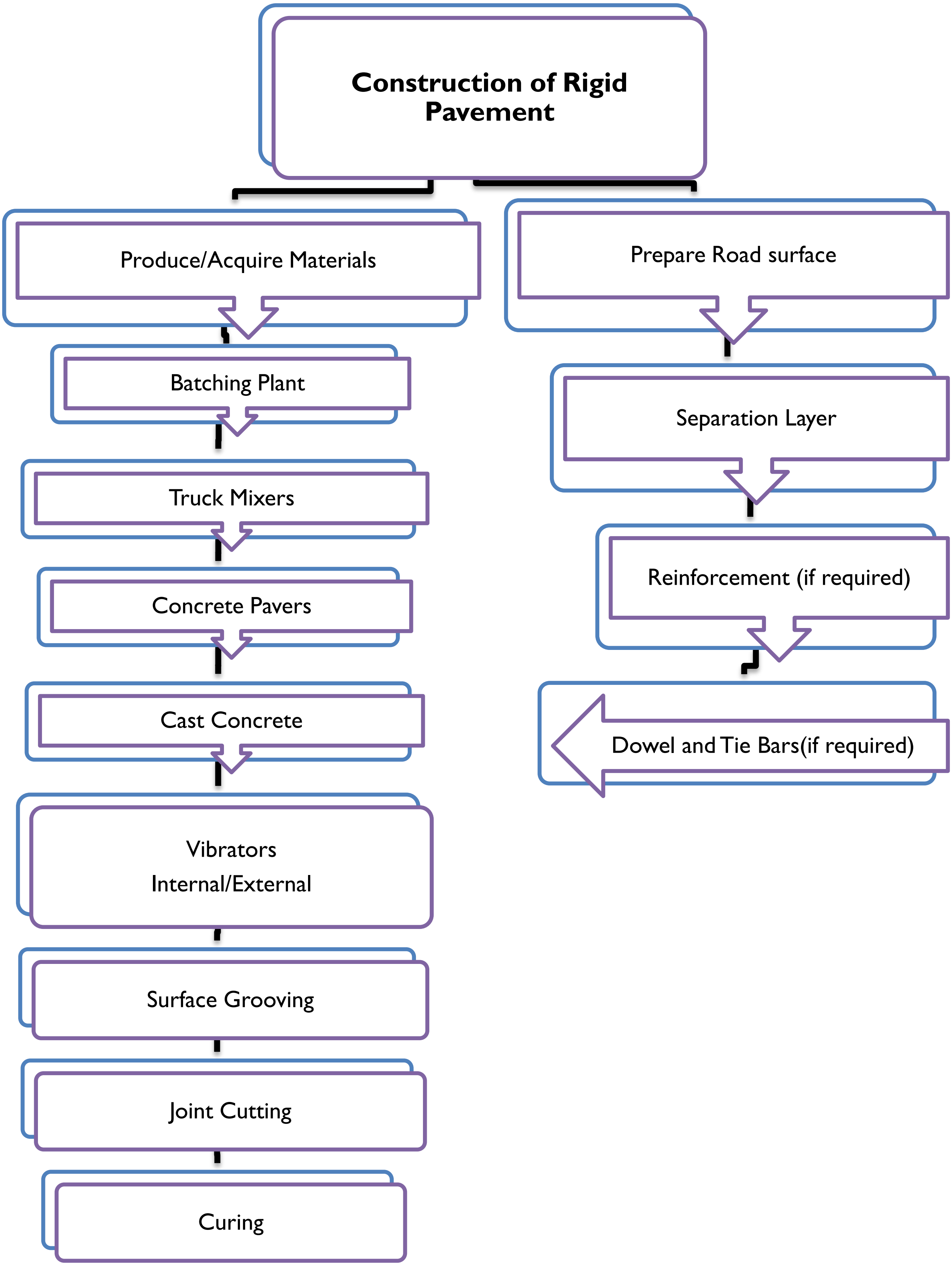


Figure2.11: Schematic diagram for the const. procedures of PCCP(by Researcher)

2.4 Characteristics of Flexible Pavements

Several major construction factors directly affect the ultimate performance of ahot mix asphalt pavement: the structural design of the pavement layers; the asphalt-aggregate mix design; the construction procedures used to produce, place, and compact the mix; and the workmanship or quality of construction. Poor workmanship can be one of the most significant factors leading to premature distress of an asphalt pavement. Causes of poor workmanship frequently include ignorance of or failure to comply with specifications, proper construction techniques, and proper equipment operation(Asphalt Institute, 1994).

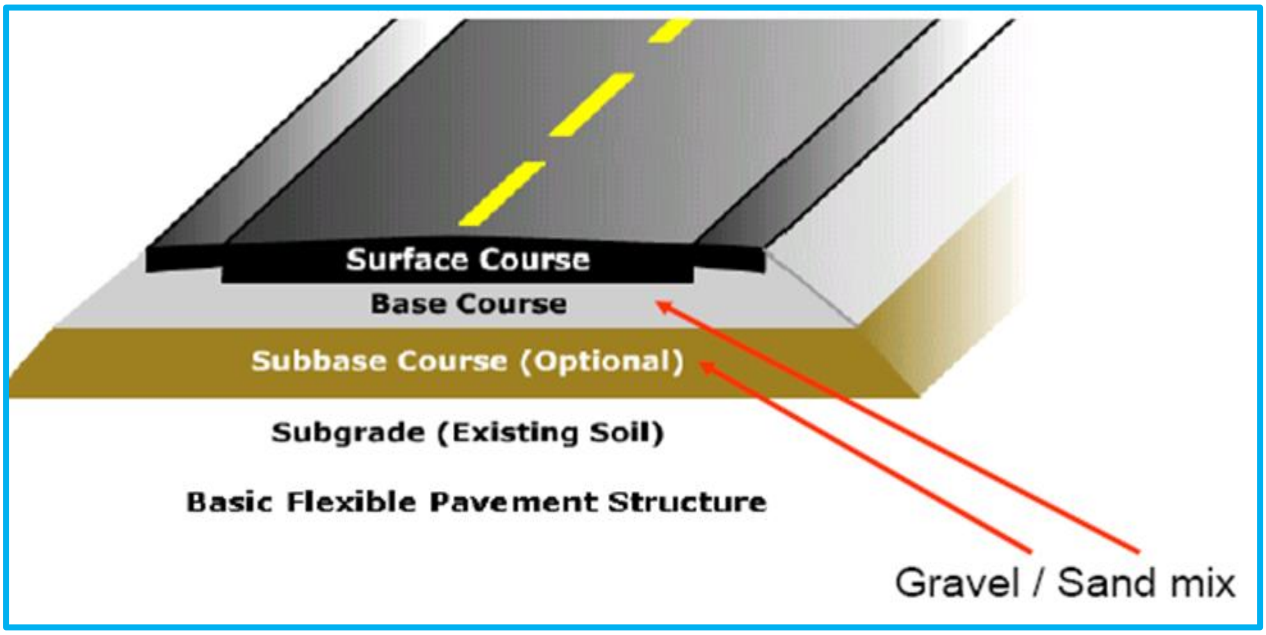


Figure2.12: Basic Flexible Pavement Structure(www.loadpavement.com)

2.4.1 Types of Hot Mix Asphalt pavement

The term “hot-mix asphalt” is used generically to include many different types of mixtures of aggregate and asphalt cement that are produced at an elevated temperature in an asphalt plant.

The types of HMA most frequently used in tropical countries, like Ethiopia, are manufactured in an asphalt plant by hot-mixing appropriate proportions of the following materials;

i. Coarse aggregate, defined as material having particles larger than 2.36mm;
ii. Fine aggregate, defined as material having particles less than 2.36mm and larger than 0.075mm;
iii. Filler, defined as material having particle sizes less than 0.075mm, which may originate from fines in the aggregate or be added in the form of cement, lime or ground rock; and
iv. A paving grade bitumen with viscosity characteristics appropriate for the type of HMA, the climate and loading conditions where it will be used.

Two generic types of Hot Mix Asphalt (HMA) are presently used in countries with tropical climates. These are:

a) Mixes in which traffic stresses are transmitted mainly through an aggregate structure which has a continuous particle size distribution. Asphalt Concrete and Bitumen Macadam are examples of this type.

b) Mixes in which stresses are passed through the fines/filler/bitumen matrix. In these mixes the aggregate particle size distribution is discontinuous or ‘gap-graded’. Hot Rolled Asphalt is in this category.

I.Asphalt Concrete (AC)

This is by far the most common type of HMA used in tropical countries and it is usually designed by the Marshall Method (Asphalt Institute, 1994). The material has a continuous distribution of aggregate particle sizes which is often designed to follow closely the Fuller curve to give the maximum particle density after compaction but adjusted slightly to make room for sufficient bitumen. However, such a dense structure makes AC sensitive to errors in composition and the effect of this becomes more critical as traffic loads increase.

II. Bitumen Macadam

This type of HMA, commonly known as Dense Bitumen Macadam (DBM), is similar to AC except that the skeleton of the compacted aggregate tends to be less dense. In Britain, where it is now known as Close Graded Macadam (BS 4987, 1993), it has traditionally been made to recipe designs and has also been used with success in tropical environments. This HMA will be referred to as DBM in ERA Flexible Pavement Design Manual Volume 1- 2013.

III. Hot Rolled Asphalt (HRA)

HRA has several advantages compared to AC. It is less sensitive to proportioning, making it easier to manufacture, and it is also easier to lay and compact. It requires fewer aggregate sizes and therefore fewer stockpiles and cold feed bins.

2.5 Life Cycle Cost (LCC) Assessment Overview

The terms Whole Life Cost (WLC) and Life Cycle Cost (LCC) have been used interchangeably and their meanings have become confused.

Furthermore, thecomponents of a whole life cost calculation have varied from country to country, client to client,consultant to consultant and among contractors.

With no common ground, clients could not be sure what they were asking for, comparisons were impossible and it was difficult to work out whether actual costs had matched up to the estimates.

The FHWA LCCA analysis enables total cost comparison of competing design alternatives with equivalent benefits. LCCA accounts for relevant costs to the sponsoring agency, owner, operator of the facility, and the roadway user that will occur throughout the life of an alternative. Relevant costs include initial construction (including project support), future maintenance and rehabilitation, and user costs (time and vehicle costs).

The LCCA analytical process helps to identify the lowest cost alternative that accomplishes the project objectives by providing critical information for the overall decision-making process. However, some instances the lowest cost option may not ultimately be selected after such considerations as available budget, risk, political, and environmental concerns are taken into account.

In general, life-cycle costs of any types of pavements include two types of cost:

1. Agency costs include (initial, maintenance, rehabilitation, support, and remaining service life value costs.)
2. Social costs: include air emission costs, health & safety costs and road user costs(include the additional travel time and related vehicle operating costs incurred by the traveling public due to potential congestion associated with planned construction throughout the analysis period.)

I. Initial Costs

Initial costs must include estimated construction costs as well as project support costs (for design, environment, construction administration and inspection, project management, etc.) to be borne by an agency for implementing a project alternative

a) Construction Costs

For each alternative, the initial construction costs should be determined from the engineer's estimate. Costs for mainline and shoulder pavement, base and subbase, drainage, joint seals, earthwork, traffic control, time-related overhead, mobilization, supplemental work, and contingencies should be included. Construction costs that will not change between alternatives such as bridges, traffic signage, and striping may be excluded if those costs can be separated from the rest of the estimate.

b) Project Support Costs

Costs for project support should be estimated based on the costs identified in the proposed work plan for a project alternative. When work plan data is not yet available, use the project support cost multipliers with the initial construction costs to estimate project support costs for a project alternative.

c) Maintenance Costs

Maintenance Costs include costs for routine, preventive, and corrective maintenance, such as joint and crack sealing, void undersealing, chip seal, patching, spall repair, individual slab replacement , thin HMA overlay, etc., whose purpose is to preserve or extend the service life of a pavement.

d) Rehabilitation Costs

Rehabilitation Costs for a particular activity should include costs for project supports and costs for all the necessary appurtenant work for drainage, safety, and other features. For those future rehabilitation activities whose project type is the same as the proposed project alternative, the user can assume its rehabilitation costs to be the same as the initial costs estimated for the project alternative.

e) Remaining Service Life Value

If an activity has a service life that exceeds the analysis period, the difference is known as the Remaining Service Life Value (RSV). Any rehabilitation activities (including the initial construction) except for the last rehabilitation activity within the AP will not have a RSV. The RSV of a project alternative at the end of the analysis period is calculated by prorating the total construction cost (agency and user costs) of the last scheduled rehabilitation activity.

f) Social Costs

Social costs assessment in pavement Life Cycle integrates the data on the project, the public issues and positions, the community and the bio-physical impacts to determine the potential socio-economic impacts. The potential impacts on households, individuals, organizations, neighborhoods and the community are identified jointly with those who may be affected by the project. The social impact assessment interms of costs practitioner works closely with the community to determine how the planning, design, construction and operational phases may affect them and their community. This typically involves the development and application of social evaluation criteria and indicators, and accepted ways of weighting and ranking the criteria interms of the affected public communities, business; land use, transportation movements etc.

However, this study only addressed the social impacts related to emission costs and road user costs in the life cycle assessment.

II.Emission Costs

The emission costs were calculated considering the cost of neutralizing CO_2, CO, NO_x, N_2O , SO_2, VOC and CH_4, and the costs based on the data reported by Kendall et al. (2005) and International Association for energy Economics Estimation shown in Table4-32 which are equivalent to the values in Global Energy Reporting Initiative Database.

III.User Costs

Best-practice LCCA calls for consideration of not only agency costs, but also costs to facility users. User costs are an aggregation of three separate cost components: vehicle operating costs (VOC), user delay costs (i.e. travel time costs), and crash costs incurred by the traveling public.

User costs arise when work zones restrict the normal flow of the facility and increase the travel time of the user by generating queues or formal or informal detours.

In the LCCA of pavement design alternatives, there are user costs associated with both normal operations and work zone operations. The normal operations category reflects highway user costs associated with using a facility during periods free of construction, maintenance, and/or rehabilitation (i.e., work zone) activities that restrict the capacity of the facility. User costs in this category are a function of the differential pavement performance (roughness) of the alternatives.

The work zone operations category, however, reflects highway user costs associated with using a facility during periods of construction, maintenance, and/or rehabilitation activities that generally restrict the capacity of the facility and disrupt normal traffic flow.

User costs are also incurred during normal operations, but they are not considered in LCCA because normal travel costs are not dependent on individual project alternatives. Additional user costs resulting from work zones can become a significant factor when a large queue occurs in a given alternative.

Calculating Life-Cycle Costs

Calculating life-cycle costs involves direct comparison of the total life-cycle costs of each alternative. However, birrs spent at different times have different present values, the anticipated costs of future rehabilitation activities for each alternative need to be converted to their value at a common point in time. This is an economic concept known as "discounting."

A number of techniques based upon the concept of discounting are available. FHWA recommends the present value (PV) approach, which brings initial and future costs to a single point in time, usually the present or the time of the first cost outlay. The equation to discount future costs to PV is:

$$PV = F \frac{1}{(1+i)^n}$$

Where:

- F = future cost at the end of n^{th} years
- i= discount rate
- n = number of years

The PV of this stream of EUAC is the same as the PV of the actual cost stream. WhetherPV or EUAC is used; the decision supported by the analysis will be same.

For this study the LCCA results to be documented using the present value approach and to be computed using Excel Templates and HDM-4 modeling.

2.6 Life Cycle Impact Assessment Overview

LCA is a tool for quantifying the environmental performance of products taking into account the complete life cycle, starting from the production of raw materials to the final disposal of the products, including material recycling if needed. The most important applications for an LCA are:

- Identification of improvement opportunities through identifying environmental hot spots in the life cycle of a product.
- Analysis of the contribution of the life cycle stages to the overall environmental load, usually with the objective of prioritizing improvements on products or processes.

- Comparison between products for internal or external communication, and as a basis for environmental product declarations.
- The basis for standardized metrics and the identification of Key Performance Indicators used in companies for life cycle management and decision support.

In recent years, life cycle thinking has taken a more prominent role in environmental policy making. Renowned institutions such as the World Resource Institute (WRI), have adopted life cycle thinking and an increasing number of different stakeholders are feeling the pressure to reduce the environmental impact associated with global consumption. As a result, we are witnessing a shift from government-led initiatives towards more private-led initiatives such as the Sustainability Consortium and Product Category Rules (PCR's) developed by trade and governmental organizations. In parallel to these activities the European Commission is working on a standard for environmental foot printing with the ILCD handbook (European Commission Life Cycle Inventory Data Base).

LCA provides the quantitative and scientific basis for all these activities. In many cases, LCA feeds the internal and external discussions and communication and being active in LCA means being able to communicate the environmental impacts of products and business processes.

An LCA study consists of four main phases:

Step 1: Defining the goal and scope of the study.

Step 2: Making a model of the product life cycle with all the environmental inputs and outputs. This data collection effort is usually referred to as life cycle inventory (LCI).

Step 3: Understanding the environmental relevance of all the inputs and outputs. This is referred to as life cycle impact assessment (LCIA).

Step 4: The interpretation of the study.

ISO Standards for LCA

The leading standards for LCA are:

- ISO 14040: Principles and Framework
- ISO 14044: Requirements and Guidelines

ISO 14040 considers the principles and framework for an LCA, while ISO 14044 specifies the requirements and guidelines for carrying out an LCA study.

The ISO standards are defined in a rather vague language, which makes it difficult to assess whether an LCA has been made according to the standard. Unlike the 14000 standard, it is not possible to get an official accreditation stating that an LCA, LCA methodology, or LCA software has been made according to the ISO standard. Therefore, no software developer can claim that LCAs made with a certain software tool automatically conform to the ISO standards.

For example, ISO 14044 does not allow weighting across impact categories for public comparisons between products. However, weighting is explicitly allowed for other applications, and thus SimaPro does support weighting. This means that it is your responsibility to use weighting in a proper way. A similar example can be made for issues such as allocation rules, system boundaries etc. (SimaPro LCA Standard Manual, 2014).

The most important consequence of aiming to adhere to an ISO standard is the need for careful documentation of the goal and scope and interpretation issues. As an LCA practitioner you can perform your LCA in a number of different ways, as long as you carefully document what you do. A second consequence of adhering to the standards is that you might need to include a peer review by independent experts(SimaPro LCA Standard Manual, 2014).

It is completely up to you to conform to these standards or to (deliberately) deviate. If you deviate, it is clear you cannot claim that your LCA has been made according to the international standards, and it will be more difficult to convince others of the reliability of your results.

2.7 Noticeable Findings from Previous LCA Studies on Pavement Type Selection

Pavements have been divided into two broad categories including rigid and flexible pavements. A flexible pavement consists of a wearing surface of asphalt concrete built over a base course and a sub-base course. Base and Sub-base courses are generally made up of granular material and rest on the compacted subgrade. A rigid pavement consists of concrete slabs placed on base course and subgrade. Flexible pavement has better ability to ride and lower noise, while rigid pavement has greater rigidity and stiffness. Concrete pavements usually comprise of less layers and total thickness than asphalt pavements.

A study of LCA of asphalt and concrete pavements was performed by Athena Institute (2006). This study presented embodied primary energy and global warming potential (GWP) over an analysis period of 50 years for the construction and maintenance of asphalt and concrete alternatives. The design alternatives include pavement structures respectively using a 200-mm concrete slab and a 175-mm asphalt layer. All pavement designs were developed using the AASHTO 1993 design method and Cement Association of Canada design method. The study did not include traffic operational considerations. Feedstock energy was considered in the analysis for asphalt. Feedstock energy is the chemical energy stored in material when not in use, it is considered as a part of embodied energy (Santero et al., 2011). Results show that the asphalt pavement consumes greater energy than the concrete pavement. The feedstock energy was found to have the highest contribution to the total energy for asphalt pavements. The GHG emissions are in higher values for concrete alternatives than asphalt alternatives.

Said et al. (2011) presented a tool developed by the Athena Sustainable Material Institute and Morrison Hershfield that is called the ATHENA Impact Estimator for Highways for LCA. It was found that asphalt pavement had approximately 83% more global-warming potential (GWP) effect during the rehabilitation stage as compared to the concrete pavement. Results suggest that the flexible pavement embodies approximately 2.9 times more primary energy than the rigid pavement.

Chan (2007) built a Life Cycle Inventory (LCI) to develop the environmental impacts of asphalt and concrete alternatives. Material production and waste treatment; material transportation to and from construction site; and construction and maintenance process are the activities for road construction/rehabilitation considered as system boundaries in this study. The environmental impacts of asphalt and concrete alternatives for 13 highway construction rehabilitation projects were computed in Michigan. The results included the impacts from construction, maintenance and equipment process and shows that concrete alternatives had higher GHG emissions than asphalt alternatives. The primary energy consumption of asphalt pavements is higher than concrete pavements and also the reconstruction process has yielded more GHG emissions than the rehabilitation process.

Hakkinen and Makela (1996) performed a similar study comparing stone-mastic asphalt (SMA) and jointed plain reinforced cement concrete (JPCP). They used a process-based LCA considering each phase of the life cycle of pavement excluding end of life module. Both types of pavements were evaluated using 18 different environmental criteria including CO_2 emissions, energy consumption, air pollutants. The construction phase includes fuel consumption and onsite paving equipment and does not consider traffic delays as it assumes completely new pavement construction. They concluded that the concrete pavement produced 40-60% more CO_2 emission as compared to the asphalt pavement.

Horvath and Hendrickson (1998) performed a study using EIO-LCA developed by Carnegie Melon University to compare the energy consumption of hot-mix asphalt (HMA) and continuously reinforced concrete pavement (CRCP). This study focused on extraction and production of different surface materials and qualitative analysis of construction phase and end of life. It did not consider feedstock energy of asphalt and concluded that the asphalt pavement consumes 40% more energy than the concrete pavement.

Nisbet et al., (2001) compared an asphalt pavement to a doweled JPCP pavement for urban collector and highway routes. They compared energy consumption, various air emissions like particulate matter, CO2, SO2, NOx etc. This study included all the phases except the use phase. They concluded that for the urban collector and highway scenarios, concrete pavements require less overall material and have a lower embodied primary energy, and thus produce lower air emissions, it includes the feedstock energy in bitumen.

Treloar et al. (2004) performed a hybrid LCA analysis on eight pavement types including a CRCP, an un-doweled JPCP, a composite pavement and various asphalt pavements. The study includes materials, construction, use and maintenance and rehabilitation phases and excludes end of life phase. They concluded that the un-doweled JPCP had the lowest energy input, while the full depth asphalt had the highest energy input.

Zainewski et al. (1982) evaluated various factors that influence vehicle fuel consumption such as speed, grade, curves, pavement condition, and pavement type. Fuel consumption reading were performed on eight vehicles, tests were done at 10 mph to 70 mph on 12 pavement sections. This study focused on the impact of pavement type (asphalt, Portland cement concrete, and gravel) on fuel consumption. Changes were found in fuel consumption between asphalt and concrete pavement up to 20%.

Ardekani and Sumitsawan (2009) used two pairs of asphalt and concrete pavements with identical gradient and roughness measurements to perform fuel consumption measurements for two driving conditions (constant speed of 48 km/h (30 mph) and acceleration from stand still). It was concluded that passenger vehicles used significantly less fuel on concrete pavements compared to asphalt pavements. Fuel consumption rates per unit distance were lower for Portland cement concrete (PCC) pavement at all times. A saving of 3% to 17% was recorded on the PCC pavement.

American concrete pavement association (ACPA) (2002) studied albedos of pavement surfaces according to pavement types. Albedo is the ratio of reflected solar radiation back to the total amount of radiation falling on the surface. A perfect absorber has an albedo value of zero and perfect reflectors have value of 1. It is concluded in the report that concrete material affects the reflectance of the concrete pavements. Asphalt surfaces are not very good reflectors because of the color of the materials. Concrete pavements can be made a better reflector by using white cement and lighter aggregate.

Researches by Adrian and Jobanputra (2005) suggested that asphalt pavements required almost 50% more lighting power than concrete pavements to achieve proper illumination. Asphalt pavements require more lighting than concrete pavements as the color of the structure plays an important role. Reflectance property of aged pavements may become moderate as asphalt pavement gets lighter with the time while concrete pavement gets darker. AASHTO (2005) roadway lighting design guide recommends that asphalt pavements need approximately 33%-50% more light power than concrete pavements to achieve sufficient illumination (Santero et al., 2011).

2.8 Current Status of PCCP Construction in Ethiopia

Due to various reasons the use of concrete pavements is not exercised in Ethiopia. Though the history of Rigid Pavements goes back to the 1890's, its use in Ethiopia and many other African countries is not significant or one can fairly say it is not used at all.

The current economic growth and the opening of many cement manufacturing factories has now eliminated one of the most detrimental input material that have been in scarce for so many years and also the current traffic volume and weight is rapidly increasing and there will be a need for stronger and maintenance free pavements especially on highly trafficked roads.

Currently the use of rigid pavements is limited to airports and there is no experience of its use for roads. Now there is an opportunity for the use of rigid pavements since one of the scarcest and expensive constituent, cement, is being manufactured in large quantities locally. It is also timely to look for alternative and strong pavements on highly trafficked and heavily loaded roads so that maintenance is minimized; traffic disruption and travel time is decreased.

Currently asphalt pavements are becoming more expensive while their quality is declining from time to time. The expensiveness of asphalt pavements is mainly due to its main component, bitumen.

Ethiopia is not oil producing country and thus bitumen is imported from Middle East countries with hard currency, and the price is increasing from time to time. Due to this fact many developed countries are searching for an alternative pavement construction materials through research and development by investing substantial amount of money every year.

Currently ERA is warming up to the idea of constructing PCCPs(Portland cement concrete pavements) since the construction and maintenance cost of flexible pavements is increasing highly and very high traffic as well heavy vehicles are being introduced to our roads.

Now concrete pavements are constructed as a trial section in order to study the material and assess the lifecycle cost of the concrete pavement and compare it to that of flexible pavement. These are Derba-Chancho-Becho road project and Adama – Methara link of which 10km and 1km of concrete pavement are constructed respectively. The latter one is specially designed for a 20yr service life is and its construction under study by ERA.

There are also design and build road projects that are on mobilization stage(e.g. Dichoto Galafi junction/ Dobi-Elidar Belho Design and Build road project and Assaita-Tendaho sugar factory Deisgn and Build road project) which are changed from flexible pavement design to concrete pavement design.

Concrete pavement was proposed for Afdera – Irebti Junction – Ert Ale Junction – Ahmedela road project is located in Afar Region during its feasibility report. This indicates ERA is now planning to exercise concrete pavements even if they are high investments.

3. RESEARCH DESIGN AND METHODOLOGY

3.1 Study Area

Comparing the sustainable benefits of JUCP and Hot-Mix Cut-Back Asphalt pavement in the context of Ethiopia

3.2 Research Design

A study design or frame is the process that guides researcher on how to collect, analyze and interpret observations. Having this in mind this section shows the procedures and methodology that the researcher follow to compare the sustainability of JUCP and Hot-Mix Cut-Back Asphalt pavement.

Hence, to achieve the desired objectives, the following tasks had been performed:

Task 1: Comprehend the backgrounds of LCCA& Impact Assessment via literature review and data collection.

Task 2: Verify types of pavement for highway construction on the basis of ERA Pavement Design Manual 2013 and AASHTO, Guide for Design of Pavement Structures1993.

Task 3: Analyze structuralcomponents depending on the types of pavement.

Task 4: Quantify each pavement alternative based on the onekilometer with 7m wide lane designof JUPC and HMA respectively.

Task 5: Estimate the initial construction, maintenance, rehabilitation, Road user and mission costs of each type of pavementsby using Excel templates and HDM_4 modeling.

Task 6: Estimate also the amount of energy consumption, emission and waste generation for each type of pavements for the life cycle using inventory data for pavement materials and construction processes of energy consumption emission and waste generation.

Task 7: Perform LCCA according to each type of pavement including impact assessments.

Task 8: Interpret the outputs analyzing economic,environmental, and social impacts.

3.3 Study Variables

3.3.1 Dependent variable

- Sustainability of pavements

3.3.2 Independentvariables

- Sustainable benefits and pavements
- Life cycle cost analysis and pavements
- Impactassessment and pavements
- Rigid pavement construction and its impactin Ethiopia
- Rigid pavement and cement manufacturing industries in Ethiopia

3.4 Research Approach

Generally, there are two research approaches which are widely recognized as qualitative and quantitative research.

Then this research was used both quantitative and qualitative approaches to identify the stated problems.

3.5 Research Data Collection Tools andIts Approach

First, the overall ideas about sustainability of pavement were extracted through referring different literatures and noticeable findings from previous studies. This helps the researcher to identify and concentrate on the theme of sustainability of pavement.

Secondly, after getting a clue a dip study was made referring different pavement guide lines, journals, books and websites.

In the third part, the results of literature was guidedthe researcher to develop research instrument to use both primary and secondarydata.

The fourth stepthe primary & secondary data were collected through data review, desk study (i.e.assessment of existing data), interview and internet. Then using different mathematical and software modeling analyzed the data and interpretationhad followed.

Finally, conclusions had been drawn and recommendationshad forwarded based on the finding of the study and reviewed literature.

In order to conduct comprehensive research on JUCP and HMA from the perspective of LCA, the proposed research approach includes literature review, data collection, economic-environmental-and-social impact analysis, and conclusions and recommendations. The research methods summarized as shown in Figure 3.1.

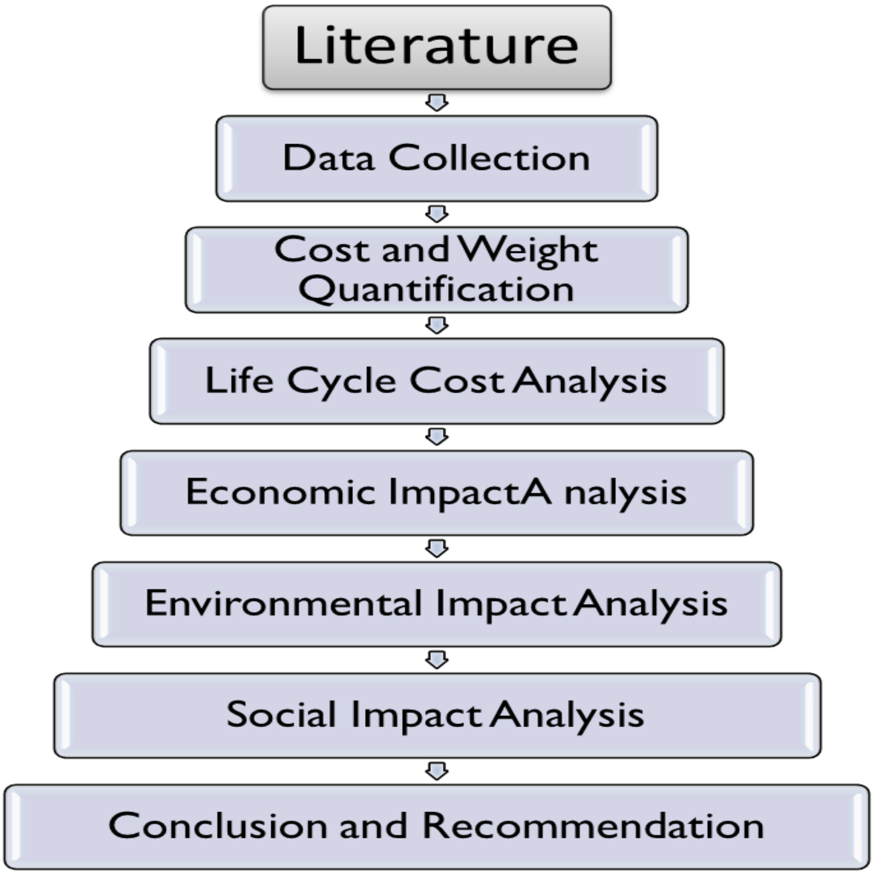


Figure 3.1: The Research Approach of the Study.

3.6 Method of Analysis and Discussion

Using the input parameters**costs** and **weights**, analyzed the data. And finally interpreted the out puts.

3.7 Ethical Considerations

I haveobeyed Jimma University all the rules and the regulations particularly related to academic and student affairs. Besides to this, I had duly acknowledged all sources of materials used for the research and proper credit have given to others for any "borrowed" words or ideas and their intellectual rights.

3.8 Data Quality Assurance

All the primary and secondary data the researcher used for this research work are reliable and purely related to the research topic and objectives based on the international and Ethiopian standards of sustainable pavement construction. Besides to this, during data analysis the researcher was kept the standard procedures and scientific approach. Finally, the researcher has declared that this research work could be my thesis if and only if approved by the legislative of Jimma University.

4. DATA COLLECTIONAND ANALYSIS

During data collection, general and average data about pavement sectors were collected from official and reliable resources including ERA- PMD, the AASHTO Guidelines, ASTM, ACI and construction price index and schedules.

4.1 Data for Life-Cycle Cost Analysis (LCCA)

Life-cycle cost analysis (LCCA) is an engineering economic analysis method for assessing the total cost of constructing, maintaining, and operating an asset or facility, or a system of assets/facilities, over an extended period of time (typically, 20 years or more). LCCA is a valuable investment analysis tool for assisting transportation managers in evaluating various design strategy alternatives, based on the costs incurred by both the investment/ agency/ and users of the facility (i.e., direct and indirect costs, respectively).

In the roadway transportation sector, LCCA can be used to quantify the differential costs of investment strategy alternatives for new construction, reconstruction, rehabilitation, and even preservation projects as a way of assisting in the selection of the alternative with the lowest total cost, not just the lowest initial cost.

In general, the LCCA process includes the formulation of design strategy alternatives, the identification of the timing of activities for each alternative (e.g., year of application for rehabilitation and preservation treatments), the estimation of initial and user costs for each alternative, and the conduct of an economic analysis that leads to the determination of the alternative with the lowest life-cycle cost. However, an LCCA should only be used in comparing project alternatives that provide equal benefits for the highway user.

In addition, LCCA is not intended to be the only process used for deciding which design strategy alternative is the most applicable; a number of other factors, such as risk, budget, and social, political and environmental issues, must also be considered.

4.2 Design and Material Composition of Pavements

In order to perform an unbiased analysis, an equivalent cross-section design of typical JUCP and cut back HMA pavement was considered. For this study, the design of each pavement type was carefully carried out to reflect the typical cross-sections of the two selected alternatives.

The highway would be 1 km long, and 7 m wide (two lane in free flow without median, and each lane is 3.5 m widewith high volumes of traffic asphalt and cement concrete pavement sections were used that have roughly the same functionality, based on ERApavement design manual plus AASHTO guidelines and it was assumed that a major trunk road was planned to be built in Ethiopia. Hence, in the design lane 100% of the loading would occur.

Traffic Growth Analysis

An overall traffic predicting approach is considered to be practical compared to a road-specific projection, for a road with a strategic rather than specific function. In general, transport demand (and hence traffic) is a derived demand driven by growth in population, the economy and personal incomes. Forecasts of these factors are therefore required to make accurate traffic forecasts. Traffic growth can also be related to the growth in fuel consumption and vehicle fleet; therefore trends can be developed for these parameters (where needed).

Generally, one of the following four methods could be adopted in order to forecast future traffic:

- Econometric Method;
- Trend based Method;
- Port based Method; and
- Vehicle Registration based Method

The most widely used econometric method has been adopted for this study project. In this approach, estimates of income elasticity, relating traffic growth directly to forecast changes in national income as well population, are applied in making forecasts; this same approach will also be adopted for this study project.

Trends in GDP

The main income development of the country for the last decade is shown in table below. The table shows average annual rates of growth of income for the period from 2004-2015. However, the GDP has well recovered from 2004/05 onwards, registering an average growth rate of 9.5% an overall GDP growth rate GDP. It is to be noted that due to unavailability of time series data of GDP at regional level, national economic data was used for calculation of the traffic growth as a proxy for the regional economy, as the latter represents the entire economy.

Table 4-1: The National Gross Domestic Product (GDP) of Ethiopia

No.	Year	Ethiopia Real GDP Growth(%)
1	2003/04	-2.1
2	2004/05	11.7
3	2005/06	12.6
4	2006/07	11.5
5	2007/08	11.8
6	2008/09	11.2
7	2009/10	10
8	2010/11	10.6
9	2011/12	11.4
10	2012/13	8.8
11	2013/14	9.7
12	2014/15	8.2
13	2015/16	8.5
Average		**9.5**

Source: IMF World Economy out Look Data Base, October 2014

Concerning future trends in GDP, long term (2010/11-2029/30) economic forecasts for Ethiopia prepared by IMF/World Bank in 2010 assume a 7.5% per annum.GDP growth. MOFED on the other hand, has set a medium term (GTP: 2010/11-2014/16) target rate of growth of at least 11 percent although very favorable circumstances would be required for this to be sustainable into the longer term. Bearing in mind that GDP projections have to be made for 20 years period from the year 2020, and based on the sources supporting the medium and long term economic development forecasts as described above, then this study has considered moderate estimates for the first period of ten years at 7.5 percent per annumand an average of 7 percent per annum for the next ten years period.

In line with the above discussion, three set of scenarios are considered for estimating annual GDP growth in Ethiopia (to be in turn used for estimating the future traffic demand) as follows:

Low: stagnant to slow growth in the Ethiopian and regional economy.

Medium: moderate growth in Ethiopian and regional economy as a result of continued government commitment to poverty reduction and a supportive policy environment.

High: Relatively high growth in Ethiopian economy and assuming that there are no significant economic shocks (domestic or foreign) to affect the economy.

Table 4-2: Expected GDP Growth in Ethiopia

Period	National GDP Growth (% per annum)		
	Low	Medium	High
2016-27	5	7.5	11.5
2028-37	5.5	7	11

Source: Researcher's assumption

Transport Demand Elasticity with respect to GDP

Empirical evidences have established that demand for transport tends to expand at somewhat faster rate than the economic growth rate as measured by national and/or regional GDPs. As the economy grows and reaches stability, the rate of growth for transport would eventually decline. This relationship is commonly referred to as income elasticity of demand for transport, measuring the relative change in travel/transport demand due to change in income, overtime.

Income elasticity is a measure of responsiveness of travel demand; generally a given rise in per capita income can be expected to result in a more than proportionate increase in demand for travel, since travel demand is usually found to be income elastic. Income elasticity would tend to decrease overtime as the economy and/or personal income grows.

The elasticity of the traffic against the National GDP growth has been determined and is calculated as the ratio of the thirteen year(2003/04 - 2015/16) average growth rates of vehicles kilometer of travel to the national GDP the resulting elasticity amounts to 1.23

In Ethiopia, detailed empirical evidences have not yet been established to estimate reasonable income elasticity of demand for transport. Hence this study used the Network Analysis Study-NAS (2003) estimation as an input and elasticity of demand for transport w.r.t economic growth are assumed initially to reflect recent trends but to decline over time.

Table4-3: Income elasticity of demand for transport

Vehicle type	Income Elasticity	
	2016-2027	2028-2037
Passenger Transport		
Passenger cars/4WD	1.4	1.3
Small Buses	1.4	1.3
Large Buses	1.3	1.2
Passenger Transport total	1.4	1.3
Freight Transport		
Small Trucks	1.4	1.3
Medium Trucks	1.3	1.2
Heavy Trucks	1.3	1.2
Articulated/truck & trailer	1.5	1.4
Freight Transport total	1.4	1.3

Source: The Network Analysis Study- NAS (2003) and Researcher's assumption

In specifying forecast traffic growth rates for the projection of stream of freight traffic using the road in the future, a simple model has been used that combines the effect of GDP growth on travel demand for freight vehicles. On the other hand, forecast growth rates for passenger traffic were computed using a model that combines the effect on travel demand of population growth and of changes in per capita incomes by considering the medium Average Annual Traffic Growth-Scenario.

Therefore, the overall growth rate adopted for the next 20 years would follow the rate of growth in GDP and population as shown in Table 4-4.

Table 4-4: Average Annual Traffic Growth-Medium Scenario

Period	National GDP(%)	Pop. Growth(%)	Elasticity		AA Traffic Growth(%)	
			Passenger Veh.	Freight Veh.	PV	FV
2020- 2029	7.5	2.7	1.4	1.3	9.42	9.75
2030- 2039	7	2.7	1.4	1.3	8.72	9.1
2040- 2049	5	2.5	1.2	1.1	5.5	5.75
2050- 2059	4	2.3	1.2	1.1	4.5	4.6
Average over the period 2020- 2039					**9.07**	**9.43**
Average over the period 2040- 2059					**5**	**5.2**

Source: Researcher's

In order to forecast future traffic on the study road, the study project planning and design phase (ongoing) was assumed to be completed in 2016, followed by the tendering stage which is assumed to take six months. The construction phase would last three years up to end of 2019. Year 2020 is therefore, considered the base year when the study road is open to traffic, upon which traffic projections are based.

Assumed that the flexible pavement was designed for 30 million CESA with an Average Traffic growth Rate 9.07% as shown Table 4-4, and then the rigid pavement should be designed for 79.6 million CESA with an Average Traffic growth Rate 5% as shown Table 4-4.

From ERA previous trends of traffic projections, summary of CESAL for each design lanedescribed as follows:

With Average Traffic Growth Rate 9.07%		With AverageTraffic Growth Rate 5%
For the Period 2020-2039		For the Period 2040-2059
Vehicle Type	Assumed % of CESA for FlexiblePavement in the Design Lane	Assumed % of CESA for Rigid Pavement in the Design Lane
Cars	1.0%	1.0%
Utilities	5.0%	5.0%
Small Truck	10.0%	10.0%
S bus	29.0%	29.0%
L Bus	4.0%	4.0%
M Truck	13.0%	13.0%
H Truck	24.0%	24.0%
Truck Trailer	14.0%	14.0%
CESA	**30,000,000.00**	**79,598,931.2**

Hence, from the above discussion and ERA previous trends of traffic projections the traffic on the study road (main alignment) with high volume traffic is assumed to be about 300 AADT in the year of opening (2020). With 20-years design-life, future stream of traffic is forecasted from 2020-2039. The forecasted total traffic will be in the range of 1,703vehicles per day (vpd) in the year of 2039 with 9.07% traffic growth rate and for 40 years design life, traffic growth rate will decrease up to5%, then the traffic is estimated to reach 4,519vehicles per day (vpd) at year 2059.

Note: $AADT_{20} = 300(1.0907)^{20} = 1{,}703$ And $AADT_{40} = 1{,}703(1.05)^{20} = 4{,}519$

Based on the traffic analysis, the study project road (main alignment) will fall under the standard of DS3 (1000-5000 AADT) according to ERA's Design standard. Hence, it is recommended that thisstudy road shall be designed as DS3-paved road and each of the design parameters shall be verified under the same standard.

Cumulative ESA of the pavement structures

The number of equivalent standard axles expected over the design life of the pavement is computed using the following formula:

$$ESA = AADT_b * EF * 365 * ((1+r)^n - 1)/r$$

Where ESA= Equivalent Standard Axles

EF= Equivalence Factor

AADTb= Baseline AADT

r = Growth Rate (fraction)

n =Design period in years

The cumulative ESA's of the assumed pavement structure is 30million when the design period of 20 years is considered for a flexible pavement option. According to ERA Flexible Pavement Design Manual 2002 &2013 structural catalogue, this traffic falls under T8 traffic class.

For a design life of 40 years the assumed cumulative equivalent standard axles became of79.6 million. The design traffic is estimated based on data obtained from ERA Pavement Design Manual 2002 & 2013 study on the major trunk road.

The cumulative ESAs over the design period of the rigid pavement are thus computed and a total of 79.6million ESAs is obtained taking 2020 as base year for traffic and assumed that the cumulative ESA's growth rate of 5% per annum forthe next 20 yrs.

I. Pavement Materials Specification

The material specifications for pavement layer construction are adapted from ERA standard specification 2002 and Appendix A of ERA Pavement Design manual volume II 2013. The following material specifications are extracted to give emphasis and the remaining material requirements given in the ERA technical specifications shall govern.

A) Base Course Material

The requirements for Base Course Material for rigid pavements are essentially the same as for flexible pavements described in ERA's Pavement Design Manual Volume 1 Flexible Pavements 2002.

The material requirements are adopted from ERA's Standard and Technical Specification 2002 similar to the base course requirement for flexible pavement design.

A wide range of materials can be used as unbound base course including crushed quarried rock, crushed and screened, mechanically stabilized, modified or naturally occurring "as dug" or "pit run" gravels.

As per the given ESAL, the recommended base course material for study pavement is Graded crushed stone (GB1). This material is produced by crushing fresh, quarried rock (GB1) and may be an all-in product, usually termed a 'crusher-run', or alternatively the material may be separated by screening and recombined to produce a desired particle size distribution, as per the specifications shown in the Table 4-1.

Table 4-5: Grading Limits for Base Course Materials (GB1)

Test sieve (mm)	Percentage by mass of total aggregate passing test sieve		
	Nominal maximum particle size		
	37.5 mm	28 mm	20 mm
50	100	-	-
37.5	95 – 100	100	-
28	-	-	100
20	60 – 80	70 - 85	90 – 100
10	40 – 60	50 - 65	60 – 75
5	25 - 40	35 - 55	40 – 60
2.36	15 – 30	25 - 40	30 – 45
0.425	7 – 19	12 - 24	13 – 27
0.075 (1)	5 – 12	5 - 12	5 – 12

B) Sub-base Material (GS)

The requirements for sub-base and capping layers for rigid pavements are essentially the same as for flexible pavements described in ERA's Pavement Design Manual Volume 1 Flexible Pavements.

The material requirements are adopted from ERA's Standard and Technical Specification 2002 similar to the sub base requirement for flexible pavement design.

- Sub-base material shall have a plasticity index of not more than 12 and the plasticity product should not be greater than 75.
- The minimum soaked CBR of the sub-base materials shall be 30% when determined in accordance with the requirements of AASHTO T-193. The CBR shall be determined at a density of 95% of the maximum dry density when determined in accordance with the requirements of AASHTO T-180 method D.
- The minimum in-situ dry density of the sub-base material shall be 97% of the modified AASHTO density.
- The material shall have a Los Angeles Abrasion value of not more than 51% when determined in accordance with the requirement of AASHTO T-96.
- The gradation of the sub-base materials shall be smooth and continuous curve that falls within the grading A of ERA Standard Technical Specification, shown in the following table

Table 4-6:Gradation Requirement for Sub–base Material

Sieve Size (mm)	Mass Percent Passing
	Grading A
63.0	100
50.0	90-100
25.0	51-80
4.75	35-70
0.075	5-15

The following criteria should be used to evaluate a sub-base as a separating or filter layer:

a) The ratio D15 (coarse layer) should be less than 5 D85 (fine layer) Where D15 is the sieve size through which 15% by weight of the material passes and D85 is the Sieve size through which 85% passes.

b) The ratio D50 (coarse layer) should be less than 25 D50 (fine layer). For a filter to possess the required drainage characteristics a further requirement is:

c) The ratio D15 (coarse layer) should lie between 5 and 40 D15 (fine layer)

C) Concrete aggregatefor Concrete Pavement

The maximum aggregate size of coarse aggregate shall be 25 mm and the gradation of concrete coarse aggregates shall meet either of the options presented in the following table extracted from Table 7100-2, Gradation for Coarse Aggregate of ERA's 2002 specification.

Table 4-7:Coarse aggregate requirements for concrete

Test sieve (mm)	Percentage by mass of total aggregate passing test sieve
	Nominal size 25 mm
50	100
37.5	100
25	95-100
19	
12.5	25-60
9.5	
4.75	0-10
2.36	0-5

D) Separation Membrane

MC-30 prime coat material with an application rate of 1.2-1.5 liters per meter square can also be used as a separation membrane between the sub base layer and the concrete slab

E) Concrete Requirements

Concrete Strength- the mix shall be designed to produce concrete with a minimum job average compressive strength of 35 Mpa and a flexural strength of 4MPa at 28 days.

F) Subgrade Conditions

The type of subgrade soil is largely determined by the location of the road. However, where the soils within the possible corridor for the road vary significantly in strength from place to place, it is desirable to locate the pavement on the stronger soils if this does not conflict with other constraints. For this reason, amongst others, the pavement engineer should be involved in the route selection process.

The strength of the road subgrade for flexible pavements is commonly assessed in terms of the California Bearing Ratio (CBR) and this is dependent on the type of soil, its density, and its moisture content. Hence, assumed that the design CBR is ranged 8-30% then a capping layer is required for the rigid pavement. The borrow material for fill and replacement should have a minimum CBR of 8% determined at 95 % of AASHTO T-180.

G) Road Surface Temperature and Pavement Structure

In determining the road surface temperature, the average mean monthly temperature of the project area should be recorded and assumed that the annual average mean temperature of the project area is 30^{o}c.Then as per TRRL Laboratory Report 1019, Surface dressing in developing countries: research in Kenya, the road surface temperature at the mean maximum air temperature is above 60^{o}c.

H) Structure layers and thickness determination

Case-1: For Flexible Pavement (Design of HMA pavement 20 years)

The asphalt pavement is designed in compliance with ERA Flexiblepavement design manual .The ERA manual is based on an empirical pavement strength/thickness approach using the AASHTO concept of Structural Number. For design of the asphalt pavement section, ERA Flexiblepavement design manuals catalogue were used.

CHART D1: HMA SURFACE, BITUMEN-BOUND ROADBASE

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

Figure4.1: Design Thicknesses for Flexible Pavement (ERA PDM)

Table4-8: Traffic and Subgrade Strength Classes for Design Thicknesses of HMA

KEY TO CATALOGUE

Traffic Classes (10^6 ESA)	
T1	< 0.3
T2	0.3 – 0.7
T3	0.7 – 1.5
T4	1.5 – 3.0
T5	3.0 – 6.0
T6	6.0 – 10
T7	10 – 17
T8	17 - 30
T9	30 - 50
T10	50 – 80*

Subgrade Strength Classes (Lowest 10-percentile CBR per cent)	
S1	2
S2	3, 4
S3	5 - 7
S4	8 - 14
S5	15 - 30
S6	> 30

* The T10 designs are suitable for traffic of 80 mesa and are considered 'long life' pavements. They should be used for all higher traffic levels.

For these layers as per ERA Flexiblepavement design manuals, the pavement thicknesses determined for the 1km proposed road are presented in the Figure4.2 as follows.

Table 4-9: Recommended flexible pavement structure for the design

Manual	ERA PDM 2013		ERA PDM 2002	
Design Traffic	T9* (30 million ESAL)		T9* (30 million ESAL)	
Subgrade Class	**S4**	**S5**	**S4**	**S5**
Design HMA Surface Thickness	90mm	90mm	50mm	50mm
Base Course Layer Thickness	190mm	190mm	200mm	200mm
Sub Base Layer Thickness	175mm	100mm	200mm	125mm

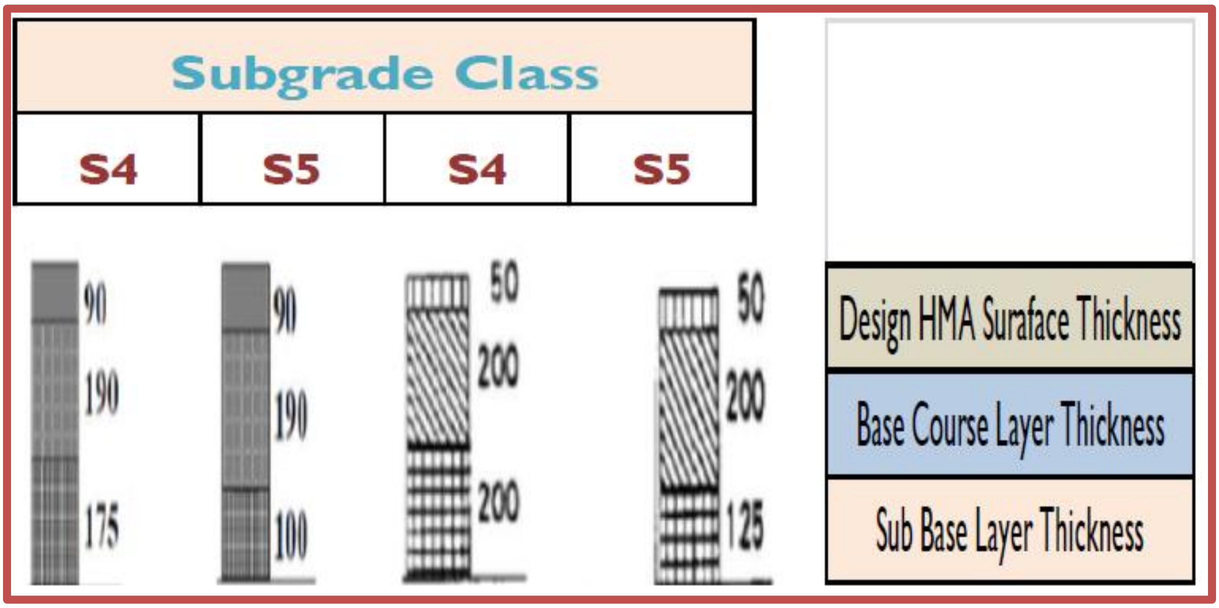


Figure4.2: Recommended Flexible Pavement Structure for the design

Moreover, based on AASHTO Design Guide 1993, it provides the following empirical equation used to determine the structure number (SN) by an iterative process, in US customary units.

This empirical equation is widely used and has the following form:

$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

(Washington University computer program for Rigid Pavement Design)

where: W_{18} = Predicted number of 80 kN (18,000 lb.) ESALs = 30 million for a design period of 20 years

Z_R = standard normal deviate

S_o = combined standard error of the traffic prediction and performance prediction

SN = Structural Number (an index that is indicative of the total pavement thickness required)

= $a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots a_i$ = i^{th}layer coefficient D_i = i^{th}layer thickness (inches)m_i = i^{th} layer drainage coefficient

ΔPSI = difference between the initial design serviceability index, p_o, and the design terminal serviceability index, p_t

MR = subgrade resilient modulus (in psi)

(These variables will be further explained in the Inputs section)

Case-2: For Rigid Pavement (Design of cement concrete pavement for40 years)

Rigid pavements are very strong in compression with flexible pavement; the strength of the pavement is contributed mainly by a concrete slab, unlike flexible pavements where successive layers of the pavement contribute cumulatively. This nature of rigid pavements has made feasible their design for a longer life, up to 60 years. It is common practice to design concrete pavements for 40 years or more. Given that the required slab thickness varies linearly with the logarithm of the cumulated number of ESAs, designing for longer periods generally requires marginal additional slab thickness and reinforcement and proves to be more economical. A design life of 40 years is recommended for this project as per ERA-2013 pavement design manual volume II.

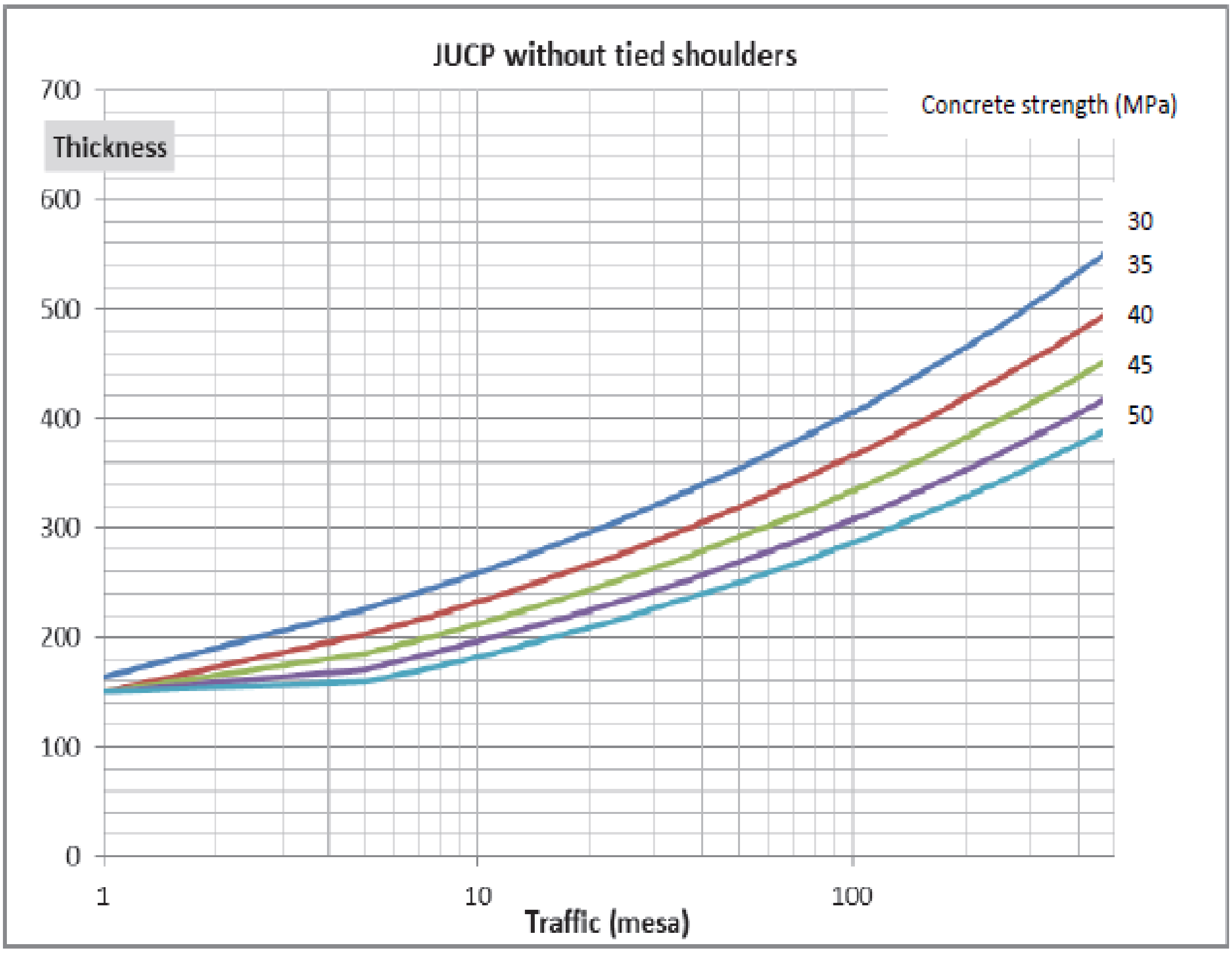
For a cumulative loading of 80 million ESA’s expected within 40 years design period and S4 and S5 subgrade classes in the project, ERA’s 2013 PDM volume II proposes three types of rigid pavements. They are Jointed Unreinforced Concrete Pavements (JUCP), Jointed Reinforced Concrete Pavements (JRCP) and Continuously Reinforced Concrete Pavements (CRCP). Among the three types of rigid pavements CRCP is not recommended as it requires a highly experienced Contractor and because of its expensiveness due to the heavy reinforcement.

JUCP Pavements are preferred to JRCP for any project for the following reasons:

- Transversal joints for JUCP pavements are found close to one another so the possibility of cracking of the slab is highly reduced compared to JRCP pavements where there is a potential for development of cracks because of thermal stresses which are induced to the concrete due to variations in the diurnal temperature of the project area.
- The slab lengths are short making the maintenance easier on isolated slabs, in cases of local failures.
- As stated in the ERA’s-2013 Pavement design manual volume II, JUCP is suitable for all levels of traffic, whenever the risk of sub grade movement is low.
- JUCP pavements require the least amount of imported material (as they are made of plain concrete).

Accordingly, the following JUCP pavement structures are designed for this project

Design Thicknesses for JUCP without tied shoulders can be determined from Figure 6.2b of the rigid pavement design manual, 2013 shown below.



b) Design Thicknesses for JUCP without tied shoulders

Figure4.3: Design Thicknesses for JUCP without tied shoulders

For a design traffic of 79.6 million ESA a C-35 concrete slab thickness of 345mm is obtained. But additional thickness 30mm for subgrade class, S4& 20mm for S5 should be provided as the rigid pavement is not laterally supported. Hence a total slab thickness for JUCP will be 375 mm for S4 and 365mm for S5.

According to ERA Pavement Rigid Design manual 2013, capping layer is required on subgrades with CBR less than 15%. A capping layer thickness of 200 mm is recommended for subgrade class S4 for both JUCP and JRCP. In addition to a capping layer, a sub-base thickness of 150 mm is recommended for both JUCP and JRCP pavements for the respective subgrade class (as indicated in tables 6-2 of ERA‟s 2013 Pavement design manual: volume II).The sub-base is provided in order to prevent "pumping" at joints and slab edges, to provide a stable "working platform" for the construction equipment and to facilitate the achievement of surface levels with the required tolerances.

Usually the thickness of the sub-base will be 150mm or 175mm, but sometimes the same material is conveniently used as the capping layer. For this project the capping layer thickness 200mm for S4 & 0mm for S5 is provided, and also the 150mm for S4 &175mm for S5 is provided for sub base layer thickness.

JUCP pavements have no reinforcement. However, the longitudinal and transverse joints are provided with dowels or tie bars depending upon the type of joint.

The JUCP pavement cross-section is shown below.

- Transverse Joints Spacing ……….5 meters
- Longitudinal Joints spacing………3.5 meter
- Dowels for transversal joints........ 25 mm diameter @ 300 mm c/c , 400 mm long
- Tie bars for longitudinal joints……12 mm diameter @600 mm c/c, 1000 mm long

Table 4-10: Recommended Rigid Pavement Structure for New Design Pavement

For Rigid Pavement: 40 years design life		
Manual	ERA PDM 2013	
Design Traffic	T10 (79.6million ESAL)	
Subgrade Class	**S4**	**S5**
Concrete Class	**C-35**	
Concrete Slab Thickness	345mm	345mm
Additional Slab Thickness	30mm	20mm
Capping Layer Thickness	200mm	0
Sub Base Layer Thickness	150mm	175mm
Design Concrete Slab Thickness	375mm	365mm
Spacing of Transverse Joints	5m	
Dowels for Transversal joints	25 mm diameter plain bars 400 mm long @ 300 mm spacing	
Spacing of Longitudinal Joints	3.5m(center line of the road , at the edge of each traffic lane)	
Tie bars for Longitudinal joints	1000 mm long 12 mm diameter reinforcement bars @600 mm spacing	

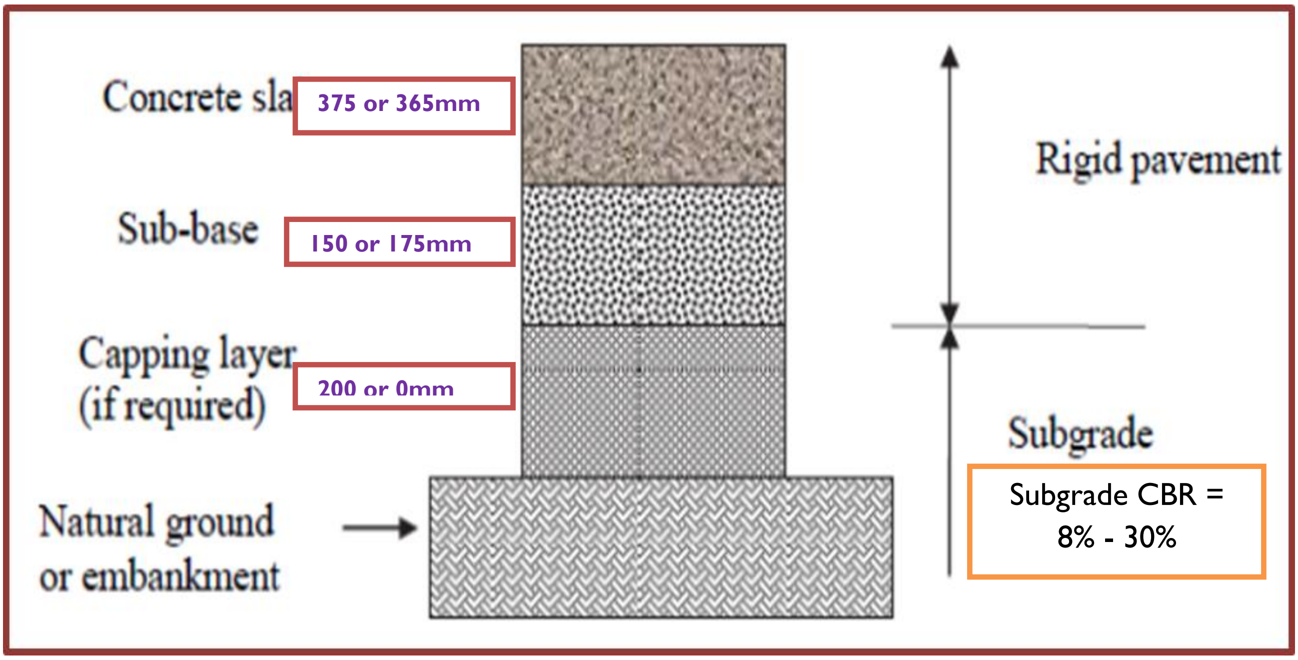


Figure4.4: Recommended Rigid Pavement Structure for the design

Similarly, for Rigid Pavement to have 20 years design life the recommended rigid pavement structure thicknesses shown in the Table 4-10.

Table 4-11: Recommended Rigid Pavement Structure for Study JUCP

For Rigid Pavement: 20 years design life		
Manual	ERA PDM 2013	
Design Traffic	T9 (30 million ESAL)	
Subgrade Class	**S4**	**S5**
Concrete Class	**C-35**	
Concrete Slab Thickness	285mm	285mm
Additional Slab Thickness	30mm	15mm
Capping Layer Thickness	200mm	0
Sub Base Layer Thickness	200mm	175mm
Design Concrete Slab Thickness	315mm	300mm
Spacing of Transverse Joints	5m	
Dowels for Transversal joints	25 mm diameter plain bars 400 mm long @ 300 mm spacing	
Spacing of Longitudinal Joints	3.5m(center line of the road , at the edge of each traffic lane)	
Tie bars for Longitudinal joints	1000 mm long 12 mm diameter reinforcement bars @600 mm spacing	

Moreover,the AASHTO Design Guide rigid pavement design manual 1993 provides the following empirical equation used to determine the slab depth D by an iterative process, in US customary units.

$$\log_{10}(W_{18}) = Z_R \times S_o + 7.35 \times \log_{10}(D+1) - 0.06 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.5-1.5}\right)}{1+\frac{1.624\times10^7}{(D+1)^{8.46}}} + (4.22 - 0.32p_t)\times\log_{10}\left[\frac{(S'_c)(C_d)(D^{0.75}-1.132)}{215.63(J)\left(D^{0.75}-\frac{18.42}{\left(E_c/k\right)^{0.25}}\right)}\right]$$

where: W_{18} = traffic carried in ESALs

Z_R = standard normal deviate

S_o = combined standard error of the traffic prediction and performance prediction

D = slab depth (inches)

p_t = terminal (final)serviceability index

ΔPSI = difference between the initial design serviceability index, p_o, and the design terminal serviceability index, p_t

S'c = modulus of rupture of PCC (flexural strength)

C_d = drainage coefficient

J = load transfer coefficient (value depends upon the load transfer efficiency)used to adjust for load transfer characteristics of a specific design

E_c = Elastic modulus of PCC

K = modulus of subgrade reaction

The Cumulative Traffic (W18)

The cumulative no of ESALs expected to use the project road is 79.6 million for a design period of 40 years.

Reliability

Reliability is a means of incorporating some degree of certainty in to the design process to ensure that various design alternatives will last the analysis period. The reliability factor is a function of the overall standard deviation (So) that accounts for both chance variation in the traffic prediction and normal variation in pavement performance prediction for a given w18. Considering variance of the projected traffic the overall standard deviation So of 0.39 is selected for rigid pavement design. The AASHTO Design Guide recommends levels of reliability for various functional classifications of the road as shown below.

Table 4-12: Levels of Reliability for Various Functional Classifications

Functional Classification	Recommended Level of Reliability	
	Urban	Rural
Interstate and other freeways	85 - 99.9	80 - 99.9
Principal Arterials	80 - 99	75 - 95
Collectors	80 - 95	75 - 95
Local	50 - 80	50 - 80

The pavement to be planned as the part of the main route to connect Ethiopia with neighbor countries and hence a reliability of 90% is taken so as to encompass safety factor in the design. The Design Guide also proposes a standard normal deviate for the corresponding Reliability

Table 4-13: ZR Values Corresponding to Selected Levels of Reliability

Intended Reliability	99.99	99.9	99	95	90	85	80	75	70	60	50
ZR	-3.75	-3.09	-2.327	-1.645	-1.282	-1.037	-0.841	-0.674	-0.524	-0.253	0

Initial and terminal serviceability Po, Pt, ΔPSI

Based on the results of the AASHTO Road Test, rigid pavements an initial serviceability Po of 4.5 is selected. Selection of the lowest allowable PSI or terminal serviceability index (Pt) is based on the lowest index that will be tolerated before rehabilitation, resurfacing, or reconstruction becomes necessary. For major highways like this project a minimum value of 2.5 is suggested by AASHTO hence the same value is incorporated for the design. In this case the difference between the initial and final serviceability index (ΔPSI) value of 2 is obtained.

Modulus of Rupture of PCC (flexural strength), S'c

Appropriate value is taken by considering the concrete compressive strength.

Drainage coefficient, Cd

Rigid pavement is assigned a drainage coefficient (Cd) that represents the relative loss of strength due to its drainage characteristics and the total time it is exposed to near-saturation moisture conditions. The drainage coefficient is used increase the required pavement thickness to compensate for poor drainage. However it is practical to solve the drainage problem rather than increasing pavement thickness. The drainage coefficient of 1(i.e. quality of drainage is good) is taken for the rigid pavement design as per Table 2.5 AASHTO 1993, II-26.

Load transfer coefficient, J

The load transfer coefficient, J, is a factor used in rigid pavement design to account for the ability of a concrete pavement structure to transfer (distribute) load across discontinuities, such as joints or cracks. Basically, the lower the J Factor the better the load transfers. For plain jointed and jointed reinforced concrete pavements a load transfer coefficient of 3.2 is recommended on the design guide (AASHTO 1993, II-26).

Concrete modulus of elasticity, Ec

The Modulus of Elasticity of concrete is expressed as a function of its compressive strength by a relationship developed by ACI is given as

$$E_c = 57{,}000\sqrt{f'_c}$$

Where: Ec = PCC elastic modulus

f''_c = PCC compressive strength

Modulus of Subgrade Reaction k

In accordance to AASHTO Design Guide the effective subgrade modulus of subgrade reaction k is determined following the following steps.

- First, the subgrade k-value is estimated by dividing the resilient modulus MR by 19.4,
- If the subgrade modulus varies substantially from season to season due to freezing and/or moisture effects, a seasonally weighted k should be determined.
- The k-value is then adjusted upward for the sub base type and thickness.

- The k-value is then adjusted downward for potential loss of support due to erosion of the sub base.
- Finally, if bedrock lies within 3.05 m (10 ft) of the surface the k-value is adjusted upward yet again.

But the procedure of determining k-value is complicated; the simplified approach of getting the value is developed by Hall et al. (1997: 80) which is a revised k-value chart for the AASHTO 1998 supplement design procedure. The k-values for different which are correlated subgrade values and it is assumed that the replacement material will fall in AASHTO soil classification subgroup A-2-6 with CBR value between 20-40%, a corresponding k-value of 300 psi is obtained. The basic input parameters for the thickness determination is summarized in the table below

Table 4-14: Basic input parameters for pavement design

W18 (Million)	ZR	So	Pt	Po	∆PSI	Sc	Cd	J	Ec(psi)	K(Psi)
79.6	-1.282	0.39	2.5	4.5	2	600	1	3.2	4,000,000.00	300

Inserting the above input parameters in the above equation and iteratively calculating for D (depth), we obtain a slab depth of **14.25 inches.**

The slab thickness needs to be rounded to the nearest 0.5 inch, so the slab thickness was 14.5 inches **(14.5*25.4 = 368.3mm).**

Joint spacing

The joint spacing in JPCP should be short enough to prevent high curling stress buildup. According to AASHTO 1993Pavement Design Guide page II-49, the spacing of both transverse and longitudinal contraction joints depends on local conditions of materials and environment. The spacing to prevent intermediate cracking decreases as the thermal coefficient, temperature change, or sub base frictional resistance increases; and the spacing increases as the concrete tensile strength increases.

The spacing also is related to the slab thickness and the joint sealant capabilities. As a rough guide, AASHTO recommends the joint spacing (in feet) for plain concrete pavements should not greatly exceed twice the slab thickness in inches. For the slab thickness of 15.4 inches is a maximum joint spacing of 30.8 ft. (9.4 meter).But whenever the joint spacing is wider the possibility of traverse cracks will be higher. In this regard the FHWA 1990a recommends a maximum joint spacing of 15 feet [4.6 m] for plain concrete slabs. Hence, a transverse joint spacing of 5 meters is taken considering the experience in our country.

Longitudinal construction joints should be placed at lane edges to maximize pavement smoothness and minimize load transfer problems. In this regard the longitudinal joints should be placed at the center of two lanes (3.5m)

Joints classified based on their direction and function. Based on the function joints could be classified as contraction, Expansion, warping and based on their direction transversal and longitudinal.

A proper jointing system will:

1. Control cracking.
2. Divide the pavement into practical construction Increments.
3. Accommodate slab movements.
4. Provide load transfer.

Proper jointing is based on controlling cracks that occur from the natural actions of the concrete pavement. Joints are placed in the pavement to control the crack location and pattern. Observing the slab behavior of unjointed plain pavements in service for many years can illustrate how joints are used to control cracking. In addition, for jointed concrete pavements to perform adequately traffic loadings must be transferred effectively from one side of the joint to the other. This is called load transfer and achieved using either dowel bars or aggregate interlock. Adequate load transfer results in lower deflections, which reduce faulting, sapling, and corner breaks, thereby increasing pavement life.

a) Transverse Joints

Transverse Joints are the joints perpendicular to the center-line of the road. They are designed to prevent contraction and expansion stresses which develop over long distances. In some specific places such as around in-pavement objects or at junctions, transverse joints are also required to limit warping stresses.

i) Contraction joint

Contraction joints is one of transverse cracks in concrete pavements, may be of two types: sawedor formed groove. Whether sawed or formed, contraction joints are designed to reduce the slabcross section at given points so that stresses in the concrete will result in cracking at the jointsrather than elsewhere in the slab. Good workmanship is essential in constructing the joint so thata smooth and durable surface free from spalling is obtained. Sawing is the most common methodof creating transverse contraction joints. The initial saw cut provides a plane of weakness wherecracking will begin. The initial saw cut in hardened concrete should be at least one fourth thethickness of the slab (D/4) and have a minimum width of (3mm).(American concrete pavementassociation)

According to ERA design manual the dowel bars should be at 300 mm spacing and 400 mmlong. The diameter of the dowels is provided 20mm for slab thickness up to 239mm and 25mmfor slabs having thickness greater than 239mm.

ii) Expansion Joints

The primary function of an expansion joint is to provide space for the expansion of the slab,thereby preventing the development of compressive stresses, which may cause the slab to buckle.

Expansion joints will be formed by fixing a strip or polystyrene foam to the edge of the hardenedslab. The strip will be extended for the full depth of the slab and be of thickness equal to thenominal width of the joint. It will be in two parts with the top part equal in depth to the sealgroove shown on the drawing. The strip will be fixed with a suitable waterproof adhesive.

Placing of adhesive will not take place until the concrete has set. When concrete has hardenedsufficiently, the top section of former strip and insert sealer as specified in the design.

Expansion joints are provided when the concrete pavement is adjacent to a permanent structure like a bridge or culvert. Normally these joints meant for relieving expansion pressure when the slabs touch against unyielding structure. Transverse and longitudinal joints must be sealed to be waterproof.

iii) Warping joint

Warping joints allow a slight relative rotation of the slabs and reduce the stresses due to warping. These joints consist of a sawn groove Tie bars a sealing groove. The tie bars must be 12 mm in diameter at 300 mm spacing and 1000 mm long.

b) Longitudinal Joints

Longitudinal joints are planned to be formed while constructing one lane rigid pavement work. Longitudinal joints are warping joints, allowing a slight relative rotation of the slab portions and reducing the stresses due to warping. They are required at such spacing that they will reduce the combination of thermal warping stresses and loading stresses to a minimum, they also reduce the risk of longitudinal random cracking, and often serve at the same time as construction joints. These joints allow a slight rotation, but differential lateral displacements between adjacent bays are prevented by tie bars provided at mid depth of the slab.

Longitudinal joints will be provided at the center line of the road. The joints will be parallel to the road. Longitudinal joints will be formed when the two lanes are constructed independently at different time. The line of longitudinal joints will not deviate from the designed position at any point by more than specified width stated in the design.

If required joint sealer will be used. The fillers will be silicone sealant, preformed elastomeric strips or preformed self-expanding cork strips as ordered by the Engineer. Tied construction joints will be provided with tie bars as detailed and in accordance with the design.

Longitudinal contraction joints are created where two or more lane widths or shoulders are paved at the same time.

c) Construction Joints

Expansion joints are defined as full depth, full width transverse joints placed at regular intervals of (15 to 150 m) (with contraction joints in between). This is an old practice that was used torelieve Compressive forces in the pavement. Unfortunately, this practice often caused other problems in the pavement Such as spalling, pumping, faulting, and corner breaks.

Good design, construction, and maintenance of contraction joints have virtually eliminated the need for expansion joints, except under special conditions. In addition to the problems listed above, the improper use of expansion joints can lead to high construction and maintenance costs, opening of adjacent contraction joints, loss of aggregate interlock, sealant failure, joint infiltration, and pavement growth. By eliminating unnecessary expansion joints, these problems are removed and the pavement will provide better performance.

Dowel Bar diameter and dimensions

Dowel bars are provided to transfer loads across a joint without restricting joint movement due to thermal contraction and expansion of the concrete. In addition dowels are used to prevent pumping and faulting. AASHTO design guide suggests that if dowels are used, the size and spacing should be determined by the local agency's procedures and/or experience. As a general guideline, the dowel diameter should be equal to the slab thickness multiplied by 1/8 inch. Accordingly, a dowel diameter of 1.93 inch (48.9 mm) is obtained. The dowel spacing and length are as per AASTHO guide are 12 inches (305 mm) and 18 inches (457 mm) respectively.

However, it seems unreasonable to use the dowel bar dimensions obtained from AASHTO as 48.9 mm appears to be impractical. In this regard from the experience in our country (ERA) and as clearly indicated in the ERA Rigid Pavement Manual, when the slab thickness in all classes of concrete is greater than 230 mm hence the maximum transverse joint interval shall be 5 meters. Load transfer between adjacent bays in a rigid slab is facilitated by dowels. The dowels shall be 25 mm diameter plain bars 400 mm in length and 300 mm spacing. Longitudinal joints allow a slight relative rotation of the slab and reduce the stress due to warping. The provision of longitudinal joints will reduce the combination of thermal warping stress and loading stresses. One longitudinal joint should be placed in the middle of the carriage way, between the two lanes (3.5m each). Tie bars for longitudinal joints shall be 1000 mm long, 12 mm diameter reinforcement bars at 600 mm spacing.

Construction joints, especially when the concrete is stopped, shall be coupled with other joints.

Generally for the rigid pavement design out puts as per AASHTO design guide is summarized as

- Slab thickness ……………………...368.3mm
- Transverse Joints Spacing ……..........5 meters
- Longitudinal Joints spacing…………3.5 meter
- Dowels for transversal joints.............25 mm diameter bars 400 mm long at 300 mm.
- Tie Bars for longitudinal joints…...100cm long, Ø 12 mm bars at 600 mm spacing.

The ERA Rigid Pavement Design Manual is based on empirical data from full scale experiment carried out by Transport Research Laboratory (TRL) in the UK. The thickness determined by AASHTO (368.3mm) is similar to the slab thickness obtained by ERA Rigid Pavement Design Manual 2013(365mm) for JUCP. However the AASHTO method requires a number of assumptions and choices of several input parameters that cannot be easily be determined. For higher level of traffic similar to the research project, the design method by ERA is more reliable than AASHTO Design Guide.

The ERA 2013 Rigid PDM gives different options for slab thickness determination depending on different class of concrete ranging from 30 Mpa to 50 Mpa in strength. However the ERA PDM 2002 considers only concrete with 28 day characteristic compressive strength of 40 Mpa. In this regard, the 2013 manual gives several options which will enable us to select the most feasible option which suits the actual project condition.

In conclusion, the AASHTO procedures is not easy to apply in Ethiopia due to a number of coefficients used in the formula not really validated for the country conditions (Climate, Soils…) and this approach has a considerably greater degree of conservatism built in to the design. Besides, the AASHTO guide is being specifically prepared for use in the United States rather than for tropical countries. Thus, the design obtained by the ERA design manual is to be adopted for this study road project.

Concrete Mix-design for JUCP slab

Conditions and Specifications**:** Concrete is required for a pavement that will be exposed to moderate environmental condition. A specified compressive strength, of 35 Mpa is required at 28 days. Air entrainment is required. Slump should be between 25 mm and 75 mm. A nominal maximum size aggregate of 25 mm is required. No statistical data on previous mixes are available.

The materials available are as follows:

Cement:OPC with a relative density of 3.0.

Coarse aggregate: Well-graded, 25-mm nominal maximum- size rounded gravel (ASTM C 33 or AASHTOM 80) with an oven dry relative density of 2.68, absorption of 0.5% (moisture content at SSD condition) and oven dry rodded bulk density (unit weight) of 1600 kg/m3. The laboratory sample for trial batching has a moisture content of 2%.

Fine aggregate: Natural sand (ASTM C 33 or AASHTO M6) with an oven dry relative density of 2.64 and absorption of 0.7%. The laboratory sample moisture content is 6%.

The fineness modulus is 2.80.

Air-entraining admixture: Wood-resin type (ASTM C 260 orAASHTO M 154).

Water reducer: ASTM C494 (AASHTOM194). This particular admixture is known to reduce water demand by 10% when used at a dosage rate of 3 g (or 3 mL) per kg of cement. Assume that the chemical admixtures have a density close to that of water, meaning that 1 mL of admixture has a mass of 1 g. From this information, the task is to proportion a trial mixture that will meet the above conditions and specifications.

Strength: The design strength of 35 MPa is greater than the 31 MPa required in ACI 318 (2002) for the exposure condition. Since no statistical data is available, f'_{cr} (required compressive strength for proportioning) from ACI 318 is equal to f'_c+ 8.5. Therefore, f'_{cr} = 35 + 8.5=43.5 MPa.

The mix design results are summarized as shown in the Table 4-11 and the detail mix-design work was annexed at the end of the paper.

Table 4-15: Summary of the materials out puts in JUCP mix-design

Components	Adjusted Batch Volume(m3) Per Cubic Meter of Concrete	Adjusted Batch Weight(kg) Per Cubic Meter of Concrete
Water	0.127	127
Cement	0.137	410
Coarse aggregate (dry)	0.4	1072
Fine aggregate (dry)	0.256	676
Coarse aggregate (SSD)	0.402	1077.36
Fine aggregate (SSD)	0.2578	680.73
Air-entraining admixture 164 g or mL		
Water reducer 1230 g or mL		

Percentage by wt.:

Components	% by Weight
Water	5.54%
Cement	17.86%
Coarse aggregate (SSD)	46.94%

Fine aggregate (SSD)	29.66%
Total Wt.	100%

Table 4-16:Design of the Compacted HMA Paving Mixture

DESIGN OF THE COMPACTED HMA PAVING MIXTURE

a) Constituents:

Material	Specific Gravity: Aparrent		Specific Gravity: Bulk Dry		Test Method: AASHTO Method	Test Method: ASTM Method	Mixture Compositon % by weight of: Total Mix		Mixture Compositon % by weight of: Dry(Total) Aggregate	
Asphalt Cement	Gb	1.03			T228	D70	Pb	?	P'b	6.5
Coarse Aggregates	Gb1	2.69	G1	2.61	T85	C127	P1	?	P'1	56.05
Fine Aggregates	Gb2	2.83	G2	2.71	T84	C128	P2	?	P'2	43.95
Mineral Filler					T100	D854				

b) Paving Mixture:

Bulk specific gravity of compacted paving mixture sample, Gmb

Maximum Specific Gravity of Paving Mixture, Gmm

Gmb =	2.340	(ASTM D 2726)
Gmm =	2.445	(ASTM D 2041)
Pmm =	100%	Total loose mixture in %

Analysis

#1). Specific Gravity of Materials(Asphalt cement, Coarse & Fine aggregates)

For Asphalt			For Coarse Aggregate			For Fine Aggregate		
Given	P'b	6.5	Given	P'b	6.5	Given	P'b	6.5
	P'1	56.05		P'1	56.05		P'2	43.95
Required	Pb =	(p'b x 100) / (p'b +100)	Required	P1 =	(p'1 x 100) / (p'b +100)	Required	P2=	(p'2 x 100) / (p'b +100)
% by wt	Pb =	6.10%	% by wt	P1 =	52.63%	% by wt	P2 =	41.27%

#2). Calculate the Bulk Specific Gravity of the aggregate combination in the paving mixture, (Gsb)

Specific Gravity of Total Aggregates (Bulk Dry) , Gsb= (P1 + P2) / ((P1/G1) +(P2/G2))

Gsb = 2.65%

#3). Calculate the EFFECTIVE Specific Gravity of Aggregate. (Gse)

Gse = (Pmm - Pb) / ((Pmm/Gmm) - (Pb/Gb))

Gse = 2.68%

#4). Calculate the Apparent Specific Gravity of the aggregate combination in the paving mixture, (Gsa)

Apparent Specific Gravity, Gsa = , Gsa= (P1 + P2) / ((P1/Gb1) +(P2/Gb2))

Gsa = 2.75%

#5). Calculate Asphalt Absorption of Aggregate. (Pba)

Asphalt Absorption Capacity of Aggregate , Pba= 100(Gse - Gsb)xGb / (Gsb xGse)

Pba = 45.86%

#6). Calculate the Effective Asphalt Content of the Mixture

EFFECTIVE Asphalt Content of the Mixture. (Pbe) = Pb - (Pba/100)xPs

Pbe = 6.10%

Where: Ps = Agrregate % by total wt of mixture(P1+P2)

#7). Calculate the % Voids in the Mineral Aggregate in the compacted paving mixture. (VMA)

VMA = 100 - (GmbxPs/Gsb)

VMA = 17.18%

#8). Calculate the % Air Voids in the compacted mixture,(Pa)

Pa = 100 (Gmm - Gmb)/Gmm

Pa = 4.29%

#9). Calculate the % Voids Filled with Asphalt in the compacted mixture. (VFA)

VFA = ((VMA - Pa)/VMA)x100

VFA = 75.01%

If the Bulk specific gravity of compacted paving mixture sample, Gmb = 2.340, then the bulk density of the compacted mixture = 2.340x1000kg/m3 = 2340kg/m3

Table 4-17: Summary of the materials out puts in HMA mix-design

Constituents	Mixture Compositon % by weight (kg) of Total Mix Per Cubic Meter of Asphalt Concrete	Adjusted Batch Weight(kg) Per Cubic Meter of Asphalt Concrete
Asphalt Cement	6.10%	142.74
Coarse aggregate	52.63%	1231.54
Fine aggregate	41.27%	965.72
4.29 % Air Voids in the compacted mixture		

4.3 Quantity Takeoff and the Bill of Quantity for Pavement Materials

Quantity Takeoff for JUCP

Assume that the pavement is to be paved one lane at a time and there are no adjacent structures available throughout 1km pavement. Then JUCP uses only tie bars as transverse joints, and dowels as longitudinal joints including longitudinal construction joint and transverse contraction joint as shown in fig 4.5.

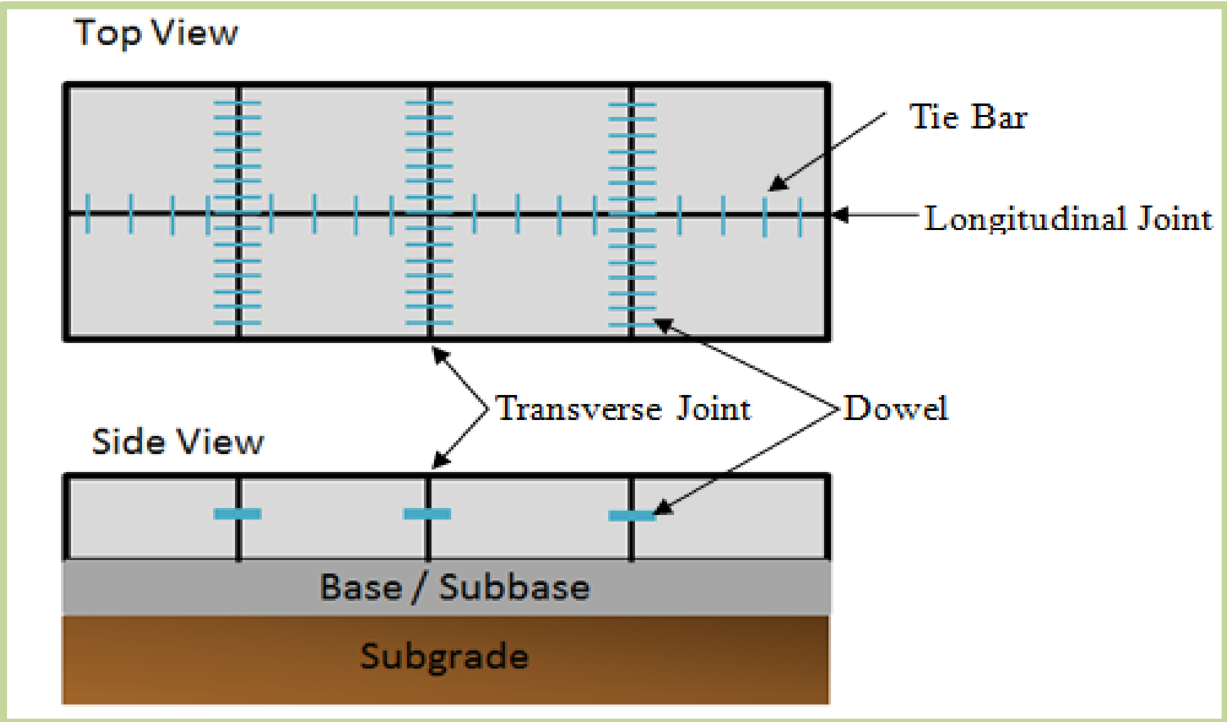


Figure 4.5: Longitudinal and Transversal Details of JUCP

Case-I: If we choose the **Subgrade class of the pavement is S4**, then quantity takeoff for JUCP as follows:

- C-35 concrete with flexural strength of 4.0 Mpa at 28 days for the concrete slabs
- For a375mm thick JUCP, the space between transverse joints was 5m. 25 mm diameter bars of 400 mm long at 300 mm intervals were used as dowel bars.
- For a 375mm thick JUCP, the space between longitudinal Joints was 3.5m. 12 mm diameter bars of 1000 mm long at 600 mm intervals were used as tie bars.
- For 1km long, 7m wide pavement, there were 4,667 (1000/5 x 7/0.3)) bars of 25 mm diameter used as dowel, and 1,667 (1000/0.6) bars of 12 mm diameter used as tie.
- Total length of dowel bars (No. bars x length of a bar) = 4,667 x0.4m = 1,866.8m
- Total volume of dowel bars (1mm2 area x total length of dowel bars) = 1mm2 x 1,866.8m = 10^{-6}m2 x 1,866.8m = 1,866.8x10^{-6}m3
- Total length of tie bars (No. bars x length of a bar) = 1,667 x1m = 1,667m
- Total volume of tie bars (1mm2 area x total length of tie bars) = 1mm2 x1,667m= 10^{-6}m2 x 1,667m3 = 1,667x10^{-6} m3
- Total area of concrete slab pavement(LxW) = 1000m × 7m = 7,000m2
- Total volume of concrete slab pavement(LxWxD) = 1000m × 7m × 0.375m = 2,625m3
- Net Total volume of concrete slab pavement = 2,625m3-1,866.8x10^{-6}m3-1,667x10^{-6} m3 =2,624.9965m3
- Total volume of sub base material(LxWxD) = 1000m × 7m × 0.15m = 1,050m3
- Total volume of capping layer material (LxWxD) = 1000m × 7m × 0.20m = 1,400m3
- AS per the mix design result, the estimated concrete = 127 + 410 + (1072 x 1.005) density (aggregates + (676 x 1.007) at SSD) = 2295 kg/m3. Then consider Design Concrete Density = 2295 kg/m3
- Linear density of 12 mm diameter tie bar is 0.89(Kg/m) and for 25 mm diameter dowel is 3.85(Kg/m)
- Total weight of the net concrete slab pavement (Net Total volume of concrete x Linear density) = 2,624.9965m3 x 2295 kg/m3= 6,024,352.02 kg
- Total weight of dowel bars (Total length of dowel bars x Linear density) = 1,866.8mx3.85 kg/m = 7187.18 Kg
- Total weight of tie bars (Total length of tie bars x Linear density) = 1,667m x 0.89(Kg/m) = 1483.63 Kg
- Total volume of MC-30 prime coat material @ 1.25 lit/m2 used as separation membrane = 1000m x 7m x 1.25 lit/m2 =8750 liters
- The specific gravity of MC-30 Cut Back liquid Asphalt prime Coat is equal to 0.966kg/lit.
- Total weight of MC-30 prime coat material = 8750 liters x 0.966kg/lit = 8452.5kg

- Total length of longitudinal construction joints = 1km = 1000m
- Total length of transverse contraction joints = (1000m/15)*7 = 466.67m

Case-II: If we choose the **Subgrade class of the pavement is S5**, then quantity takeoff for JUCP as follows:

- C-35 concrete with flexural strength of 4.0 Mpa at 28 days for the concrete slabs
- For a 365mm thick concrete slab pavement, the space between transverse joints was 5m. 25 mm diameter bars of 400 mm long at 300 mm intervals were used as dowel bars.
- For a 365mm thick concrete slab pavement, the space between longitudinal Joints was 3.5m. 12 mm diameter bars of 1000 mm long at 600 mm intervals were used as tie bars.
- For 1 km long 7m wide pavement, there were 4,667 (1000/5 x 7/0.3)) bars of 25 mm diameter used as dowel, and 1,667 (1000/0.6) bars of 12 mm diameter used as tie.
- Total length of dowel bars (No. bars x length of a bar) = 4,667 x0.4m = 1,866.8m
- Total l volume of dowel bars (1mm2 area x total length of dowel bars) = 1mm2 x 1,866.8m = 10^{-6}m2 x 1,866.8m = 1,866.8x10^{-6}m3
- Total length of tie bars (No. bars x length of a bar) = 1,667 x1m = 1,667m
- Total volume of tie bars (1mm2 area x total length of tie bars) = 1mm2 x1,667m = 10^{-6}m2 x 1,667m3 = 1,667x10^{-6} m3
- Total area of concrete slab pavement(LxW) = 1000m × 7m = 7,000m2
- Total volume of concrete slab pavement(LxWxD) = 1000m × 7m × 0.365m = 2,555m3
- Net Total volume of concrete slab pavement = 2,555m3-1,866.8x10^{-6}m3-1,667x10^{-6} m3 =2,554.9965m3
- Total volume of sub base material(LxWxD) = 1000m × 7m × 0.175m = 1,225m3
- Total volume of capping layer material (LxWxD) = 1000m × 7m × 0.0m = 0m3
- AS per the mix design result, the estimated concrete = 127 + 410 + (1072 x 1.005) density (aggregates + (676 x 1.007) at SSD) = 2295 kg/m3. Then consider Design Concrete Density = 2295 kg/m3
- Linear density of 12 mm diameter tie bar is 0.89(Kg/m) and for 25 mm diameter dowel is 3.85(Kg/m)
- Total weight of the net concrete slab pavement (Net Total volume of concrete x Linear density) = 2,554.9965m3 x 2295 kg/m3 = 5,863,715.82kg
- Total weight of dowel bars (Total length of dowel bars x Linear density) = 1,866.8mx3.85 Kg/m = 7187.18 Kg
- Total weight of tie bars (Total length of tie bars x Linear density) = 1,667m x 0.89(Kg/m) = 1483.63 Kg

- Total volume of MC-30 prime coat material @ 1.25 lit/m2 used as separation membrane = 1000m x 7m x 1.25 lit/m2 =8750 liters
- The specific gravity of MC-30 Cut Back liquid Asphalt prime Coat is equal to 0.966kg/lit.
- Total weight of MC-30 prime coat material = 8750 liters x 0.966kg/lit = 8452.5kg
- Total length of longitudinal construction joints = 1km = 1000m
- Total length of transverse contraction joints = (1000m/15)*7 = 466.67m

Bill of Quantity for JUCP

For the unit rate determination of the rigid concrete pavements, 2016 Heavy Construction Cost Data from ERA was used for cost calculation. The cost data are sourced from manufacturers, dealers, distributors, consultants and contractors in Addis Ababa Ethiopia, and included10% waste. Hence, the unite rates were computed as per the cost breaks down annexed Excel template.The following rates in Table4-12 were used in this study.

Table4-18: Bill of Quantity for JUCP under S4

Bill of Quantity for JUCP Under S4					
No.	Rigid Pavement	Main Pavement Only			
	Item Description	Unit	Quantity	Rate	Amount in Birr
1	**Concrete Pavement**				
1.1	Concrete Pavement **375** mm thick (C-35 concrete with flexural strength of 4.0 Mpa at 28 days for the concrete slabs including form work)	m2	7,000.00	1,286.71	9,007,003.05
1.2	Burlap dragged and/or grooved texture	m2	7,000.00	11.00	77,000.00
1.3	Curing the pavement including covering material	m2	7,000.00	25.10	175,700.00
2	**Roadway and Sub Base Pavement**				0.00
2.1	Sub-base layer(s) constructed from lateritic or non lateritic natural gravel material, 95% MDD, AASHTO T-180 (compacted layer thickness of maximum 150mm)	m3	1,050.00	241.14	253,192.72
2.2	Capping layer constructed from natural gravel material, compacted to 95% AASHTO density	m3	1,400.00	169.59	237,419.93
3	**Joints**				0.00
3.1	Dowel bars (mild steel plain bars, epoxy coated 25 mm diameter and 400 mm long at 300 mm spacing)	kg	7,187.18	39.70	285,314.59
3.2	Tie Bars (Ø 12 mm high strength deformed bars ,1000 mm long @ 600mm spacing)	kg	1,483.63	44.84	66,520.28
3.4	Longitudinal construction joints	m	1,000.00	26.06	26,059.00
3.5	Transverse contraction joints	m	466.67	29.45	13,742.03
3.7	Separation membrane (MC-30 prime coat material @ 1.25 lit/m2)	lit	8,750.00	56.50	494,405.83
	Total Sum				**ETB 10,636,357.44**

Table4-19: Bill of Quantity for JUCP under S5

Bill of Quantity for JUCP Under S5					
No.	Rigid Pavement	Main Pavement Only			
	Item Description	Unit	Quantity	Rate	Amount in Birr
1	**Concrete Pavement**				
1.1	Concrete Pavement **365 mm** thick (C-35 concrete with flexural strength of 4.0 Mpa at 28 days for the concrete slabs including form work)	m2	7,000.00	1,252.40	8,766,816.30
1.2	Burlap dragged and/or grooved texture	m2	7,000.00	11.00	77,000.00
1.3	Curing	m2	7,000.00	25.10	175,700.00
2	**Roadway and Sub Base Pavement**				-
2.1	Sub-base layer(s) constructed from lateritic or non lateritic natural gravel material, 95% MDD, AASHTO T-180 (compacted layer thickness of maximum 175mm)	m3	1,225.00	241.14	295,391.51
2.2	Capping layer constructed from natural gravel material, compacted to 95% AASHTO density	m3	-	169.59	-
3	**Joints**				-
3.1	Dowel bars (mild steel plain bars, epoxy coated 25 mm diameter and 400 mm long at 300 mm spacing)	kg	7,187.18	39.70	285,314.59
3.2	Tie Bars (Ø 12 mm high strength deformed bars ,1000 mm long @ 600mm spacing)	kg	1,483.63	44.84	66,520.28
3.4	Longitudinal joints	m	1,000.00	26.06	26,059.00
3.5	Transverse contraction joints	m	466.67	29.45	13,742.03
3.7	Separation membrane (MC-30 prime coat material @ 1.25 lit/m2)	lit	8,750.00	56.50	494,405.83
	Total Sum				**ETB 10,200,949.55**

Table 4-20: Summary of Quantity Takeoff for JUCP

Elements	Total Volume(m3)	Total Weight(kg)	Total Volume(m3)	Total Weight(kg)
	Subgrade class, S4		Subgrade class, S5	
Concrete	2,625	6,024,352.02	2,555	5,863,715.82
Dowels	$1,866.8x10^{-6}$	7,187.18	$1,866.8x10^{-6}$	7,187.18
Tie bars	$1,667x10^{-6}$	1,483.63	$1,667x10^{-6}$	1,483.63
Sub base Material	1,050		1,225	
Capping Layer Material	1,400		0	
MC-30 prime coat material	8,750 liters	8,452.5	8,750 liters	8,452.5

Quantity Takeoff for HMA Pavement

Case-I:AS per ERA PDM-2013, if we choose the **Subgrade class of the pavement is S4**, then quantity takeoff for HMA as follows:

- Total volume of Gravel Sub base Compaction to layer thickness of 175mm (LxWxD) = 1000m × 7m × 0.175m = 1,225m3
- Total volume of road base (Dense Bitumen Macadam) final compacted layer thickness 190 mm (LxWxD) = 1000m × 7m × 0.19m = 1,330m3
- Total volume of MC-30 Cut Back Asphalt prime Coat= 1000m × 7m × 1.25 lit/m2 = 8,750liters
- Total volume of Tack Coat= 1000m × 7m × 0.5 lit/m2 = 3,500 liters
- Total volume of Asphaltic Concrete (Ac) in Binder Course Compacted thickness 50mm(LxWxD) = 1000m × 7m × 0.05m = 350m3
- Total volume of Asphaltic Concrete (Ac) in Wearing Course Compacted thickness 40mm(LxWxD) = 1000m × 7m × 0.04m = 280m3
- Conventional Asphalt concrete normally used in pavements has a density (unit weight) in the range of 2200 to 2400 kg/m3 (137 to 150 lb/ft3). But the Bulk specific gravity of compacted paving mixture sample, Gmb = 2.340, then the bulk density of the compacted mixture = 2.340x1000kg/m3 = 2340kg/m3

- The specific gravity of MC-30 Cut Back liquid Asphalt prime Coat is equal to 0.966kg/lit.
- The specific gravity of MC-30 Cut Back liquid Asphalt Tack Coat is equal to 0.933kg/lit.
- Total weight of MC-30 Cut Back liquid Asphalt prime Coat (Total volume of MC-30 prime Coat x MC-30 prime Coat Density) = 8,750lit x0.966kg/lit = 8452.5kg
- Total weight of Tack Coat(Total volume of Tack Coatx Tack CoatDensity) = 3,500litx0.933 = 3265.5kg
- Total weight of the asphalt concrete pavement (Total volume of asphalt concrete x Asphalt Concrete Density) = 630m3 x 2340 kg/m3 = 1474200 kg

Case-II: AS per ERA PDM-2013, if we choose the **Subgrade class of the pavement is S5**, then quantity takeoff for HMA as follows:

- Total volume of Gravel Sub base Compaction to layer thickness of 100mm (LxWxD) = 1000m × 7m × 0.1m = 700m3
- Total volume of road base (Dense Bitumen Macadam) final compacted layer thickness 190 mm (LxWxD) = 1000m × 7m × 0.19m = 1,330m3
- Total volume of MC-30 Cut Back Asphalt prime Coat = 1000m × 7m × 1.25 lit/m2 = 8,750liters
- Total volume of Tack Coat= 1000m × 7m × 0.5 lit/m2 = 3,500 liters
- Total volume of Asphaltic Concrete (Ac) in Binder Course Compacted thickness 50mm(LxWxD) = 1000m × 7m × 0.05m = 350m3
- Total volume of Asphaltic Concrete (Ac) in Wearing Course Compacted thickness 40mm(LxWxD) = 1000m × 7m × 0.04m = 280m3
- Conventional Asphalt concrete normally used in pavements has a density (unit weight) in the range of 2200 to 2400 kg/m3 (137 to 150 lb/ft3). But the Bulk specific gravity of compacted paving mixture sample, Gmb = 2.340, then the bulk density of the compacted mixture = 2.340x1000kg/m3 = 2340kg/m3
- The specific gravity of MC-30 Cut Back liquid Asphalt prime Coat is equal to 0.966kg/lit.
- The specific gravity of MC-30 Cut Back liquid Asphalt Tack Coat is equal to 0.933kg/lit.
- Total weight of MC-30 Cut Back liquid Asphalt prime Coat (Total volume of MC-30 prime Coat x MC-30 prime Coat Density) = 8,750lit x0.966kg/lit = 8452.5kg
- Total weight of Tack Coat (Total volume of Tack Coat x Tack Coat Density) = 3,500litx0.933 kg/lit = 3265.5kg

- Total weight of the asphalt concrete pavement (Total volume of asphalt concrete x Asphalt Concrete Density) = 630m3 x 2340 kg/m3 = 1474200 kg

Table4-21: Bill of Quantity for Flexible Pavement under S4

Bill of Quantity for Flexible Pavement Under S4					
	Flexible Pavement	Main Pavement Only			
No.	Item Description	Unit	Quantity	Rate	Amount in Birr
	Carriageway				
1	Granular Sub base				
1.1	Sub-base layer(s) constructed from lateritic or non lateritic natural gravel material, 95% MDD, AASHTO T-180 (compacted layer thickness of maximum 175mm)	m3	1,225.0	241.14	295,391.51
2	Base Course(Roadbase)				-
2.1	Asphaltic Concrete roadbase (Dense Bitumen Macadam) final compacted layer thickness 190 mm	m3	1,330.0	1239.18	1,648,102.86
3	Priming, Primer Sealing and Sealing				-
3.1	Supply and spray MC-30 Cut Back Asphalt Prime Coat (application Rate 1lit/m2)	lit	7,000.0	56.50	395,524.66
4	Hot Laid Asphaltic Concrete Surfacing				-
4.1	Supply and apply Tack Coat (application Rate 0.5Lit/m2)	lit	3,500.0	56.50	197,762.33
4.2	Dense Graded Asphaltic Concrete (Ac) in intremediate Courses (Binder Course) Compacted thickness 50mm	m2	7,000.0	326.10	2,282,690.95
4.3	Dense Graded Asphaltic Concrete (Ac) Wearing Course Compacted thickness 40mm	m2	7,000.0	260.88	1,826,152.76
	Total Sum				ETB 6,645,625.07

Table4-22: Bill of Quantity for Flexible Pavement under S5

Bill of Quantity for Flexible Pavement Under S5					
	Flexible Pavement	Main Pavement Only			
No.	Item Description	Unit	Quantity	Rate	Amount in Birr
	Carriageway				
1	**Granular Sub base**				
1.1	Sub-base layer(s) constructed from lateritic or non lateritic natural gravel material, 95% MDD, AASHTO T-180 (compacted layer thickness of maximum 100mm)	m3	700.0	241.14	168,795.15
2	**Base Course(Roadbase)**				-
2.1	Asphaltic Concrete roadbase (Dense Bitumen Macadam) final compacted layer thickness 190 mm	m3	1,330.0	1239.18	1,648,102.86
3	**Priming, Primer Sealing and Sealing**				-
3.1	Supply and spray MC-30 Cut Back Asphalt Prime Coat (application Rate 1lit/m2)	lit	7,000.0	56.50	395,524.66
4	**Hot Laid Asphaltic Concrete Surfacing**				-
4.1	Supply and apply Tack Coat (application Rate 0.5Lit/m2)	lit	3,500.0	56.50	197,762.33
4.2	Dense Graded Asphaltic Concrete (Ac) in intremediate Courses (Binder Course) Compacted thickness 50mm	m2	7,000.0	326.10	2,282,690.95
4.3	Dense Graded Asphaltic Concrete (Ac) Wearing Course Compacted thickness 40mm	m2	7,000.0	260.88	1,826,152.76
	Total Sum				**ETB 6,519,028.71**

Table4-23: Summary of Quantity Takeoff for Flexible Pavement

Elements	Total Volume(m3)	Total Weight(kg)	Total Volume(m3)	Total Weight(kg)
	Subgrade class, S4		Subgrade class, S5	
Gravel Sub base	1,225		700	
Base Course	1,330		1,330	
MC-30 Cut Back Asphalt prime	8,750 liters	8,452.5	8,750 liters	8,452.5
MC-30 Cut Back Asphalt TackCoat	3,500 liters	3,265.5	3,500 liters	3,265.5
Asphalt Concrete (Ac)	630	1,474,200	630	1,474,200

4.4 Computation of Maintenance and Rehabilitation Costs

As per ERA Road Asset Management Directorate consideration of rate of maintenance cost per year is about 0.8% of estimated construction costs for flexible pavement and, the substantial maintenance is expected after the opening of each first year and rehabilitation is also expectedafter the end of seventh year and rate of rehabilitation for flexible pavement is equal to 38% (i.e. 1/3 + 0.8x6) of estimated initial construction costs of the project. However, as the cement concrete pavement technology is new for the country, the researcher took assumed value of its maintenance cost of 0.4%(i.e. 0.8% per yr. divided by 40yr of 20yr) of its initial cost even if literatures say only joint maintenance is required in concrete pavements and rehabilitation does not occur within design period(i.e. 40 years).

Table 4-24: Summary of M&R cost analysis assumptions each alternative

M & R costs Anlysis Assumptions	Flexible pavement	Rigid pavement
Analysis period in yrs	20	40
Rate of Maintanance cost per yr	0.80%	0.40%
Rate of Rehabilitation per 7 yr	38%	0
Discount rate(r)	10.23%	10.23%
Adjusted Inflation rate per yr	5%	5%
Initial Construction cost per Km	6,582,326.89	10,418,653.50
Maintanance costs per km	52,658.62	41,674.61
Rehabilitation Cost per km per 7yrs	2,510,060.65	-

Therefore, by using the net present worth economic analysis, the estimated Maintenance and Rehabilitation costs of each alternative with the entire design periods were computed as per the Excel template as shown below.

Table 4-25: M&R Costs per km for 40 yrs. Entire Service of Pavements

	M&R Costs per km for 40 yrs Entire Service of Pavements					
	Flexible Pavement			Rigid Pavement		
		M&R cost			M&R cost	
Yr	Initial Construction cost	In FV(1+r)^n	In NPV(1/(1+r)^n	Initial Construction cost	In FV(1+r)^n	In NPV(1/(1+r)^n
0	6,582,326.89		6,582,326.89	10,418,653.50		10,418,653.50
1		52,658.62	47,771.58		41,674.61	37,806.96
2		55,291.55	45,505.00		43,758.34	43,305.14
3		58,056.12	43,345.96		45,946.26	45,897.12
4		60,958.93	41,289.36		48,243.58	48,238.29
5		64,006.88	39,330.33		50,655.75	50,655.19
6		67,207.22	37,464.25		53,188.54	53,188.48
7	Rehabilitation Period -2yrs	3,531,907.41	1,786,120.10		55,847.97	55,847.96
8		74,095.96	33,993.51		58,640.37	58,640.37
9		77,800.76	32,380.65		61,572.39	61,572.39
10		81,690.80	30,844.31		64,651.00	64,651.00
11		85,775.34	29,380.86		67,883.55	67,883.55
12		90,064.10	27,986.85		71,277.73	71,277.73
13		94,567.31	26,658.98		74,841.62	74,841.62
14		99,295.67	25,394.11		78,583.70	78,583.70
15	Rehabilitation Period -2yrs	5,218,235.83	1,210,672.26		82,512.89	82,512.89
16		109,473.48	23,041.57		86,638.53	86,638.53
17		114,947.15	21,948.33		90,970.46	90,970.46
18		120,694.51	20,906.96		95,518.98	95,518.98
19		126,729.24	19,915.01		100,294.93	100,294.93
20		133,065.70	18,970.12		105,309.67	105,309.67
Sum			3,562,920.10			1,373,634.96

	Flexible pavement			Rigid pavement		
		M&R cost			M&R cost	
yr	Initial Construction cost after 20 yrs	In FV(1+r)^n	In NPV(1/(1+r)^n		In FV(1+r)^n	In NPV(1/(1+r)^n
20	17,464,872.83		2,489,827.62			
21	Rehabilitation Period -2yrs	146,704.93	18,973.56		110,575.16	15,763.82
22		154,040.18	18,073.33		116,103.92	15,015.88
23		161,742.19	17,215.82		121,909.11	14,303.44
24		169,829.30	16,398.99		128,004.57	13,624.79
25		178,320.76	15,620.92		134,404.80	12,978.35
26		187,236.80	14,879.77		141,125.03	12,362.57
27	Rehabilitation Period -2yrs	9,371,201.82	675,616.88		148,181.29	11,776.02
28		206,428.57	13,501.29		155,590.35	11,217.29
29		216,750.00	12,860.70		163,369.87	10,685.07
30		227,587.50	12,250.51		171,538.36	10,178.10
31		238,966.88	11,669.27		180,115.28	9,695.19
32		250,915.22	11,115.61		189,121.04	9,235.19
33		263,460.98	10,588.21		198,577.10	8,797.01
34		276,634.03	10,085.84		208,505.95	8,379.63
35	Rehabilitation Period -2yrs	13,845,533.14	457,948.27		218,931.25	7,982.05
36		304,989.02	9,151.48		229,877.81	7,603.33
37		320,238.47	8,717.27		241,371.70	7,242.58
38		336,250.39	8,303.67		253,440.29	6,898.95
39		353,062.91	7,909.69		266,112.30	6,571.62
40		370,716.06	7,534.41		279,417.92	6,259.82
Sum			3,848,243.12			206,570.69
Total M&R Costs per km for 40 yrs Entire Service in NPV			7,411,163.22			1,580,205.65

Thus, the total estimated Maintenance and Rehabilitation costs per km for entire 40 yrs. service of each alternative are summarized as shown in the table below and the detail calculations were done in Excel template shown in Table 4-25.

4.5 Computation of Pavement Social Costs

Social impact assessment in pavement Life Cycle integrates the data on the project, the public issues and positions, the community and the bio-physical impacts to determine the potential socio-economic impacts.However, this study only addressed the social impacts related to emission costs and road user costs in the life cycle assessment.

4.5.1 Road User Costs of the Pavements

Best-practice LCCA calls for consideration of not only agency costs, but also costs to facility users. User costs are an aggregation of three separate cost components: vehicle operating costs (VOC), user delay costs (i.e. travel time costs), and crash or accident costs incurred by the traveling public.

HDM-4 Modeling to estimate Road Maintenance, Rehabilitation and RU costs

To estimate Road Maintenance, Rehabilitation and Road Usercosts per km per yr. of each alternative can modelled in HDM-4 as follows:

First, two maintenance types are considered in the analysis:

i. Routine Maintenance: Includes grading, patching, crack sealing, slab replacement and partial depth repair for the main alignment only.
ii. Periodic Maintenance: Includes re-gravelling, reseal, overlay and joint sealing.

The estimates for maintenance works have been estimated based on unit rates from ERA database; the figures have then been verified against similar studies. The unit costs adopted for maintenance operation are given in Table4-26; economic unit costs for maintenance interventions are then derived using conversion factor of 0.83.

HMA Flexible Pavement: Newly Pavement constructing option consisting of 90mm surface thickness and 190 mm Dense Bitumen Macadam with initial IRI of 3.5. Proper maintenance afterwards for the newly constructed road consisting of: a) pothole patching when number of potholes is greater than 6/km b) surface reseal when total carriageway cracked >=25% c) overlay when roughness >=7 IRI and d) total carriageway rehabilitation to done after each seven yrs. service gone with rate of rehabilitation is equal to 38% of estimated initial construction costs of the project.

JUCP Rigid Pavement: Newly Pavement constructing option consisting of 375mm surface thickness (concrete slab) with initial IRI of 2.5. Preventive maintenance afterwards for the newly constructed road consisting of a) partial depth repair when spalling >=10% b) slab replacement when total carriageway cracked >=20% and c) Joint sealing every 10 years.

Table 4-26: Unit Costs of Work for Maintenance (for HDM-4 Analysis)

Work Item	Unit	Financial unit cost(Birr)	Economic unit Cost(Birr)
Grading	per km	1,243	1,032
Re-gravelling	per m3	224	186
Spot re-gravelling	per m3	208	173
Pothole Patching	per m2	231	192
Crack Sealing	per m2	215	179
Resealing	per m2	228	189
Overlay	per m2	216	179
Joint sealing	per m	270	224
Slab replacement	per m2	182	151
Partial Depth repair	per m2	107	88.8
Note: For rehabilitation, rate of rehabilitation for flexible pavement is equal to 38% of estimated initial construction costs of the project.			

Source: Maintenance Needs Assessment and Updating Road Financing Study, 2010 (updated to reflect current costs).

Table 4-27: M and R interventions by Alternative (for HDM-4 Analysis)

Alternative	Maintenance (M) and Rehabilitation (R) strategy	Work Items	Intervention Criteria
HMA concrete pavement	Regular HMA Concrete maintenance (M)for (2020-2059)	Pothole Patching	No. of potholes >=6 /km
		Surface Reseal Overlay	Total carriageway cracked >=25%
		Overlay	Roughness >=7 IRI (m/km)
	Regular HMA Concrete Rehabilitation (R) after each 7yrs. services given for (2020-2059)	Pavement Rehabilitation (R) option consisting of 90mm surface thickness and improvement option Consisting of 190 mm Dense Bitumen Macadam with initial IRI of 3.5.	Preplanned the program
JUCP	Regular PCC maintenance (M) (2020-2059)	Partial depth repair	Spalling >=5%
		Joint sealing	Every ten years
		Slab replacement	Total carriageway cracked >=20%

Source: Researcher

Table 4-28: Engineering Input data for newly development options

Engineering Property	Engineering Input data	Unit	Main Alignment
Road Geometry	Length	km	1
	Carriageway Width	m	7
	Number of Lanes	No.	2
	Rise + Fall	m/km	10
	No. of Rises & Falls	no./km	2
	Av. Horizontal Curve	deg/km	15
	Speed Limit	km/hr.	80
	Super Elevation	%	2.5
Structure	Surface thickness (mm)	HMA	90
		JUCP	375
	Roughness – IRI (m/km)	HMA	3.5
		JUCP	2.5

Source: Researcher

Similarly, in order to compute road user costs of the alternatives, first we have to assess the economic data that uses as the inputs for transport economics prediction throughout the design period of the pavements. Hence, this study investigates the issues related to transport economy such as Discount Rate, Vehicle Fleet Characteristics, Traffic Growth, Trends in GDP and Transport Demand Elasticity w.r.t GDP have already computed at the traffic growth analysis in this chapter-4.

The Table 4-29 and 4-30summarized the vehicle fleet characteristics as well as economic VOC data. The following data has been cross-checked against data from recent feasibility studies to ensure consistency. Costs are expressed in economic terms based on financial prices expressed as market prices. The financial costs have been converted to economic costs by using the standard conversion factor recommended in the recently updated "National Economic Parameters and Conversion Factors for Ethiopia" by the MoFED (June 2008).

Vehicle Fleet Characteristics

The vehicle fleet characteristics are based on data gathered by recent studies similar to this study project and combined with some assumptions by the Researcher's. The vehicle fleet characteristics and road user costs by vehicle categories are used as technical input to the HDM-4 modeling. For further information the modeling out puts were annexed.

Table 4-29: Vehicle Fleet Characteristics

	Cars	Utilities	Small Buses	Large Buses	Small Trucks	Medium Trucks	Heavy Trucks	Trucks & Trailers
Passenger Car Space Equivalent	1	1	1.2	1.6	1	1.4	1.6	1.8
No. of wheels	4	4	4	10	6	10	10	14
No.of axles	2	2	2	3	2	3	3	5
Tyre type	Redia-ply	Bias-ply	Redia-ply	Bias-ply	Bias-ply	Bias-ply	Bias-ply	Bias-ply
Base no. of recaps	1.3	1.3	1.3	2.4	1.3	2.4	2.4	3.6
Retread costs(%)	20%	20%	20%	20%	20%	20%	20%	20%
Annual km	25,000.00	38,000.00	58,000.00	65,000.00	50,000.00	75,000.00	85,000.00	85,000.00
Annual working hours	550	990	1980	2200	1760	1980	2200	2200
Average life(years)	15	15	20	20	20	20	20	20
Private use	90%	25%	20%	0%	0%	0%	0%	0%
Passengers(No.)	4	4	21	45	2	2	2	2
Work related passenger trips(%)	20%	85%	90%	100%	100%	100%	100%	100%
Operating weight(ton)	1.2	2.5	2.5	9	3.5	15	30	40
ESALF	0.001	0.07	0.07	0.72	0.12	0.92	4.5	8.5

Source: Recent studies and Researcher's assumption

A summary of road user costs are presented in table 5-4 by vehicle categories.

Table 4-30: A summary of VOC input costs (Economic unit prices in ETB)

Type of Costs	Type of Vehicles							
	Cars	Utilities	Small Buses	Large Buses	Small Trucks	Medium Trucks	Heavy Trucks	Trucks & Trailers
New Vehicle Price	537,524.56	1,197,194.43	697,736.75	1,569,908.34	852,898.76	1,134,140.44	1,702,056.21	2,020,022.43
Tyer Replacement	1,414.41	3,373.23	3,373.23	4,669.24	3,373.23	4,669.24	5,570.14	5,570.14
Fuel(per liter)	16.90	16.90	16.90	16.90	16.90	16.90	16.90	16.90
Lubricant oil(per liter)	64.82	64.82	64.82	64.82	64.82	64.82	64.82	64.82
Mainenance labor cost(ETB/hour)	35.37	35.37	35.37	35.37	35.37	35.37	35.37	35.37
Crew wages (ETB/hour)	15.44	18.31	20.98	17.10	19.94	19.46	18.52	30.89
Annual Overheads	9,961.38	12,870.00	11,969.10	25,740.00	11,969.10	11,969.10	25,740.00	38,610.00
Annual Interest(%)	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Passenger working time (per hour)	2.27	2.27	1.63	1.63	2.49	2.49	2.49	2.49
working time (per hour)	0.80	0.80	0.57	0.57	0.88	0.88	0.88	0.88
Cargo Costs(per hour)					0.47	1.12	1.33	2.84

Source: Recent studies and Researcher's Estimation.

Discount Rate

Reference has been made to the publication "National Economic Parameters and Conversion Factors for Ethiopia" by the MoFED (June 2008), which sets discount rates applicable to Ethiopia and is subject to infrequent revision. Therefore, based on this document, the opportunity cost of capital (or discount rate) has been taken as 10.23%. The discount base year has been taken to be 2016(i.e. present worth values are often referred to as discounted cash flow).

Inflation Adjusted Rate

Inflation is the rate of increase in the prices of goods per period. So, it has a compounding effect. Thus, prices that are inflated at a rate of r% per year will increase r% in the first year, and for the next year the expected increase will be r% of these new prices. The same is true for succeeding years and hence the rate of inflation is compounded in the same manner that an interest rate is compounded.

But there is always difficulty in determining the rate of inflation. The worldwide trend/wish is to curtail inflation. But due to various reasons, it is very difficult to forecast the exact inflation rate. Hence, for this proposal, an average estimate has taken for the analysis period 5% per year.

HDM-4 analysis

The HDM-4 model includes modules to calculate vehicle operating costs (VOCs) and Travel time Costs and was considered to be an appropriate tool for this analysis. Typically HDM-4 is not used in the UK as the road network is, by international standards, relatively smooth and vehicle operating costs are not sensitive to roughness until the pavement has an IRI of around 4 or 5. Based on this threshold it is only the worst parts, in terms of longitudinal profile variance, of the Ethiopian trunk road network that will have any impact on vehicle operating costs.

Two sets of Trunk 1km road lengths were modeled in HDM-4, using IRI values ranging from 2 to 5.5 in increments of IRI 0.5. The entire modelled road lengths were of HMA and PC concrete construction had a width of 7m, a Rise and Fall of 10m/km and a curvature of 15 degrees/km as shown in Table4-28

Hence, with application HDM-4 modeling, the total Vehicle Operating and Travel time Costs per vehicle/km for Asphalt Concrete and Jointly Unreinforced Concrete Pavement summarized shown in the Table4-31. However, the accident costs are not considered in LCCA because the data were not available in the country. And also only considered 10% of HDM-4 analysis results because the study design is a simulation design and the configuration of HDM_4 has some constraints regards to road networks, vehicle fleets and work standards.

Table4-31: A summary of RUC costs for each alternative from HDM-4 modeling.

Road User Cost for the Entire 40yrs					
Type of pavement	Total Vehicle Operating Cost per vehicle/km in Birr	Total Vehicle Travel Time Cost per vehicle/km in Birr	Vehicle Operating Cost per vehicle/km in Birr	Vehicle Travel Time Cost per vehicle/km in Birr	10% Road User Cost
JUCP Pavement	ETB 25,497,727.20	ETB 1,200,000.00	ETB 2,549,772.72	ETB 120,000.00	ETB 2,669,772.72
HMA Pavement	ETB 34,421,931.72	ETB 1,692,000.00	ETB 3,442,193.17	ETB 169,200.00	ETB 3,611,393.17

From summary of road user costs of each alternative, the study explained that that the road user costs are directly related to the performance of the pavement. Hence, the frequent maintenance and rehabilitation activities on roads the publics exposed to high vehicle operating and user delay costs.

4.5.2 Emission Costs of the Pavements

Greenhouse Gases Emission

Greenhouse Gases (hazardous wastes) are potentially harmful not only to the health of human beings but also to the environment.

Global Warming Potential (GWP) measures how much heat greenhouse gases trap in the atmosphere and the Global Warming Potential (GWP) and Greenhouse Gases assess the amount of greenhouse gases released into the air (Shine et al. 2005).

The metric ton of carbon dioxide equivalent emission (tCO2e) is the unit of GWP. In the sector of greenhouse gases, outputs are CO2 fossil, CO2 process, methane (CH4), nitrous dioxide (N2O), and other gases such as Hydro Fluoro Carbons (HFC) and Per Fluoro Compounds (PFCs). In other words, the CO2 fossil and process cause the emission of CO2 into the atmosphere.

According to United States EPA ,2011study results, over 45 percent of the tCO2e of the total GWP comes from cement manufacturing and other nonresidential structure sectors, followed by power generation and supply, and oil and gas extraction(Hao Wang,2014).

The study attempted to estimate the amount of Greenhouse Gases Emission to air, for the construction of JUCP and HMA pavement roadways from extraction of raw materials through the end of construction. It should be noted that this paper presents the results for only extraction of raw materials through the end of construction and does not address the entire roadway lifecycle.

Starting with a flowchart of the pavement lifecycles, the researchers identified through reviews of literature and discussions with material trade associations, possible points within the initial stages of the pavement lifecycles (extraction of raw materials, manufacturing, and placement) where energy is released. This was followed by the: selection of the type and characteristics of the roadways to be investigated, identification of energy emission data sources, collection of data from the identified sources, and finally analysis of the data.

All of the values are taken from web data base of: Environmental Life-Cycle Inventories of Energy Systems, Bundesamt für Energiewirtschaft, Sauter PSwiss Federal Institute of Technology, Zurich, Switzerland.

Table4-32: Energy Emission of JUCP and HMA Materials

Sub-step	Material or Process	Emission of Product/Process						
		CO2	SO2	NOX	CO	CH4	N2O	VOC
Extraction and Initial Transformation	Portland cement(kg/ton)							
	Bitumen(kg/ton)							
	Dowel & Tie steel Bar (kg/ton)							
	Fine aggregate(kg/ton) used for JUCP	2.22E-02	1.42E-05	1.82E-04	2.24E-05	1.15E-07	7.02E-07	1.34E-05
	Coarse aggregate(kg/ton) used for JUCP	7.45E-01	4.12E-04	6.41E-03	7.80E-04	2.00E-06	1.89E-05	4.66E-04
	Fine aggregate(kg/ton)used for HMA	1.42E+00	7.88E+00	1.23E+00	1.49E+00	3.82E+00	3.61E+00	8.90E+00
	Coarse aggregate(kg/ton)used for HMA	1.56E+00	8.67E+00	1.35E+00	1.64E+00	4.20E+00	3.97E+00	9.79E+00
Manufacturing	Portland cement(kg/ton)	1.41E+02	1.75E-01	3.49E-01	1.43E-04	9.50E-06	2.85E-05	7.49E-05
	Dowel & Tie steel Bar (kg/ton)	2.20E+00	7.34E-03	4.86E-03	1.00E-03	9.10E-03	3.00E-05	1.20E-03
	Bitumen Production(kg/ton)	4.44E+00	1.57E-02	2.62E-02	2.85E-03	9.06E-07	2.72E-06	5.13E-03
	Asphalt mixing andaggregate drying(kg/ton)	5.85E-02	1.03E-04	1.41E-04	3.23E-05	2.15E-06	4.91E-06	1.69E-05
	PC Concrete mixing(kg/ton)	2.77E-02	4.88E-05	6.71E-05	1.53E-05	1.02E-06	3.06E-06	8.02E-06
Placement	PC Concrete(kg/ton)	1.68E-02	8.06E-06	1.51E-04	1.80E-05	1.06E-08	3.39E-07	1.08E-05
	HMA Concrete(kg/ton)	9.62E+00	6.11E-03	1.95E-02	1.59E-03	4.1E-06	6.30E-06	5.11E-05

Source: Environmental Life-Cycle Inventories of Energy Systems, Bundesamt für Energiewirtschaft, Sauter PSwiss Federal Institute of Technology, Zurich, Switzerland, Database.

JUCP				
Total wt.(ton)	5.94E+03			
Component	Cement	Coarse Aggre.	Fine Aggre.	Steel wt.(ton)
% wt(ton)	17.86%	46.94%	29.66%	8.67E+00
HMA				
Total wt.(ton)	1.49E+03			
Component	Asphalt concrete	Coarse Aggre.	Fine + Filler Aggre.	
% wt(ton)	6.10%	52.63%	41.27%	

Table4-33: Energy Emission for a Lane-1km JUCP and HMA Pavements

Energy Emission to Air (kg)										
From Life Cycle of JUCP										
Emission of Product/Process										
		CO2	SO2	NOX	CO	CH4	N2O	VOC	Total	%
Extractio + Manufacturing + Placement	FA	3.91E+01	2.51E-02	3.21E-01	3.96E-02	2.02E-04	1.24E-03	2.37E-02	3.95E+01	0.026%
	CA	2.08E+03	1.15E+00	1.79E+01	2.18E+00	5.57E-03	5.26E-02	1.30E+00	2.10E+03	1.380%
	PC	1.49E+05	1.85E+02	3.71E+02	1.52E-01	1.01E-02	3.03E-02	7.96E-02	1.50E+05	98.51%
	Bars	1.91E+01	6.36E-02	4.21E-02	8.67E-03	7.89E-02	2.60E-04	1.04E-02	1.93E+01	0.013%
	Con. Mix	1.64E+00	2.90E-03	3.99E-03	9.09E-04	6.06E-05	1.82E-04	4.77E-04	1.65E+00	0.001%
	Con.place	9.97E+01	4.79E-02	8.96E-01	1.07E-01	6.29E-05	2.02E-03	6.42E-02	1.01E+02	0.066%
Total		151,649.45	1.87E+02	3.90E+02	2.48E+00	9.49E-02	8.66E-02	1.48E+00	1.52E+05	100.000%
As Per the Global Energy Reporting Initiative Database (2014), the total amounts of GHG emission to be forecasted for 40 yrs service 50% from maintenance work becomes...										
Grand Total		227,474.18	280.17	584.48	3.73	0.14	0.13	2.22	2.28E+05	
%		99.619%	0.123%	0.256%	0.002%	0.000%	0.000%	0.001%		
From Life Cycle of HMA									Total	%
Extractio + Manufacturing + Placement	FA	8.71E+02	4.83E+03	7.54E+02	9.14E+02	2.34E+03	2.21E+03	5.46E+03	1.74E+04	30.72%
	CA	1.22E+03	6.78E+03	1.06E+03	1.28E+03	3.29E+03	3.11E+03	7.66E+03	2.44E+04	43.09%
	Bitu.produ.	4.03E+02	1.42E+00	2.37E+00	2.58E-01	8.21E-05	2.46E-04	4.65E-01	4.07E+02	0.72%
	Asphalt.mix	8.70E+01	1.53E-01	2.10E-01	4.80E-02	3.20E-03	7.30E-03	2.51E-02	8.74E+01	0.15%
	HMA place	1.43E+04	9.08E+00	2.90E+01	2.36E+00	6.09E-03	9.36E-03	7.59E-02	1.43E+04	25.32%
Total		1.69E+04	1.16E+04	1.84E+03	2.20E+03	5.63E+03	5.32E+03	1.31E+04	5.66E+04	100.00%
As Per the Global Energy Reporting Initiative Database (2014), the total amounts of GHG emission to be forecasted for 40 yrs service 50% from each rehabilitation(per 7yr) and 25% from total maintenance work becomes...										
Grand Total		7.17E+04	4.94E+04	7.84E+03	9.34E+03	2.39E+04	2.26E+04	5.57E+04	2.41E+05	
%		30%	21%	3%	4%	10%	9%	23%		

Where: *Energy Emission to Air (Kg) by Component GHG. = Emission of Product in phase (Kg/Ton) x Component Wt. in (10^{-3}Ton)*

For instance, *emission of CO2 from extraction of fine aggregate, 2.22E-02(kg/Ton) x 5.94E+03(Tons) x29.66% =* ***3.91E+01(kg)***

For energy emission results from each life cycle phase the pavements to the total energy emission to air by each greenhouse gas was also calculated shown in Table4-33.

Moreover, the emission costs were calculated considering the cost of neutralizing CO2, CO, NOx, N2O , SO2, VOC and CH4, and the costs based on the data reported by Kendall et al. (2005) and International Association for energy Economics Estimation shown in Table4-34which are equivalent to the values in Global Energy Reporting Initiative Database.

Table 4-34: Urban Emission Cost in Dollars per Ton by Kendall et al (2005) and IAEE

CO2	SO2	NOX	CO	CH4	N2O	VOC
Cost $ per Ton						
26.00	208.00	8,712.00	100.00	28.00	28.00	2,750.00
Cost ETB per Ton(ETB22/$)						
572.00	4,576.00	191,664.00	2,200.00	616.00	616.00	60,500.00

Table 4-35: Emission Cost at life cycle of each pavement

CO2	SO2	NOX	CO	CH4	N2O	VOC	Total Sum
Cost $ per Ton							
26.00	208.00	8,712.00	100.00	28.00	28.00	2,750.00	
Cost ETB per Ton(ETB22/$)							
572.00	4,576.00	191,664.00	2,200.00	616.00	616.00	60,500.00	
Estimated Emission Cost of GHG from JUCP(ETB)							
130,115.23	1,282.06	112,024.41	8.20	0.09	0.08	134.24	243,564.31
Estimated Emission Cost of GHG from HMA(ETB)							
41,010.63	226,018.52	1,502,004.47	20,552.69	14,735.95	13,925.88	3,372,077.54	5,190,325.69

***Where**: Emission cost in each gases (ETB) = Energy Emission to Air (Kg) xUrban Emission Cost in Birr per Kg.*

For instance, emission cost of CO2 = 227,474.18 (kg) x 572(ETB/Ton) x10^{-3} per Ton= ETB130, 115.23

4.6 Remaining Service Life Value

If an activity has a service life that exceeds the analysis period, the difference is known as the Remaining Service Life Value (RSV). Any rehabilitation activities (including the initial construction) except for the last rehabilitation activity within the analysis period will not have a RSV.

The road pavement itself can be expected to have expired after 20 years but other components of the upgrading, such as structures and earthworks will have remaining reusable life for incorporation within subsequent reconstruction or rehabilitation projects.

Even though the contribution of these re-usable components to the total costs and their anticipated service lives, but this study project only consider road pavement investment cost, hence the overall residual value of the flexible pavement option is considered to zero.

On the other hand, the rigid pavement option is expected to serve double the design life of flexible pavement option (i.e. 40 years); therefore, its residual life has been taken as 20.29%.

Table 4-36: Estimation of Residual value for Flexible & Rigid pavements

Investment Componen	% Investment	Assumed Economic Life	Residual Life After 20 years	% of Economic Life Remaining	Remaining Service Life Value in %
Flexible Pavement					
Asphalt Concrete & Road Base	97%	20	0	0.00	0.000
Sub base	3%	20	20	30%	0.008
Total	100%				0.78%
Rigid pavement					
Concrete slab	97%	40	20	20%	0.194
Sub base	3%	40	20	30%	0.009
Total	100%				20.29%

Source: Researcher's estimation

The Remaining Service Life Value of this project alternative at the end of the analysis period is calculated by prorating the total construction cost (agency and user costs) of the last scheduled rehabilitation activity summarized shown in the Table4-37.

Table4-37: Remaining Service Life Value of the alternative projects

Pavement Type	Estimated Residual Value
Flexible Pavement	ETB 19,340.50
Rigid pavement	ETB 302,457.36

Source: Researcher's estimation

4.7 Environmental Impact assessment in pavement Life Cycle

Using a lifecycle inventory assessment, to assess the environmental a separate research studywas conducted to investigate the sustainability of pavements from energy and waste perspectives.

The studies attempted to estimate the amount of energy consumed and the amount of waste generated for the construction of JUCP and HMA pavement roadways from extraction of raw materials through the end of construction. It should be noted that this paper presents the results also for only extraction of raw materials through the end of construction and does not address the entire roadway lifecycle. Starting with a flowchart of the pavement lifecycles, the researchers identified through reviews of literature and discussions with material trade associations, possible points within the initial stages of the pavement lifecycles (extraction of raw materials, manufacturing, and placement) where energy is consumed and waste generated. This was followed by the: selection of the type and characteristics of the roadways to be investigated, identification of energy use and waste generation data sources, collection of data from the identified sources, and finally analysis of the data.

Inventory data for significant materials and construction processes of energy consumption and waste generation were collected in two ways. First, an extensive literature review of previous research and of the industries and processes involved in the manufacture and construction of both pavement materials were conducted. The second source of information was construction companies and the most known ecoinvent data-bases such as Swiss Environmental Life-Cycle Inventories of Energy Systems Database, SimaPro Software Developer Database, USA Life Cycle Database, ETH-ESU (Energy-Materials-Environment Group Database), ISO Database, European Life Cycle Database (ELCD), Global Energy Reporting Initiative Database, Australia Life Cycle Database etc. through website. For material processing data was also collected through interviews with domestic and foreign heavy-civil construction (including CRBC, MEPO, ERCC, Sunshine Const. ASER Const. etc.) contractors and material manufacturers with offices located in the AA.

Computational Results from Data Collection

No attempts were made to verify whether the values provided by the producers and contractors were an accurate representation of the actual percentages of wastes and similarly for energy consumption from different previous findings or databases. Some of the materials exhibit a wide range of values. The wide range can be attributed to the differences in study methodologies and system boundaries.

Results related to the percent of material wasted for different materials at various initial stages of the lifecycle are provided in Table4-39. The values shown in the table are the mean values calculated from the survey responses, and include waste generated from all different causes, e.g., poor workmanship, procurement errors, falls, spills etc.

Table4-38: Energy Use/Consumption of JUCP and HMA Materials

Process	Energy Consumption (J/Ton of Material)	Data Source	Mean Value
Cement Manufacturing	4.77×10^{9}	Stripple, 2001	
	5.35×10^{9}	Häkkinen and Mäkelä, 1996	
	6.36×10^{9}	Twinshare, 2003	
	6.7×10^{9}	Stammer and Stodolsky, 1995	
	$6.33\ 10^{9}$	USA School of Resources, Environ.,and Society (PCA 1990 data)	5.90E+09
Extraction of Aggregates (coarse and fine aggregate)	38.18 x 106 (crushed aggregates)	Stripple, 2001	
	74×10^{6}	Stammer and Stodolsky, 1995	
	22.2×10^{6}	Berthiaume and Bouchard, 1999	
	53×10^{6}	ETH-ESU (Energy-Materials-Environment Group Database)	
	24×10^{6} (gravel)	Häkkinen and Mäkelä, 1996	
	52×10^{6} (crushed aggregates for	Häkkinen and Mäkelä, 1996	4.23E+07
Steel Manufacturing	2.53×10^{10}	Stripple, 2001	
	0.62×10^{10}	Häkkinen and Mäkelä, 1996	
	1.90×10^{10}	Stubbles, 2000	1.68E+10
Concrete Mixing	6.875×10^{6}	SimaPro Ecoinvent Database	
	6.358×10^{6}	EIO-LCA (www.eiolca.net)	6.62E+06
PCC Pavement Placement	3.40×10^{7} (concrete)	European Life Cycle Database	
	2.35×10^{7} (concrete)	Stammer and Stodolsky, 1995	2.88E+07
	0 (Dowel & Tie steel Bar)	ETH-ESU (Energy-Materials-Environment Group Database)	0.00E+00
Production of Bitumen	2.93×10^{9}	Stripple, 2001	
	6×10^{9}	Häkkinen and Mäkelä, 1996	
	0.63×10^{9}	Stammer and Stodolsky, 1995	
	0.42×10^{9}	EIO-LCA (www.eiolca.net)	2.50E+09
Asphalt Storage	5.43×10^{8}	Stripple, 2001 and Australia Life Cycle Database	5.43E+08
Asphalt Mixing and Drying of Aggregates	0.32 x 109 – 0.39×10^{9} (per ton of AC mixture)	Ang et al., 1993 and USA Life Cycle Database	3.55E+08
HMA Pavement Placement	1.34×10^{7}	European Life Cycle Database and ETH-ESU (Energy-Materials-Environment Group Database)	
	1.02×10^{7}	EIO-LCA (www.eiolca.net)	1.18E+07

Where multiple energy consumption values were found, as shown in Table4-38, the mean of these values was used in the energy calculations for Tables4-40.

For the waste quantities, the values for manufacturing of the materials include the waste of PCC and HMA in production (mixing) plants. For placement of the PCC and HMA, the percentage of waste is shown for the material as a whole with the individual quantities obtained from the mix design.

Table 4-39: Waste Generated for JUCP and HMA Materials

Process	Waste (% of Material)	Data Source
Cement Manufacturing	2 (Raw materials) 37.25 (Production) 0.2 (Finished product)	The Local Dangote & Messebo Cement Factory & Global Cement Producer Facotory Database.
Extraction and Processing of Aggregates (coarse and fine aggregate)	0.5 (Extraction) 10 (Processing-materials remaining in wash ponds and stockpiles)	European Pavement Materials LC Database , SimaPro Ecoinvent Database and Local Aggregate producer interviews in A.A areas
Steel Raw Materials Extraction and Manufacturing	0.01	Global Steel Manufacturer and Trade Associations Database
Concrete Production	0.2 (Concrete) 0.5 (Aggregates) 1.0 (Cement)	Local Ready mix c oncrete producers interviews (MEPO & ASER Construction) and USA Ready Mix Concrete producers
Returned Concrete	0.4	Local Ready Mix Concrete producers interviews and Global Concrete Trade Associations Database
PCC Pavement Placement	2.3	Local Contractor interviews(ERCC & CGC) & SimaPro Ecoinvent Database
Production and storage of Bitumen	0.85	Local Asphalt producers interviews & USA Asphalt producer Company database
HMA Production	0.1	Contractor interviews(ERCC & CGC) & USA Asphalt producer Company database
AC Pavement Placement	0.5	Local Contractor interviews(ERCC &CGC) & Global Asphalt producer Company database

Waste and Energy Quantification for Selected Pavement Designs

The Portland Cement Concrete mix design includes the following percentages by weight: with 5.54% water, 17.86% cement, 46.94% coarse aggregates and 29.66% fine aggregates.

For the asphalt pavement design also includes the following percentages by weight, with 6.1% bitumen, 52.63% coarse aggregate and 41.27% fine aggregate.

The total amounts of energy consumed and waste created for the specific pavement designs being considered were then calculated as the sum of the expenditures of energy and waste generated of the individual processes and subsystems, respectively.

These values reflect the specific mix design and physical characteristics of the pavement alternatives selected for the study. The results of these calculations are shown in Table4-38&39 for JUCP and HMA pavements respectively.

Table4-40: Energy Consumption and Waste Generation for JUC Pavement

For JUCP Pavement					
Sub-step	**Material or Process**	**Energy Consumed (J/Ton)**	**Total Energy Consumed (MJ)**	**Waste Generated (%)**	**Total Waste Generated (Metric tons)**
Raw Materials Extraction and Initial Transformation	Portland cement	0.00E+00	0.00E+00	2%	21.23
	Dowel & Tie steel Bar	4.23E+07	3.67E+02	0.01%	0.001
	Fine aggregate	4.23E+07	7.45E+04	0.50%	8.815
	Coarse aggregate	4.23E+07	1.18E+05	0.50%	13.95
	Sub total		**1.93E+05**		**43.999**
Manufacturing	Portland cement	5.90E+09	6.27E+06	37.25%	395.448
	Dowel & Tie steel Bar	1.68E+10	1.46E+05	0.01%	0.001
	Fine aggregate	0.00E+00	0.00E+00	10%	0.000
	Coarse aggregate	0.00E+00	0.00E+00	10%	0.000
	Concrete mixing	6.62E+06	3.93E+04	0%	0%
	Sub total		**6.45E+06**		**395.449**
Placement	Concrete	2.88E+07	1.71E+05	2.30%	136.71
	Dowel & Tie steel Bar	0.00E+00	0.00E+00	0.5%	0.000
	Sub total		**1.71E+05**		**136.713**
Total			**6.81E+06**		**576.16**
AS Per the Global Energy Reporting Initiative Database (2014), the total amounts of energy consumed and waste created to be forecasted for 40 yrs service 25% from maintenance work becomes…			**8.52E+06**		**720.20**

***Where:**Energy Consumed (Mega Joule) by Component Element= Energy Consumed (J/Ton) x Component Wt. (Tonx10^{-3}) x (10^{-6}M)*

Waste Generated (Metric Tons) by Component Element= Waste Generated (%) x Component Wt. (Ton)

*For instance, Energy Consumed during manufacturing of PC (MJ) =5.90E+09(J/Ton) x 5,944.03 (Ton) x*17.86% x (10^{-6}M) = **6.27E+06(MJ)**

*For instance, Waste Generated during manufacturing of PC (Metric Ton)) =37.25% x5,944.03 (Ton) x*17.86% =**395.448(Metric Tons)**

Table 4-41: Energy Consumption and Waste Generation for HMA Pavement

For HMA Pavement					
Sub-step	**Material or Process**	**Energy Consumed (J/Ton)**	**Total Energy Consumed (MJ)**	**Waste Generated (%)**	**Total Waste Generated (Metric Tons)**
Raw Materials Extraction and Initial Transformation	Bitumen	0.00E+00	0.00E+00	0%	-
	Fine aggregate	5.20E+07	3.19E+04	0.50%	3.066
	Coarse aggregate	5.20E+07	4.07E+04	0.50%	3.910
	Sub total		**7.26E+04**		**6.976**
Manufacturing	Bitumen Production	2.50E+09	2.26E+05	0.85%	0.770
	Bitumen Storage	5.43E+08	4.92E+04	0.0%	-
	Asphalt mixing and aggregate drying	3.55E+08	5.28E+05	0.0%	-
	Aggregates	0.00E+00	0.00E+00	10.0%	139.528
	Sub total		**8.03E+05**		**140.298**
Placement	HMA Concrete	1.18E+07	1.75E+04	0.50%	7.430
	Sub total		**1.75E+04**		**7.430**
		Total	**8.93E+05**		**154.704**
AS Per the Global Energy Reporting Initiative Database (2014),the total amounts of energy consumed and waste created to be forecasted for 40 yrs service 75% from each rehabilitation(per 7yr) and 25% from total maintenance work becomes…			**4.69E+06**		**812.20**

Table4-41 indicates that no energy is consumed for the extraction and initial transformation of bitumen. In this process it is not easy to differentiate how much energy is used in the distillation of each oil sub-product, and the consumption of energy is affected by the type of petroleum and the conditions and location of the oil field. Hence, while some energy is consumed for bitumen in this phase of the lifecycle, the amount consumed was not included in the study because of the difficulties in accurately quantifying it during extraction, transformation, and transportation.

Similarly for Portland cement due to lack of available data, assumed that no energy is consumed for the extraction and initial transformation, while huge amount of energy is consumed for Portland cement in this phase of the lifecycle.

5. RESULTS AND DISCCUSION

5.1.Estimated Initial Construction Costs ofJUCP and HMAPavements

Quantity Takeoff, unit rate and engineering estimation were computed for each pavement materials with respect to different subgrade quality as per the design specifications in the bill of quantity. The unit rates for each item were calculated from the detail cost break down preparation of direct cost analysis shown in the Annex-2. All the costs (materials, labors & equipments) were fixed from the current market price at Addis Ababa from January, 2016 to June, 2016.

For each alternative, the initial construction costs should be determined from the engineering estimation and for this study only consider the initial construction costs ofthe main road under subgrade class S4 &S5 such as surface pavement, base and sub basebut project support costs (for design, environment, construction administration and inspection, project management, etc.) were assumed equal and ignored, and does not affect the cost analysis. Hence, the average estimated initial construction costs per km of each alternative summarized as shown in the Table 5-1below.

Table 5-1: Summary of estimated initial construction costs of each alternative

An Average Initial Construction Costs of Concrete Pavement Per km (Birr)	An Average Intial Construction Costs of Flexible Pavement Per km(Birr)
ETB 10,418,653.50	ETB 6,582,326.89

From estimated initial construction costs of each alternative, the study JUCP and HMA pavements were incurred ETB 10,418,653.50 and ETB 6,582,326.89 per km respectively. This concluded that the initial construction costs of the study JUCP pavement was highly expensive than the HMA and it has a cost increment of just over 58.28%.

Thus, it could result in economic cost that varies according to the pavement type. In addition to pavement type, Figure5.2 and 5.3 shows that the highest construction cost generated from the specific costs of PC Concrete and Hot Laid Asphaltic Concrete Surfacing construction materials that used for rigid and flexible pavement respectively.

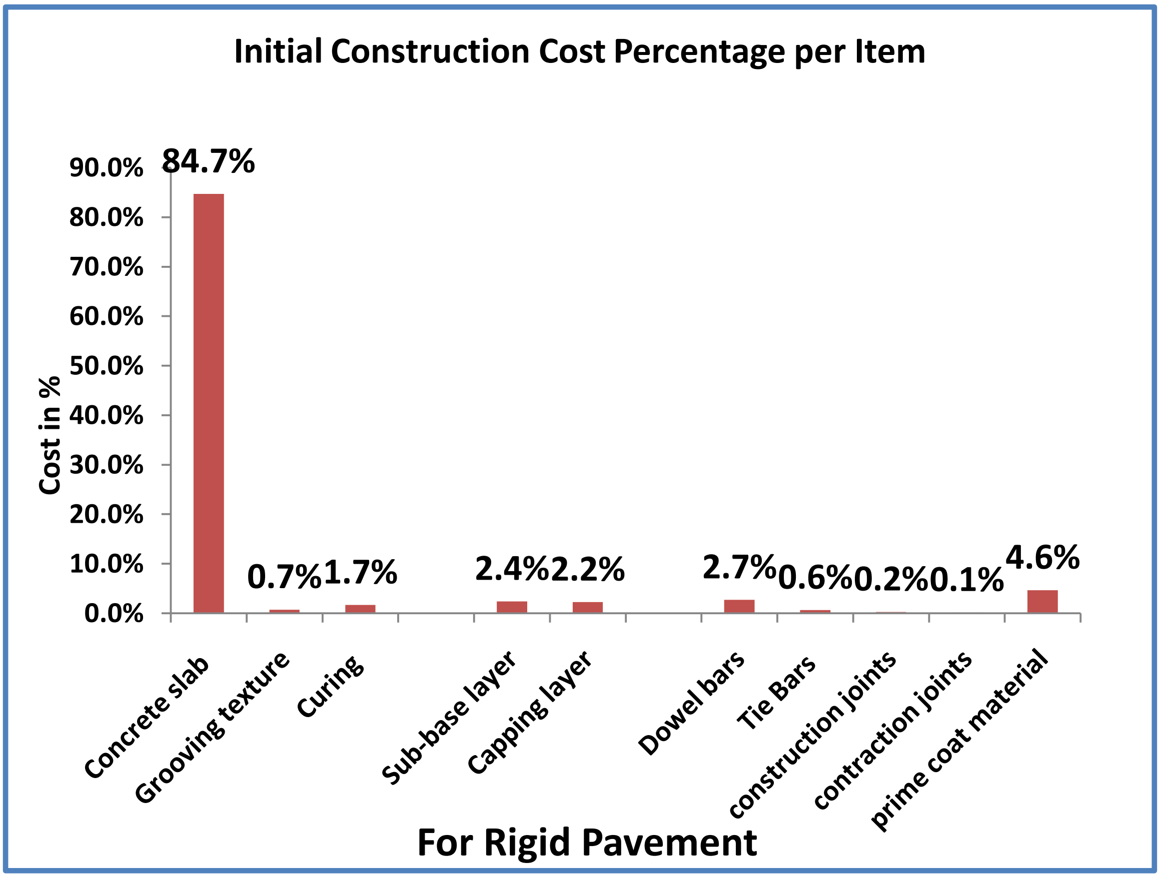


Figure5.1: The Initial Construction Costs Percentage % per Item

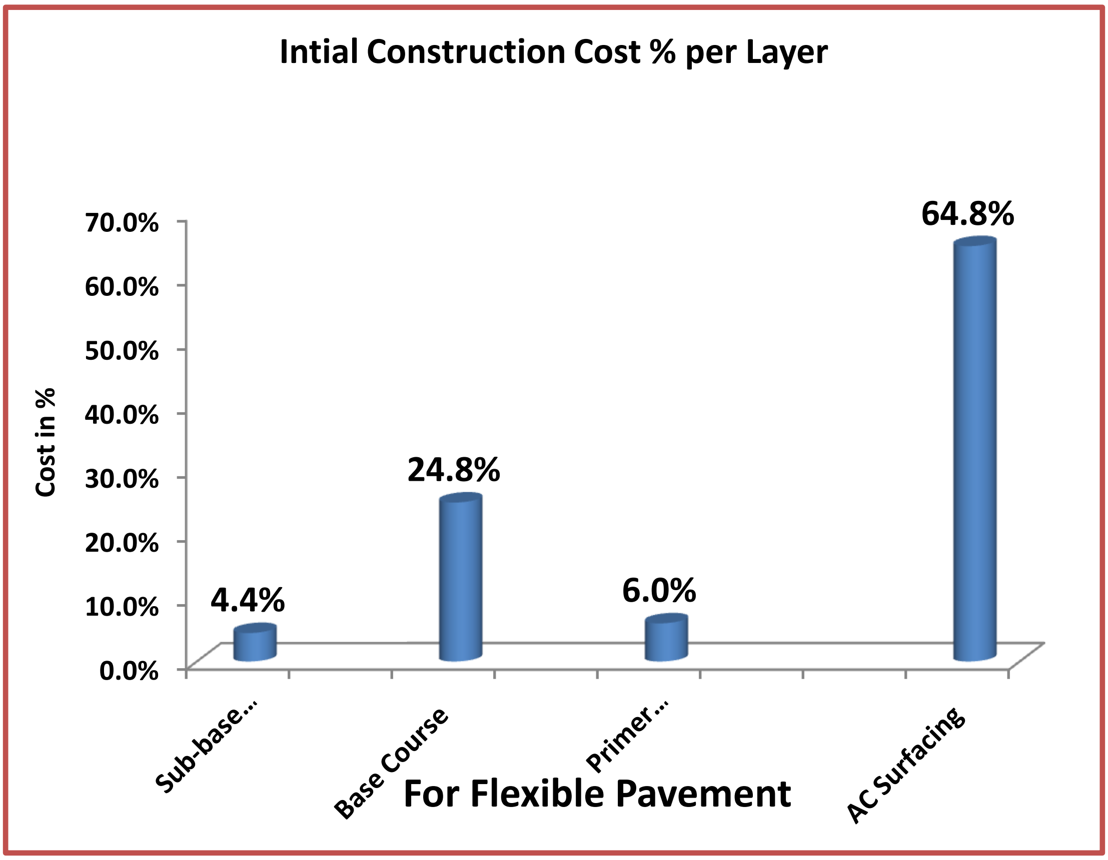


Figure 5.2: TheInitial Construction Costs % Share per Item

Therefore, the outputsin Fihure5.1& 2 show that, important interaction exists between costs of pavement materials and the total construction costs of pavement on the different types of pavement.

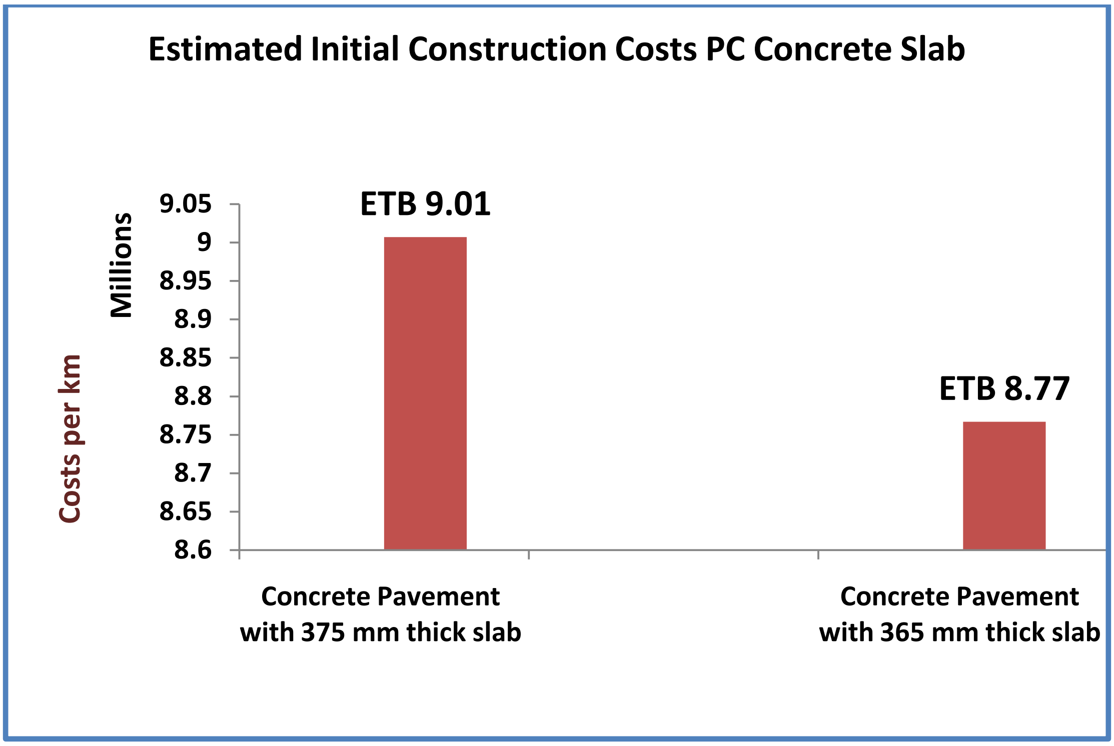


Figure5.3:Initial Construction Costs of Slab with DifferentThickness.

In order to further understand the relation between the materials costs and pavement type, additional analyses of the data also were made.

First, to comprehend the economic impact of PC concrete on the total construction costs for JUCP pavement, the relationship between the thickness of slab in design and the total construction costs was studied. It was found that for every 10mmthickness reduction in concrete slab, there was a decrease of construction costs roughly ETB250, 000 per km of PC concrete pavement as shown in Figure5.3. In the similar manner for every 10mm thickness reduction in AC surfacing, there was a decrease of construction costs roughly ETB450, 000 per km of flexible main pavement construction.

Therefore, we can also conclude that use of high performanceof pavement materials can significantly reduce the thickness and the total construction costs in both JUCP and HMA pavements construction.

5.2.Future Maintenance and Rehabilitation costsof JUCP and HMA Pavements

The total estimated Maintenance and Rehabilitation costs per km of each alternative with the entire 40 yrs. service were computed and are summarized as shown in the table5-2 below.

Table 5-2: Summary of estimated M& R costs per km per yr. of each alternative

Total Estimated Maintenance and Rehabilitation Costs of Flexible Pavement Per km (Birr) for the entire 40 yrs	Total Estimated Maintenance Costs of Concrete Pavement Per km(Birr) for the design period
ETB 7,411,163.22	**ETB 1,580,205.65**

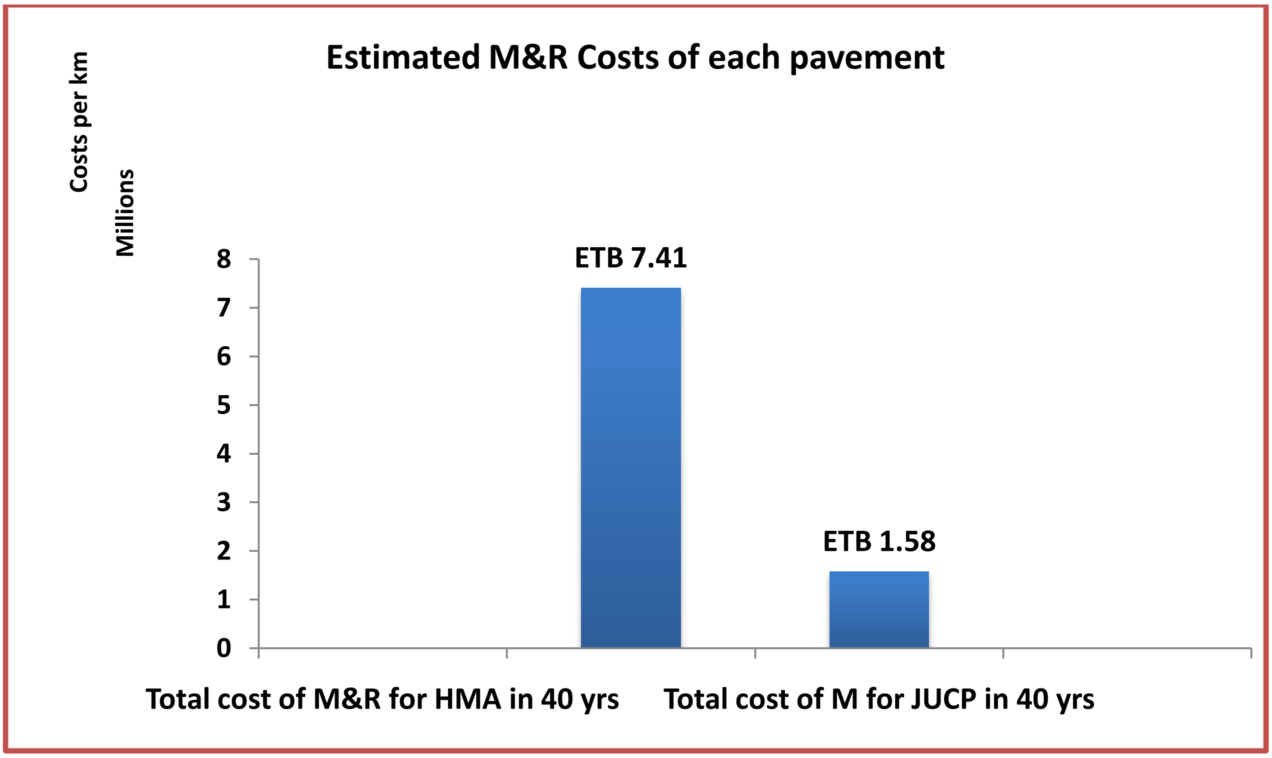


Figure5-4: Estimated M&R Costs of each pavement in Entire 40 yrs. Service

From estimated M&R Costs of each pavement, the study JUCP and HMA pavements were incurred ETB 1,580,205.62 and ETB 7,411,163.22 per km respectively. This inferred that the M&R Costs for the entire 40 yrs. serviceof the study HMA pavement was highly expensive than the JUCP and it has a cost increment of just over 369%.

M&R Costs per km of HMA for ths first 20 yrs Entire Service	M&R Costs per km of HMA for ths 2nd 20 yrs Entire Service
3,562,920.10	3,848,243.12
Each % share	
54.13%	58.46%
Average % share	
56.30%	

Hence, for 20 yrs. design life, the HMA flexible pavement accounted in average 56.30% of the total initial investment costs for Maintenance and Rehabilitation work.

In sum,we realized thatHMApavement had the higher economic impact with respect toits performance and a huge capital and resources are used when designing the HMA concrete for long service life in the normal trend in Ethiopia.

5.3.EstimatedSocial (road user and emission) CostsofJUCP and HMA Pavements

Road User Costs

The out puts show that the study JUCP and HMA pavements were incurred ETB 2,669,772.72 and ETB 3,611,393.17 per km respectively only considered 10% of HDM-4 analysis results.

From summary of road user costs of each alternative, the study explained that that the road user costs are directly related to the performance of the pavement. Hence, the frequent maintenance and rehabilitation activities on roads the publics exposed to high vehicle operating and user delay costs.

Energy Emission and its Costs

The result show that the study JUCP and HMA pavements emit 2.28 x 10^5 kg and 2.41 x 10^5 kg total greenhouse gases, respectively as shown in Figure5.9, in the first three sub-phases of the pavements lifecycle (extraction, manufacturing, and placement). This inferred that the amount of energy emission for the entire 40 yrs. service of the study HMA pavement was somehow higher thanthe JUCP.

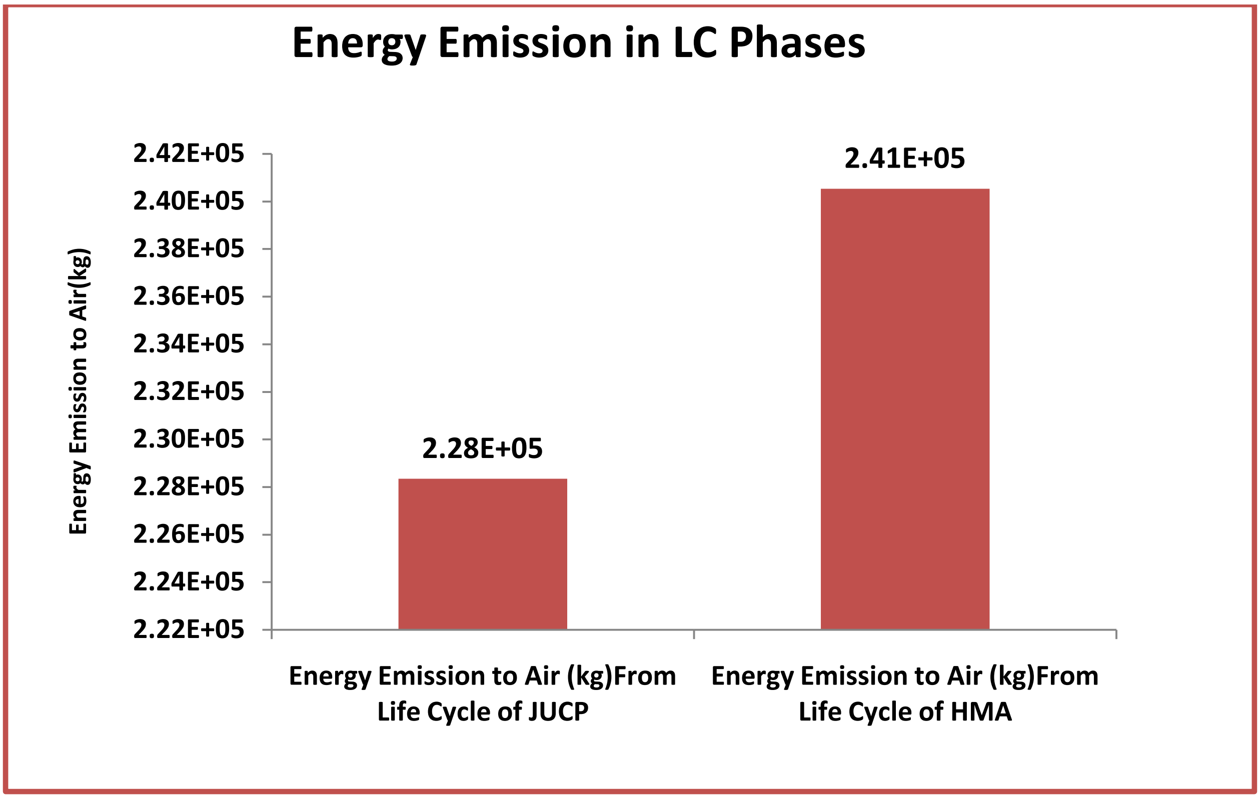


Figure5.5: Total Energy Emission in LC Phases Pavements

For JUCP type of pavement the emission of SO_2, NOX, CO, H_4, N_2O and VOC greenhouse gases for the life cycle pavement materials is almost negligible compared with the emission of CO_2 from the life cycle of pavement up to the construction stage.

Table 5-3: Percent Contribution of GHG in Lifecycle Phases of JUCP Pavement

	CO2	SO2	NOX	CO	CH4	N2O	VOC
Energy Emission to Air (kg)	227,474.18	280.17	584.48	3.73	0.14	0.13	2.22
%	99.619%	0.123%	0.256%	0.002%	0.000%	0.000%	0.001%

Table 5-3 shows that, the emission of SO_2, NOX, CO, H_4, N_2O and VOC account for only 0.4% of the total amount of greenhouse gases emission in JUCP pavement. The remaining 99.6% of the greenhouse gas emission is CO2.

From Figure5.6 it can also be seen that the emission of CO_2, SO_2 and VOC account around 74% of the total amount of greenhouse gases emission in HMA pavement, while the rest processes account only 26% greenhouse gases emission.

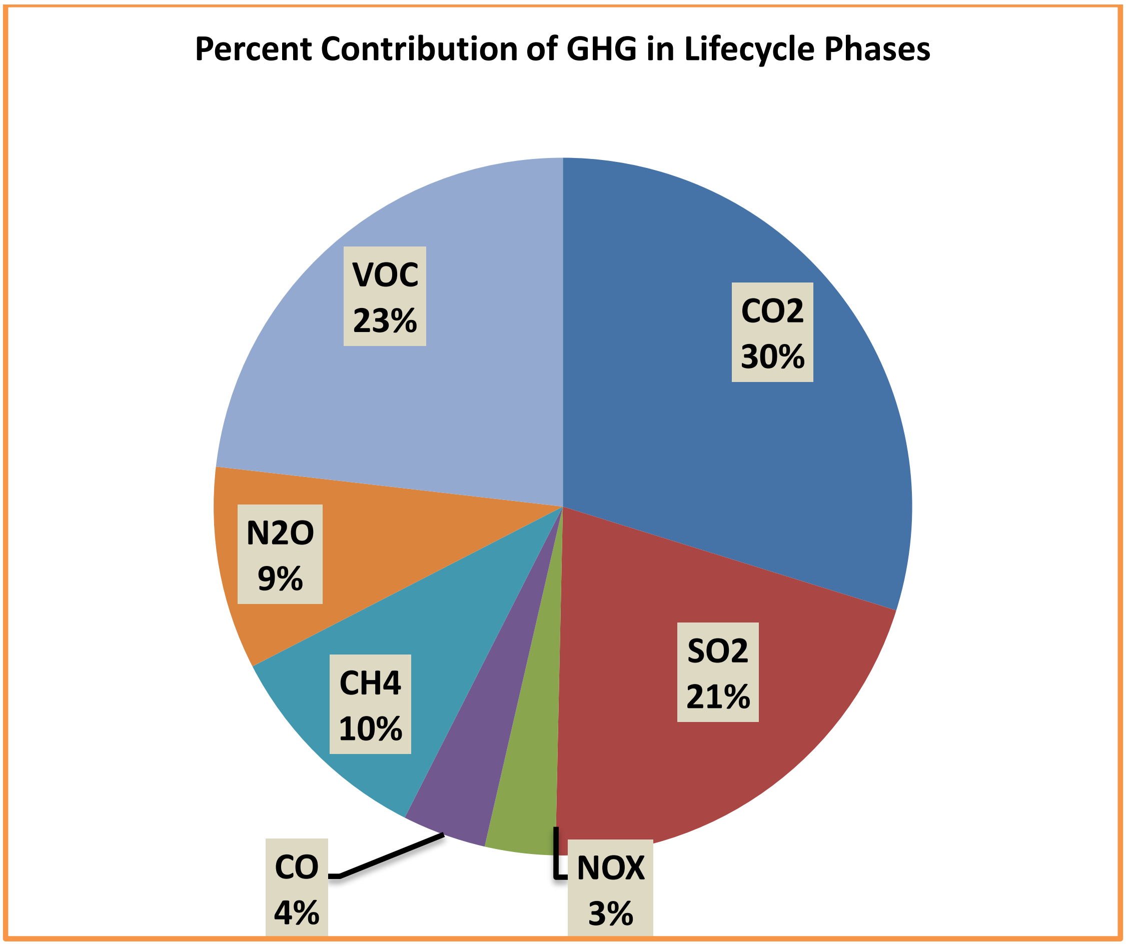


Figure5.6: Percent Contribution of GHG in Lifecycle Phases of HMA Pavement

Therefore, the out puts show that JUCP has a greater amount of global warming potential than HMA and cement is the driving element in the emission of highest greenhouse gases in the construction of Portland cement concrete pavements.

Emission Costs

The emission costs were calculated considering the cost of neutralizing CO2, CO, NOx, N2O, SO2, VOC and CH4, and the respective costs were summarized as follows.

Estimated Emission Cost of GHG from JUCP	Estimated Emission Cost of GHG from HMA
ETB 243,564.31	ETB 5,190,325.69

The study JUCP and HMA pavements were incurred ETB 0.244 million and ETB 5.2 million as an emission costs in the life cycle as shown above. Hence, it inferred that HMA pavement had the higher emission costs in the life cycle of pavement than JUCP because of highest amount emission of NOX and VOC, which accounted 94% of the total emission cost, in the life cycle and their corresponding cost of neutralizing (emission costs) are highly expensive as shown below.

Estimated Emission Cost of GHG from HMA(ETB)							Total
41,010.63	226,018.52	1,502,004.47	20,552.69	14,735.95	13,925.88	3,372,077.54	
0.8%	4.4%	29%	0.4%	0.3%	0.3%	65.0%	5,190,325.69

Road User Costs in the Life Cycle Assessment

From summary of road user costs of each alternative, the total road user costs of JUCP and HMA are accounted ETB 2, 669,772.72 and ETB 3,611,393.17 respectively. Hence, the total social costs of the alternative pavement summarized as follows:

Estimated Emission Cost of GHG from JUCP	Estimated Emission Cost of GHG from HMA
ETB 243,564.31	ETB 5,190,325.69
Total Road User Costs	
ETB 2,669,772.72	ETB 3,611,393.17
Total Social Costs	
ETB 2,913,337.03	ETB 8,801,718.86

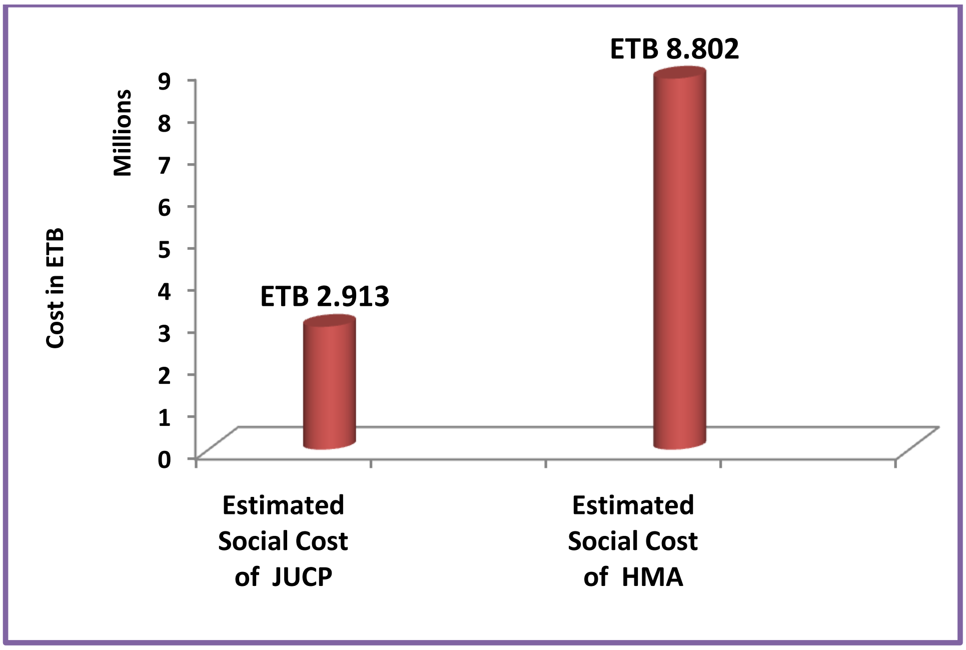


Figure5.7: Total Social Costs of JUCP and HMA in Life Cycle Assessment

The study JUCP and HMA pavements were incurred ETB 2,913,337.03and ETB 8,801,718.86as social costs in the life cycle as shown in Figure5.7. Hence, we understood that HMA pavement had the higher social impact than JUCPin the life cycle costs of pavement. Thus, in regards to social impact life cycle assessment, the study JUCP was socially more acceptable than HMA pavement in the entire life cycle.

5.4.Summary of theLife Cycle CostResultsof JUCP and HMA Pavements

Life Cycle Cost Analysis(LCCA)		
Type of Costs	JUCP	HMA
Construction Costs	10,418,653.50	6,582,326.89
M&R Costs	1,580,205.65	7,411,163.22
Residual Value	(302,457.36)	(19,340.50)
Road User Costs	2,669,772.72	3,611,393.17
Emission Cost (of GHG)	243,564.31	5,190,325.69
Life Cycle Cost per km	**ETB 14,609,738.82**	**ETB 22,775,868.47**

From Life Cycle Cost Analysis (LCCA) of the alternatives, the study JUCP and HMA pavements were incurred ETB 14,609,738.82and ETB 22,775,868.47 per km respectively. This concluded that the Life Cycle Cost of the study HMA pavement was more expensive than the JUCP.

From the analysis, we can also observe that the initial cost of the study concrete rigid pavement is substantially higher than that of flexible pavement. It has a cost increment of just over 58.3%.

However,in the long run or LCC, the study concrete rigid pavement has the upper hand over flexible pavement with a cost saving of above 56%. This is mainly due to the longer design life of concrete rigid pavement its lesser maintenance, rehabilitation and social costs. We can therefore safely conclude that concrete rigid pavement in addition to its technical superiority over flexible pavement; it is worthwhile economically as well.

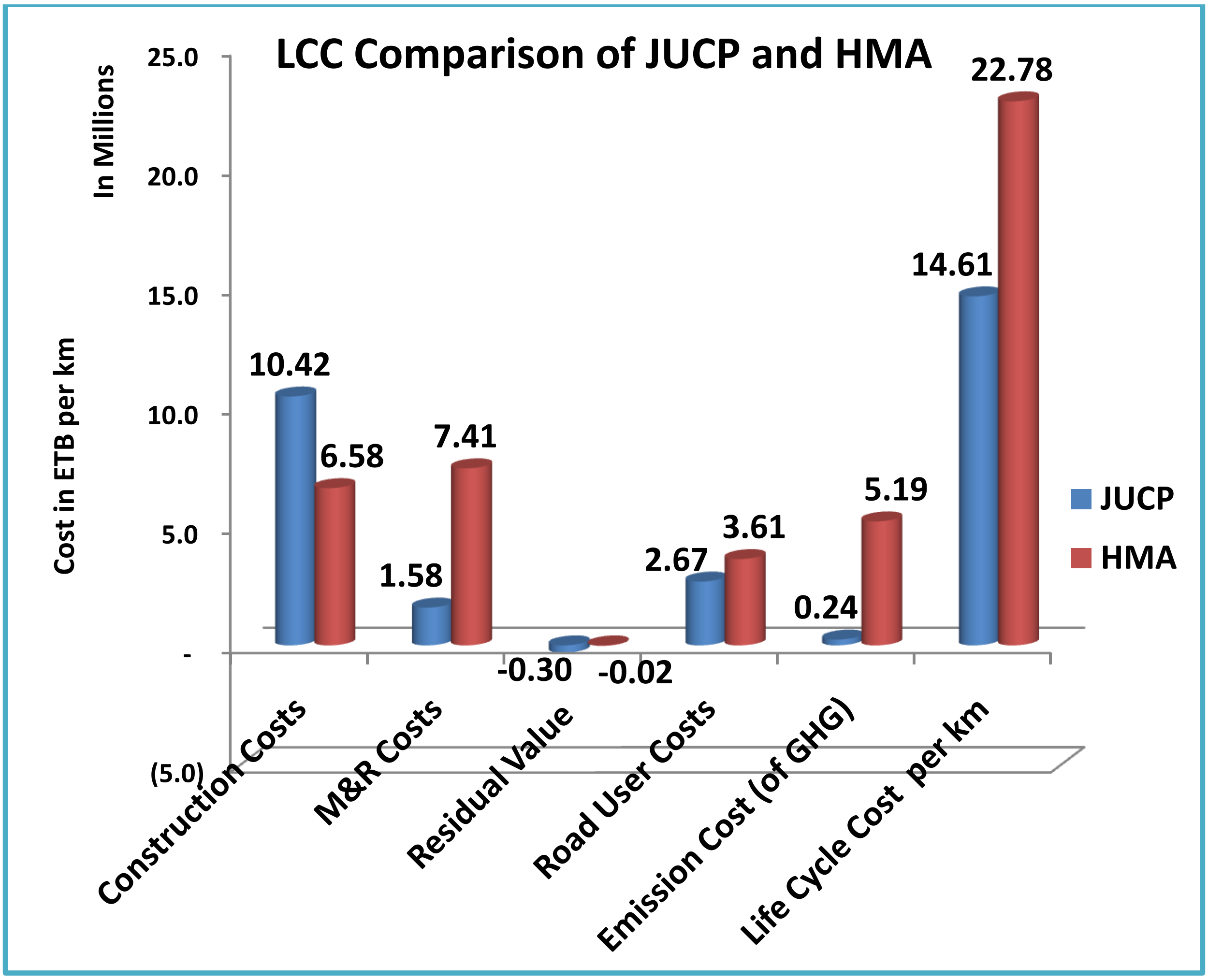


Figure5.8: Summary of Life Cycle Cost Analysis for Each Pavement

From the analysis summary below, we can also observe that the Social (RUC and Emission) cost of HMA pavement is substantially higher than that of PC concrete pavement. It has a cost increment of just over 94%.

Life Cycle Cost Analysis(LCCA)		
Type of Costs	**JUCP**	**HMA**
Construction Costs	**71.3%**	**28.9%**
M&R Costs	**10.8%**	**32.5%**
Residual Value	**-2.1%**	**-0.1%**
Road User Costs & Emission Cost (of	**19.9%**	**38.6%**

Therefore, the analysis results indicated that JUCP be the better cost-efficient and sustainable choice between the selected pavement alternatives as it requires the lower life-cycle cost and has the less unfavorable impact on environment and socio-economic when compared to the HMA flexible pavement.

5.5.Environmental Impact Assessment in Pavement Life Cycle

The total quantity contributions of each life cycle phase to the total energy consumption and waste generation were calculated for both JUCP and HMA pavement.

According to the study, the construction of a 1-km section of a typical two-lane free flow highway requires 8.52 x 10^6MJ of energy in the case of JUCP pavement, and 4.69 x 10^6 MJ for HMA pavement in the entire life cycle. This shows that in the entire life cycle, the study JUCP pavement is consumed more energy than HMA asphalt.

Total Energy Consumed (Mega Joule)		Total Waste Generated (Metric Tons)	
JUCP	HMA	JUCP	HMA
8.52E+06	4.69E+06	720.20	812.20

From the results shown in Figure5.9 the percent contributions of each life cycle phase to the total energy consumption and waste generation were calculated for both JUCP and HMA pavement.

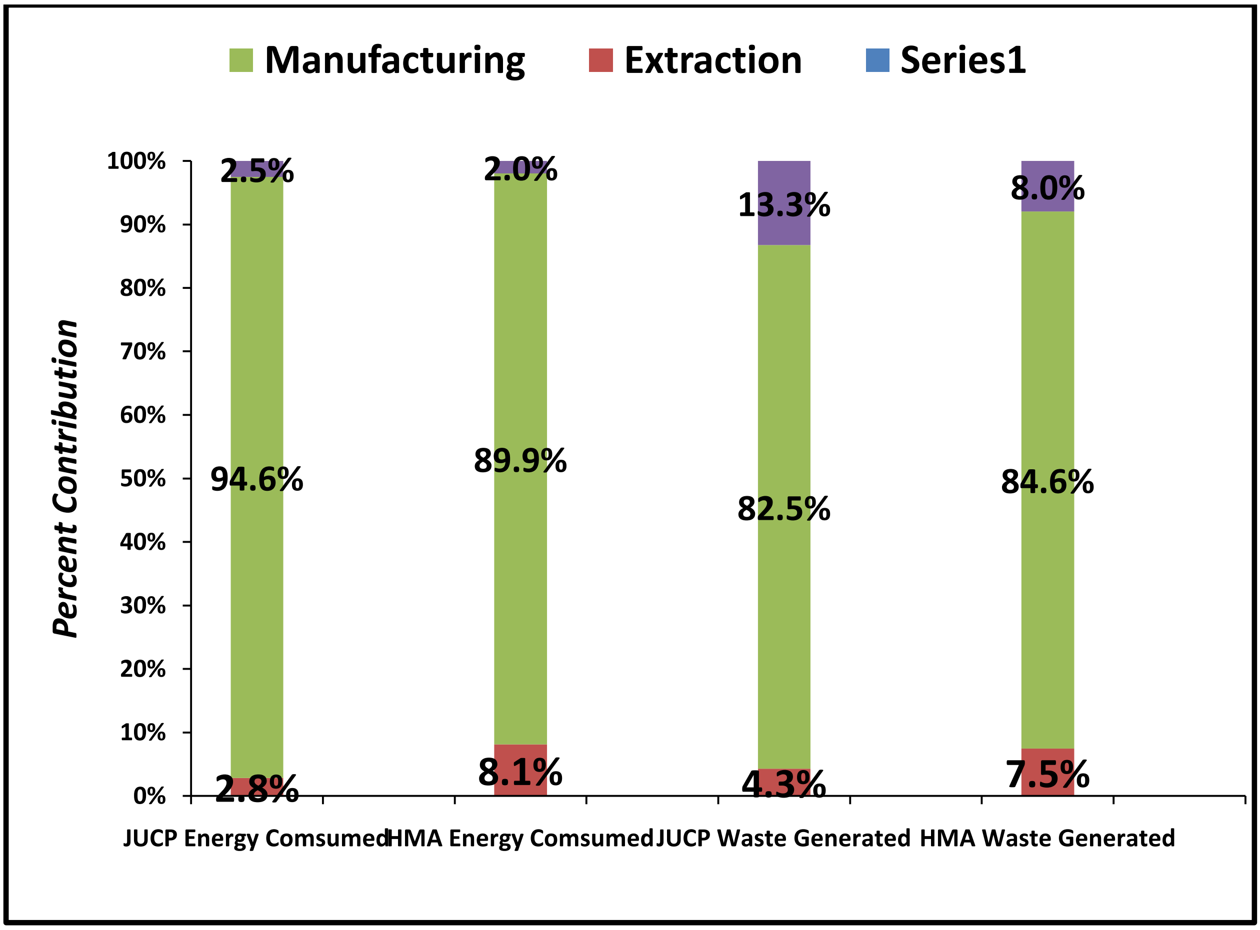


Figure5.9: Percent Contribution of LC Phases to Energy Use and Waste Generation

JUCP and HMA pavements consume 8.52 x 10^6 MJ and 4.69 x 10^6 MJ, respectively, in the first three sub-phases of the pavements lifecycle (extraction, manufacturing, and placement). For both types of pavement the consumption of energy for the extraction of aggregates and the placement of pavement materials is almost negligible compared with the energy required for the manufacture of JUCP and HMA.

Figure5.9 illustrates that the extraction of raw materials and the placement of concrete account for only 5.4% of the total amount of energy consumed in JUCP pavement. The remaining 94.6% of the energy is spent in the manufacturing process, where the production of cement makes up 92% of the energy consumed, while the production of steel and concrete mixing process account for 2% and 0.6%, respectively.

From Figure5.9 it can also had been seen that the extraction of raw materials and the placement of HMA pavement account for 10% of the total energy consumption of the system. The remaining 90% of the energy is consumed in the manufacturing process, where the asphalt mixing and drying of aggregates accounts for 66% of the energy consumed and the production of bitumen and its storage account for 28% and 6%, respectively.

Since cement production consumes a significant amount of energy, an analysis was made to test its impact on total energy consumption. It was found that if part of the cement in the JUCP mix design is replaced by other pozzolanic materials, the consumption of energy is dramatically reduced. When the content of Portland cement is reduced from its original value of 17.86% by weight to 13.4 %(i.e. reduced by 25%), the consumption of energy will drop from 6.27 x10^6 MJ to 4.7 x 10^6 MJ.

Similarly, JUCP and HMA pavements generate 720.20 and 812.20 metric tons of waste, respectively, in the first three sub-phases of the alternative pavement in lifecycle. Similar to energy consumption, for both types of pavement the amount of waste generated in the extraction of aggregates and in the placement of course materials is almost negligible compared with the waste created during the manufacture of concrete and asphalt. Figure5.9 shows that the extraction of raw materials and the placement of concrete account for only 17.5% of the total waste generated from theJUCP pavement. The remaining 82.5% of the waste comes from the manufacturing process where the production of cement accounts for 46.5% of the materials wasted.

And also Figure5.9 shows that the extraction of raw materials and the placement of HMA pavement account for a mere 15% of the total waste output from the system. The remaining 85%

of the waste is the result of the manufacturing process. In order to further understand the relation between the materials and waste, additional analyses of the data were made.

First, to understand the impact of cement on the total waste generated for JUCP pavement, the relationship between the percent of cement in the concrete mix design and the total waste was studied. It was found that for every one percent replacement of cement by pozzolanic materials, there was a decrease of roughly23 metric tons in total waste.

A second analysis was made with respect to the aggregate used. A large quantity of waste materials is created during the virgin aggregate production processes. Use of recycled aggregates can significantly reduce the total energy consumption and waste generation in both JUCP and HMA Pavements construction.

5.6.Social Impact Assessment in Pavement Life Cycle

The social impact assessment practitioner works closely with the community to determine how the planning, design, construction and operational phases may affect them and their community.

However, this study only addressed the social impacts related to emission costs and road user costs in the life cycle assessment.

Social Costs includes: Loss of business ,Environmental loss (noise, vibration, air pollution), Loss of amenity or Public facility, Disruption to traffic/vehicular activities, Land use, Increased levels of traffic accidents, Increased fuel consumption, raising potential environmental impacts and citizen complaints, significantly bargain site restoration costs, and increased legal costs.

Therefore, the study JUCP and HMA pavements were incurred ETB 2,913,337.03 and ETB 8, 801,718.86as social costs in the life cycle as shown in Figure5.8. Hence, we agreed that HMA pavement had the higher social impact than JUCPin the life cycle costs of pavement. Thus, in regards to social impact life cycle assessment, the study JUCP was socially more acceptable than HMA pavement.

Furthermore, the global trend suggested that cement plant are growing automated with modern larger cement plant manned from 200 to 300 employees, in Ethiopia, however, from the total nineteen factories larger cement plants employee as high as 1935 employees and smaller plants employee around 100 employees (as per the FDRE Ministry of Industry Cement Industry Development Strategy study, 2014) andthe total asphalt concrete road network of the country has reached 1,2640kms in 2014 with growth rate 8.4%, then in the coming 10 years ERA will construct 17,173kms new asphalt concrete roads.

Hence,as result to construct 17,173kms JUCP main alignment in the coming 10 years it demands about 18,236,008.70 tons (17,173kms x 2,590m3/km x 0.41ton/m3) of Portland cement which will be produced in Ethiopia. Due to the more demanded 18,236,008.70 tons amount of Portland cement in the Cement Factories would create new employment roughly for 36,018.9=(18,236,008.70 /6,600,000)x(1,935 x 6 +100x13) citizens.

Total Wt. Bitumen(Kg/Km)	Pavement const. in the coming 10 years(kms)	Expected Total Bitumen Wt.(kg)	Unit price of Bitumen(ETB/kg)	Total Price(ETB)
1,474,200.0	17,173.0	25,316,436,600.00	9.953	251,976,455,143.07

In addition to generate billion birr of tax revenue, the alternative choice of the study JUCP will have a foreign exchange saving effect about 251,976,455,143.07(1,474,200kg/km x 17,173 km x 9.96Birr/kg) birr to the country in the coming 10yrs. by substituting the current imports of bitumen mixture cut-backs asphalt for flexible pavement construction.

5.7.Impact of PCCPavement on Cement Manufacturing Industries inEthiopia

According to the Ethiopia Ministry of Mining and Development Bank of Ethiopia (DBE), 2011report, Ethiopia has more than 350 million tons cement raw material reserves but the current actual cement production capacity is estimated to be 6.6 million ton/ year.

As a result of road sector investment under the RSDP, the total asphalt concrete road network of the country has reached 12,640kms in 2014(RSDP report, 2014) with an average road network growth rate 8.4% and after 10 years the asphalt concrete roads will be reached 33,273kms in 2026. This indicates that in the coming 10 years ERA will construct 17,173kms new asphalt concrete road in the country.

From Life Cycle Cost Analysis (LCCA) of the alternatives, the study JUCP and HMA pavements were incurred ETB 14,609,738.82and ETB 22,775,868.47 per km respectively. This inferred that the Life Cycle Cost of the study HMA pavement was incurred ETB8,166,129.65per kmmore against JUCP.

Moreover, if the newly to be constructed 17,173kms of HMA concrete road is replaced by JUCP in the coming 10 years, ERA can save roughly ETB 140,236,944,479.45 (=17,173 x 8, 166,129.65)because the study HMA pavement was incurred ETB8,166,129.65 per km more against JUCP.

Hence the decision of the study JUCP alternative derived from due to having 6.6million ton of current cement production capacity in the country, as result to construct 17,173kms JUCP in the coming 10 years it demands about 18,236,008.70 tons (17,173kms x 2,590m3/km x 0.41ton/m3)of Portland cement which will be produced in Ethiopia and this drives the local cement factories to produce cement in their full capacity. So this explains that there is the mutual benefit between constructing PCC pavement and Cement Manufacturing Industries in Ethiopia.

The average road network growth rate 8.4%, then in the coming 10 years ERA will construct 17,173kms new asphalt concrete roads.As result to construct 17,173kms JUCP in the coming 10 years it demands an additional amount about 18,236,008.70 tons (17,173kms x 2,590m3/km x 0.41ton/m3) of Portland cement which will be produced in Ethiopia.

6. CONCLUSION AND RECOMMENDATION

6.1.Conclusion

Sustainability is critical in development of a newhighway construction and rehabilitation projects. This study handled the sustainability to analyze the economic, environment, and social impacts for jointed unreinforced concrete rigid pavement and hot mix cut back asphalt flexible pavement under the category of main trunk road with in Ethiopia. As a design parameter the researcher assumed that the flexible pavement was designed for 30 million CESAL with an average traffic growth rate 9%, and then the rigid pavement had been designed for 80million CESAL with an average traffic growth rate 5% per annum for the next 20 yrs.

These two pavementswere designed in pavement newly constructingor up grading projects and would be 1 km longitudinal length , and 7 m wide (a typical two-lane in free flow without median, and each lane is 3.5m wide) with high volumes of traffic asphalt and cement concrete roadwaysections were used that have roughly the same functionality.

The quantities of pavement were computed based on the ERA Pavement Design Manuals, 2013 and specifications. Pavement materials Price for each alternative was estimated based on 2016 market prices. In this study, 40 years was assumed as the life cycle term for the analysis boundary, because it only applied JUCP, which has a 40 year life cycle as a pavement design. For the input data the costs, the energy consumptions, the energy emissions and the waste generations of each pavement alternatives were used, which were followed by explanation of the outputs, were explained.

The economic analysis result together with the qualitative comparison in the life cycle cost analysis,the environmental and the social impacts had been considered to select the pavement alternativeto be adopted for the study project.

The result indicated that the estimated initial construction costs of each alternative, the study JUCP and HMA pavements were incurred ETB 10,418,653.50 and ETB 6,582,326.89 per km respectively. This concluded that the initial construction costs of the study JUCP pavement was highly expensive than the HMA and it has a cost increment of just over 58.28%.

However, from life cycle cost analysis of the alternatives, the study JUCP and HMA pavements were incurred ETB 14,609,738.82and ETB 22,775,868.47 per km respectively. Reversely, the resultinferred that the life cycle cost of the study HMA pavement was more expensive than the JUCP and the study jointed unreinforced cement concrete rigid pavement have the upper hand over flexible pavements with a cost saving of about56%. This is the result of the unique properties of cement concrete which give its durability and hence lower maintenance, rehabilitation and social cost and high load bearing capacity and longer design life.

The study also found that social costs (road user and emission costs) play an important role in pavement life cycle costing and it is necessary to take it into account to conclusively choose the best alternative, then the study cement concrete rigid pavement was consumed lower social cost than HMA pavementfor the entire 40years life cycle.

The research work also analyzed that, the construction of a 1-km section of a typical two-lane free flow roadway requires 8.52 x 10^6 MJ of energy in the case of JUCP pavement, and 4.69 x 10^6 MJ for HMA pavementin the first three sub-phases(extraction, manufacturing & placement) of the alternative pavement in the entire 40years life cycle. This shows that for the design life cycle, the study JUCP is consumed more energy than HMA flexible pavement.

Moreover, JUCP and HMA pavements generate 720.20 and 812.20 Metric Tons of wastes, respectively, in the first three sub-phases of the alternative pavement in life cycle.This indicates that for the entire 40years life cycle, the study HMA pavement is generated more waste than JUCP.

At last, the study also addressed that the mutual and consequential benefits of developing rigidpavementsto Cement Manufacturing Industries in Ethiopia.Hence the decision of the study JUCP alternative derived from due to having 6.6million tons of current cement production capacity in the country, as result to construct 17,173kms JUCP in the strategy plan of ERA in the coming 10 years it demands about 18,236,008.70 tons (17,173kms x 2,590m3/km x 0.41ton/m3) of Portland Cement which will be produced in Ethiopia as an additional product and this drives the local cement factories to produce cement in their full capacity to maximize their profit and would create new employment roughly for 36,000 citizensfor the employment of ten years. In addition to generate billion birr of tax revenue, the alternative choice of the study JUCP will have a foreign exchange saving effect about 252 billion birr to the country in the coming ten years by substituting the current imports of bitumen mixture cut-backs asphalt for flexible pavement construction. So this explains that there are the mutual and consequential benefitsbetween developing rigid pavements and the Cement Manufacturing Industries in Ethiopia.

Therefore, the analysis results indicated that the study JUCP is the better sustainable choice between the alternatives as it requires the lower life-cycle cost and has relativelythe less unfavorable impact on environment and social when compared to the HMA flexible pavement andthe use of cement concrete as a road construction material is eminent.

6.2.Recommendation

A key aspect of this research is the application of the sustainability concept to the roadway life cycle from economy, socialand energy perspectives. The associated findings enhance our understanding of the relationship between sustainability and roadway pavements.

Likewise, the purpose of this research was to generate findings from the hypothesized problems addressed in the research questions. Therefore the recommendation was focused in addressing the sustainability between jointed unreinforced cement concrete rigid pavement and hot mix cut back asphalt flexible pavement in the context of Ethiopia.

Even though the initial investment of Portland cement concrete (rigid) pavement alternative is high, maintenance expenditure in later years would be insignificant in relative terms. This will also reduce the frequency maintenance activities on the road, hence reduced disruptions to traffic resulting in savings in travel time as well as vehicle operating costs.Moreover cement concrete rigid pavements use less granular material or aggregate throughout the pavement structure because base layers are not needed. These materials are growing scarcer, and hauling aggregates represents a significant fraction of the environmental and social impact of highway construction.

Therefore, the substantial recommendations from the study are as follows:-

- To ensure that roadway construction is fully sustainable, other factors such as Resource Consumption (land &water), Health &Safety (physical &psychological), Ecological effects, Inflows which have not been traced all the way from the “cradle” and Outflows which have not been traced all the way to the “grave” should be considered in addition to economic, environmental and social impacts. Sufficient knowledge of all of these factors will help material producers and suppliers, construction contractors, Government Agencies, and other project stakeholders involved in the roadway lifecycle create sustainable roadways.
- Although the study JUCP is an economical and sustainable choice than HMA pavement, in practice, more factors will be considered when a pavement decision needs to be made. For instance, the factors of climate, foundation type, source of funds, and design requirements all need to be taken into consideration.
- For pavement sustainability performance is also critical. A huge budget and quantity of materials are used when designing the normal strength PC and HMA concrete for

construction of pavements. Use of high performance can significantly reduce the thickness and the total construction costs in both JUCP and HMA main Pavements construction.

- The study indicated that material extraction and production are two critical stages whereoptimization of energy and material is required in both alternatives.Then use of recycled materials in the construction of roadways will eliminate the energy consumed andwaste generated during the production of virgin materials.
- Cement is the driving element in the consumption of energy and generation of waste forPCC pavements. If low percentages of cement are replaced with pozzolanic materials, the amounts of energy consumed and waste generated in the productionof cement concrete pavements will be substantially reduced.Hence, by using PPC instead of OPC for cement concrete pavement one can reduce up to 25% greenhouse gases emission to the air.
- A preplanned material waste management plan should be developed and implemented onroad projects. The plan should use the "principle of 4R's" (Reduce, Recover, Reuse, andRecycle) for the materials wasted during the roadway lifecycle. Incorporation of arequirement for a waste management plan in contracts can help minimize waste duringthe construction process.
- As indicated in the conclusions, the extensive use of cement concrete pavement is expected in the future thus it should be accompanied with multiple researches to optimize it usage, to study its performance and to investigate its suitability to the erratic and variable climate zones of Ethiopia and selection of the appropriate pavement type has great impact to ensure the sustainability of road construction in the future generation of Ethiopia.
- Finally, in this study, only one type of rigid pavement was reflected and future studies try to include other types of rigid pavements (like JRCP &JCRCP) to get a broader view on this issue in the context of Ethiopia.

RESEARCH DISSEMINATION

The aim of this researchwas to investigate the existing conditions and to propose expanding the use of rigid pavements in the future development of road infrastructure in Ethiopia for sustainability.

This finding provided recommendations to ERA and other stakeholders for better-informed decision making for road construction projects that choose concrete pavement as alternative, and the result can serve as a basis for further study.

Finally, it can be published and distributed for other stakeholders through different electronic Medias and presenting to ERA sessions and also in the annual meeting of Ethiopian Civil Engineers and Ethiopian Construction Technology and Management Professional Associations and the likes.

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ANNEXES

Annex-1:Design ofthe Compacted Asphalt Paving Mixture Using Ms Excel.

DESIGN OF THE COMPACTED HMA PAVING MIXTURE

a) Constituents:

Material	Specific Gravity				Test Method		Mixture Compositon % by weight of:			
	Aparrent		Bulk Dry		AASHTO Method	ASTM Method	Total Mix		Dry(Total) Aggregate	
Asphalt Cement	Gb	1.03			T228	D70	Pb	?	P'b	6.5
Coarse Aggregates	Gb1	2.69	G1	2.61	T85	C127	P1	?	P'1	56.05
Fine Aggregates	Gb2	2.83	G2	2.71	T84	C128	P2	?	P'2	43.95
Mineral Filler					T100	D854				

b) Paving Mixture:

	Bulk specific gravity of compacted paving mixture sample, Gmb	
	Maximum Specific Gravity of Paving Mixture, Gmm	
Gmb =	2.340	(ASTM D 2726)
Gmm =	2.445	(ASTM D 2041)
Pmm =	100%	Total loose mixture in %

Analysis

#1). Specific Gravity of Materials(Asphalt cement, Coarse & Fine aggregates)

For Asphalt

Given	P'b	6.5
	P'1	56.05
Required	Pb =	(p'b x 100) / (p'b +100)
% by wt	Pb =	6.10%

For Coarse Aggregate

Given	P'b	6.5
	P'1	56.05
Required	P1 =	(p'1 x 100) / (p'b +100)
% by wt	P1 =	52.63%

For Fine Aggregate

Given	P'b	6.5
	P'2	43.95
Required	P2=	(p'2 x 100) / (p'b +100)
% by wt	P2 =	41.27%

#2). Calculate the Bulk Specific Gravity of the aggregate combination in the paving mixture, (Gsb)

Specific Gravity of Total Aggregates (Bulk Dry) , Gsb= P1 + P2 / ((P1/G1) +(P2/G2))

Gsb = 2.65%

#3). Calculate the EFFECTIVE Specific Gravity of Aggregate. (Gse)

Gse = Pmm - Pb / (Pmm/Gmm) - (Pb/Gb)

Gse = 2.68%

#4). Calculate the Apparent Specific Gravity of the aggregate combination in the paving mixture, (Gsa)

Apparent Specific Gravity, Gsa = , Gsa= P1 + P2 / ((P1/Gb1) +(P2/Gb2))

Gsa = 2.75%

#5). Calculate Asphalt Absorption of Aggregate. (Pba)

Asphalt Absorption Capacity of Aggregate , Pba= 100(Gse - Gsb)xGb / (Gsb xGse)

Pba = 45.86%

#6). Calculate the Effective Asphalt Content of the Mixture

EFFECTIVE Asphalt Content of the Mixture. (Pbe) = Pb - (Pba/100)xPs

Pbe = 6.10%

Where: Ps = Agrregate % by total wt of mixture(P1+P2)

#7). Calculate the % Voids in the Mineral Aggregate in the compacted paving mixture. (VMA)

VMA = 100 - (GmbxPs/Gsb)

VMA = 17.18%

#8). Calculate the % Air Voids in the compacted mixture,(Pa)

Pa = 100 (Gmm - Gmb)/Gmm

Pa = 4.29%

#9). Calculate the % Voids Filled with Asphalt in the compacted mixture. (VFA)

VFA = ((VMA - Pa)/VMA)x100

VFA = 75.01%

DESIGN OF THE COMPACTED HMA PAVING MIXTURE

a) Constituents:

Material	Specific Gravity				Test Method		Mixture Compositon % by weight of:			
	Aparrent		Bulk Dry		AASHTO Method	ASTM Method	Total Mix		Dry(Total) Aggregate	
Asphalt Cement	Gb	1.03			T228	D70	Pb	?	P'b	5.6
Coarse Aggregates	Gb1	2.69	G1	2.61	T85	C127	P1	?	P'1	56.05
Fine Aggregates	Gb2	2.83	G2	2.71	T84	C128	P2	?	P'2	43.95
Mineral Filler					T100	D854				

b) Paving Mixture:

Bulk specific gravity of compacted paving mixture sample, Gmb		
Maximum Specific Gravity of Paving Mixture, Gmm		
Gmb =	2.340	(ASTM D 2726)
Gmm =	2.445	(ASTM D 2041)
Pmm =	100%	Total loose mixture in %

Analysis

#1). Specific Gravity of Materials(Asphalt cement, Coarse & Fine aggregates)

For Asphalt

Given	P'b	5.6
	P'1	56.05
Required	Pb =	(p'b x 100) / (p'b +100)
% by wt	Pb =	5.30%

For Coarse Aggregate

Given	P'b	5.6
	P'1	56.05
Required	P1 =	(p'1 x 100) / (p'b +100)
% by wt	P1 =	53.08%

For Fine Aggregate

Given	P'b	5.6
	P'2	43.95
Required	P2=	(p'2 x 100) / (p'b +100)
% by wt	P2 =	41.62%

#2). Calculate the Bulk Specific Gravity of the aggregate combination in the paving mixture, (Gsb)

Specific Gravity of Total Aggregates (Bulk Dry) , Gsb=	P1 + P2 / ((P1/G1) +(P2/G2))
Gsb =	2.65%

#3). Calculate the EFFECTIVE Specific Gravity of Aggregate. (Gse)

Gse =	Pmm - Pb / (Pmm/Gmm) - (Pb/Gb)
Gse =	2.65%

#4). Calculate the Apparent Specific Gravity of the aggregate combination in the paving mixture, (Gsa)

Apparent Specific Gravity, Gsa = , Gsa=	P1 + P2 / ((P1/Gb1) +(P2/Gb2))
Gsa =	2.75%

#5). Calculate Asphalt Absorption of Aggregate. (Pba)

Asphalt Absorption Capacity of Aggregate , Pba=	100(Gse - Gsb)xGb / (Gsb xGse)
Pba =	-6.23%

#6). Calculate the Effective Asphalt Content of the Mixture

EFFECTIVE Asphalt Content of the Mixture. (Pbe) =	Pb - (Pba/100)xPs
Pbe =	5.30%

Where: Ps = Agrregate % by total wt of mixture(P1+P2)

#7). Calculate the % Voids in the Mineral Aggregate in the compacted paving mixture. (VMA)

VMA =	100 - (GmbxPs/Gsb)
VMA =	16.48%

#8). Calculate the % Air Voids in the compacted mixture,(Pa)

Pa =	100 (Gmm - Gmb)/Gmm
Pa =	4.29%

#9). Calculate the % Voids Filled with Asphalt in the compacted mixture. (VFA)

VFA =	((VMA - Pa)/VMA)x100	
VFA =	73.94%	But not equal to 75%

Annex-2: Concrete Mix Design for Jointed Unreinforced Concrete Pavement.

JUCP Concrete Mix Design

Absolute Volume Method(Metric)

Conditions and Specifications: Concrete is required for a pavement that will be exposed to a moderate hot environment. A specified compressive strength, of 35 MPa is required at 28 days. Air entrainment is required. Slump should be between 25 mm and 75 mm (ACI 211.1). A nominal maximum size aggregate of 25 mm is required.

The materials available are as follows:

Cement: OPC with a relative density of 3.0.

Coarse aggregate: Well-graded, 25-mm nominal maximum- size rounded gravel (ASTM C 33 or AASHTOM 80) with an oven dry relative density of 2.68, absorption of 0.5% (moisture content at SSD condition) and oven dry rodded bulk density (unit weight) of 1600 kg/m3. The laboratory sample for trial batching has a moisture content of 2%.

Fine aggregate: Natural sand (ASTM C 33 or AASHTO M6) with an oven dry relative density of 2.64 and absorption of 0.7%. The laboratory sample moisture content is 6%.

The fineness modulus is 2.80.

Air-entraining admixture: Wood-resin type (ASTM C 260 orAASHTO M 154).

Water reducer: ASTM C494 (AASHTOM194). This particular admixture is known to reduce water demand by 10% when used at a dosage rate of 3 g (or 3 mL) per kg of cement. Assume that the chemical admixtures have a density close to that of water, meaning that 1 mL of admixture has a mass of 1 g. From this information, the task is to proportion a trial mixture that will meet the above conditions and specifications.

Strength: The design strength of 35 MPa is greater than the 31 MPa required in ACI 318 (2002) for the exposure condition. Since no statistical data is available, f'_{cr} (required compressive strength for proportioning) from ACI 318 is equal to $f'_c + 8.5$. Therefore, $f'_{cr} = 35 + 8.5 = 43.5$ MPa.

Water to Cement Ratio: For the exposure condition, the maximum water to cementitious material ratio should be 0.45. The recommended water to cementitious material ratio for an f'_{cr} of 43.5 MPa is 0.31 from ASTM C 150 (AASHTO M 85), ASTM C 1157 and ASTM C 595 (AASHTO M240) or interpolated from ACI 211.1 and ACI 211.3 or ASTM C 31 (AASHTO T 23). [(45 – 43.5)(0.34 – 0.30)/(45 – 40)] + 0.30=0.312. Since the lower water to cement ratio governs, the mix must be designed for 0.31. If a plot from trial batches or field tests had been available, the water to cement ratio could have been extrapolated from that data.

Air Content: For moderate exposure condition, ACI 211.1 and ACI 318 recommend a target air content of 4.5% for a 25-mm aggregate. Therefore, design the mix for 3.5% to 8% air and use 8% (or the maximum allowable) for batch proportions. The trial-batch air content must be within ±0.5 percentage points of the maximum allowable air content.

Note: The air content in job specifications should be specified to be delivered within –1 to +2 percentage points of the table target value for moderate and severe exposures.

Slump: The slump is specified at 25 mm to 75 mm. Use 75 mm ±20 mm for proportioning purposes.

Water Content: ACI 211.1 and ACI 318 recommend that a 75-mm slump, air-entrained concrete made with 25-mm nominal maximum-size aggregate should have a water content of about 175 kg/m3. However, rounded gravel should reduce the water content of the table value by about 25 kg/m3. Therefore, the water content can be estimated to be about 150 kg/m3 (175 kg/m3 minus 25 kg/m3). In addition, the water reducer will reduce water demand by 10% resulting in an estimated water demand of 135 kg/m3.

Note: ACI 211.1 assured that, for some concretes and aggregates, the water estimates can be reduced by approximately 10 kg for sub-angular aggregate, 20 kg for gravel with some crushed particles, and 25 kg for a rounded gravel to produce the specified slumps.

Cement Content. The cement content is based on the maximum water-cement ratio and the water content.

Therefore, 135 kg/m3 of water divided by a water-cement ratio of 0.31 requires a cement content of 435 kg/m3; this is greater than the 310 kg/m3 required for exposure condition.

Coarse-Aggregate Content: The quantity of 25-mm nominal maximum-size coarse aggregate can be estimated from ASTM C 29 (AASHTO T 19) and ACI 211.1. The bulk volume of coarse aggregate recommended when using sand with a fineness modulus of 2.80 is 0.67. Since it has a bulk density of 1600 kg/m3, the oven dry mass of coarse aggregate for a cubic meter of concrete is 1600 x 0.67 = 1072 kg

Admixture Content: For 4.5% air content, the air entraining admixture manufacturer recommends a dosage rate of 0.5 g per kg of cement. From this information, the amount of air-entraining admixture per cubic meter of concrete is 0.5 x 435 = 218 g or 0.218 kg

The water reducer dosage rate of 3 g per kg of cement results in 3 x 435 = 1305 g or 1.305 kg of water reducer per cubic meter of concrete

Fine-Aggregate Content: At this point, the amounts of all ingredients except the fine aggregate are known. In the absolute volume method, the volume of fine aggregate is determined by subtracting the absolute volumes of the known ingredients from 1 cubic meter. The absolute volume of the water, cement, admixtures and coarse aggregate is calculated by dividing the known mass of each by the product of their relative density and the density of water. Volume computations are as follows:

Water = 135/1 x 1000 = 0.135 m3

Cement = 435/3.0 x 1000 = 0.145 m3

Air = 8.0/100 = 0.080 m3

Coarse aggregate = 1072/2.68 x 1000 = 0.400 m3

Total volume of known ingredients = 0.760 m3

The calculated absolute volume of fine aggregate is then 1 – 0.76 = 0.24 m3.The mass of dry fine aggregate is 0.24 x 2.64 x 1000 = 634 kg

The mixture then has the following proportions before trial mixing for one cubic meter of concrete:

Water -----------------------------------135 kg

Cement ---------------------------------435 kg

Coarse aggregate (dry) ------------- 1072 kg

Fine aggregate (dry) -------------------634 kg

Total mass ================2276 kg

Air-entraining admixture -----------0.218 kg

Water reducer -----------------------1.305 kg

Slump 75 mm (±20 mm for trial batch)

Air content 8% (±0.5% for trial batch)

Estimated concrete = 135 + 435 + (1072 x 1.005*) density (using + (634 x 1.007*)

SSD aggregate) = 2286 kg/m3

The liquid admixture volume is generally too insignificant to include in the water calculations. However, certain admixtures, such as shrinkage reducers, plasticizers, and corrosion inhibitors are exceptions due to their relatively large dosage rates; their volumes should be included.

Moisture: Corrections are needed to compensate for moisture in and on the aggregates. In practice, aggregates will contain some measurable amount of moisture. The dry batch weights of aggregates, therefore, have to be increased to compensate for the moisture that is absorbed in and contained on the surface of each particle and between particles. The mixing water added to the batch must be reduced by the amount of free moisture contributed by the aggregates. Tests indicate that for this mix, coarse aggregate moisture content is 2% and fine-aggregate moisture content is 6%.

With the aggregate moisture contents (MC) indicated, the trial batch aggregate proportions become

Coarse aggregate (2% MC) = 1072 x 1.02 = 1093 kg

Fine aggregate (6% MC) = 634 x 1.06 = 672 kg

Water absorbed by the aggregates does not become part of the mixing water and must be excluded from the water adjustment. Surface moisture contributed by the coarse aggregate amounts to 2% – 0.5% = 1.5%; that contributed by the fine aggregate is, 6% – 0.7% = 5.3%. The estimated requirement for added water becomes 135 – (1072 x 0.015) – (634 x 0.053) = 85 kg

The estimated batch weights for one cubic meter of concrete are revised to include aggregate moisture as follows:

Water (to be added) ----------------------------85 kg

Cement ---435 kg

Coarse aggregate (2% MC, wet) -----------1093 kg

Fine aggregate (6% MC, wet) -----------------672 kg

Total ---2285 kg

Air-entraining admixture---------------------0.218 kg

Water reducer -------------------------------1.305 kg

Trial Batch: At this stage, the estimated batch weights should be checked by means of trial batches or by full-size field batches. Enough concrete must be mixed for appropriate air and slump tests and for casting the three cylinders required for 28-day compressive-strength tests, plus beams for flexural tests if necessary. For a laboratory trial batch it is convenient, in this case, to scale down the weights to produce 0.1 m3 of concrete as follows:

Water 85 x 0.1 -------------------------------= 8.5 kg

Cement 435 x 0.1 --------------------------= 43.5 kg

Coarse aggregate (wet) 1093 x 0.1 = 109.3 kg

Fine aggregate (wet) 672 x 0.1 = 67.2 kg

Total 228.5 kg

Air-entraining admixture 218 g x 0.1 = 21.8 g or 21.8 mL

Water reducer 1305 g x 0.1 = 130 g or 130 mL

The above concrete, when mixed, had a measured slump of 100 mm, an air content of 9%, and a density of 2274 kg per cubic meter. During mixing, some of the premeasured water may remain unused or additional water may be added to approach the required slump. In this mix, although 8.5 kg of water was calculated to be added, the trial batch actually used only 8.0 kg. The mixture excluding admixtures therefore becomes:

Water ----------------------------------8.0 kg

Cement -------------------------------43.5 kg

Coarse aggregate (2% MC) ------109.3 kg

Fine aggregate (6% MC) -----------67.2 kg

Total ---------------------------------228.0 kg

The yield of the trial batch is 228.0 kg /2274 kg/m3 = 0.10026 m3

The mixing water content is determined from the added water plus the free water on the aggregates and is calculated as follows:

Water added 8.0 kg

Free water on coarse aggregate = (109.3/ 1.02) x 0.015* = 1.61 kg

Free water on fine aggregate = (16.7/0.62)x 0.053* = 3.36 kg

Total water……………………………………………………12.97 kg

The mixing water required for a cubic meter of the same slump concrete as the trial batch is 12.97/0.10026 = 129 kg

Note: (2% MC – 0.5% absorption) ÷ 100 = 0.015

(6% MC – 0.7% absorption) ÷ 100 = 0.053

Batch Adjustments: The measured 100-mm slump of the trial batch is unacceptable (above 75 mm ±20 mm max.), the yield was slightly high, and the 9.0% air content as measured in this mix is also too high (more than 0.5% above 8.5% max.). Adjust the yield and re-estimate the amount of air-entraining admixture required for 8% air content and adjust the water to obtain a 75-mm slump.

Increase the mixing water content by 3 kg/m3 for each 1% by which the air content is decreased from that of the trial batch and reduce the water content by 2 kg/m3 for each 10 mm reduction in slump. The adjusted mixture water for the reduced slump and air content is (3 kg water x 1 percentage point difference for air) – (2 kg water x 25/10 for slump change) + 129 = 127 kg of water.

With less mixing water needed in the trial batch, less cement also is needed to maintain the desired water-cement ratio of 0.31. The new cement content is 127/0.31 = 410 kg

The amount of coarse aggregate remains unchanged because workability is satisfactory. The new adjusted batch weights based on the new cement and water contents are calculated after the following volume computations:

Water = 127/1 x 1000 = 0.127 m3

Cement = 4103.0 x 1000 = 0.137 m3

Coarse aggregate (dry) = 1072/2.68 x 1000 = 0.400 m3

Air = 8/100 = 0.080 m3

Total 0.744 m3

Fine aggregate volume = 1 – 0.744 = 0.256 m3

The weight of dry fine aggregate required is 0.256 x 2.64 x 1000 = 676 kg

Air-entraining admixture (the manufacturer suggests reducing the dosage by 0.1 g to reduce air 1 percentage point) = 0.4 x 410 = 164 g or mL

Water reducer = 3.0 x 410 = 1230 g or mL

Adjusted batch weights per cubic meter of concrete are:

Water ------------------------------127 kg

Cement ----------------------------410 kg

Coarse aggregate (dry) --------1072 kg

Fine aggregate (dry) -------------676 kg

Total ------------------------------2285 kg

Air-entraining admixture 164 g or mL

Water reducer 1230 g or mL

Estimated concrete = 127 + 410 + (1072 x 1.005) density (aggregates + (676 x 1.007) at SSD) = **2295 kg/m3**

Annex-3: Cost Break down Analysis of Direct Costs

	I. Manpower Index Factor			
I.	Working Hours per week	8 hrs 6 days	**48.00**	hrs
II.	Working day per week		**6.00**	days
III.	Working Hours per month	52we/mo	**208.00**	hrs/month
IV.	Working days per month		**26.00**	days/month
No.	**Description**	**Number of Days**	**Calculations**	**Index**
A.	Basic Salary			1.00
B.	Index Factors			
B1	Annual Leave	16 days		
B2	Sick Leave	10 days		
B3	Mourning Leave	3 days		
	(Total)	**29 days**	**=29/(12x26)**	**0.09**
B4	Public Holiday		=13/(12*26)	0.04
B5	Compensation (1year)		=30/(12*26)	0.10
B6	Accident Compensation			0.02
B7	Health Insurance			0.01
B8	Labor Affairs			0.01
B9	Idle Time Pay (Rain and Others)		=60/(12*26)	0.19
B10	Dislocation Benefit*			0.60
B11	Desert Allowance			0.00
B12	Company Cost Related to Travel*			0.03
B13	Contingency			0.05
	Total IF (A+B)			**2.14**
	Take IF = 2.14	**(for skilled labor)**		**2.14**
	Take IF = 1.42	**(for daily labor)**		**1.45**

DAYWORKS			
Item No.	**Item Description**	**Unit**	**Rate (ETB)**
D.1	**Labour**		
D.1.1	Headman (Trades)	Hr	123.64
D.1.2	Headman (Labourer)	Hr	11.13
D.1.3	Labourer	Hr	10.43
D.1.4	Driver (Light)	Hr	41.21
D.1.5	Driver (Heavy – License A)	Hr	41.21
D.1.6	Plant Operator, Light	Hr	51.52
D.1.7	Plant Operator, Heavy	Hr	82.43
D.1.8	Mason	Hr	30.91
D.1.9	Carpenter	Hr	25.76
D.1.10	Steel Fixer	Hr	25.76
D.1.11	Welder	Hr	25.76
D.1.12	Fitter	Hr	25.76
D.1.13	Electrician	Hr	30.91
D.1.14	Machine Attendant	Hr	30.91
D.1.15	Watchman	Hr	6.96
D.1.16	Surveyor	Hr	51.52
D.1.17	Surveyor Assistant	Hr	41.21
D.2	**Materials**		
D.2.1	Cement, Ordinary Portland (or equivalent in bags)	ton	3,099.80
D.2.2	Coarse crushed aggregate	m3	751.56
D.2.3	Mild steel bars	ton	26,549.55
D.2.4	High yield steel bars	ton	29,499.50
D.2.5	Sawn Hardewood	m^3	3,599.80
D.2.6	Sawn Softwood	m^3	1,799.90
D.2.7	Plywood 6mm	No.	90.00
D.2.8	Road Chippings	m^3	394.89
D.2.9	Sand	m^3	733.77
D.2.11	Wire Nails(Various size)	Kg	26.50
D.2.12	Crusher Dust	m3	322.65
D.2.13	Cutback Bitumen MC-30	lt	56.50
D.2.14	Bitumen, pen grade 60/70	lt	29.25
D.3	**Equipment**		
D.3.1	Rubber tyred loader 2.5m3	Hr	1,122.00
D.3.2	Tipper Truck 12m3	Hr	462.68
D.3.3	Tipper truck, 8m3	Hr	267.31
D.3.4	Wheel Loader 2.5m3	Hr	592.27
D.3.5	Flat-bed truck, 10 tonnes	Hr	744.75
D.3.6	Low loader, minimum capacity 30 tonnes	Hr	476.82
D.3.7	Excavator, back-actor 1.5 - 3m3	Hr	644.52
D.3.8	Dozer, 120 kw	Hr	1,232.31
D.3.9	Dozer, 200 kw	Hr	2,039.65
D.3.10	Motor Grader(130-140HP)	Hr	1,334.34
D.3.11	Water truck(with spray bar) 5,000 litres	Hr	531.25
D.3.12	Compactor, steel wheeled, 10-12 tonnes	Hr	545.13
D.3.13	Compactor, vibratory, 10-12 tonnes	Hr	38.68
D.3.14	Compactor, pneumatic, 10 - 12 tonnes	Hr	546.51
D.3.15	Compactor, vibratory, 1.5 tonnes	Hr	180.03
D.3.16	Air Compressor, 4,000 l/min	Hr	101.36
D.3.17	Water Pump, 100mm	Hr	38.54
D.3.18	Bitumen distributor, with spray bar, minimum capacity 3,000 litres	Hr	862.50
D.3.19	Concrete mixer, minimum capacity 500 litres of loose aggregates	Hr	48.77
D.3.20	Power Generator 4KVA	Hr	836.55
D.3.21	Mobile Crane 10t	Hr	1,557.15
D.3.22	Welding Set(500AMP)	Hr	34.93
D.3.23	Concrete Vibrator	Hr	29.30
D.3.24	4WD Pickup	Hr	238.03

	INDEXED HOURLY WAGE Civil Workers, Technicians, Crafts Men & Others			
Item	Classification	Monthly Rate In Birr	Hourly Rate In Birr	Indexed Hourly Rate In Birr
I	Supervisors			
1	Project Manager	50,000.00	240.38	515.16
2	Office Engineer	22,000.00	105.77	226.67
3	Construction Forman III	16,000.00	76.92	164.85
4	Construction Forman II	12,000.00	57.69	123.64
5	Construction Forman I	8,000.00	38.46	82.43
6	Chief Surveyor	8,000.00	38.46	82.43
II	Technicians			
1	Surveyor III	5,000.00	24.04	51.52
2	Assistant Surveyor II	4,000.00	19.23	41.21
3	Roadman II	1,500.00	7.21	15.45
4	Soil Technician II	4,000.00	19.23	41.21
5	Surveyor II & Quantity Surveyor	4,000.00	19.23	41.21
6	Draftsman II	4,000.00	19.23	41.21
7	Engineering Aid III	4,000.00	19.23	41.21
8	Powder man	4,500.00	21.63	46.36
III	Craftsman			
1	Carpenter I	2,000.00	9.62	20.61
2	Carpenter II	2,500.00	12.02	25.76
3	Carpenter III	3,000.00	14.42	30.91
4	Bar Bender I	1,500.00	7.21	15.45
5	Bar Bender II	2,500.00	12.02	25.76
6	Mason I	2,000.00	9.62	20.61
7	Mason II	3,000.00	14.42	30.91
8	Mason III	3,500.00	16.83	36.06
IV	Operator & Drivers			
1	Equipment Operator I	4,000.00	19.23	41.21
2	Light Equipment Operator II	5,000.00	24.04	51.52
3	Heavy Equipment Operator III	6,000.00	28.85	61.82
4	Heavy Equipment Operator IV	8,000.00	38.46	82.43
5	Heavy Equipment Operator V	10,000.00	48.08	103.03
6	Light Vehicle Driver	4,000.00	19.23	41.21
7	Heavy Truck Driver	4,000.00	19.23	41.21
8	Helper I	1,750.00	8.41	12.17
V	Others			
1	Plant Administrator	4,500.00	21.63	46.36
2	Project Administrator	4,500.00	21.63	46.36
3	Secretary II	2,000.00	9.62	20.61
4	Clerk III	2,250.00	10.82	23.18
5	Clerk II	1,800.00	8.65	18.55
6	Clerk I	1,350.00	6.49	13.91
7	Accountant II	3,500.00	16.83	36.06
8	Accountant I	3,000.00	14.42	30.91
9	Health Assistant	3,750.00	18.03	38.64
10	Semi Skilled Labour	1,600.00	7.69	11.13
11	Unskilled Labour	1,500.00	7.21	10.43
12	Ganger	1,600.00	7.69	11.13
13	Mechanic	4,000.00	19.23	41.21
14	Electrician and Plumbers	3,000.00	14.42	30.91
15	Machinist	3,000.00	14.42	30.91
16	Welder	2,500.00	12.02	25.76
17	Chies Guard	1,500.00	7.21	10.43
18	Guards	1,000.00	4.81	6.96

III. Basic Material Price List for Cost Analysis

Item	Material Description	Unit	Unit Price in Birr at A.A.	Transport cost	Total Cost	Remark
1	Cement Muger Cement	Qut.	250.00	59.98	309.98	Total Cost is at project site
2	Gas Oil (NOC)	Lts.	16.10	1.80	17.90	"
3	Gasoline (NOC)	Lts.	17.10	1.50	18.60	"
4	Lubricants	Kg.	46.00	1.50	47.50	"
5	Reinforcement Bar Ø6	Kg.	18.00	1.50	19.50	
6	Reinforcement Bar Ø8 - Ø20 Grade 60	Kg.	28.00	1.50	29.50	
7	Reinforcement Bar Ø24 - Ø32 Grade 60	Kg.	28.00	1.50	29.50	"
8	Nails	Kg.	25.00	1.50	26.50	"
9	Reinforcement Wire	Kg.	20.00	1.50	21.50	"
10	Eucalyptus Poles Ø12, 4 mts long	Pcs.	24.00	1.50	25.50	"
11	Lumber 2.5 or 5 cm	m^3	3,000.00	599.80	3,599.80	"
12	Dynamite	Ton	56,000.00	2,999.00	58,999.00	"
13	Fuses	Lm	1.54	1.50	3.04	"
14	Detonator	Pcs.	8.64	1.50	10.14	"
15	Cut back Asphalt grades MC-30	kg.	38.52	1.50	40.02	"
16	Cut back Asphalt grades RC-70	kg.	39.67	1.50	41.17	"
17	Bitumen grade AC 80/100 & 85/100	kg.	21.00	1.50	22.50	"
18	Sand	m^3	733.77		733.77	"
19	Coarse Aggregate	m^3	751.56		751.56	"
20	Gabion Boxes	m^3	640.00	16.00	656.00	"
21	Gabion Mattress	m^3	640.00	16.00	656.00	"
22	Hot applied Thermoplastic	lt	608.50	1.50	610.00	"
23	Reflectorising Glass	Kg	368.50	1.50	370.00	"
24	100mm PVC Pipe	No	107.50	1.50	109.00	"
25	150mm PVC Pipe	No	120.00	1.50	121.50	"
26	Elastomer	No	20,264.12	59.98	20,324.10	"
27	Expansion Joint Material	No	480.00	12.00	492.00	"
28	Sealant joint material	m	220.00	.	220.00	"
29	Bolts and Accessories	Ea	2,200.00		2,200.00	"
30	Paint	No	10.00		10.00	"
N.B.	Tthe unit prices are not inclusive of VAT					

EQUIPMENT RENTAL RATE

						Gas oil	15.60						
Item	Equipment Type	Make Model or Supplier	Delivery Price in Birr	Owning Cost		Total Amount Cost	Operating Cost				Total Operating Cost	Rate/Hr	Remark
				Cost	Investment Cost		Fuel Cost	Lub. Cost	Maint.& Rep. Cost	Tire Cost			
				A	B	C=A+B	D	E	F	G	H=D+E+F+G	I=C+H	
	I. Earth Work Equipment												
1	Dozer D9N	CAT - D9N	8,566,074.00	571.07	142.77	713.84	936.00	140.40	571.07		1,647.47	2,361.31	
2	Dozer D8R	CAT - D8R	7,962,690.00	530.85	132.71	663.56	764.40	114.66	530.85		1,409.91	2,073.46	
3	Dozer D7R	CAT - D74	5,410,152.00	360.68	90.17	450.85	577.20	86.58	360.68		1,024.46	1,475.30	
4	Grader 14 k	CAT - 14K	2,351,105.00	156.74	39.19	195.93	873.60	131.04	156.74	15.67	1,177.05	1,372.98	
5	Grader 140 H	CAT - 140K	2,211,883.00	147.46	36.86	184.32	748.80	112.32	147.46	14.75	1,023.32	1,207.65	
6	Track Type Loader	950H	4,030,000.00	268.67	67.17	335.83	468.00	70.20	268.67		806.87	1,142.70	
7	Wheel Loader	250 HP	2,869,020.00	191.27	47.82	239.09	218.40	32.76	191.27	19.13	461.55	700.64	
8	Wheel Loader	200 HP	2,459,160.00	163.94	40.99	204.93	187.20	28.08	163.94	16.39	395.62	600.55	
9	Dumper	1 m3	405,761.40	27.05	6.76	33.81	46.80	7.02	27.05	2.71	83.58	117.39	
10	Track Type Excavator	324DL	4,180,000.00	278.67	69.67	348.33	561.60	84.24	278.67		924.51	1,272.84	
11	Backhoe Excavator	120 Hp	3,606,768.00	240.45	60.11	300.56	93.60	14.04	240.45		348.09	648.66	
12	Backhoe Excavator	80 Hp	2,028,807.00	135.25	33.81	169.07	156.00	23.40	135.25		314.65	483.72	
14	Vibratory Compactor	8-10 ton	2,254,230.00	150.28	37.57	187.85	187.20	28.08	150.28		365.56	553.41	
14	Static Compactor	8-10 ton	1,803,384.00	120.23	30.06	150.28	249.60	37.44	120.23		407.27	557.55	
14	Pneumatic Tired Roller	20 ton	2,557,526.40	170.50	42.63	213.13	280.80	42.12	170.50		493.42	706.55	
15	Hand Tamper		1,200,178.00	80.01	20.00	100.01			80.01		80.01	180.03	
16	Crushing plant	75 ton	12,172,550.00	608.63	152.16	760.78	2,808.00	421.20	304.31		3,533.51	4,294.30	
17	Crushing plant	120 ton	16,295,800.00	814.79	203.70	1,018.49	3,588.00	538.20	407.40		4,533.60	5,552.08	
18	Generator	90 kw	891,832.00	59.46	14.86	74.32	795.60	119.34	59.46		974.40	1,048.71	
19	Generator	45 kw	631,986.60	42.13	10.53	52.67	670.80	100.62	42.13		813.55	866.22	
20	Wagon Driller		989,160.00	65.94	16.49	82.43	1,372.80	205.92	65.94		1,644.66	1,727.09	
21	Jack Hammer		1,963,451.00	130.90	32.72	163.62			130.90		130.90	294.52	
20	Hand Held Rock Driller	50kg	163,944.00	27.32	6.83	34.16			27.32		27.32	61.48	
22	Sand Washing Machine		1,501,120.00	100.07	25.02	125.09			100.07		100.07	225.17	
23	Air Compressor		445,722.75	29.71	7.43	37.14	31.20	4.7	29.71		65.59	102.74	
	II. Hauling Equipment												
1	Dump Truck 18m^3		2,140,000.00	107.00	26.75	133.75	234.00	35.10	107.00	26.75	402.85	536.60	
2	Dump Truck 14m^3		1,644,370.00	82.22	20.55	102.77	218.40	32.76	82.22	20.55	353.93	456.71	
3	Dump Truck 12m^3		1,769,440.00	88.47	22.12	110.59	218.40	32.76	88.47	22.12	361.75	472.34	
4	Dump Truck 8m^3		1,034,510.00	51.73	12.93	64.66	124.80	18.72	51.73	12.93	208.18	272.83	
5	Water Truck 14,000 Lit.		2,456,000.00	122.80	30.70	153.50	202.80	30.42	122.80	30.70	386.72	540.22	
6	Flat-bed truck, 10 tonnes		2,200,000.00	110.00	27.50	137.50	390.00	58.50	110.00	66.00	624.50	762.00	
7	Lowbed, 30 ton		2,869,020.00	143.45	35.86	179.31	624.00	93.60	143.45	86.07	947.12	1,126.44	
8	Station wagon 4 WD		2,854,782.61	142.74	35.68	178.42	15.60	2.34	142.74		160.68	339.10	
9	Pick up 4 WD		1,732,173.91	86.61	21.65	108.26	31.20	4.68	86.61	8.66	131.15	239.41	
10	Mobile Crane		4,966,555.00	248.33	62.08	310.41	858.00	128.70	248.33	49.67	1,284.69	1,595.10	
11	Tractor		621,000.00	31.05	7.76	38.81	187.20	28.08	31.05	6.21	252.54	291.35	
	III. Concrete Machine												
1	Concrete mixer 750/500 lts		304,376.57	38.05	9.51	47.56	31.20	4.68	38.05		73.93	121.49	
2	Concrete mixer 100/75 lts		50,750.00	6.34	1.59	7.93	31.20	4.68	6.34		42.22	50.15	
3	Concrete vibrator		76,182.21	9.52	2.38	11.90	15.60	2.34	9.52		27.46	39.37	
4	Concrete vibrator (small)		42,840.00	5.36	1.34	6.69	15.60	2.34	5.36		23.30	29.99	
5	Bar bend. & Cutting		76,240.08	9.53	2.38	11.91			9.53		9.53	21.44	
6	Welding machine		124,200.00	15.53	3.88	19.41			15.53		15.53	34.93	
7	Leath machine		331,200.00	41.40	10.35	51.75			41.40		41.40	93.15	
8	Drilling Machine		93,150.00	11.64	2.91	14.55			11.64		11.64	26.20	
	IV. Other Equipments												
1	Jack hammer		52,585.94	6.57	1.64	8.22			6.57		6.57	14.79	
2	Hand drill		65,700.15	8.21	2.05	10.27			8.21		8.21	18.48	
3	Centrifugal W/Pump		75,706.11	9.46	2.37	11.83	15.60	2.34	9.46		27.40	39.23	
4	Water Tanker		20,700.00	2.59	0.65	3.23					0.00	3.23	
5	Total Station with acc.		333,012.44	41.63	10.41	52.03			41.63		41.63	93.66	
6	Automatic Level		50,000.00	6.25	1.56	7.81			6.25		6.25	14.06	
	V. Pavement Equipment												
1	Asphalt Kittle		828,000.00	41.40	10.35	51.75	249.60	37.44	41.40	8.28	336.72	388.47	
2	Power Broom		589,320.72	29.47	7.37	36.83	31.20	4.68	29.47	7.37	72.71	109.55	
3	Asphalt Distributer		3,312,000.00	165.60	41.40	207.00	405.60	60.84	165.60	41.40	673.44	880.44	
4	Aggregate Spreader		3,989,000.00	199.45	49.86	249.31	780.00	117.00	199.45	119.67	1,216.12	1,465.43	
5	Asphalt Plant	100 ton/h	24,840,000.00	1,242.00	310.50	1,552.50	2,808.00	421.20	1,242.00	0.00	4,471.20	6,023.70	
6	Asphalt Paver		8,580,000.00	429.00	107.25	536.25	2,496.00	374.40	429.00	257.40	3,556.80	4,093.05	
7	Heavy Duty Generator		2,203,992.99	110.20	27.55	137.75	1,684.80	252.72	110.20		2,047.72	2,185.47	

ANALYSIS OF DIRECT COSTS
(FORMAT)

Date: October-2016

Work Item: **32.09 (b) Steel Reinforcement (High yield stress steel bars in culverts**

Quantity of Work: 8,170.00 kg

Total Qty. of Work Item: **8,170.00** kg

Monthly Output

Labor:

Equipment:

Resultant Taken: 320.00 kg/d

40.00 kg/h

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
	Reinforcement Bar	1.10	26.55	29.20	Bar Bending Forman	1	0.50	25.76	12.88					
	Black wire	0.05	21.50	1.07	Bar Bender	8	1.00	15.45	123.64	Bar bending & Cutting machine	1	1.00	21.44	21.44
					Daily Laborer	1	1.00	10.43	10.43					
	Sub Total (A)		=	30.28	Sub Total (B)			=	146.95	Sub Total (C)			=	21.44

Purchase+Fabic's+Transport+Waste+Store

(D) Material		(E) Manpower			(F) Equipment	
Unit Price=Sub Total (A) =	30.28 Birr/kg	Unit Cost =	Sub Total(B) = 146.95 / Hourly output 40.00	3.67	Unit Cost = Sub Total(C) = 21.44 / Hourly output 40.00	0.54
Direct Cost = D+E+F =	34.49 Birr/kg					
Indirect Cost = 35% of DC =	12.07 Birr/kg					
Total Unit Rate = DC + IC =	**46.56** Birr/kg					

Remarks: Total Unit Rate= 1.3 x 34.49 = **44.84**

44,836.17 ETB/Ton

UF - Utilization Factor H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: June-2016

Project:

Page No.

Work Item: **Dowels for joining old and new concrete**

Labor:

Equipment:

Resultant Taken: 640.00 kg/d

80.00 kg/h

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
	Reinforcement Bar	1.10	26.55	29.20	Bar Bending Forman	1	0.50	25.76	12.88					
					Bar Bender	4	1.00	15.45	61.82	Bar bending & Cutting machine	1	1.00	21.44	21.44
					Daily Laborer	1	1.00	10.43	10.43					
	Sub Total (A)		=	29.20	Sub Total (B)			=	85.13	Sub Total (C)			=	21.44

Purchase+Fabic's+Transport+Waste+Store

(D) Material		(E) Manpower			(F) Equipment	
Unit Price=Sub Total (A) =	29.20 Birr/kg	Unit Cost =	Sub Total(B) = 85.13 / Hourly output 80.00	1.06	Unit Cost = Sub Total(C) = 21.44 / Hourly output 80.00	0.27
Direct Cost = D+E+F =	30.54 Birr/kg					
Indirect Cost = 35% of DC =	10.69 Birr/kg					
Total Unit Rate = DC + IC =	**41.22** Birr/kg					

Remarks: Total Unit Rate= 1.3 x 30.54 = **39.70**

39,697.71 ETB/Ton

UF - Utilization Factor H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: **Capping Layer Material Hauling**

Total Qty. of Work Item:

Note: Average Haule distance is considered to be 6.15 km
AverageTruck speed is considered as 30 km per hr.

Cycle time	
Fixed Time	10 min
Hauling Time	12 min
Return Time	12 min
Total Cycle Time	35 min

Monthly Output
Labor:
Equipment:
Resultant Taken: 960.00 m³./d
Assume 60min: 120.00 m³./S.P.H

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
					Construction Forman II	1	1.00	82.43	82.43	Loader	1	1.00	592.27	592.27
					H.D.E operator III	1	1.00	51.52	51.52	Dump Trucks	10	1.00	267.31	2,673.14
					D/ Truck Operator	10	1.00	41.21	412.13					
	Sub Total (A)		=	0.00		Sub Total (B)		=	546.07		Sub Total (C)		=	3,265.41

Purchase+Fabic's+Transport+Waste+Store

(D) Material
Unit Price=Sub Total (A) = 0

(E) Manpower
Unit Cost = Sub Total(B) = 546.07 / Hourly output 120.00 = 4.55

(F) Equipment
Unit Cost = Sub Total(C) = 3,265.41 / Hourly output 120.00 = 27.21

Direct Cost = D+E+F = 31.76 Birr/m³.

Remarks:

UF - Utilization Factor
H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: **Capping Layer Material Production**

Average Hauling Distance	6.15	km
Average Speed	30	km/hr
Loading Un loading	0.167	hr

Labor:
Equipment:
Resultant Taken: 960.00 m³./d
120.00 m³./S.P.H

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
					Quarry Forman	1	1.00	82.43	82.43	Dozer 300 Hp	2	1.00	2,039.65	4,079.31
					H.D.E operator III	2	1.00	61.82	123.64					
					Helper I	2	1.00	12.17	24.35					
					Laborer	4	1.00	10.43	41.74					
	Sub Total (A)		=	0.00		Sub Total (B)		=	272.15		Sub Total (C)		=	4,079.31

Purchase+Fabic's+Transport+Waste+Store

(D) Material
Unit Price=Sub Total (A) = 0

(E) Manpower
Unit Cost = Sub Total(B) = 272.15 / Hourly output 120.00 = 2.27

(F) Equipment
Unit Cost = Sub Total(C) = 4,079.31 / Hourly output 120.00 = 33.99

Direct Cost = D+E+F = 36.26 Birr/m³.

Remarks:

UF - Utilization Factor
H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: **Capping layer constructed from natural gravel material, compacted to 95% AASHTO density**

Average Hauling Distance	6.15	km	Labor:		
Average Speed	30	km/hr	Equipment:		
Loading Un loading	0.167	hr	Resultant Taken:	1,000.00	m^3./d
				125.00	m^3./S.P.H

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
	Production*	1.00	36.26	36.26	Construction Forman III	1	0.50	164.85	82.43					
	Hauling	1.00	31.76	31.76	H.D.E operator III	2	1.00	82.43	164.85	Grader (185 HP)	2	1.00	1,334.34	2,668.68
					L. Eq. Operator	4	1.00	51.52	206.07	Roller	4	1.00	545.13	2,180.54
					Helper I	2	1.00	12.17	24.35	Water Truck	4	1.00	531.25	2,125.00
					Truck Operator	2	1.00	41.21	82.43	Small Vehicle	1	0.50	238.03	119.02
					L. Vehicle Driver I	1	1.00	41.21	41.21					
	Sub Total (A)		=	68.0244659	Sub Total (B)		=		601.33	Sub Total (C)		=		7,093.23

Purchase+Fabic's+Transport+Waste+Store

(D) Material
Unit Price=Sub Total (A) = 68.02

(E) Manpower
Unit Cost = Sub Total(B) = 601.33 / Hourly output 125.00 = 4.81

(F) Equipment
Unit Cost = Sub Total(C) = 7,093.23 / Hourly output 125.00 = 56.75

Direct Cost	=	D+E+F =	129.58	Birr/m3
Indirect Cost	=	35% of DC =	45.35	Birr/m3
Total Unit Rate	=	DC + IC =	**174.93**	Birr/m3

Remarks: Total Unit Rate= 1.3 x 129.58 = **168.46**

UF - Utilization Factor H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: **Capping layer constructed from natural gravel material, compacted to 95% AASHTO density**

Average Hauling Distance	6.15	km	Labor:		
Average Speed	30	km/hr	Equipment:		
Loading Un loading	0.167	hr	Resultant Taken:	1,000.00	m^3./d
				125.00	m^3./S.P.H

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
	Production*	1.00	36.83	36.83	Construction Forman III	1	0.50	164.85	82.43					
	Hauling	1.00	32.29	32.29	H.D.E operator III	2	1.00	82.43	164.85	Grader (185 HP)	2	1.00	1,372.98	2,745.96
					L. Eq. Operator	4	1.00	51.52	206.07	Roller	4	1.00	553.41	2,213.66
					Helper I	2	1.00	12.17	24.35	Water Truck	4	1.00	540.22	2,160.88
					Truck Operator	2	1.00	41.21	82.43	Small Vehicle	1	0.50	239.41	119.71
					L. Vehicle Driver I	1	1.00	41.21	41.21					
	Sub Total (A)		=	69.1169659	Sub Total (B)		=		601.33	Sub Total (C)		=		7,240.20

Purchase+Fabic's+Transport+Waste+Store

(D) Material
Unit Price=Sub Total (A) = 69.12

(E) Manpower
Unit Cost = Sub Total(B) = 601.33 / Hourly output 125.00 = 4.81

(F) Equipment
Unit Cost = Sub Total(C) = 7,240.20 / Hourly output 125.00 = 57.92

Direct Cost	=	D+E+F =	131.85	Birr/m3
Indirect Cost	=	35% of DC =	46.15	Birr/m3
Total Unit Rate	=	DC + IC =	**178.00**	Birr/m3

Remarks: Total Unit Rate= 1.3 x 131.85 = **171.40**

UF - Utilization Factor H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: **Natural Gravel Material Production**

Resultant Taken: 960.00 m^3./d

120.00 m^3./S.P.H

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
					Construction Forman	1	1.00	82.43	82.43	Dozer 300 Hp	2	1.00	2,039.65	4,079.31
					H.D.E operator III	2	1.00	61.82	123.64					
					Helper I	2	1.00	12.17	24.35					
					Laborer	4	1.00	10.43	41.74					
Sub Total (A)			=	0.00	Sub Total (B)			=	272.15	Sub Total (C)			=	4,079.31
Purchase+Fabic's+Transport+Waste+Store														

(D) Material
Unit Price=Sub Total (A) = 0

(E) Manpower
Unit Cost = Sub Total(B) = 272.15 / Hourly output 120.00 = 2.27

(F) Equipment
Unit Cost = Sub Total(C) = 4,079.31 / Hourly output 120.00 = 33.99

Direct Cost = D+E+F = 36.26 Birr/m^3.

Remarks:

UF - Utilization Factor H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: **Select Material Hauling**

Note: Average Haule distance in km 6.15 km — 6.15 min. — 9.22 — Equipment:

AverageTruck speed is considered as inkm per hr. — 40 min. — 9.22 — Resultant Taken: 880.00 m^3./d

Total Cycle Time **18.45** **Assume 60min** 110.00 m^3./S.P.H

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
					Construction Forman	1	1.00	82.43	82.43	Loader	1	1.00	592.27	592.27
					H.D.E operator III	1	1.00	51.52	51.52	Dump Trucks	5	1.00	267.31	1,336.57
					D/ Truck Operator	5	1.00	41.21	206.07					
					Labourer	20	1.00	10.43	208.69					
Sub Total (A)			=	0.00	Sub Total (B)			=	548.70	Sub Total (C)			=	1,928.84
Purchase+Fabic's+Transport+Waste+Store														

(D) Material
Unit Price=Sub Total (A) = 0

(E) Manpower
Unit Cost = Sub Total(B) = 548.70 / Hourly output 110.00 = 4.99

(F) Equipment
Unit Cost = Sub Total(C) = 1,928.84 / Hourly output 110.00 = 17.53

Direct Cost = D+E+F = 22.52 Birr/m^3.

Remarks:

UF - Utilization Factor H.D.E - Heavy Duty Equipment

Date: June-2016

Work Item: **Gravel Aggregate Placing 95% compaction**

Quantity of Work

Total Qty. of Work Item:

Note: Average Haule distance in km 6.15km

AverageTruck speed is considered as inkm per hr.

Cycle Time		**Output**		
Fixed Time	15 min	Labor:		
Hauling Time	12 min	Equipment:		
Return Time	12 min	Taken:	480.00	m^3./d
Total Cycle Time	**40 min**	**60min**	60.00	m^3./S.P.H

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
					Construction Forman	1	1.00	123.64	123.64					
					Heavy Equ. Operat	1	1.00	103.03	103.03	Grader	1	1.00	1,334.34	1,334.34
					Light Eq. Op	2	1.00	41.21	82.43	Water Truck	1	1.00	531.25	531.25
					Dump Trucks	2	1.00	41.21	82.43	Rollers	1	1.00	545.13	545.13
					Vehicle Ope.	1	1.00	41.21	41.21	Small Vehicle	1	1.00	238.03	238.03
					Helpers	1	1.00	12.17	12.17					
					Labourers	20	1.00	10.43	208.69					
	Sub Total (A)		=	0			Sub Total (B)	=	653.60			Sub Total (C)	=	2,648.75

Purchase+Fabic's+Transport+Waste+Store

(D) Material
Unit Price=Sub Total (A) = 0.00

(E) Manpower
Unit Cost = Sub Total(B) = 653.60 / Hourly output 60.00 = 10.89

(F) Equipment
Unit Cost = Sub Total(C) = 2,648.75 / Hourly output 60.00 = 44.15

Direct Cost D+E+F = 55.04 Birr/m^3.

Remarks:

UF - Utilization Factor H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: Sub-base layer(s) **constructed from lateritic or non lateritic natural gravel material, 95% MDD, AASHTO T-180 (compacted layer thickness of maximum 200mm)**

Labour:		
Equipment:		
Resultant Taken:	480.00	m^3/d
Assume 4.14 km hauling distance, Truck speed 30km/hr	68.57	m^3/h

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labour by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipmrnt Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
	Natural Gravel Production*	1.00	36.26	36.26										
	Crushed Aggregate (for blending)	1.00	71.66	71.66										
	Hauling	1.00	22.52	22.52										
	Gravel Aggregate Placing 95%	1.00	55.04	55.04										
		Sub Total (A)	=	185.49			Sub Total (B)	=	0.00		Sub Total (C)		=	0.00

Purchase+Fabic's+Transport+Waste+Store

(D) Material
Unit Price=Sub Total (A) = 185.49

(E) Manpower
Unit Cost = Sub Total(B) = 0.00 / Hourly output 68.57 = 0.00

(F) Equipment
Unit Cost = Sub Total(C) = 0.00 / Hourly output 68.57 = 0.00

Direct Cost = D+E+F = 185.49 Birr/m3

Indirect Cost = 35% of DC = 64.92 Birr/m3

Total Unit Rate = DC + IC = **250.41** Birr/m3

Remarks: Total Unit Rate= 1.3 x 185.49 = 241.14

UF - Utilization Factor H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: **Quarry production for Gravel Surface Course**

Labor:

Equipment:

Resultant Taken: **800.00** m³./d

100.00 m³./S.P.H

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
	Dynamite	0.0005	58,999.00	29.4995	Quarry Forman	1	0.50	82.43	41.21	Dozer 300 Hp	1	1.00	2,039.65	2,039.65
	Detoneter	0.5	10.14	5.06975	H.D.E operator III	1	1.50	61.82	92.73	Excavator	1	0.50	1,248.00	624.00
	Fuses	1	3.04	3.0395	Detonator	1	1.00	46.36	46.36	Air Compressor	1	1.00	101.36	101.36
					Helper I	1	1.00	12.17	12.17	Drill	1	1.00	1,666.37	1,666.37
					Laborer	10	1.00	10.43	104.35					
	Sub Total (A)		=	37.60875		Sub Total (B)		=	296.83	Sub Total (C)			=	4,431.39
	Purchase+Fabic's+Transport+Waste+Store													

(D) Material
Unit Price=Sub Total (A) = 37.60875

(E) Manpower
Unit Cost = Sub Total(B) = 296.83 / Hourly output 100.00 = 2.97

(F) Equipment
Unit Cost = Sub Total(C) = 4,431.39 / Hourly output 100.00 = 44.31

Direct Cost = D+E+F = **84.89** Birr/m³.

Remarks:

UF - Utilization Factor

Note: The crusher is assumed to be errected at quarry site

ANALYSIS OF DIRECT COSTS

Date: October-2016

Work Item: **Base Aggregate Crushing**

Labor:

Equipment:

Resultant Taken: 400.00 m³./d

50.00 m³./S.P.H

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
					Construction Forman	1	1.00	123.64	123.64	Loader	1	1.00	592.27	592.27
					L.E.O operator	1	1.00	51.52	51.52	Crusher Plant, 75t/	1	1.00	4,170.10	4,170.10
					Electrician	1	1.00	30.91	30.91					
					Mechanic	1	1.00	41.21	41.21					
					Labourors	30	1.00	10.43	313.04					
	Sub Total (A)		=	0		Sub Total (B)		=	560.31	Sub Total (C)			=	4,762.37
	Purchase+Fabic's+Transport+Waste+Store													

(D) Material
Unit Price=Sub Total (A) = 0

(E) Manpower
Unit Cost = Sub Total(B) = 560.31 / Hourly output 50.00 = 11.21

(F) Equipment
Unit Cost = Sub Total(C) = 4,762.37 / Hourly output 50.00 = 95.25

Direct Cost = D+E+F = **106.45** Birr/m³.

Remarks:

UF - Utilization Factor

H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: October-2016

Work Item: **Crushed stone base material Hauling**

Quantity of Work

Total Qty. of Work Item:

Cycle Time		Monthly Output	
Fixed Time in min	10 min	Labor:	
Note: Average Haule distance in km 54 min.	81 min	Equipment:	
AverageTruck speed is considered as inkm per hr. 40 Return Time in	81 min	Resultant Taken:	800.00 m^3./d
Total Cycle Time	172 min	Assume 100min	114.29 m^3./S.P.H

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
					Construction Forman	1	0.00	123.64	0.00	Loader	1	1.00	592.27	592.27
					Heavy Equ. Operat	1	1.00	82.43	82.43	Dump Trucks	15	1.00	462.68	6,940.20
					Trucks Drivers	15	1.00	41.21	618.20					
					Load Counter	1	1.00	12.17	12.17					
	Sub Total (A)		=	0		Sub Total (B)		=	712.79		Sub Total (C)		=	7,532.47

Purchase+Fabic's+Transport+Waste+Store

(D) Material
Unit Price=Sub Total (A) = 0.00

(E) Manpower
Unit Cost = Sub Total(B) = 712.79 / Hourly output 114.29 = 6.24

(F) Equipment
Unit Cost = Sub Total(C) = 7,532.47 / Hourly output 114.29 = 65.91

Direct Cost = D+E+F = 72.15 Birr/m^3.

UF - Utilization Factor H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: **Base Aggregate Placing to 100% compaction**

Quantity of Work

Total Qty. of Work Item:

Cycle Time		Monthly Output	
Fixed Time	10 min	Labor:	
Note: Average Haule distance in 54km Hauling Time	108 min	Equipment:	
AverageTruck speed is considered as in 40km per hr. Return Time	108 min	Resultant Taken:	400.00 m^3./d
Total Cycle Time	226 min		50.00 m^3./S.P.H

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
					Construction Forman I	1	1.00	123.64	123.64	Aggregate Spreader	1	1.00	1,430.93	1,430.93
					Heavy Equ. Operat	1	1.00	103.03	103.03	Grader	1	0.50	1,334.34	667.17
					Light Eq. Op	2	1.00	41.21	82.43	Water Truck	1	1.00	531.25	531.25
					Dump Trucks	2	1.00	41.21	82.43	Rollers	1	1.00	545.13	545.13
					Vehicle Ope.	1	1.00	41.21	41.21	Pneumatic Tired Roller	1	1.00	694.13	694.13
					Helpers	1	1.00	12.17	12.17	Small Vehicle	1	1.00	238.03	238.03
					Labourers	20	1.00	10.43	208.69					
	Sub Total (A)		=	0		Sub Total (B)		=	653.60		Sub Total (C)		=	4,106.65

Purchase+Fabic's+Transport+Waste+Store

(D) Material
Unit Price=Sub Total (A) = 0.00

(E) Manpower
Unit Cost = Sub Total(B) = 653.60 / Hourly output 50.00 = 13.07

(F) Equipment
Unit Cost = Sub Total(C) = 4,106.65 / Hourly output 50.00 = 82.13

Direct Cost = D+E+F = 95.20 Birr/m^3.

Remarks:

UF - Utilization Factor H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS
(FORMAT)

Date: June-2016

Work Item: **Gravel wearing course and shoulders constructed from gravel: compacted to 95% of modified AASHTO density**

Quantity of Work

Labour:
Equipment:
Resultant Taken: 800.00 m^3/d
100.00 m^3/h

Assume 15 km hauling distance, Truck speed 30km/hr

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labour by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipmrnt Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
	Natural Gravel Production*	1.00	36.26	36.26										
	Gravel Crushing/Screening	1.00	71.66	71.66										
	Hauling	1.00	22.52	22.52										
	Gravel Aggregate Placing 95%	1.00	55.04	55.04										
		Sub Total (A)	=	185.49		Sub Total (B)		=	0.00		Sub Total (C)		=	0.00
	Purchase+Fabic's+Transport+Waste+Store													

(D) Material
Unit Price=Sub Total (A) = 185.49

(E) Manpower
Unit Cost = Sub Total(B) = 0.00 / Hourly output 100.00 = 0.00

(F) Equipment
Unit Cost = Sub Total(C) = 0.00 / Hourly output 100.00 = 0.00

Direct Cost =	D+E+F =	185.49	Birr/m3
Indirect Cost =	35% of DC =	64.92	Birr/m3
Total Unit Rate =	DC + IC =	**250.41**	Birr/m3

Remarks: Total Unit Rate= 1.3 x 185.49 = 241.14

UF - Utilization Factor   H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: **Prime Coat MC-30 Cutback Bitumen**

Labor:
Equipment:
Resultant Taken: 4,000.00 lt./d
571.43 lt./h

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
	Asphalt MC-30	1	40.02	40.02	Construction Forman	1	1.00	123.64	123.64	Asphalt Distributor	1	1.00	862.50	862.50
					Stationary eq. Op.	1	1.00	41.21	41.21	Stationary Heater	1	1.00	377.43	377.43
					Light Eq. Op	1	1.00	51.52	51.52	Power Broom	1	1.00	108.17	108.17
					Dump Truck Driver	1	0.50	41.21	20.61	Water Truck	1	0.50	531.25	265.63
					Asphalt Truck Driver	1	1.00	41.21	41.21					
					Helpers	2	1.00	12.17	24.35					
					Labourers	5	1.00	10.43	52.17					
		Sub Total (A)	=	40.02		Sub Total (B)		=	354.71		Sub Total (C)		=	1,613.72
	Purchase+Fabic's+Transport+Waste+Store													

(D) Material
Unit Price=Sub Total (A) = 40.02

(E) Manpower
Unit Cost = Sub Total(B) = 354.71 / Hourly output 571.43 = 0.62

(F) Equipment
Unit Cost = Sub Total(C) = 1,613.72 / Hourly output 571.43 = 2.82

Direct Cost =	D+E+F =	43.46	Birr/l
Indirect Cost =	35% of DC =	15.21	Birr/l
Total Unit Rate =	DC + IC =	**58.68**	Birr/l

Remarks: Total Unit Rate= 1.3 x 43.46 = 56.50

UF - Utilization Factor

ANALYSIS OF DIRECT COSTS

										Date	June-2016			
Work Item:		Asphalt Concrete Production												
Total Qty. of Work Item:										Monthly Output				
										Labor:				
										Equipment:				
										Resultant Taken:	300.00		m3./d	
											37.50		m3./S.P.H	
No.	**D) Material Type**	**Qty. Per Measure**	**Unit Price**	**Cost Per Measure**	**E) Labor by Skills**	**No.**	**U.F.**	**Indexed Hourly Rate**	**Hourly Cost**	**F) Equipment Type**	**No.**	**U.F.**	**Hourly Rental Rate**	**Hourly Cost**
m3	14mm nominal size Aggregate	0.53	375.00	197.36	Construction Forman	1	1.00	164.85	164.85	Asphalt Plant	1	1.00	5,899.50	5,899.50
m3	Asphalt (60/70)	142.74	17.91	2,557.09	Bach Plant Operator	1	1.00	103.03	103.03	Loader	1	1.00	592.27	592.27
m3	Filler	0.41	312.50	128.97	Equipment Operator	1	1.00	51.52	51.52					
					Mechanic	1	1.00	41.21	41.21					
					Electrician	1	1.00	30.91	30.91					
					Welder	1	1.00	25.76	25.76					
					Helpers	1	1.00	12.17	12.17					
					Labourers	10	1.00	10.43	104.35					
		Sub Total (A)	=	2,883.42		Sub Total (B)		=	533.80		Sub Total (C)		=	6,491.77
Purchase+Fabic's+Transport+Waste+Store														
(D)	Material				(E) Manpower					(F) Equipment				
	Unit Price=Sub Total (A) =		2883.42		Unit Cost =	Sub Total(B) = / Hourly output		533.80 / 37.50	14.23	Unit Cost =	Sub Total(C) = / Hourly output		6,491.77 / 37.50	173.11
	Direct Cost =	D+E+F =	3,070.76	Birr/m3										

ANALYSIS OF DIRECT COSTS

										Date	June-2016			
Work Item:		Asphalt Concrete Hauling												
Total Qty. of Work Item:							Cycle Time			Monthly Output				
							Fixed Time in min		20.00	Labor:				
	Note:	Average Haule distance is considered to be 32.5km				54	min.		81.00	Equipment:				
		AverageTruck speed loaded 20 km per hr.				40	Return Time in		81.00	Resultant Taken:	300.00		m3./d	
		AverageTruck speed for return/empity 30 km per hr.					Total Cycle Time		182.00		50.00		m3./S.P.H	
No.	**D) Material Type**	**Qty. Per Measure**	**Unit Price**	**Cost Per Measure**	**E) Labor by Skills**	**No.**	**U.F.**	**Indexed Hourly Rate**	**Hourly Cost**	**F) Equipment Type**	**No.**	**U.F.**	**Hourly Rental Rate**	**Hourly Cost**
					Construction Forman	1	0.00	123.64	0.00	Loader	1	0.50	592.27	296.13
					Heavy Equ. Operat	1	1.00	82.43	82.43	Dump Trucks	7	1.00	462.68	3,238.76
					Trucks Drivers	7	1.00	41.21	288.49					
					Load Counter	1	1.00	12.17	12.17					
		Sub Total (A)	=	0		Sub Total (B)		=	383.09		Sub Total (C)		=	3,534.89
Purchase+Fabic's+Transport+Waste+Store														
(D)	Material				(E) Manpower					(F) Equipment				
	Unit Price=Sub Total (A) =		0.00		Unit Cost =	Sub Total(B) = / Hourly output		383.09 / 50.00	7.66	Unit Cost =	Sub Total(C) = / Hourly output		3,534.89 / 50.00	70.70
	Direct Cost =	D+E+F =	78.36	Birr/m^3.										
	UF - Utilization Factor			H.D.E - Heavy Duty Equipment										

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: **Installation of Expansion joint, including 20mm compressible joint filler board**

Quantity of Work

Total Qty. of Work Item:

Monthly Output

Labour:

Equipment:

Resultant Taken: 20.00 m^2/d

2.50 m^2/h

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labour by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipmrnt Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
	Bitumen	0.8	22.50	18.00	Construction Forman III	1	0.50	164.85	82.43					
	Expansion joint mate	1	492.00	492.00	carpenter	2	1.00	30.91	61.82					
					Labourer	10	1.00	10.43	104.35					
	Sub Total (A)		=	510.00		Sub Total (B)		=	248.59		Sub Total (C)		=	0.00

Purchase+Fabic's+Transport+Waste+Store

(D) Material

Unit Price=Sub Total (A) = 510.00

(E) Manpower

Unit Cost = Sub Total(B) = 248.59 / Hourly output 2.50 = 99.44

(F) Equipment

Unit Cost = Sub Total(C) = 0.00 / Hourly output 2.50 = 0.00

Direct Cost =	D+E+F =	609.44	Birr/lm
Indirect Cost =	35% of DC =	213.30	Birr/lm
Total Unit Rate =	DC + IC =	**822.74**	Birr/lm

Remarks: Total Unit Rate= 1.3 x 609.44 = 792.27

UF - Utilization Factor H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: **Asphaltic surfacing: 50mm asphaltic surfacing with (penetration grade 60/700 bitumen)**

Quantity of Work

Total Qty. of Work Item:

Monthly Output

Labor:

Equipment:

Resultant Taken: 2,240.00 m2./d

182 min 280.00 m2./S.P.H

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
	Production	0.05	3,070.76	153.54	Construction Forman	1	1.00	164.85	164.85	Asphalt Paver	1	1.00	3,982.65	3,982.65
	Hauling	0.05	78.36	3.92	Heavy Equ. Operat	1	1.00	103.03	103.03	Punematic Roller	2	1.00	694.13	1,388.26
					Light Eq. Op	6	1.00	51.52	309.10	Steel Wheel Rollers	2	1.00	546.51	1,093.02
					Water Truck	1	1.00	41.21	41.21	Power Broom	1	1.00	108.17	108.17
					Helpers	1	1.00	12.17	12.17	Power Blower	1	1.00	101.36	101.36
					Labourers	10	1.00	10.43	104.35	Water Truck	1	1.00	531.25	531.25
	Sub Total (A)		=	157.45619		Sub Total (B)		=	734.71		Sub Total (C)		=	7,204.70

Purchase+Fabic's+Transport+Waste+Store

(D) Material

Unit Price=Sub Total (A) = 157.46

(E) Manpower

Unit Cost = Sub Total(B) = 734.71 / Hourly output 280.00 = 2.62

(F) Equipment

Unit Cost = Sub Total(C) = 7,204.70 / Hourly output 280.00 = 25.73

Direct Cost =	D+E+F =	185.81	Birr/m2
Indirect Cost =	35% of DC =	65.03	Birr/m2
Total Unit Rate =	DC + IC =	**250.85**	Birr/m2

Remarks: Add 3% for Anti-stripping agent Total Unit Rate= 1.3 x 250.85 = 326.10

UF - Utilization Factor Note The crusher is assumed to be errected at quarry site

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: **Binder variations: Bitumen binder (80/100 penetration grade)**

Quantity of Work

Total Qty. of Work Item:

Monthly Output

Labor:

Equipment:

Resultant Taken:

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
	Ac 60/700	1000	22.50	22,499.50										
	Sub Total (A)		=	22,499.50	Sub Total (B)			=	0.00	Sub Total (C)			=	0.00

Purchase+Fabic's+Transport+Waste+Store

(D) Material

Unit Price=Sub Total (A) = 22499.50

(E) Manpower

Unit Cost = Sub Total(B) = 0.00 / Hourly output 0.00

(F) Equipment

Unit Cost = Sub Total(C) = 0.00 / Hourly output 0.00

Direct Cost =	D+E+F =	22,499.50	Birr/ton
Indirect Cost	= 35% of DC =	7,874.83	Birr/ton
Total Unit Rate =	DC + IC =	**30,374.33**	Birr/ton

Remarks: Total Unit Rate= 1.3 x 22,499.50 = 29,249.35 Birr/ton

29.25 Birr/Lit

UF - Utilization Factor

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: **Steel Reinforcement (a) Mild steel bars (Grade 40, 300MPa)**

Quantity of Work

Total Qty. of Work Item:

Monthly Output

Labor:

Equipment:

Resultant Taken: 250.00 kg/d

40.00 kg/h

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
	Reinforcement Ba	1.10	26.55	29.20	Bar Bending Forman	1	0.50	25.76	12.88					
	Black wire	0.05	21.50	1.07	Bar Bender	8	1.00	15.45	123.64	Bar bending & Cutt	1	1.00	21.44	21.44
					Daily Laborer	1	1.00	10.43	10.43					
	Sub Total (A)		=	30.28	Sub Total (B)			=	146.95	Sub Total (C)			=	21.44

Purchase+Fabic's+Transport+Waste+Store

(D) Material

Unit Price=Sub Total (A) = 30.28 Birr/kg

(E) Manpower

Unit Cost = Sub Total(B) = 146.95 / Hourly output 40.00 — 3.67

(F) Equipment

Unit Cost = Sub Total(C) = 21.44 / Hourly output 40.00 — 0.54

Direct Cost =	D+E+F =	34.49	Birr/kg
Indirect Cost	= 35% of DC =	12.07	Birr/kg
Total Unit Rate =	DC + IC =	**46.56**	Birr/kg

Remarks: Total Unit Rate= 1.3 x 34.49 = 44.84

44,836.17 ETB/Ton

UF - Utilization Factor H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: **Steel Reinforcement (b) High yield stress steel bars (Grade 60, 420MPa)**

Quantity of Work

Total Qty. of Work Item:

Monthly Output

Labor:

Equipment:

Resultant Taken: 250.00 kg/d

35.00 kg/h

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
	Reinforcement Ba	1.10	29.50	32.45	Bar Bending Forman	1	0.50	25.76	12.88					
	Black wire	0.05	21.50	1.07	Bar Bender	8	1.00	15.45	123.64	Bar bending & Cutt	1	1.00	21.44	21.44
					Daily Laborer	1	1.00	10.43	10.43					
			Sub Total (A) =	33.52			Sub Total (B)	=	146.95			Sub Total (C)	=	21.44

Purchase+Fabic's+Transport+Waste+Store

(D) Material

Unit Price=Sub Total (A) = 33.52 Birr/kg

(E) Manpower

Unit Cost = $\frac{\text{Sub Total(B)} = 146.95}{\text{Hourly output } 35.00}$ 4.20

(F) Equipment

Unit Cost = $\frac{\text{Sub Total(C)} = 21.44}{\text{Hourly output } 35.00}$ 0.61

Direct Cost = D+E+F = 38.34 Birr/kg

Indirect Cost = 35% of DC = 13.42 Birr/kg

Total Unit Rate = DC + IC = **51.75** Birr/kg

Remarks: Total Unit Rate= 1.3 x 38.34 = 49.84

49,836.43 ETB/Ton

UF - Utilization Factor H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: Concrtete Aggregate Crushing

Quantity of Work m^3

Monthly Output

Labor:

Equipment:

Resultant Taken: 75.00 m^3/d

9.38 m^3/h

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
					Forman II	1	0.25	123.64	30.91	Crusher Set 75 ton	1	1.00	4,170.10	4,170.10
					Crusser operator	1	1.00	61.82	61.82	Loader	1	0.25	1,122.00	280.50
					Electrician	1	1.00	30.91	30.91					
					Mechanic	1	1.00	10.43	10.43					
					Labourer	10	1.00	10.43	104.35					
					Equipment Operator	1	0.25	51.52	12.88					
			Sub Total (A) =	0			Sub Total (B)	=	251.30			Sub Total (C)	=	4,450.60

Purchase+Fabic's+Transport+Waste+Store

(D) Material

Unit Price=Sub Total (A) = 0.00

(E) Manpower

Unit Cost = $\frac{\text{Sub Total(B)} = 251.30}{\text{Hourly output } 9.38}$ 26.81

(F) Equipment

Unit Cost = $\frac{\text{Sub Total(C)} = 4,450.60}{\text{Hourly output } 9.38}$ 474.73

Direct Cost = D+E+F = 501.54 Birr/m^3.

UF - Utilization Factor H.D.E - Heavy Duty Equipment

Resultant Taken is assumed by taking 2 hours over time work

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: Concrete Aggregate Hauling to the Site

Quantity of Work: m^3

Quantity of Work: m^3

			Cycle time	
		Fixed Time in min	15 min	Monthly Output
Note: Average Haule distance	54.0 Km	min.	81 min	Labor:
AverageTruck speed is considered as inkm per hr.	40	Return Time in	81 min	Equipment:
		Total Cycle Time	177 min	Resultant Taken: 50.00 m^3./d
				6.25 m^3./S.P.H

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
					Construction Forman	1	0.00	82.43	0.00	Loader	1	0.50	592.27	296.13
					H.D.E operator III	1	0.13	61.82	7.73	Dump Trucks	2	1.00	267.31	534.63
					D/ Truck Operator	2	1.00	41.21	82.43					
	Sub Total (A)		=	0.00		Sub Total (B)		=	90.15		Sub Total (C)		=	830.76

Purchase+Fabic's+Transport+Waste+Store

(D) Material
Unit Price=Sub Total (A) = 0

(E) Manpower
Unit Cost = Sub Total(B) = 90.15 / Hourly output 6.25 = 14.42

(F) Equipment
Unit Cost = Sub Total(C) = 830.76 / Hourly output 6.25 = 132.92

Direct Cost = D+E+F = 147.35 Birr/m^3.

UF - Utilization Factor   H.D.E - Heavy Duty Equipment

ANALYSIS OF DIRECT COSTS

Date: June-2016

Work Item: Aggregate Production

Quantity of Work: m^3

Monthly Output
Labor:
Equipment:
Resultant Taken: 1.00 m^3/d
0.13 m^3/h

No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
	Quarry Productio	1.30	84.89	110.36										
	Crushing	1.00	501.54	501.54										
	Aggregate Haulin	1.00	147.35	147.35										
	Sub Total (A)		=	759.240153		Sub Total (B)		=	0.00		Sub Total (C)		=	0.00

Purchase+Fabic's+Transport+Waste+Store

(D) Material
Unit Price=Sub Total (A) = 759.24

(E) Manpower
Unit Cost = Sub Total(B) = 0.00 / Hourly output 0.13 = 0.00

(F) Equipment
Unit Cost = Sub Total(C) = 0.00 / Hourly output 0.13 = 0.00

Direct Cost = D+E+F = 759.24 Birr/m^3.

UF - Utilization Factor   H.D.E - Heavy Duty Equipment
Resultant Taken is assumed by taking 2 hours over time work

ANALYSIS OF DIRECT COSTS

									Date		June-2016			
Work Item:		Sand Production												
Quantity of Work				m^3		Cycle time			Monthly Output					
							Fixed Time		60 min	Labor:				
		Note:	Average Haule distance is considered to be 54 km				Hauling Time		108 min	Equipment:				
			AverageTruck speed is considered as 30 km per hr.				Return Time		108 min	Resultant Taken:	16.00		m^3/d	
							Total Cycle Time		276 min		8.00		m^3/h	
No.	D) Material Type	Qty. Per Measure	Unit Price	Cost Per Measure	E) Labor by Skills	No.	U.F.	Indexed Hourly Rate	Hourly Cost	F) Equipment Type	No.	U.F.	Hourly Rental Rate	Hourly Cost
	Production	1.00	84.89	84.89										
	Crushing	1.00	501.54	501.54										
	Hauling	1.00	147.35	147.35										
		Sub Total (A)	=	733.772892		Sub Total (B)		=	0.00		Sub Total (C)		=	0.00
Purchase+Fabic's+Transport+Waste+Store														
(D)	Material				(E) Manpower					(F) Equipment				
	Unit Price=Sub Total (A) =		733.77		Unit Cost =	Sub Total(B)		0.00	0.00	Unit Cost =	Sub		0.00	0.00
						Hourly		8.00			Hourly		8.00	
	Direct Cost	D+E+F =	733.77	Birr/m^3.										
	UF - Utilization Factor			H.D.E - Heavy Duty Equipment										
	Resultant Taken is assumed by taking 2 hours over time work													

ANALYSIS OF DIRECT COSTS

									Date	June-2016				
Project:									Page No.					
Work Item:				Cast in situ concrete, C-35 Slab Pavement										
									Resultant Taken:	45.0		m^3/d		
										5.63		m^3/h		
Unit	**D) Material Type**	**Qty. Per Measure**	**Unit Price**	**Cost Per Measure**	**E) Labor by Skills**	**No.**	**U.F.**	**Indexed Hourly Rate**	**Hourly Cost**	**F) Equipment Type**	**No.**	**U.F.**	**Hourly Rental Rate**	**Hourly Cost**
Qt	Cement	8.20	309.98	2541.84	Construction Forman III	1	0.50	164.85	82.43	Concrete Mixer	1	1.00	48.77	48.77
m3	Aggregate	0.42	759.24	318.88	Mason & Carpentor	4	1.00	30.91	123.64	Concrete Vibrator	2	1.00	38.68	77.35
m3	Sand	0.26	733.77	187.85	Bar bender II	1	1.00	25.76	25.76	Water Tanker	1	1.00	3.23	3.23
Lit	Water	127.00	0.04	5.08	Equ. Operator I	3	1.00	41.21	123.64	Water Truck	1	0.25	531.25	132.81
Lit	Water reducer	1.23	45.00	55.35	Un skilled Laborers	15	1.00	10.43	156.52	Concrete distributor	1	1.00	862.50	862.50
Lit	Air-entraining admixture	0.164	43.40	7.12	Heavy Truck Driver	1	0.25	41.21	10.30					
		Sub Total (A)	=	3116.11			Sub Total (B)	=	522.28			Sub Total (C)	=	1,124.67
Purchase+Fabic's+Transport+Waste+Store														
(D)	Material			(E)	Manpower					(F) Equipment				
	Unit Price=Sub Total (A) =		3116.11		Unit Cost =	Sub Total(B) = / Hourly output		522.28 / 5.63	92.77	Unit Cost =	Sub Total(C) = / Hourly output		1,124.67 / 5.63	199.76
	Direct Cost	D+E+F =	3,408.64	Birr/m3										
	Indirect Cost	30% of DC	1,022.59	Birr/m3										
	Total Unit Rate	DC + IC =	**4,431.24**	Birr/m3										
	Remarks:				Total Unit Rate=	1.3	x	3,408.64	=	4,431.24	per m3			
	UF - Utilization Factor			H.D.E - Heavy Duty Equipment										
	Resultant Taken is assumed by taking 2 hours over time work													

Annex-4: Pavement M&R costs Analysis Templates.

Summary of M&R cost analysis assumptions each alternative		
M & R costs Anlysis Assumptions	Flexible pavement	Rigid pavement
Analysis period in yrs	20	40
Rate of Maintanance cost per yr	0.80%	0.40%
Rate of Rehabilitation per 7 yr	38%	0
Discount rate(r)	10.23%	10.23%
Adjusted Inflation rate per yr	5%	5%
Initial Construction cost per Km	6,582,326.89	10,418,653.50
Maintanance costs per km	52,658.62	41,674.61
Rehabilitation Cost per km per 7yrs	2,510,060.65	-
Remaining Service Life percentage	0.78%	20.29%
Remaining Service Life Value in NF	135,663.73	14,881,833.98
Remaining Service Life Value in NP	19,340.50	302,457.36

M&R Costs per km for 40 yrs Entire Service of Pavements						
	Flexible Pavement			Rigid Pavement		
		M&R cost			M&R cost	
Yr	Initial Construction cost	In FV(1+r)^n	In NPV(1/(1+r)^n	Initial Construction cost	In FV(1+r)^n	In NPV(1/(1+r)^n
0	6,582,326.89		6,582,326.89	10,418,653.50		10,418,653.50
1		52,658.62	47,771.58		41,674.61	37,806.96
2		55,291.55	45,505.00		43,758.34	43,305.14
3		58,056.12	43,345.96		45,946.26	45,897.12
4		60,958.93	41,289.36		48,243.58	48,238.29
5		64,006.88	39,330.33		50,655.75	50,655.19
6		67,207.22	37,464.25		53,188.54	53,188.48
7	Rehabilitation Period -2yrs	3,531,907.41	1,786,120.10		55,847.97	55,847.96
8		74,095.96	33,993.51		58,640.37	58,640.37
9		77,800.76	32,380.65		61,572.39	61,572.39
10		81,690.80	30,844.31		64,651.00	64,651.00
11		85,775.34	29,380.86		67,883.55	67,883.55
12		90,064.10	27,986.85		71,277.73	71,277.73
13		94,567.31	26,658.98		74,841.62	74,841.62
14		99,295.67	25,394.11		78,583.70	78,583.70
15	Rehabilitation Period -2yrs	5,218,235.83	1,210,672.26		82,512.89	82,512.89
16		109,473.48	23,041.57		86,638.53	86,638.53
17		114,947.15	21,948.33		90,970.46	90,970.46
18		120,694.51	20,906.96		95,518.98	95,518.98
19		126,729.24	19,915.01		100,294.93	100,294.93
20		133,065.70	18,970.12		105,309.67	105,309.67
	Sum		3,562,920.10			1,373,634.96

yr	Flexible pavement			Rigid pavement		
		M&R cost			M&R cost	
	Initial Construction cost after 20 yrs	In FV(1+r)^n	In NPV(1/(1+r)^n		In FV(1+r)^n	In NPV(1/(1+r)^n
20	17,464,872.83		2,489,827.62			
21	Rehabilitation Period -2yrs	146,704.93	18,973.56		110,575.16	15,763.82
22		154,040.18	18,073.33		116,103.92	15,015.88
23		161,742.19	17,215.82		121,909.11	14,303.44
24		169,829.30	16,398.99		128,004.57	13,624.79
25		178,320.76	15,620.92		134,404.80	12,978.35
26		187,236.80	14,879.77		141,125.03	12,362.57
27	Rehabilitation Period -2yrs	9,371,201.82	675,616.88		148,181.29	11,776.02
28		206,428.57	13,501.29		155,590.35	11,217.29
29		216,750.00	12,860.70		163,369.87	10,685.07
30		227,587.50	12,250.51		171,538.36	10,178.10
31		238,966.88	11,669.27		180,115.28	9,695.19
32		250,915.22	11,115.61		189,121.04	9,235.19
33		263,460.98	10,588.21		198,577.10	8,797.01
34		276,634.03	10,085.84		208,505.95	8,379.63
35	Rehabilitation Period -2yrs	13,845,533.14	457,948.27		218,931.25	7,982.05
36		304,989.02	9,151.48		229,877.81	7,603.33
37		320,238.47	8,717.27		241,371.70	7,242.58
38		336,250.39	8,303.67		253,440.29	6,898.95
39		353,062.91	7,909.69		266,112.30	6,571.62
40		370,716.06	7,534.41		279,417.92	6,259.82
Sum			**3,848,243.12**			**206,570.69**
Total M&R Costs per km for 40 yrs Entire Service in NPV			**7,411,163.22**			**1,580,205.65**

Annex-5: HDM_4 out puts for Road User Costs.

HDM-4
HIGHWAY DEVELOPMENT & MANAGEMENT

Road Agency and User Cost Streams (Discounted)

Study Name: Research Based Simulated Design Road Project
Run Date: 18-09-2016
Currency: Ethiopian Birr (millions)
Discount Rate: 10.23 %

Road Agency and User Cost Streams (Discounted)

Section: Research Based Simulation Design Road Project
Alternative: HMA

Sect ID: Main Alignment Only   Road Class: Primary or Trunk
Length: 1.00 km   Width: 7.00 m   Rise+Fall: 10.00 m/km   Curvature: 15.00 deg/km

Year	Road Agency Costs (RAC)				Road User Costs (RUC)					Net Exogenous Cost	Total Transport Cost
	Capital	Recurrent	Special	Total RAC	MT Vehicle Operation	MT Travel Time	NMT Travel & Operation	Accidents	Total RUC		
2020	1.890	0.000	0.000	1.890	1.172	0.047	0.000	0.000	1.219	0.000	3.109
2021	1.950	0.000	0.000	1.950	1.728	0.064	0.000	0.000	1.792	0.000	3.742
2022	2.500	0.000	0.000	2.500	1.800	0.066	0.000	0.000	1.866	0.000	4.366
2023	0.000	0.000	0.000	0.000	1.782	0.066	0.000	0.000	1.848	0.000	1.848
2024	0.000	0.000	0.000	0.000	1.749	0.066	0.000	0.000	1.805	0.000	1.805
2025	0.000	0.000	0.000	0.000	1.653	0.063	0.000	0.000	1.716	0.000	1.716
2026	0.000	0.000	0.000	0.000	1.619	0.062	0.000	0.000	1.682	0.000	1.682
2027	0.000	0.000	0.000	0.000	1.586	0.062	0.000	0.000	1.648	0.000	1.648
2028	0.000	0.000	0.000	0.000	1.554	0.061	0.000	0.000	1.615	0.000	1.015
2029	0.000	0.000	0.000	0.000	1.521	0.061	0.000	0.000	1.582	0.000	1.982
2030	0.000	0.000	0.000	0.000	1.489	0.060	0.000	0.000	1.549	0.000	1.949
2031	0.000	0.000	0.000	0.000	1.458	0.059	0.000	0.000	1.517	0.000	1.917
2032	0.000	0.000	0.000	0.000	1.427	0.059	0.000	0.000	1.486	0.000	1.886
2033	0.000	0.000	0.000	0.000	1.396	0.058	0.000	0.000	1.454	0.000	1.855

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Road Agency and User Cost Streams (Discounted)

2034	0.000	0.000	0.000	0.000	1.366	0.058	0.000	0.000	1.824	0.000	1.824
2035	0.000	0.000	0.000	0.000	1.336	0.057	0.000	0.000	1.794	0.000	1.794
2036	0.000	0.000	0.000	0.000	1.307	0.057	0.000	0.000	1.764	0.000	1.764
2037	0.000	0.000	0.000	0.000	1.278	0.056	0.000	0.000	1.734	0.000	1.734
2038	0.000	0.000	0.000	0.000	1.250	0.056	0.000	0.000	1.705	0.000	1.705
2039	0.000	0.000	0.000	0.000	1.125	0.053	0.000	0.000	1.578	0.000	1.578
2040	0.000	0.000	0.000	0.000	1.006	0.051	0.000	0.000	1.456	0.000	1.456
2041	0.000	0.000	0.000	0.000	0.892	0.048	0.000	0.000	1.341	0.000	1.341
2042	0.000	0.000	0.000	0.000	0.784	0.046	0.000	0.000	1.231	0.000	1.231
2043	0.000	0.000	0.000	0.000	0.723	0.045	0.000	0.000	1.168	0.000	1.168
2044	0.000	0.000	0.000	0.000	0.582	0.042	0.000	0.000	1.024	0.000	1.024
2045	0.000	0.000	0.000	0.000	0.489	0.040	0.000	0.000	0.929	0.000	0.929
2046	0.155	0.000	0.000	0.155	0.400	0.038	0.000	0.000	0.839	0.000	0.994
2047	0.141	0.000	0.000	0.141	0.316	0.037	0.000	0.000	0.752	0.000	0.893
2048	0.171	0.000	0.000	0.171	0.235	0.035	0.000	0.000	0.670	0.000	0.841
2049	0.000	0.000	0.000	0.000	0.342	0.012	0.000	0.000	0.755	0.000	0.755
2050	0.000	0.000	0.000	0.000	0.310	0.012	0.000	0.000	0.721	0.000	0.721
2051	0.000	0.000	0.000	0.000	0.277	0.011	0.000	0.000	0.689	0.000	0.689
2052	0.000	0.000	0.000	0.000	0.247	0.011	0.000	0.000	0.658	0.000	0.658
2053	0.000	0.000	0.000	0.000	0.218	0.010	0.000	0.000	0.628	0.000	0.628
2054	0.000	0.000	0.000	0.000	0.190	0.010	0.000	0.000	0.600	0.000	0.600
2055	0.083	0.000	0.000	0.083	0.163	0.009	0.000	0.000	0.573	0.000	0.656
2056	0.000	0.000	0.000	0.000	0.116	0.009	0.000	0.000	0.525	0.000	0.525
2057	0.000	0.000	0.000	0.000	0.153	0.009	0.000	0.000	0.562	0.000	0.562
2058	0.000	0.000	0.000	0.000	0.180	0.010	0.000	0.000	0.590	0.000	0.590
2059	0.000	0.000	0.000	0.000	0.221	0.012	0.000	0.000	0.633	0.000	0.633
Total:	6.890	0.000	0.000	6.890	34.422	1.692	0.000	0.000	36.114	0.000	43.004

All costs are discounted at: 10.23 %

Section: Research Based Simulation Design Road Project
Alternative: JUCP

Sect ID: Main Alignment Only   Road Class: Primary or Trunk
Length: 1.00 km   Width: 7.00 m   Rise+Fall: 10.00 m/km   Curvature: 15.00 deg/km

Year	Road Agency Costs (RAC)				Road User Costs (RUC)					Net Exogenous Cost	Total Transport Cost
	Capital	Recurrent	Special	Total RAC	MT Vehicle Operation	MT Travel Time	NMT Travel & Operation	Accidents	Total RUC		
2020	2.572	0.000	0.000	2.572	1.572	0.047	0.000	0.000	2.619	0.000	5.191
2021	2.776	0.000	0.000	2.776	1.128	0.064	0.000	0.000	3.192	0.000	5.968
2022	2.519	0.000	0.000	2.519	1.094	0.063	0.000	0.000	3.157	0.000	5.676
2023	3.047	0.000	0.000	3.047	0.759	0.063	0.000	0.000	3.122	0.000	6.169
2024	0.000	0.000	0.000	0.000	1.059	0.023	0.000	0.000	1.382	0.000	1.382
2025	0.000	0.000	0.000	0.000	1.063	0.023	0.000	0.000	1.386	0.000	1.386
2026	0.000	0.000	0.000	0.000	1.052	0.023	0.000	0.000	1.375	0.000	1.375
2027	0.000	0.000	0.000	0.000	1.038	0.022	0.000	0.000	1.361	0.000	1.361
2028	0.000	0.000	0.000	0.000	1.025	0.022	0.000	0.000	1.347	0.000	1.347
2029	0.000	0.000	0.000	0.000	1.011	0.022	0.000	0.000	1.333	0.000	1.333
2030	0.000	0.000	0.000	0.000	0.998	0.022	0.000	0.000	1.320	0.000	1.320
2031	0.000	0.000	0.000	0.000	0.985	0.022	0.000	0.000	1.306	0.000	1.306
2032	0.000	0.000	0.000	0.000	0.972	0.021	0.000	0.000	1.294	0.000	1.294
2033	0.000	0.000	0.000	0.000	0.960	0.021	0.000	0.000	1.281	0.000	1.281
2034	0.000	0.000	0.000	0.000	0.949	0.021	0.000	0.000	1.270	0.000	1.270
2035	0.000	0.000	0.000	0.000	0.937	0.021	0.000	0.000	1.258	0.000	1.258
2036	0.000	0.000	0.000	0.000	0.926	0.021	0.000	0.000	1.247	0.000	1.247
2037	0.000	0.000	0.000	0.000	0.915	0.020	0.000	0.000	1.236	0.000	1.236
2038	0.000	0.000	0.000	0.000	0.904	0.020	0.000	0.000	1.224	0.000	1.224
2039	0.000	0.000	0.000	0.000	0.850	0.019	0.000	0.000	1.169	0.000	1.169
2040	0.000	0.000	0.000	0.000	0.798	0.018	0.000	0.000	1.116	0.000	1.116
2041	0.000	0.000	0.000	0.000	0.748	0.018	0.000	0.000	1.066	0.000	1.066
2042	0.000	0.000	0.000	0.000	0.701	0.017	0.000	0.000	1.018	0.000	1.018
2043	0.000	0.000	0.000	0.000	0.656	0.016	0.000	0.000	0.972	0.000	0.972
2044	0.000	0.000	0.000	0.000	0.613	0.015	0.000	0.000	0.928	0.000	0.928
2045	0.000	0.000	0.000	0.000	0.572	0.015	0.000	0.000	0.886	0.000	0.886
2046	0.000	0.000	0.000	0.000	0.532	0.014	0.000	0.000	0.846	0.000	0.846
2047	0.000	0.000	0.000	0.000	0.495	0.013	0.000	0.000	0.808	0.000	0.808
2048	0.000	0.000	0.000	0.000	0.459	0.013	0.000	0.000	0.772	0.000	0.772
2049	0.000	0.000	0.000	0.000	0.425	0.012	0.000	0.000	0.737	0.000	0.737
2050	0.000	0.000	0.000	0.000	0.392	0.012	0.000	0.000	0.704	0.000	0.704
2051	0.000	0.000	0.000	0.000	0.361	0.011	0.000	0.000	0.672	0.000	0.672
2052	0.000	0.000	0.000	0.000	0.331	0.011	0.000	0.000	0.642	0.000	0.642
2053	0.000	0.000	0.000	0.000	0.303	0.010	0.000	0.000	0.613	0.000	0.613
2054	0.000	0.000	0.000	0.000	0.276	0.010	0.000	0.000	0.586	0.000	0.586
2055	0.000	0.000	0.000	0.000	0.250	0.009	0.000	0.000	0.560	0.000	0.560
2056	0.000	0.000	0.000	0.000	0.226	0.009	0.000	0.000	0.535	0.000	0.535
2057	0.000	0.000	0.000	0.000	0.202	0.009	0.000	0.000	0.510	0.000	0.510
2058	0.300	0.000	0.000	0.000	0.179	0.008	0.000	0.000	0.188	0.000	0.488
2059	0.059	0.000	0.000	0.059	0.158	0.008	0.000	0.000	0.166	0.000	0.225
Total:	11.273	0.000	0.000	11.273	25.498	1.2000	0.000	0.000	26.698	0.000	37.971

All costs are discounted at: 10.23 %

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Road Agency and User Cost Streams (Discounted)

Annex-6: The data collecting format.

Instructions

You are kindly requested to contribute to this thesis. All the information gathered here and the results of this assessment are intended to serve only for academic purpose.

Thank you in advance for your willingness to participate in this interview!

Opinion of participant in the sector/ Profile:____________________________________

Name of contractor /Organization/Firm: ____________________________________

Interview for the Thesis "The Sustainability of Jointed Unreinforced Concrete Pavements In Comparison to Hot-Mix Cut-Back Asphalt Pavements in the Context of Ethiopia"

Life Cycle Phase		Material or Process	The Amount of Waste Generated in Each Metric Ton (in %)
Raw Materials Extraction and Initial Transformation	1	Portland cement	
	2	Bitumen	
	3	Dowel & Tie steel Bar	
	4	Fine aggregate	
	5	Coarse aggregate	
Manufacturing	1	Portland cement	
	2	Dowel & Tie steel Bar	
	3	Bitumen Production	
	4	Bitumen Storage	
	5	Asphalt mixing and aggregate drying	
	6	Fine aggregate	
	7	Coarse aggregate	
	8	Cement Concrete mixing	
Placement	1	Cement Concrete	
	2	HMA Concrete	
	3	Dowel & Tie steel Bar	