**Addis Ababa Institute of Technology**

**School of Civil and Environmental Engineering**

# Review of Design and Construction of Rigid Pavement in Hot Weather Area: The Case of Ditchoto Galafi Junction-Ellidar-Belho Road Project, In Ethiopia.

**A Thesis Submitted in Partial fulfillment for the Requirements for the Award of the Degree of Master of Engineering in Construction Technology and Management**

**By**

**Ermias Fekadu**

**Advisor**

**Abrham Gebre (PhD)**

**June, 2022**

**Addis Ababa, Ethiopia**

**Addis Ababa Institute of Technology**

**School of Civil and Environmental Engineering**

# Review of Design and Construction of Rigid Pavement In Hot Weather Area: The Case of Ditchoto Galafi Junction-Ellidar-Belho Road Project In Ethiopia.

**BY**

**ERMIAS FEKADU TAMIRU**

**APPROVED BY BOARD OF EXAMINERS**

| | |
|---|---|
| ______________________ | ______________________ |
| **Chairman** | **Signature** |
| ______________________ | ______________________ |
| **Advisor** | **Signature** |
| ______________________ | ______________________ |
| **External Examiner** | **Signature** |
| ______________________ | ______________________ |
| **Internal Examiner** | **Signature** |

# STATEMENT OF CERTIFICATION

This is to certify that Ermias Fekadu has carried out this project work on the topic entitled –Review of Design and Construction of Rigid Pavement In Hot Weather: The Case of Ditchoto- Galfi-Ellidar-Belcho Road construction Project In Ethiopia.‖ Under my supervision. This work is original in nature and it is sufficient for submission for the partial fulfillment for the award of Degree of Master of Engineering in Construction Technology and Management.

Abrham Gebre (PhD)

Signiture ______________________

Date ___________________________

# DECLARATION

I, who has signed below, would like to state that the research project is entirely unique and has not previously been submitted for Degree at any other university. Each and every source of information used in the thesis has been properly recognized.

Name: Ermias Fekadu

Signature: ________________

Place: Addis Ababa Institute of Technology

Date: __________________

# ABSTRACT

Most major road networks in Ethiopia are constructed with flexible pavement, this type of pavement used as the only option considered during the pavement type selection process for many years. Rigid pavement structure which distributes loads to the subgrade having, as the main load bearing course, a Portland cement concrete slab of relatively high-bending resistance, is considered as an alternative option for the first time in Ethiopia with a total length of about 80Kms and a thickness of 40cms in hot weather area, Afar Region. The purpose of this thesis was to review the Design and construction of rigid pavement in hot weather area: The case of Ditchoto-Galafi Junction –Ellidar-Belho Road Project. Ditchoto Galafi Junction- Ellidar- Belho Road project 80kms long located in Afar Region is the first of its kind to be built with Rigid Pavement in Ethiopia, the maximum temperature will vary from 27oc to 52oc and the annual rainfall is about 500mm.The design of this Rigid pavement has been reviewed briefly against the standard of Ethiopian Roads Authority (ERA) Pavement Design Manual.

The findings of construction of Rigid Pavement Road in hot climate area are: water isscarce and full of salt, long hauling distance of concrete from batching plant, how to minimize thermal crack and shrinkage in this hot climate, long hauling distance of concrete which affects setting time of concrete, the manpower is new for construction of rigid pavement having long distance.

The recommendation includes provision of Special Equipment like water treatment plant, Chiller machine for cooling, Deep water well (>500m) drilling machines, large Concrete batching plants, 40cm thick Paver and Bulk Cement trucks. Modified cement and different admixtures including curing compound has been used in the mix design to withstand the hot weather and heat of hydration. Special constructionmethodology has been used like night time concrete paving. The design can be reviewed comparing the results obtained by ERA manual and AASHTO procedures, mix design optimization has to be made to incorporate the challenges, water treatment plant should be used to de-saline the water, and Chiller machines are required to reduce the temperature of water drilled out from wells of 500m depth in order to use for concrete. The study can be used for similar projects to be built in our country since it will be better to use local cement than importation of bitumen with foreign currency and also it has less maintenance cost with longer design life.

**KEYWORDS; Pavement, Rigid, Temperature, Concrete, Cement, Water, Aggregates, Mix Design, Curing, Admixtures.**

ACKNOWLEDGEMENTS

I want to thank GOD for his help to complete my study. Then I want to express my respect and deep appreciation to my kind and very humble advisor, Dr. Abrham Gebre for his valuable comment, suggestions and advice during preparing this paper.

Next, I want to acknowledge Addis Ababa Institute of Technology for allowing me to complete this educational program and Ethiopian Roads Authority for giving me the chance for this study.

I owe a lot to my late father, Fekadu Tamiru, whose support and advice lifted me to succeed by enabling me to stand on my own without assistance and to endure life'sups and downs. My dear friend Yared Tefera has made a significant contribution to support from the beginning of my undergraduate studies at AAIT to the present, and without his encouragement and counsel, my current achievement could not have been possible. I owe a great deal of gratitude to my instructor, Dr. Girmay Khassay, without his help I could not have achieved this result. I wish to acknowledge the previous Project Manager of the subject Road Project and my Dear friend Yalelet Alemnew in Defense Construction Enterprise who has shown his keen interest of cooperation by providing me with the necessary information and data required for the thesis.

Finally, I want to express my gratitude to my parents and other family members for their unwavering love, support, and encouragement.

Ermias Fekadu,

Addis Ababa, Ethiopia.

# Table of Contents

# ABBREVIATION

| | |
|---|---|
| **ERA**:- | Ethiopian Roads Authority |
| **ACI**:- | American Concrete Institute |
| **ESA**:- | Equivalent Standard Axle |
| **AASHTO**:- | American Association of state Highway and Transport Office |
| **CBR**:- | California Bearing Ra |
| **JUCP**:- | Jointed Unreinforced Concrete Pavement |
| **JRCP:-** | Jointed Reinforced Concrete Pavement |
| **CRCP**:- | Continuously Reinforced Concrete |
| Pavement**PPC**;- | Portland Pozzolanic Cement |
| **OPC**;- | Ordinary Portland Cement |

## DEFINITION OF KEY TERMS

**Rigid Pavement:** A pavement structure which distributes loads to the subgrade having, as the main load bearing course, a Portland cement concrete slab of relatively high-bending resistance.

**Asphalt Concrete:** A mixture to predetermined proportions of aggregate, filler and bituminous binder material plant mixed and usually placed by means of a paving machine.

**Capping Layer:** (Selected or improved subgrade). The top of embankment or bottom of excavation prior to construction of the pavement structure. Where very weak soils and/or expansive soils (such as black cotton soils) are encountered, a capping layer is sometimes necessary. This consists of better-quality subgrade material imported from elsewhere or subgrade material improved by stabilization (usually mechanical), and may also be considered as a lower quality sub-base.

**Contraction Joint:** A joint normally placed at recurrent intervals in a rigid slab to control transverse cracking.

**Design Period:** The period of time that an initially constructed or rehabilitated pavement structure will perform before reaching a level of deterioration requiring more than routine or periodic maintenance

**Dowel:** A load transfer device in a rigid slab, usually consisting of a plain round steel bar. Unlike a tie bar, a dowel may permit horizontal movement.

**Equivalent Standard Axles (ESAs)** A measure of the potential damage to a pavement caused by a vehicle axle load expressed as the number of 8.16 metric tons single axle loads that would cause the same amount of damage. The ESA values of all the traffic are combined to determine the total design traffic for the design period.

**Equivalency Factors** Used to convert traffic volumes into cumulative equivalent standard axle loads.

**Equivalent Single Axle Load (ESA**) Summation of equivalent 8.16 ton single axle loads used to combine mixed traffic to calculate the design traffic loading for the design period.

**Flexible Pavements:** Includes primarily those pavements that have a bituminous (surface dressing or asphalt concrete) surface. The terms "flexible and rigid" are somewhat arbitrary and were primarily established to differentiate between asphalt and Portland cement concrete pavements.

**Tie Bar:** A deformed steel bar or connector embedded across a joint in a rigidconcrete slab to prevent separation of abutting slabs. (Not to be confused with Dowels.)

**Sub-base:** The layer of material of specified dimensions on top of the subgrade and below the road base. The secondary load-spreading layer underlyingthe base course. Usually consisting of a material of lower quality than that used in the base course and particularly of lower bearing strength. Materials may be unprocessed natural gravel, gravel-sand, or gravel-sand-clay, with controlled gradation and plasticity characteristics. The sub-base also serves as a separating layer preventing contamination of the base course by the subgrade material and may play a role in the internal drainage of the pavement.

**Subgrade:** The surface upon which the pavement structure and shoulders are constructed. The top portion of the natural soil, either undisturbed (but recompacted) local material in cut sections, or soil excavated in cut or borrow areas and placed as compacted embankment.

# List of Figure

# List of Table

# CHAPTER ONE

## INTRODUCTION

The actual travel surface is called a pavement, and it is made to be strong and reliable so that it can handle the traffic load that commuters place on it. The traffic load is transferred from the upper surface to the natural soil via the pavement, which also provides comfort for the driver.

The rigid characteristic of the pavement is associated with rigidity or flexural strength or slab action so the load is distributed over a wide area of subgrade soil.

The foundation of rigid pavement design is a structural slab of cement concrete that is strong enough to withstand the loads brought on by traffic. The stiff pavement's rigidity and high elastic modulus help it disperse the weight over a wide area of soil.

Minor variations in subgrade strength have little influence on the structural capacityof a rigid pavement.

The main consideration in the design of a rigid pavement is the concrete's flexural strength, not the subgrade's strength. This characteristic of pavement allows the concrete slab to bridge over localized failures rather than the subgrade's overall strength when the subgrade flexes beneath the rigid pavement. Because of this pavement attribute, when the subgrade flexes beneath the rigid pavement, the concrete slab can cross over localized failures and regions where the subgrade provides insufficient support.

Rigid pavement is made of Portland cement concrete. Portland cement concrete is the most important part of the rigid pavement. Cement concrete roads are very high standard. They are costliest than all other types of roads.

These roads have good aesthetic and a great riding surface. Because they do not allow for any flexibility, they are known as rigid pavements. These roads need a significant initial investment, but because of extended lifespan, good riding surface, and little maintenance requirements, they are less expensive than bitumen roads. Portland cement concrete is composed of basically, Binding material, mostly Portland cement, Gravel, Sand, Water, Admixture, both mineral and chemical admixture and fibers. Aggregates, both sand and gravel take 65 – 75% of the total volume of concrete.

One of the most crucial elements influencing the design and functionality of both flexible and rigid pavements is temperature. The pavement structure might be distressed and even fail as a result of temperature fluctuations in many different ways. Knowledge of temperature effects is essential for the determination of the design and maintenance requirements especially in the desert climates like Afar Region in Ethiopia.

## 1.1. Background

The construction of port of Tadjoura is part of the Djibouti Government plan to develop, in a harmonic way, the different regions of the Country, and creating alternate connections with Ethiopia. The government gave high attention on the development of the roads, ports, airports and telecommunications of the Northern area of the Country in order to make of Djibouti the center of the regional traffic, Direct connection to this port by a paved road from Tadjoura to Belho has been managed by the Republic of Djibouti while the section from Belho to Galafi by Ethiopian government.

Ethiopian Roads Authority (ERA) has been given the mandate for the restoration, expansion and maintenance of Ethiopia's Federal road network, and major work has been done under the Road Sector Development Programme (RSDP). Its goal is to improve transport operating efficiency and reduce road transport costs, provide access to rural, neglected and food-deficit areas, and develop institutional capacity of the sector.

In accordance with the above and its overall road sector strategy, the EthiopianGovernment, with all work being administered by the Ethiopian Roads Authority (ERA) on its behalf, has allocated budget for design and construction of Galafi Junction - Elidar - Belho Road. The provision of this contract was procured by Bidding with ID No. W/18/ICB/OC/GOE/2006E.F.Y. Pursuant to the aforesaid invitation for Proposal, Deference Construction Enterprise submitted a winning proposal and entered into an agreement with the project employer ERA on the 14th day of April 2015 to undertake the work through design and the build type of service.

The key contract data and descriptions are provided in the table below:

Table 1-1: Key Contract Data

| | |
|---|---|
| **Proiect Name:** | Ditchoto Galafi Junction – Elidar – Belho Design and Build Road Project |
| **Proc. ID No:** | W/18/ICB/OC/GOE/2006E.F.Y. |
| **Funding:** | Government of the Federal Democratic Republic of Ethiopia |
| **Contractor:** | FDRE Ministry of Defence<br>Defence Construction Enterprise (DCE) |
| **Type of Service:** | Design and Build Project |
| **Contract Period:** | 1,170 Calendar days including 120 calendar days of mobilization plus 365 calendar days of defect liability period. |
| **Contract Signed on:** | April 14, 2015 |
| **Commencement Date:** | October 15, 2015 |
| **Project Cost:** | **ETB 2,663,664,021.75** (Ethiopian Birr: Two Billion Six Hundred Sixty Three Million Six Hundred Sixty Four Thousand Twenty One and 75/100 Only) including 15% VAT. |

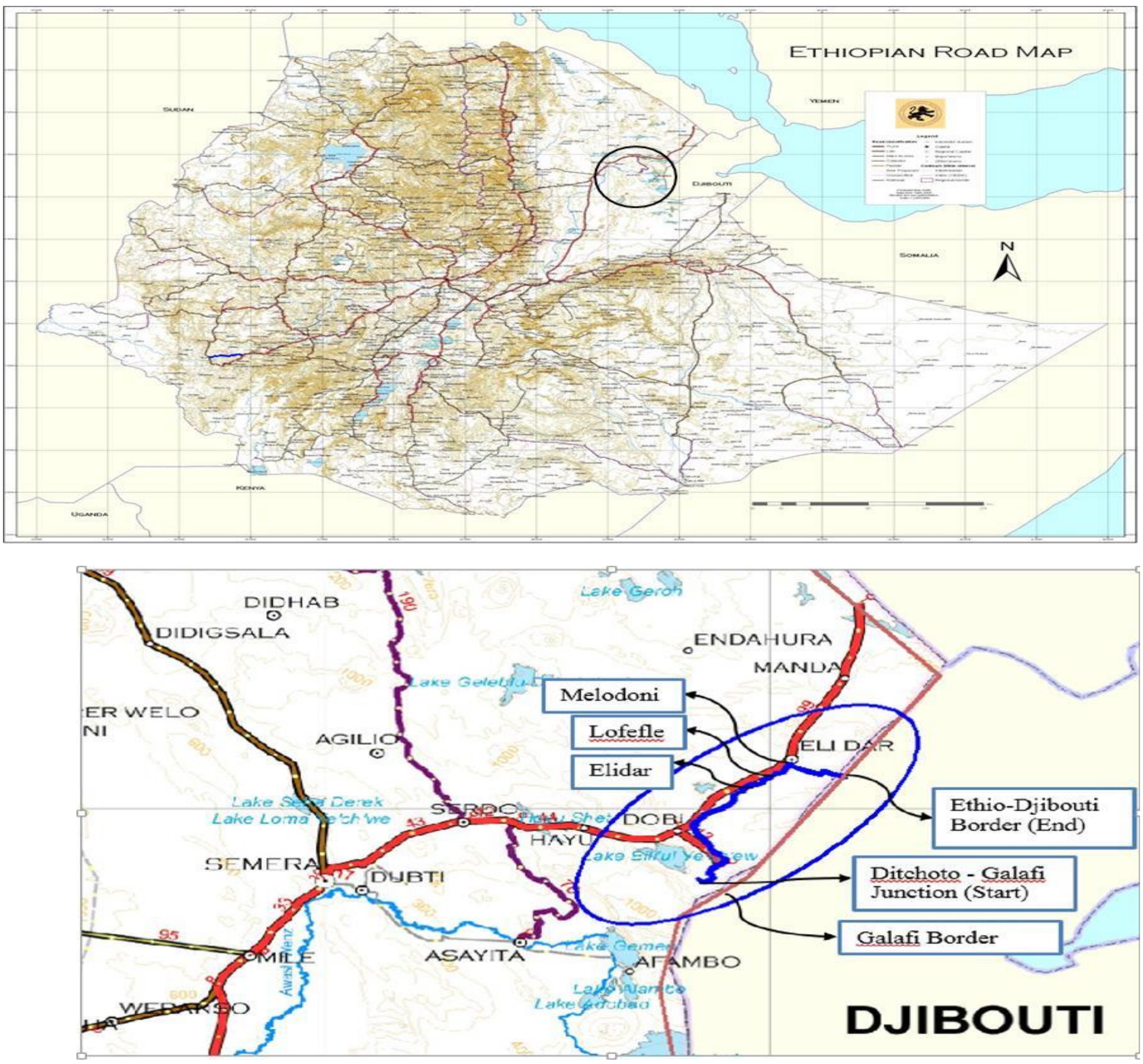



Fig 1.1 Project Location and Accessibility

### 1.2. Statement of Problem

Flexible pavement is the only alternative used as highway infrastructure for many years in Ethiopia. However, Rigid pavement which is very strong in compression is advantageous than flexible one since it has longer design life, little maintenance cost, not easily deformed under traffic, resistant to abrasion, it does not demand foreign currency like bitumen.

### 1.3. General Objectives

The aim of the study was to Review of Design and Construction of Rigid (Concrete) pavement in Hot weather Area, The Case of Ditchoto Galafi Junction-Ellidar-Belho Road Project, in Ethiopia.

#### 1.3.1. Specific objectives

- To review the design procedure.
- To identify construction measures to be taken for the hot temperature of theconstruction area, scarce water source and salty nature.
- To identify the appropriate concrete pavement materials for the area of hot weather.
- To identify measures to be taken to minimize the effect of thermal crack andshrinkage.
- To identify methodology of construction of rigid pavement to meet very hottemperature.
- To identify construction equipment’s which can meet the work performance and hotweather.
- To identify proper mix design for the concrete pavement construction in hot area.

### 1.4. Significance of the study

The goal of this study was to review the design and construction of Rigid pavement construction in hot climate: the case of Ditchoto Galafi Junction-Ellidar-Belho Road Project in Ethiopia. Design facts and challenges of constructing Concrete pavement about 80kms long in Hot climate area , Afar Region which is the first of its kind where water is scarce and full of salt, manpower is new for such work, Special construction methodology is required to minimize cracks, Type of Equipment’s to be used for treatment of water, developing deep well, cooling hot water, paving 40cm thick concrete has to be well identified. The output of this study can be used for similar projects to be constructed in our country, Ethiopian Roads Authority, Contractors, Researchers and Policy makers.

## 1.5. Limitation of Study

The drawback of this study is that it is limited to reviewing a case study which is not back upped by interview and questionnaires. It focuses only on design review and construction challenges and possible solutions of rigid pavements in hot climate.

## 1.6 Organization of the study

The research will organize into five chapters as follows;

**Chapter one**; contains the introduction to the research, statement of problem, study objectives, significance of the study, limitation of the study and organization of the study.

**Chapter two**: literature review will present theoretical and empirical reviews of related literatures on the various aspects concerning the topic and will develop conceptual framework.

**Chapter Three:** the following topics are captured; Findings and Discussions about the topic.

**Chapter four:** the following topics are outlined; the summary of conclusion and recommendations of the study.

# CHAPTER TWO:

# LITERATURE REVIEW

## 2.1 Rigid Pavements

As per Ethiopian Roads authority (ERA) Standard Technical Specification 2002, as their name suggests, rigid pavements (also known as concrete pavements) are inflexible and extremely powerful in compression. Contrary to flexible pavements, which rely on the cumulative strength of subsequent pavement layers, a concrete slab contributes the majority of the pavement's strength. By sweeping stiff brooms transversely across the paved concrete slab, it is possible to create the textured surface needed for resistance to skidding in wet situations. This can bring the following benefits:

- Rigid pavements with design lives of up to 60 years are technicallyconceivable.
- In general, little maintenance is needed.
- Rigid pavement doesn't bend whenever there's traffic load
- Due to its high stiffness, a relatively thin pavement slab disperses the load across a large area. This greater distribution area makes it possible to overcome locally poor strength subgrade materials.
- Because concrete is so resistant to abrasion, the surface texture that prevents slipping will stay longer.
- Unlike flexible pavements, concrete does not deteriorate from weathering in the absence of harmful components. Temperature fluctuations have no appreciable impact on the material's stiffness or strength.

The major drawbacks from flexible pavements are:

- The initial cost is frequently more expensive.
- They tend to be more problematic and harder to reconstruct or repair if theyare poorly built or constructed.

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

## 2.2 Types of Rigid Pavements

Depending on the level of reinforcement, the rigid pavements are categorized intothree basic types:

- Jointed and Unreinforced Concrete Pavements (JUCP)
- Jointed and Reinforced Concrete Pavements (JRCP)
- Entirely Reinforced Concrete Pavements (CRCP)

### 2.2.1 Jointed and unreinforced concrete pavement

An unreinforced concrete slab is continuously formed in place and separated into panels of predefined proportions by the construction of joints in joined unreinforced concrete pavements (JUCP). In order to prevent cracking, the panels' dimensions havebeen shortened. The tie bars that connect the panels' together serve to keep them from moving horizontally and ensure that the load pass through the aggregates.

### 2.2.2 Jointed and reinforced concrete pavement

In Jointed Reinforced Concrete Pavements (JRCP), the pavement is often separated into reinforced concrete panels that are spaced apart by joints. The reinforcement is designed to stop cracks from forming. Compared to unreinforced ones, this allows the construction of significantly larger bays. Tie bars join the bays together to ensure load transfer through the aggregates and to prevent horizontal movement. The longitudinal reinforcement is the major reinforcement. Most often, a transverse reinforcement is provided to aid in the placement of longitudinal bars.

### 2.2.3 Continuously reinforced concrete pavement

The finished products of reinforced concrete slabs without joints are called Fully Reinforced Concrete Pavements (CRCP). The expansion and contraction movements are restricted by a severe sub-base constraint. The numerous transverse breaches are totally sealed by a sizeable amount of continuous high tensile steel longitudinalreinforcement.

**Figure 2-1: Tie bars in place to connect to parallel concrete slab**

Rigid pavements comprise of, as shown in Figure 1 below, subbase, and concrete slab built above the subgrade. (With a capping layer as required

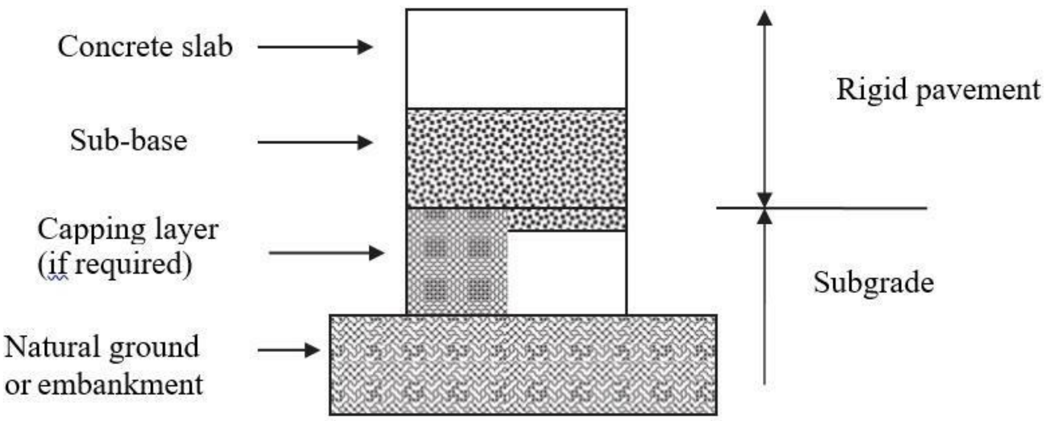



**Figure 2.2 Rigid Pavement structure**

When there is a poor subgrade, the capping layer is applied and has selected fill. It makes it possible to reduce the pavement thickness by increasing the subgrade's bearing capacity.

Between the subgrade and the concrete slab are compacted layers of material that make up the subbase of rigid (stiff) pavement structures. In some circumstances, the material can be stabilized to improve quality. If the subgrade has quality material and if design traffic is low (less than one million equivalent standard axles (ESAs)), subbase layer is not necessary between the concrete slab and subgrade.

Subbase is provided under the rigid pavement for the following reasons:

- To enable firm –working platform‖ for the construction machines
- To protect –pumping‖ at joints and slab edges.

The concrete slab consists of Portland cement concrete, reinforcing steel (as needed), load management mechanism and joint Seals.

Transverse reinforcement is provided to ensure that the longitudinal bars remain in their right locations during the slab's construction. It also helps shield against any potential longitudinal cracking.

## 2.3 Joints

Whether reinforced or  not, joints are incorporated into concrete pavements to allow for slab warping, expansion, and contraction. This reduces strains brought on by friction and environmental changes (such as temperature and moisture), and it also makes construction easier. Joints are categorized based on their function as well as their direction—either transverse or longitudinal. Contraction, expansion,  warping, and they frequently do more than one of these tasks.

### 2.3.1 Transverse Joints

The joints that are perpendicular to the road's centerline are known as transversejoints. They are made to stop the strains caused by long distance contraction and expansion. Transverse joints are also necessary to reduce warping loads in particular specific locations, such as around in-pavement items or at junctions.

### 2.3.2 Contraction Joints

The most common variety type of transverse joints is contraction joints. They are offered in JRCP and JUCP to relieve tensile stresses brought on by friction, temperature fluctuations, or moisture changes. In order to cause tension cracking at desired locations in the concrete after it has been laid. Pavement surface cracking would be erratic and out of control if contraction joints weren't installed. They also help to keep the warping stresses under control.

Load transfer between panels is provided by dowels. Contraction joints shall consist of:

- a sawn joint groove
- dowel bars
- a sealing grooves

The groove and sealant will be as proposed. The dowel bars need to be 20 mm in diameter at 300 mm spacing, 400 mm long for slabs up to 239 mm thick, and 25 mm in diameter for slabs 240 mm thick or more.

### 2.3.3. Expansion joints

The main purpose of an expansion joint is to give the slab space to expand, reducing the development of compression load that could cause the slab to buckle. Contraction joints are equivalent to expansion joints. Transverse expansion joints are employed in JUCP and JRCP occasionally at regular intervals and at the interface between CRCP and other forms of pavement or structures.

### 2.3.4. Longitudinal Joints

Warping joints, or longitudinal joints, permit a small amount of relative rotation of the slab sections while lowering the pressures brought on by warping. They must be placed at intervals that will minimize the combined effects of thermal warping and loading stresses, as well as the possibility of longitudinal random cracking. They are frequently used in conjunction with construction joints. These joints permit a little amount of rotation, however tie bars installed in the middle of the slab prevent differential lateral displacements between neighboring bays.

Additionally, these tie bars stop cracks from forming, and aggregate interlock allows for load transfer.

Longitudinal joints shall consist of:

- bottom crack inducer
- a sawn groove
- tie bars
- a sealing grooves

The sealant shall be as per the Specifications. The tie bars for all longitudinal joints, except where transverse reinforcement is permitted in lieu, shall be 12 mm in diameter at 600 mm spacing, and 1000 mm long.

## 2.4. Selection of the pavement type

The choice of pavement type for a particular set of conditions cannot be made by the highway engineer or administration using an absolute or unchallengeable technique.

In the beginning, a decision must be taken for a wide range of variables, including traffic, soil, weather, materials, construction, maintenance, and environment.

Pavement type may occasionally be determined by various criteria. For instance, the requirement to reduce disruptions and traffic hazards may motivate the use of CRCP for heavily used facilities in congested areas.

It is common practice to design typical sections of the road using each of the available options and then to compare them from an economic standpoint when there is no overriding factor, which may frequently be the case.

Unavoidably, there will be situations where financial constraints force first cost to take precedence over other considerations, notwithstanding the possibility of greater maintenance or repair costs in the future.

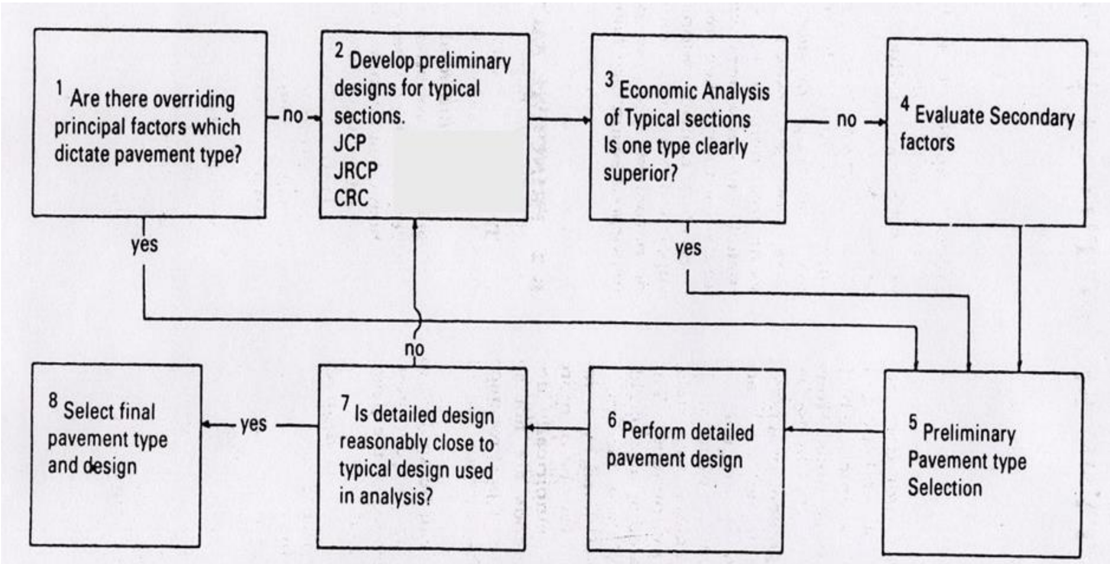



**Figure 2.3 Pavement type selection process**

Although pavement structures are based on an initial design period, few are abandoned at the end of this period and continue to serve as part of the futurepavement structure. For this reason, the analysis period should be of sufficient duration to include a representative reconstruction of all pavement types.

Rigid pavement types can be used as follows:

- JUCP is appropriate for all traffic levels whenever there is a low likelihood of subgrade movement.
- JRCP is appropriate for all traffic volumes and is used when it is impossible to ignore the possibility of subgrade settlements.
- CRCP can primarily only be taken into account for designs with large traffic volumes (>30 msa). They can also be used in less busy projects where the

benefit of less maintenance over the course of the design life may be valuable. Where subsoil settling is expected, they are especially useful.

## 2.5. Design of rigid pavements

### 2.5.1 Design life

Concrete slabs are incredibly durable and can be built to last up to 60 years because of their structural qualities. If the pavement is built appropriately, it will have a long lifespan, good serviceability, and few maintenance needs.

Concrete pavements are typically designed to last at least 40 years. Designing for longer periods often involves only a small amount of additional slab thickness and reinforcement and is more cost-effective because the needed slab thickness varies linearly with the logarithm of the total number of ESAs.

Rigid pavements are typically more cost-effective in the long run due to the ability to design them for more than twice the maximum design life of flexible pavements and the lower associated maintenance costs.

### 2.5.2. Design Traffic Loading

The method for computing Cumulative Equivalent Axle Load over the design life is described in in ERA Pavement Design Manual 2002, volume 1, Chapter 2. The same method is used for rigid pavement but the equivalency factors to be used are those given in table 2.1

Table 2.1 **Equivalency Factors for Different Axle Loads (Rigid Pavements)**

| Wheel load ($10^3$ kg) | Axle load ($10^3$ kg) | Equivalency factor |
|---|---|---|
| 2.0 | 4 | 0.05 |
| 2.5 | 5 | 0.1 |
| 3.0 | 6 | 0.3 |
| 3.5 | 7 | 0.5 |
| 4 | 8 | 0.9 |
| 4.5 | 9 | 1.5 |
| 5 | 10 | 2.4 |
| 5.5 | 11 | 3.6 |
| 6 | 12 | 5.2 |
| 6.5 | 13 | 7.4 |
| 7 | 14 | 10.2 |
| 7.5 | 15 | 13.7 |
| 8 | 16 | 18.0 |
| 8.5 | 17 | 23.4 |
| 9 | 18 | 29.9 |
| 9.5 | 19 | 37.8 |
| 10 | 20 | 47.1 |

## 2.6. Thickness Design

### 2.6.1. Capping and subbase

The subbase layer is only necessary when the subgrade material does not meet the criteria for a subbase (CBR is less than 30%), but it is virtually always utilized to make it easier to obtain surface levels that are within the necessary tolerances. Typically, the subbase will have a consistent 15 cm thickness and can be cement stabilized. Rigid pavements are typically more cost-effective in the long run due to the ability to design them for more than twice the maximum design life of flexible pavements and the lower associated maintenance costs.

Subgrade materials need to be addressed by replacement or in-situ stabilization if their CBR values are less than 2%. In order to reduce friction between the concrete slab and the subbase in JUCP and JRCP pavements, which prevents the development of mid-bay fractures, a separating membrane (such as a polythene sheet) is needed between the two. Additionally, it reduces the water loss from newly laid concrete.

### 2.6.2. Concrete slab thickness and reinforcement

The pavement thickness can be computed based on the design traffic volume expressed in equivalent standard axles. The methods for figuring out the thickness and reinforcement for each type of pavement are represented by the following.

**Jointed Unreinforced Concrete Pavement (JUCP)**

For a given traffic volume in terms of ESAs, the thickness of JUCP concrete slab can be determined using Fig 2.6. An additional slab thickness is required, and this additional thickness can be determined using Figure 2.8

There is no reinforcement in JUCP pavements. However, depending on the type of joint, dowels or tie bars are provided for the longitudinal and transverse joints. The section above provides a description of the joint details.

**Transverse join spacing**

Maximum transverse joint spacing for JUCP pavements is 4 m for slab thickness up to 230 mm and is 5 m for slab thickness over 230 mm. For JRCP, contraction joints are generally at a standard distance of 25m.Expansion joint are required at the limit with other pavementtypes or with structures like bridges.

In the current section, expansion joints shall be avoided in casting the concrete slab at the hottest period of the year. If required, expansion joints should replace every third contraction joint.

### 1.1.1. Longitudinal joint spacing

Longitudinal joints shall be placed at the edge of each traffic lanes.

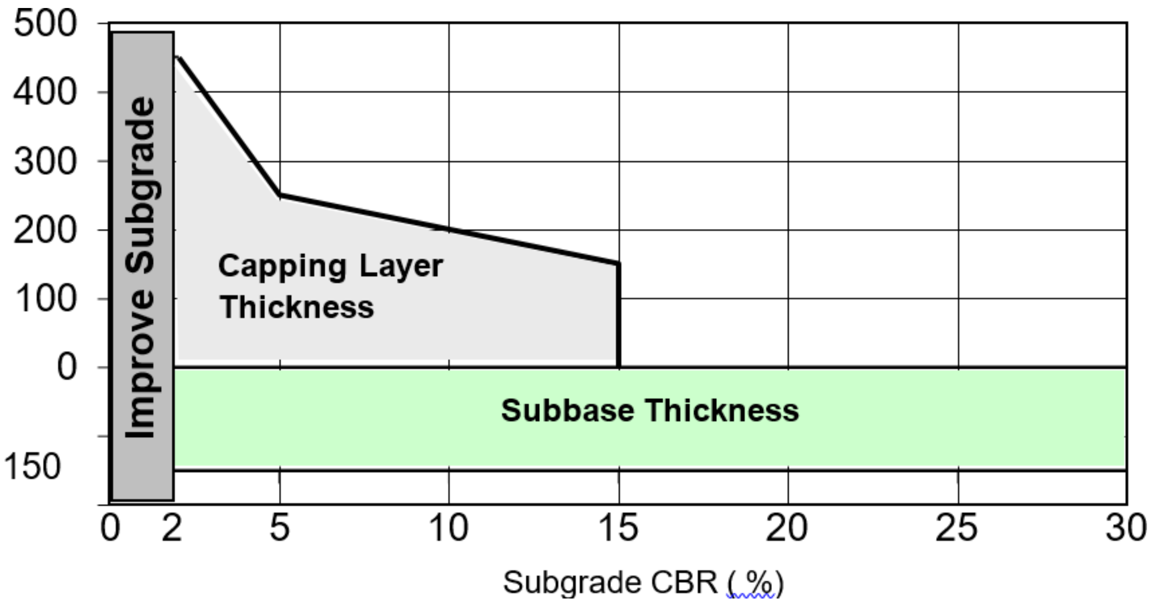



Fig 2.4 Capping Layer and Subbase Thickness design

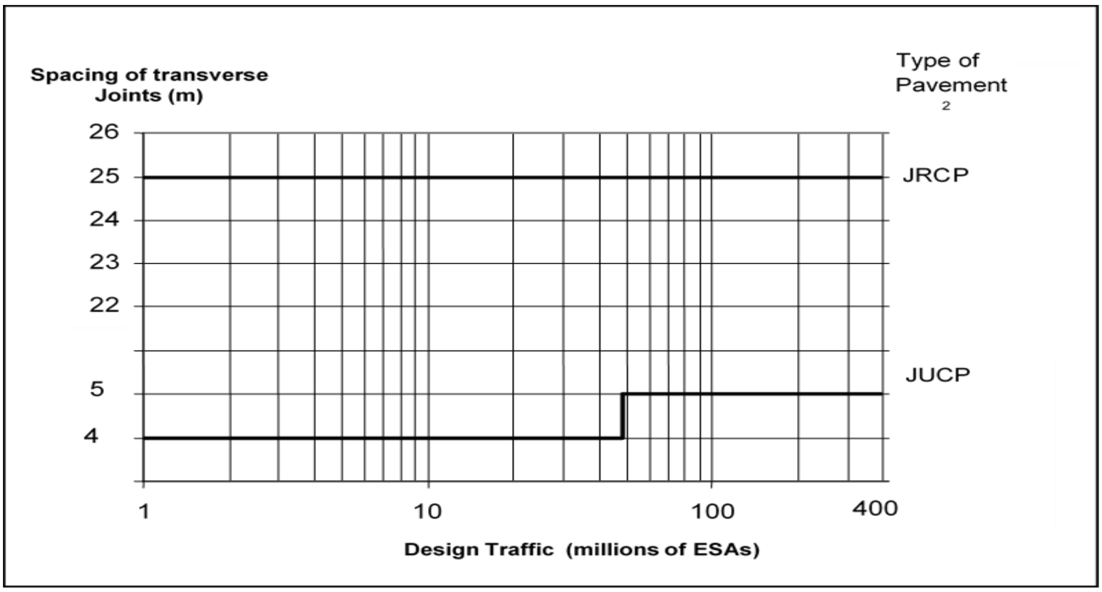



Fig 2.5 Joint spacing for JUCP and JRCP Slabs

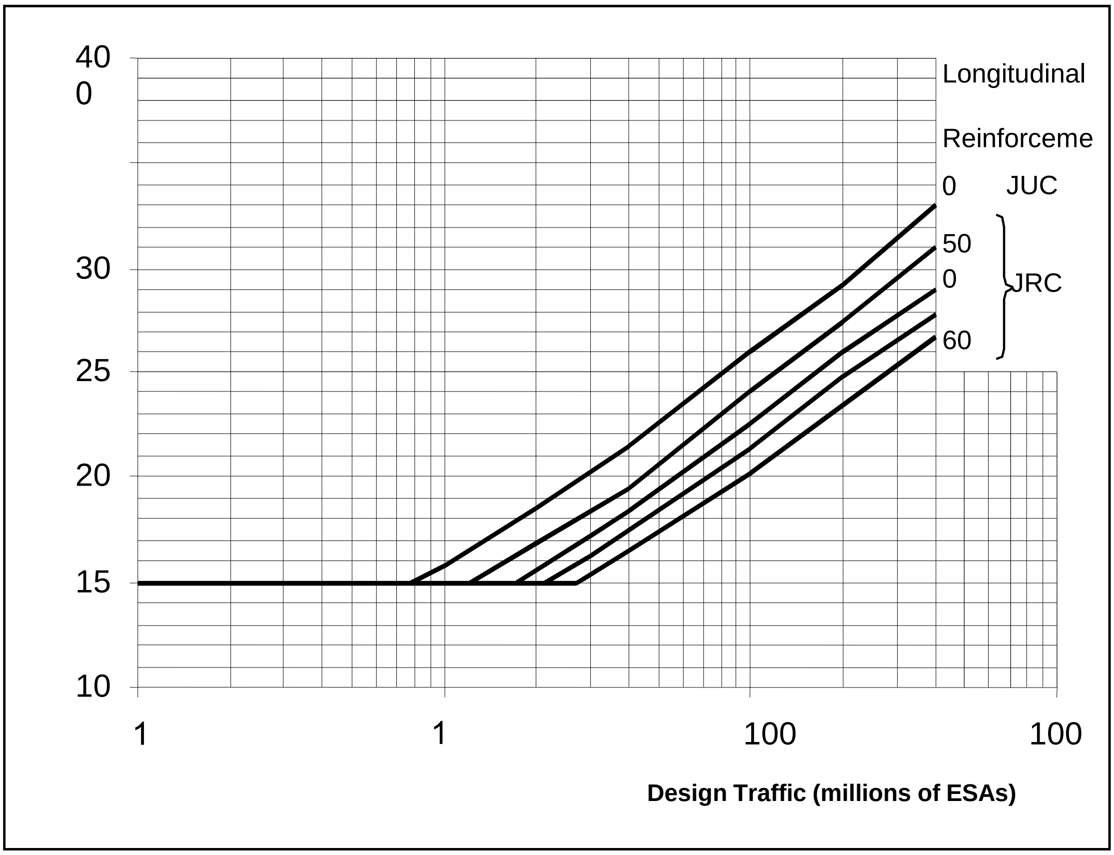



Fig 2.6 Design Thickness for JUCP and JRCP Slabs

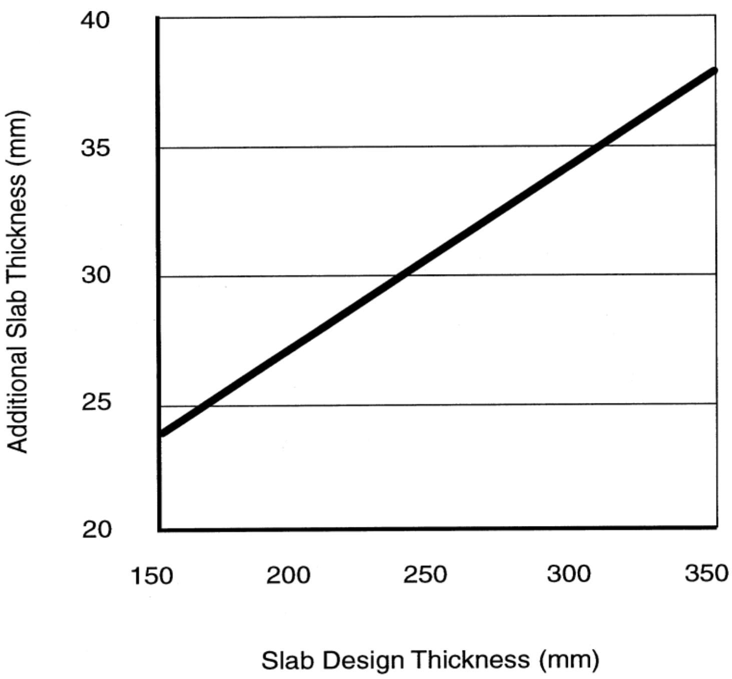



Fig 2.7 Additional Concrete Slab Thickness for Rigid Pavements without Lateral Support

## 2.7. Composite Pavement Structure

When the components of an asphalt and concrete pavement system are combined, the result is a composite pavement structure that functions as a single composite material. While the majority of composite pavements are made of an asphalt surface applied over a layer of concrete (either a fresh base or an existing concrete pavement surface), they can also be made of an asphalt layer applied over a concrete surface (either anew base or an existing Asphalt pavement surface). The advantages of the former construction's strong support from the inflexible base and the latter structure's stronger, less erosive bound base are utilized by the former structure (compared to an unbound base). In Nigeria, most of Europe, and the United States of America, this pavement is typical.

**Benefits of Composite Pavement**

The majority of composite pavements have a concrete layer below an asphalt surface. When compared to conventional flexible or rigid pavements, composite pavements have the potential to offer higher levels of performance in both structural and functional (technical aspects) areas while still being an economically sensible substitute (economic aspect). Among the advantages of composite pavements are (Donald, 2003).

- The hard foundation layer offers the Asphalt layer strong support.
- Creating a smooth and quiet driving surface will improve the ride quality of the pavement and the comfort of the driver.
- Making sure the pavement has enough skid resistance (i.e., friction).
- Performing preventive maintenance on the asphalt surface course will preserve the firm base's structural integrity and guarantee a long- lasting pavement system.
- The asphalt layer's impermeable quality prevents the infiltration of deicing salts and surface water into the stiff foundation.
- The asphalt layer that is placed on top of the stiff layer reduces the temperature gradient.

## 2.8. Composition of Concretes.

Concrete is a composite material that primarily consists of a binding medium that has particles or pieces of relatively inert mineral fillers. Cement and water are combined to form the matrix, or binder, of concrete; this substance is frequently referred to as "cement paste." The "aggregate" filler material is typically graded in size from fine sand to pebbles or stone fragments. In addition to aggregates and binders, concrete can also contain a material known as an additive to enhance particular qualities. In concretes, the proportions of these principal components, the binder and the aggregate are controlled by the requirement that;

1. The mass must be workable or placeable when it is freshly mixed.
2. After the mass has hardened, it has the strength and durability necessary for the intended use.
3. The cost of the final product is a minimum consistent with acceptable quality.

### 2.8.1 Chemical Composition of Portland Cement

Lime, silica, alumina, and iron oxide compounds, which make up the majority of the raw materials required to make Portland cement, interact with one another in the kiln to create a variety of more complicated products. They are typically viewed as the primary ingredients in cement. These are the tricalcium silicate (C3S), Dicalcium silicate (C2S), tricalciu aluminate (C3A) and tetracalcium alumino ferite or ironcompound (C4AF). Table 2.1 gives approximate oxide composition limits of Portlandcement.

| Oxide | Content in percent |
|---|---|
| CaO | 60 -67 |
| $SiO_2$ | 17-25 |
| $Al_2O_3$ | 3 - 8 |
| MgO | 0.1 - 4.0 |
| A1kalis | 0.2 - 1.3 |
| $SO_3$ | 1-3 |

Table 4.1 Approximate oxide composition limits of Portland cement.

## Hydration of cement

When water is present, the silicates and aluminate compounds in cement react to form products of hydration, which over time produce a firm and hard mass. This is the process by which cement transforms into a bonding agent.

During the initial few minutes of mixing, hydration is rapid, and it gradually declines with time. Even after a long time, there is still a significant amount of anhydrate cement due to the decline in hydration rate. As a result, hydration occurs any time after concrete has hardened, usually at lower rate.

The various compounds of cements mentioned previously has different rate of hydration, the rate of hydrations of C4AF is higher than the three major compounds ofcement. C3A has higher rate than C3S and C2S; and C3S has higher rate of hydration than C2S.

The hydration products of the major cement compounds, C3S and C2S, gives calcium silicate hydrates which is commonly designated as C-S-H. This hydrate product determines the basic physical properties of concrete such as setting and strength gain.

## Heat of hydration of cement

Exothermic hydration of cement compounds results in considerable heat energy release during hydration, with up to 500 joules per gram (120 cal/gram). Concrete works as an insulator because its conductivity is very low, and hydration can cause a significant temperature increase inside a large concrete mass. A sharp temperature gradient may be created as a result of the exterior of the concrete mass losing some heat at the same time, and major cracking may develop during cooling of the interior's

. The importance of cement selection must be underlined because Ethiopia has a variety of climate zones, including both lowland hot parts and highland cold places. Hence the use of low heat Portland cement such as PPC in hot areas of Ethiopia like Afar should be better preferred than OPC for cement.

## Ordinary Portland and Portland Pozzolana Cement

There are various types of Portland cements. The two, namely, Ordinary and pozzolanic Portland cements, are cements which are mostly produced by the factories in Ethiopia. So, here is a detailed discussion of the qualities of these two cements.

When there is no exposure to sulphates in the soil or in ground water, ordinary Portland cement is perfectly suitable for use in general concrete construction. In order to create Portland pozzolana cement, a portion of Portland cement is replaced with pozzolanic material made from volcanic ash. The pozzolana added varies commonly between 10 and 30 %. Pozzolanas aren't reactive by themselves but becomes reactive when it gets in contact with Portland cement. It reacts with the calcium hydroxide liberated from Portland cement at ordinary temperatures to form compounds possessing cementitious properties.

Portland pozzolana cements require somewhat long periods of curing since they build strength slowly, although their ultimate strength is comparable to that of ordinary Portland cement alone.

low heat Portland cement, such as Portland pozzolana cement, is around half as strong as regular Portland cement after seven days, two-thirds as strong after twenty-eight days, and roughly equal at three months.

Portland cement is more expensive than pozzolanas. It is crucial for mass concrete construction because of its delayed hydration and the consequently sluggish rate of heat buildup. Additionally, it demonstrates strong resistance to sulphate attack and several other damaging chemicals. This is true because the pozzolanic reaction lowersthe permeability of concrete and minimizes the amount of lime that can be leached out.

## 2.9. Aggregates

### General

By volume, aggregate makes up the majority of concrete. As a result, it is crucial for concrete quality, particularly strength. This is due to the fact that high-quality aggregate is recognized to have superior impact resistance and crushing strength. In addition to affecting the strength of concrete, aggregates also have other effects on durability and structural performance.

Aggregate is cheaper than cement. It is, therefore, economical to put in to the mix inas much proportion as possible.

A relatively inert mineral filler known as aggregate is used to create concrete. Sand, crushed stone or rock, crushed gravel, crushed or artificially created inorganic elements, or crushed stone or gravel make up this aggregate.

**Physical Properties of Aggregates**

The final concrete quality is greatly influenced by the aggregates' physical characteristics, including size, shape, texture, porosity, absorption, moisture content, bulking of fine components, presence of harmful compounds, etc.

## 2.10. Water

The most crucial and affordable component of concrete is water. In order to hydrate the cement and create the binding matrix, some of the mixing water is needed. The remains make concrete workable by acting as a lubricant between the fine and coarse material.

For hydration, cement needs about 30% of its weight of water. However, concrete that contains this much water will be very harsh and challenging to lay. As a result, more water is needed to make it workable. The issue arises, though, if there is too much extra water present, it must be minimized. Too much water in the mix can lead to issues like decreased strength and laitance on concrete surfaces due to bleeding. Additionally, the extra moisture could seep through the formwork's joints and cause the concrete to crack.

- **Curing Water**

We can use the same water for curing that we would use for mixing. There shouldn't be any undesirable stains or unattractive deposits left behind by curing water on the surface. Particularly when concrete is subjected to extended wetness, even a very low concentration of these can produce staining. Iron and organic debris in the water are the main causes of staining or discoloration.

## 2.11. Admixtures

These are materials or chemicals that are added to concrete in order to enhance or impart certain qualities. A concrete property should not be negatively impacted by the application of admixture, and it should provide an improvement that is not economically feasible by modifying the cement and concrete proportions.

Admixtures are not a replacement for good concreting techniques. Only after a thorough assessment of an admixture's effects on the concrete that is planned to be used should be used. In order to gain accurate information on the properties of concrete containing admixtures, tests on representative samples of the materials for a specific application under realistic job conditions are frequently required.

Workability, rate of hydration or setting time, i.e., either accelerating or delaying the setting period, and air entertainment are the qualities of concrete that are frequently adjusted. In general, only a modest amount of admixture is added. A certain amountof control must be used to ensure the right amount of additive is used, as using too much could harm the concrete's qualities. Pay close attention to the directions provided by the product's manufacturer before applying any admixture.

## 2.12 Specification of Concrete

When making concrete, the proportioning of the component elements must be done ina way that the finished concrete performs well in both the fresh and hardened states. Various national standards have established mix design processes to achieve this purpose. The two most popular mix design methodologies are the British DOE method and the American (ACI) method.

There are three different ways of specifying concrete. These are the designed, prescribed and standard or nominal mixes.

Compressive strength as well as other parameters like aggregate size, minimum cement content, and workability are specified in the planned mix. Given that the designer specifies the mix proportion and provides it to the manufacturer, the designeris forced to assume full responsibility for creating the mix in the prescribed mix.

## 2.13 Concrete Production

Introduction

To achieve the desired concrete quality, a structure's concrete must be of uniform quality, free of voids and discontinuities, and properly cured. A good concrete mix design alone is insufficient. As a result, achieving the necessary quality depends onthe efficient execution of the production process's operations, including batching, mixing, transportation, placement, compaction, finishing, and curing.

The qualities of concrete mixtures in both their fresh and hardened states are governedby a scientific process known as concrete manufacturing, which is based on some well-established principles. The impact on concrete quality of the various stages of the aforementioned production processes will be covered in detail in the section that follows.

## 2.14. Batching

The best way to batch solid granular ingredients is by weight, such as aggregates and cement. Volume measurements are only accurate for liquid admixtures and water. Following quick and practical changes is batching by weight. when variations in aggregate moisture levels occur.

During batching, batching quantities should be measured with a high degree of accuracy.

The batching equipment falls into three general categories. These are manual, semiautomatic and fully automatic.

## 2.15 Mixing

The primary goals of mixing are to evenly distribute the components throughout the mixture and to thoroughly coat all aggregate surfaces with the cement-water paste. Concrete mixing is often done by equipment referred to as batching plants.

The mixing process goes through two visible stages. In the initial step, aggregates and cement paste are both simultaneously absorbing water. The cement paste covers the aggregate particles in the second stage. Until a thoroughly and well mixed concrete is obtained, the mixing procedure should be continued. The concrete looks to be a consistent color and gradation at the conclusion of this stage. When removing the concrete from the mixer, the homogeneity must be preserved.

## 2.16. Transport of Concrete

Concrete from the mixer should be delivered as quickly as possible to the location where it will be deposited using a technique that prevents ingredient segregation or loss. Before setting has started, the concrete must be laid. If the concrete is delivered in a truck mixer or agitator, a maximum of two hours may pass between mixing and discharge. The period is shortened to just one hour in the absence of an agitator. If the concrete temperature is between 5°C and 32°C, this maximum allowable time between mixing and discharging is valid. Transporting concrete slowly might cause pour planes, cold joints, or construction joints to form at the intersections of previously placed and freshly poured concrete. These joints are prone to water leakage and leave weak structural parts.

The use of a retarding admixture could assist extend the setting time by two to four hours and decrease the amount of water needed by 5 to 10% in situations where the mixing and putting locations are far apart or concrete transportation takes longer.

The most crucial factor to keep in mind when handling and moving concrete is preventing segregation. Before segregation occurs, it should be avoided and fixed. As a non-homogeneous composite material with significantly different particle sizes and specific gravities, concrete is vulnerable to internal and external forces during transportation and placement that tend to separate the diverse constituents.

The approach should shield concrete from weather impacts like heat or cold that have an impact on the performance of concrete. This is another factor to be taken into account while handling and transporting concrete.

### 2.17. Placement of Concrete

Concrete's homogeneity, density, and behavior in service are significantly impactedby the techniques employed to place it in its final location. To maintain homogeneity in putting, the same caution that was used to ensure homogeneity in mixing and avoid segregation in shipping must be applied.

Rapid placement of the concrete in its ultimate location will prevent it from becoming too stiff for use. After the concrete has come out of the mixer, water shouldn't be added. The concrete must be put and as near to its final location as possible.

### 2.18 Curing Concrete

Theoretically, the water provided during mixing is adequate to completely hydrate concrete without the need for further water supplies. In reality, there is a large loss of water via evaporation or from water absorption by aggregates, formwork, or subgrade. Therefore, the placement of an acceptable mix must be followed by curing in a suitable environment during the early phases of hardening in order to produce good concrete. Additionally, if the concrete has just not grown strong enough to sustain these stresses, evaporation might result in early and rapid drying shrinkage, creating tensile stresses that are likely to lead to cracking.

Different techniques are used for curing. These include directly supplying moisture orwater, preventing evaporation by providing an impermeable surface or by misting chemical compounds to form a barrier, and accelerating strength increase by supplying heat and moisture. The final curing method, which involves curing with heat and moisture, is mostly employed in the manufacture of prefabricated elements and occasionally for testing concrete on manufacturing sites. Considering that the 28- day strength might be attained in a few days or hours.

# CHAPTER THREE

## 3. FINDINGS AND DISCUSSIONS

### 3.1. General project information

- Project Name: Dichoto Galafi Junction –Elidar – Balho.
- Project Total Length: 80.54 km
- Project Contract Cost: Birr 2.66 Billion/133.1 Million USD.
- Contract Time: 1170 Calendar Day (3 Years And 3 Month)
- Location: Afar Regional State
- Employer: Ethiopian Roads Authority
- Contractor: Defense Construction Enterprise
- Contract Type: Design and Build (DB)
- Source of Fund: Ethiopian Government
- Procurement Method: International Competitive bidding.

### 3.2. Project Purpose

The road is to connect Ethiopia with the port of Tadjoura, which is about 120km from Belho, in Djibouti.

- To provide another outlet to the second port in Djibouti to facilitate thegrowing import export demand.

Climate: According to the Meteorological Map of Ethiopia,

- Annual Rain Fall: 100mm–500 mm
- Maximum Temperature is About: 50oc
- The Rainy Season: From June to September

### 3.3. Project major construction material and their source

- Natural gravel: is abundantly available in the project area but may requiresome collection.
- Rock source for crushing and masonry work are deemed to be abundant in theproject area.
- Source of borrow material: is sufficiently available in the project area
- Water and Fine Aggregate source: Water is very scarce in this project and the possible option is to use the limited ground water.
- Natural sand is also not abundantly available or it may encounter long hauling distance. There four crushing is the possible option.

### 3.4. Estimated Construction Materials Requirement for Rigid Pavement

| Description | Unit | Quantity |
|---|---|---|
| Cement | ton | 118,000 |
| Reinforcement Bar | ton | 1,110 |
| Fine Aggregate | $m^3$ | 100,555 |
| Coarse Aggregate | $m^3$ | 188,808 |
| Concrete C35 | m3 | 236,047 |

### 3.5. Topography

- Flat to rolling with some escarpments.
- Wide depression areas are also located between escarpments where seasonal swamps with thick salty alluvial deposits are stretching in parallel orientationto escarpments.

**Road Project Crossing Terrain Classification**

**Terrain Slope:**

- Flat = 0-5%
- Rolling = 5-25%
- Mountainous = 25-50%
- Escarpment = > 50%

### 3.6. Performance Requirement

The following need will be demanded by the Contractor in with respect to designing and produce pavement:

- Design and Construct a Rigid Pavement Road (Jointed Unreinforced Concrete Pavements) with Equivalent Standard Axel Load (ESAL) of 150.670 million ESAs in each direction.
- Design and Construct a Rigid pavement (Jointed Unreinforced Concrete
- Pavements) with subgrade strength class of S4 (8 – 14%) as defined in ERA 2002 Pavement Design Manual

- Provide a shoulder with Natural Gravel Sub base Material with 1.5m shoulderwidth.
- Replace poor subgrade materials with improved subgrade having minimumCBR of 8%.
- The section from Ditchoto to Elider and Melodoni village to the project end(65.44 km), with slab thickness 400 mm.
- The section from Elidar town up to Melodoni village (15.1km) with slab thickness 352 mm
- Provide pavement with no distress.
- Use C35 Class concrete for constructing the rigid pavement structure
- The works include design and construction of a new road DS-3 Rigidpavement standard.
- The road shall have a cross-section width of 10m (7m rigid pavement and.5m gravel shoulder on each side).
- The work includes the Design and Construction of Minor and Major drainage structures.

| Sub grade | | Concrete slab thickness | Crushe / Natural Subbase | Cappin gLayer (mm) | Rock | Total Thicknes |
|---|---|---|---|---|---|---|
| Non Expansiv su grad materia l | For 65.44 ne rigi Pavemen tRoad | 40 | 15 | 20 | - | - |
| | For 15.1 km Existing Asphalt Roadfrom Elider to | 35 | - | - | - | - |

| | |
|---|---|
| Spacing of Transversal Joints | 5 meters |
| Dowels for transversal joints 300 mm | 25 mm diameter plain bars 400 mm long @ |
| | s p a |
| Tie bars for longitudinal reinforcement barsjoints | 1000 mm long ,12 mm diameter @ 600 mm spacing |

**JOINTS**

- Expansion joints are used to allow for slab expansion while preventing the buildup of compression stresses that could lead to the slab buckling. Tie bars are provided.
- Contraction joint is used to relieve the tensile stress developed due to change in temperature and moisture. Dowel bars are provided.

## 3.7. Project location

The Project Road is named as Dichoto - Galafi Junction / Dobi –Elidar – Balho where the beginning point is found in the North-Eastern part of Ethiopia of Afar National Regional State and the last point is Village Balho which is found in the Western part of the Republic of Djibouti at an offset distance of about 6 to 7km from the border line of the Federal Democratic Republic of Ethiopia. This Road Project is intended to increase the efficiency of the Road transport network particularly an access to the portof Tadjoura which is about 120km from Balho.

The project location is bounded by 11o,46‟,32.02‖ N Latitude,41o,48‟,56.62‖E Longitude and 12o,03‟,24.56‖N Latitude, 42o,11‟,43.14‖E Longitude. Datum of Topo- Map is Adindan in Zones (37 & 38) and the projection is of Universal Transverse Mercator.

## 3.8 Pavement Design

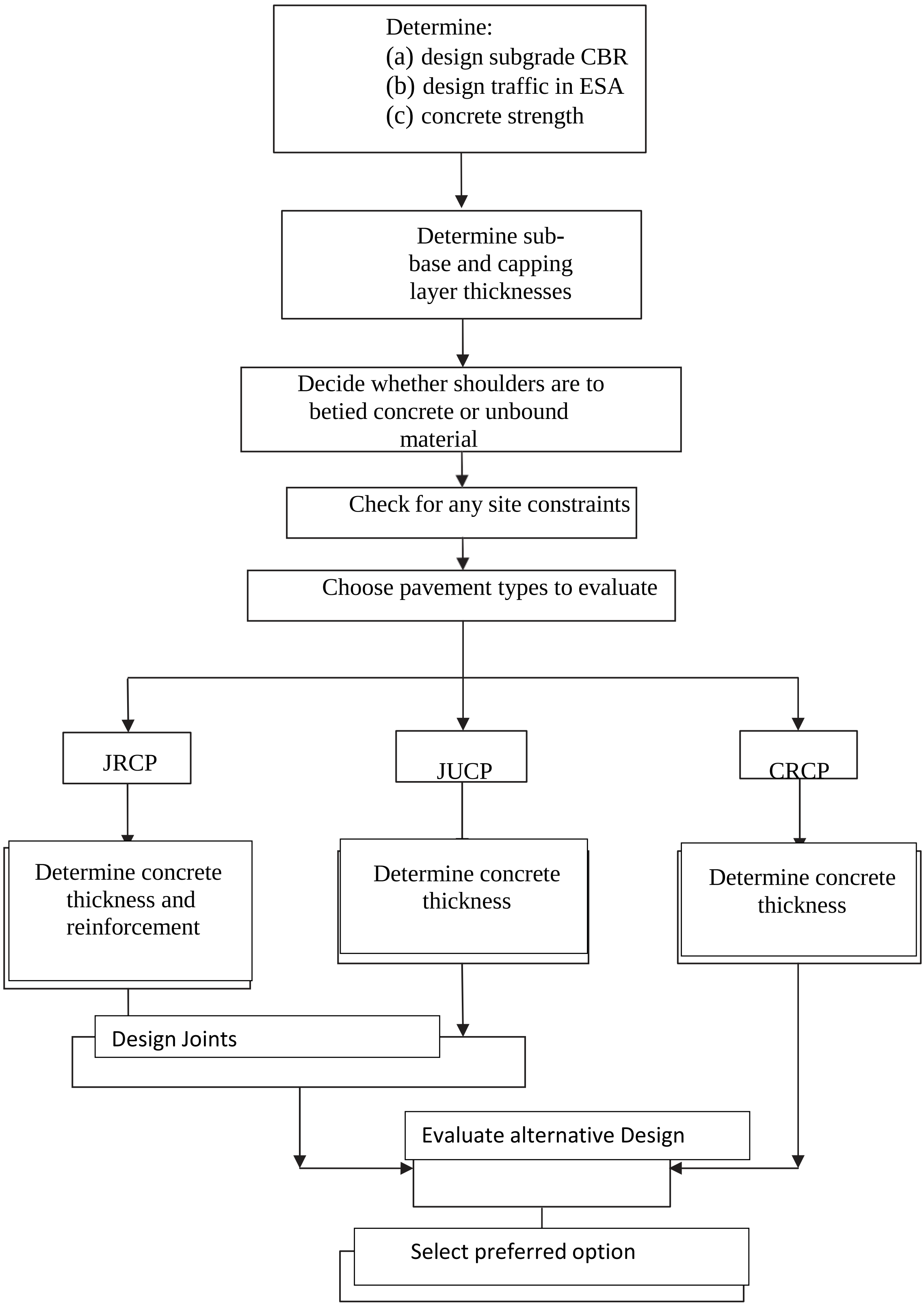
The main goal of structural pavement design is to provide a surface for the road that can withstand the anticipated traffic loads for a given amount of time without degrading below a predetermined level of service. This goal is accomplished by constructing the pavement structure to decrease to a manageable level the stresses thattraffic-induced on subgrade

As learned from the associated concept design documents, the pavement design of theproject was done based on ERA Pavement Design Manual – 2013, which was selected after examination of the available alternate design manuals such as ERA 2002 and AASHTO Pavement Design Guide 1993. Accordingly, pavement structure of 400mm concrete slab, 150mm subbase, and 200mm capping specified for new road section, and 352mm for overlay section has been specified. As per the Employer Requirement, the Contractor is expected to analyze and prepare a rigid pavement surfacing of Jointed Unreinforced Concrete type. The Employer Requirement further requires that the analysis shall follow ERA 2013 Pavement Design Manual Volume II as the highest priority manual and ERA’s 2002 relevant design manuals and AASHTO design manuals as the supplementary manuals that can be referred for the design of the pavement structure. On the other hand, the nature of the Employer

Requirement is 'Restrictive Type' which stipulates the design to bebased on traffic load of 150.670 million ESAs in each direction and Subgrade class of S4 (CBR 8-14%), and with specified thickness and material requirements of each pavement layer.

The task therefore will be verification of these design inputs and to make necessary design consideration to meet the same (e.g., subgrade improvement if S4 not met or determine the life of the pavement if the design traffic is above the specified ESAs, etc) as will be briefed in next section.

### 3.9. Pavement Design flow chart as per ERA Pavement Design Manual Volume II (Rigid Pavement)



### 3.9.1. Design Methodology

There are many pavement design standards which have been developed and widely used in different parts of the world. Portland Cement Association (PCA) method, the American Association of State Highway and Transportation Officials (AASHTO) method, and ERA Pavement Design Manual Vol II- 2013/2002, can be cited here.

ERA brought out updated road design manuals in 2013 to provide a standardized approach for the design, construction and maintenance of roads in the country. This current version of the manual has particular reference to the prevailing conditions in Ethiopia and reflects the experience gained through activities within the road sector during the last 10, years particularly for flexible pavements.

In rigid pavement design revision, there is no clear reason mentioned why and how the revision has been made except stating its advantages as compared to AASHTO method. Moreover, the manual stipulates that ―the standards set out shall be adhered to unless otherwise directed by ERA‖ (Page i, paragraph 4 line 2). In addition to this, due to the fact that the manual has been developed from current practice, it will be used as the main reference. The following two shortcomings related with the other methods further support the statement:

- Normally, the required slab thicknesses using the AASHTO method and PCA method are much thicker than those using the ERA method, which in turn means more uneconomical section.
- The adaptation of the AASHTO method and PCA method require the calibration of design input parameter values to past and present practice, experience and pavement performance. However, such a precedent is not available in our country and hence those values to be adopted are those recommended by the Guide; not consider the prevailing condition.

However, value obtained will be cross checked using the AASHTO method.

### 3.9.2. Rigid Pavement Type

The Employer Requirement here again specified Jointed unreinforced (JUCP) to be designed and constructed. Jointed unreinforced (JUCP), jointed reinforced (JRCP) and continuously reinforced (CRCP) were candidates. Due to its often lower construction costs, JUCP is the most popular type of concrete pavement. Because there is no need to pay for manpower to lay the steel or for any reinforcing steel in the slabs, it is cost-effective. This is crucial for our nation because the price of reinforcement bar is very high. The cost of the steel, the poor performance of the joints, and the cracks outweigh the one benefit that JRCP offers over JUCP, which is fewer joints.. Because the joints are spaced further apart than JUCP, they open and close more, and load transfer suffers as joints open wider. CRCP provides a smoother ride and a longer life than any other type of pavement but because of the steel reinforcement, it is very costly and less frequently used.

Considering the risk associated with longer expansion joints and expense related with reinforcement, the use of jointed unreinforced rigid concrete type as specified in the contract seems rational.

### 3.9.3 Design Inputs

**Subgrade Strength**

The pavement is required to be designed and constructed with subgarde strength class of S4 (8-14% CBR). The task here, therefore, is to check if this minimum strength is available or not on the sections under consideration. The general strategy toward such evaluation is based on the following key backgrounds:

- As part of the roadbed preparation, detail subgarde evaluation will be made prior to placement of fill or pavement layers. A minimum depth of 60cm will be considered but this need to be clear that it is not a depth to which recompaction and reworking would be anticipated. Rather, it is the depth to which the Contractor will confirm that the nominal subgrade strength is available.
- Even if a section can satisfy the expected minimum CBR8%, use of a minimum 200 mm layer of ordinary fill will be considered except rocky and very good subgrade sections (CBR >15%) sections where the subbase will take this role. . Over the course of the pavement's design life, a uniform subgrade will help produce a pavement with consistent strength, roughness, and other characteristics. Premature pavement roughness development may be caused by an irregular subgrade.
- To avoid reconstruction of the existing subgrade, wherever any, it is recommended that the existing pavement remain in place and be overlaid with fill and pavement materials for the fill sections. This strategy will also contribute to cost benefits as far as removals and subgrade improvements are concerned.

- Improved subgrade with minimum CBR of 8% will be constructed wherever the subgrade soil is not problematic type but weak (<8% CBR).
- Sections with expansive soil will be replaced with suitable fill material of minimum CBR 8% to a depth of 1m in accordance with the EmployersRequirements.

In accordance with the general subgrade treatment strategy above, table below summarizes the recommendations for sections covered at this stage. Please note that this is based on laboratory test results of samples collected at 500m interval and experience on similar material. Minor adjustment may be required during detailed sampling and testing in the course of roadbed preparation.

**Design Traffic Considerations**

The design ESAL for the project has been adopted from the Employer Requirements, 150.7Million.

**Material PropertiesCapping**

The requirement of capping is based on the design method. As per ERA 20113, a capping layer is required if the design CBR of the subgrade is less than 15%. The capping will have minimum CBR of 15%.

**Subbase**

A subbase course provides a stable platform for construction of the concrete slab, improves the smoothness achieved in the paving of the slab and the drainage of the pavement structure. The estimated elastic modulus, its erodibility, its potential for friction and bond with the concrete slab, and its drainability are factors considered in characterizing the support to the concrete slab and the quality of subsurface drainage.

As per ERA 2013, a subbase 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.

**Concrete Material Properties**

In accordance with ERA 2013design, concrete is characterized by a 28-day cube compressive strength. Particularly, the project requirement is 35MPa cube strength at 28 days.

ERA 2002 and ERA 2013 rigid pavement design manuals however recommend the least among referenced guides. They state that the dowel bars shall be 20 mm in diameter at 300 mm spacing, 400 mm long for slabs up to 239 mm thick, and 25 mm in diameter, keeping the length and spacing, for slabs 240 mm thick or more.

**Tie bars and Dowels**

In accordance with Division 7102(g)iii of the Standard Technical Specification:

'...Tie bars shall be deformed bars conforming to AASHTO M 31 M. All bars shallhave the tensile requirements of Grade 400.

Dowel bars shall be plain, round bars conforming to AASHTO M 254 type A or B.They shall be free from burring or other deformation restricting slippage in concrete...'

### 3.8.4 Thickness Design

**Based on ERA 2013**

ERA 2013 pavement design manual adopt Transport Research Laboratory report RR87. The design method is based primarily on empirical data from full scale experiments carried out by TRL in the UK. Once the design inputs have been prepared, the method is directly utilizable one.

**Carriageway**

The required thickness of capping and subbase for the corresponding subgrade strength CBR of 8-14% is 200mm and 150mm, respectively, referring Table 3.1 of ERA Pavement Design Vol II, 2013. The table further shows that capping is not required if CBR of the subgrade is greater than 15%.

Referring Figure 3.1. ERA Pavement Design Vol II, 2013 (attached here under for immediate reference), for corresponding design traffic of 150.67 million ESAs, the slab thickness is 393mm using C35 concrete.

The design charts for the concrete pavement thicknesses presented below are based on the assumption that the foundation of subbase, capping and subgrade has a minimum effective modulus that is achieved by adopting the thicknesses shown in Table 6.2 and with a stabilized subbase. If the sub-base is not stabilized the thickness of the concrete pavement need to be increased as shown in Tables 3.2 of the manual. Accordingly, additional 35mm thickness is required to account for use of unsterilized subbase, which was disregarded during concept Engineering Design stage. This brings the totalslab thickness to 428mm.

**Capping and Sub-base**

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 Table 3.1

Table 3.1: Thickness of Sub-base and Capping Layers

| Sub grade Class | CBR range in % | Sub base thickness in mm | Capping layer thickness in 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 |

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.

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 very weak subgrades with CBR values less than 3%, the subgrade material needs to be improved by stabilisation or replaced. Soil improvement is described in ERAs Pavement Design Manual Volume I Flexible Pavements.

For good performance of the rigid pavement the sub-base material should be very resistant to erosion. To ensure this it should, ideally, be stabilised with cement or lime (Class CS with unconfined compressive strength in the range 0.75-1.5 MPa), especially if the traffic level is high (i.e. the higher classes of road).

The design charts for the concrete pavement thicknesses presented below are based on the assumption that the foundation of sub-base, capping and subgrade has a minimum effective modulus that is achieved by adopting the thicknesses shown in Table 3.1 andwith a stabilized sub-base. If the sub-base is not stabilized the thickness of the concrete pavement must be increased as shown in Tables 3.2 for unreinforced pavements .In JUCP and JRCP pavements, a separation membrane (such as a polythene sheet) is required between the sub-base and the concrete slab, mainly to reduce the friction between the slab and the sub-base and thus inhibit the formation of mid-bay cracks. The polythene sheet also reduces the loss of water from the fresh concrete. For CRCP pavements, a bituminous spray should be used on the sub-base instead of polythene because a high degree of restraint is required.

| | **T3** | **T4** | **T5** | **T6** | **T7** | **T8** | **T9** | **T10** | **T11** |
|---|---|---|---|---|---|---|---|---|---|
| **S1** | 20 | 25 | 25 | 30 | 35 | 35 | 40 | 45 | 50 |
| **S2** | 20 | 25 | 25 | 30 | 35 | 35 | 40 | 45 | 50 |
| **S3** | 20 | 25 | 25 | 30 | 35 | 35 | 40 | 45 | 50 |
| **S4** | 15 | 15 | 20 | 20 | 25 | 25 | 30 | 30 | 35 |
| **S5** | 10 | 10 | 10 | 10 | 15 | 15 | 15 | 20 | 20 |
| **S6** | | | | | | | | | |

Table 3.2**: Additional Thickness for JUCP with Unsterilized Sub-bases (mm)**

Concrete Slab Thickness and Reinforcement

Based on the design traffic volume expressed in Equivalent Standard Axles, thestrength of the concrete, the type of rigid pavement, the shoulder design, and the thickness of the pavement are determined as described below.

Jointed Unreinforced Concrete Pavement (JUCP)

The thickness of a JUCP concrete slab is determined from Figure 3.1, depending on the strength of the concrete. The Figures show the thicknesses required for concrete slabs that have effective support to the edge of the most heavily-trafficked lane (i.e. the right lane) by means of tied shoulders. In the absence of a tied shoulder an additional slab thickness is required as shown in the Figures.

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

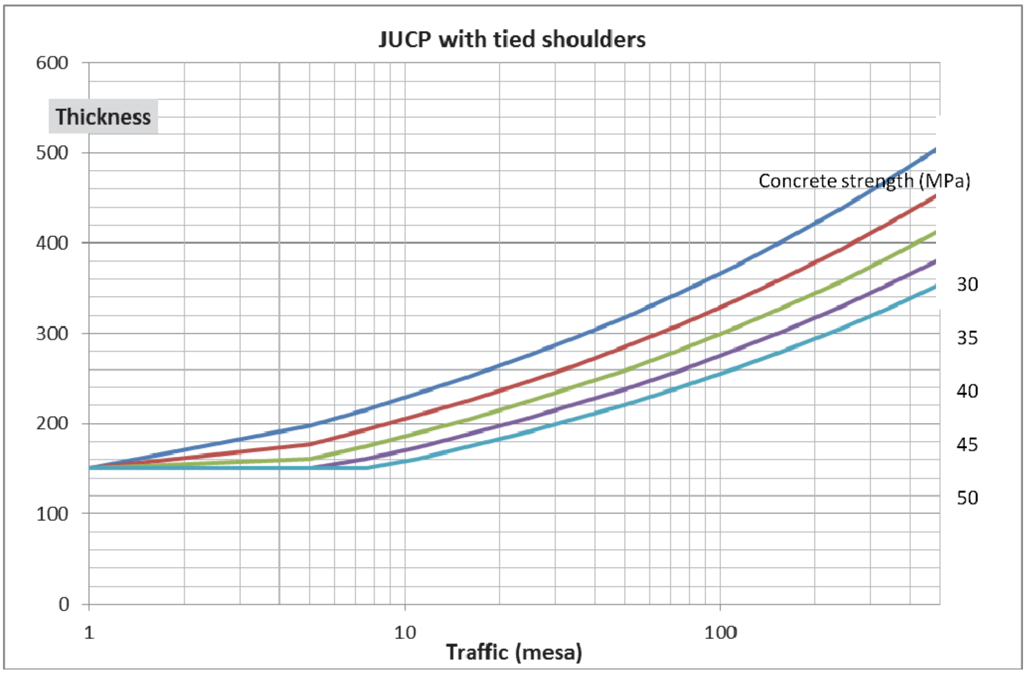



Fig 3.1 Design Thicknesses for JUCP with tied shouldersJoint Design

Pavement joint layout is a matter of selecting the proper joint types and dimensions so as to reduce the detrimental effects of stresses and minimize random cracking.

Joint Spacing: With JUCP, the joint spacing should be short enough to prevent high curling stress buildup.

The Employers Requirement prescribe joint spacing of 5m, which is based on ERA 2013 Pavement Design Manual Volume II recommendation that states maximum of 5m for slab thickness in excess of 230mm.

### 3.10 DESIGN REVISION

The thickness of the concrete slab found is about 428mm thick when using ERA 2013 method while the number is about 395mm for AASHTO method, which all are comparable to the specified 400m slab thickness.

When the AASHTO and ERA methods are compared, the slab layer thickness by the AASHTO method comes out slightly lower than by the ERA method. Similar result was also obtained by varying the reliability of AASHTO method. Detailed analysis of the results at various ESAL shows that both give similar results for ESA in excess of 100million but AASHTO method is somehow conservative for lower traffic ranges.

Literatures confirm that there is every reason to place reasonable trust in all the major published design approaches; after all each has been compiled by professionals with considerable experience of concrete pavement performance. This means that whether Westergaard, Meyerhof or an adaptation of multi-layer linear elastic theory has been used, or the basis is purely empirical, one can be reasonably certain that sensible calibration has been built into the procedure, ensuring that predictions match experience. However, it must be remembered that each method is therefore only as good as the evidence and experience upon which it is based.9

Since the pavement composition obtained by both methods (with slight modification) are comparable each other, and consistent with the employer requirement for the specified traffic loading, the 400mm slab thickness will be used. However, it is to be noted that the specified design ESAL is much less than the present study findings. The outcome of this is that the service life of the pavement may not be as envisaged; only 21 to 30 years of service is estimated. Since traffic estimation for long design period has inherent uncertainties, and the possibility that any under-estimation can usually be remedied by carrying out deferred works later as required (e.g, in the form of overlay), revision of pavement is not proposed.

## 3.11. BREIF SUMMARY OF DESIGN REVISION3.11.1Design Parameters:

**Design parameters taken from employer's requirement**

| No. | Design Parameters | |
|---|---|---|
| 1 | Design Period | 60 years |
| 2 | Traffic Category | T11 (150.67 MESA) |
| 3 | Subgrade Class | S 4 (CBR 8-14%) |

In addition to the above design parameters the following assumptions are considered:

- 28 day characteristic compressive strength for concrete slab 35 Mpa(C-35)
- Yield strength of the steel reinforcement baris is greater than 400 Mpa(G-60)
- As per the Employer Requirement, the Contractor is expected to analyze and prepare a rigid pavement surfacing of **Jointed** **Unreinforced Concrete type.**

**Determination of Sub base and capping layer thicknesses: Capping Layer:**

A capping layer is required if the design CBR of the subgrade is less than **15%.** As theproject's subgrade class is **S4** (Design CBR between 8-14%), a capping layer is required. Hence, the thickness of the capping layer for the specified subgrade class shall be **200 mm** as per table 4 below.

***Natural sub base:***

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. For good performance of the rigid pavement the sub-base material should be very resistant to erosion. To ensure this it should, ideally, be stabilized with cement or lime (Class CS with unconfined compressive strength in the range 0.75-1.5 MPa), especially if the traffic level is high (i.e. the higher classes of road). Usually the thickness of the sub-base will be 150mm or 175mm, but sometimes the same material is conveniently used as the capping layer.

If the sub-base is not stabilized the thickness of the concrete pavement must be increased asshown in Table 5 for reinforced pavements. In JRCP pavements, a separation membrane (such as a polythene sheet) is required between the sub-base and the concrete slab, mainly to reduce the friction between the slab and the sub-base and thus inhibit the formation of mid-bay cracks. The polythenesheet also reduces the loss of water from the fresh concrete.

For Subgrade class S4 CBR in the range of 8-14%, the sub-base thickness shall be **150mm** as shown in table 4 below.

**Table 4: Thickness of Sub-base and Capping Laye**

| 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 |

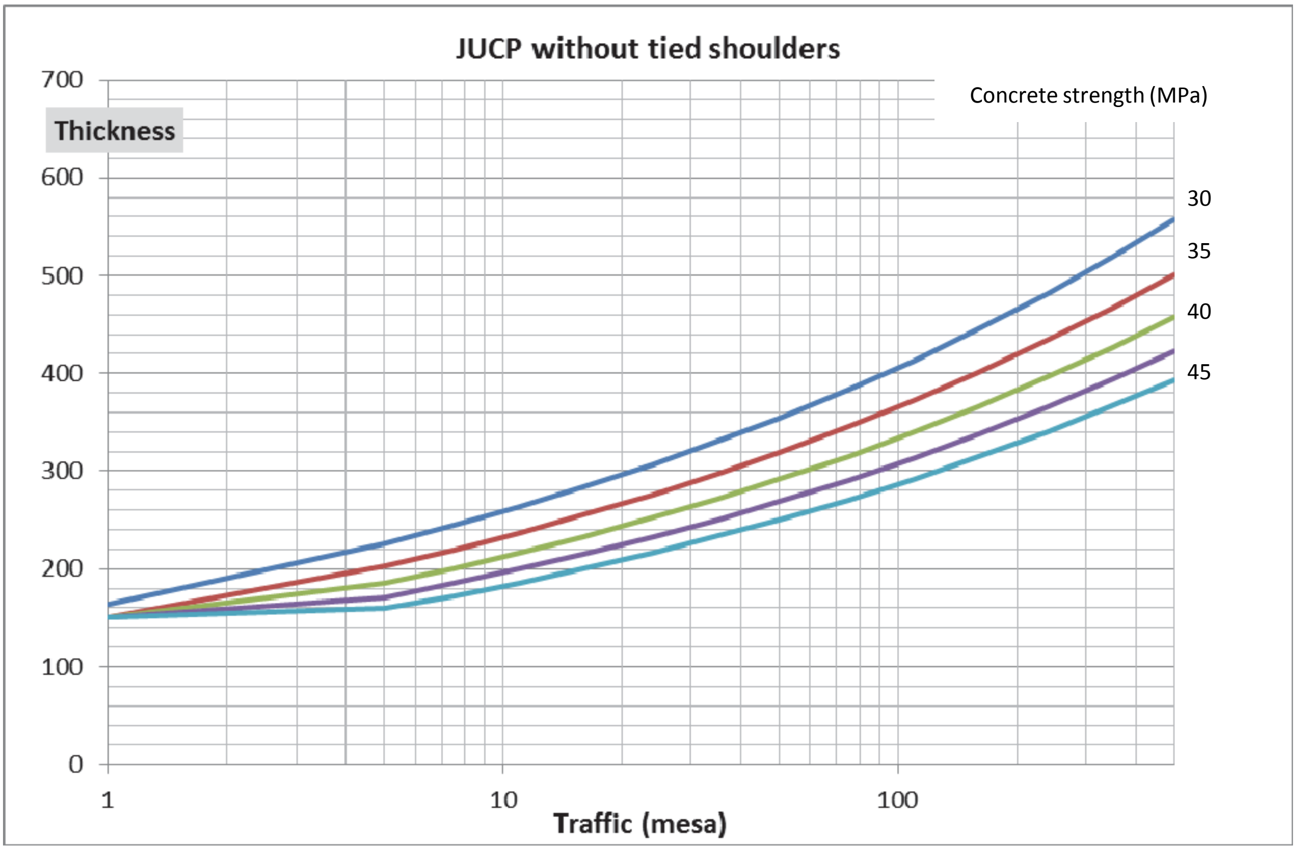
### *Determination of Concrete Slab Thickness*

The determination of the slab thickness is related to the traffic expressed in ESAL (Equivalent Standard Axle Load), the foundation class and the flexural strength of concrete.
Based on the design traffic volume expressed in Equivalent Standard Axles, the strength of the concrete, the type of rigid pavement, the shoulder design, and the thickness of the pavement are determined as described below.

Referring Figure 6.2 (b), ERA Pavement Design Vol II, 2013 (attached here under for immediate reference, Fig 1), for corresponding design traffic of 150.67 million ESAs,the slab thickness is 393mm using C35 concrete.

The design charts for the concrete pavement thicknesses presented below are based on the assumption that the foundation of subbase, capping and subgrade has a minimum effective modulus that is achieved by adopting the thicknesses shown in Table 6.2 of ERA Pavement Design Vol II, 2013 and with a stabilized subbase. If the sub-base is not stabilized the thickness of the concrete pavement need to be increased as shown in Tables 5. Accordingly, additional 35mm thickness is required to account for use of unstabilized subbase, which was disregarded during concept Engineering Design stage. This brings the total slab thickness to 428mm.

**Fig. 1** Design Thicknesses for JUCP without tied shoulders




| | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 | T11 |
|---|---|---|---|---|---|---|---|---|---|
| S1 | 20 | 25 | 25 | 30 | 35 | 35 | 40 | 45 | 50 |
| S2 | 20 | 25 | 25 | 30 | 35 | 35 | 40 | 45 | 50 |
| S3 | 20 | 25 | 25 | 30 | 35 | 35 | 40 | 45 | 50 |
| S4 | 15 | 15 | 20 | 20 | 25 | 25 | 30 | 30 | 35 |
| S5 | 10 | 10 | 10 | 10 | 15 | 15 | 15 | 20 | 20 |
| S6 | | | | | | | | | |

Table 5: Additional Thickness for JUCP with unstabilized Sub-bases (mm)

***Determination of Longitudinal and Transverse Reinforcement:***

Dowels: The transverse joints will be doweled to prevent faulting.

AASHTO 1993 doesn't explicitly states as to dowels diameter and spacing. AASHTO 2008 however states that small diameter (1in or less) dowels are relatively inefficient in preventing joint faulting, while large diameter (e.g., 1.5in) dowels are highly effective.

FHWA 1990 recommended that the minimum dowel diameter be D/8, where D is the thickness of the pavement. However, the dowel diameter should not be less than [32 mm] 1 1/4 inches. It is also recommended that [450 mm] 18-inch long dowels be used at [300 mm] 12-inch spacing.

ACI 325 recommends a different approach to dowel bar diameter selection for highways based on the traffic level. For >90million ESAL, dowel diameter of 41mm, 450mm length and 300mm spacing is recommended. ACPA 1991 recommend similar to ACI except that the diameter of the bar is 38mm for slab >250mm thick.

ERA 2002 and ERA 2013 rigid pavement design manuals however recommend the least among referenced guides. They state that the dowel bars shall be 20 mm in diameter at 300 mm spacing, 400 mm long for slabs up to 239 mm thick, and 25 mm in diameter, keeping the length and spacing, for slabs 240 mm thick ormore.

Tie Bar. Adequate tie bar system is critical to ensuring the effectiveness of the longitudinal construction joints.

AASHTO recommends maximum Tie Bar spacing values for 1/2in diameter Tie Bars, Grade 40 Steel, and Subgrade Friction Factor of 1.5. Where this friction is different, as when plastic membrane introduced, suggested values cannot be adopted

- Design for Movement:

Joints are placed in concrete pavements to permit expansion, contraction and warping of the slab, thereby relieving stresses due to environmental changes (temperature and moisture) and to facilitate construction. Joints are classified according to their direction, either transverse or longitudinal, and their function. They are basically called contraction, expansion, warping or construction joints but in most cases they combine several of these functions.

- **Transverse Joint Spacing:**

Transverse Joints are the joints perpendicular to the centerline 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.

For Jointed Unreinforced Concrete Pavement (JRCP), contraction joints are generally at a standard distance of 5 m..

- *Longitudinal Joint Spacing:*

Longitudinal joints must be placed at the edge of each traffic lane.

**Design Review Conclusion**

| Pavement layer composition | Designed thickness in mm | Standard thickness in mm | Actual construction thickness in mm | Remark |
|---|---|---|---|---|
| **JUCP** | **400** | **428** | **400** | **Under the standard,but as ERA standard** |
| **Sub base** | **150** | **150** | **150** | |
| **Capping layer** | **200** | **200** | **200** | |
| **Dowel bar ( in mm)** | **25** | **32** | **25** | **Under the standard,but as ERA standard** |
| **Tie bar ( in mm)** | **12** | **12** | **12** | |

## 3.11. DISCUSSIONS AND RESULTS

Rigid Pavement General Characteristics: It is called concrete pavements and very strong in resisting compression. The strength of the pavement is contributed mainly by a concrete slab, unlike flexible pavements where successive layers of the pavementcontribute cumulatively

**Challenges of the project to be Resolved**

- As the temperature is very hot and water is scarce, we need some measures on how to keep water cement ratio, curing and workability without affecting the required strength.
- How can we minimize the cement content of the concrete without compromising minimum strength requirement and workability required for thejob?
- The batching plant may become far away from the concrete site whereby it can affect the setting time of concrete therefore which type of retarder Admixture and in what amount can be used to improve concrete setting time for such project.

- How can we reduce the thermal crack and shrinkage?
- What type of Cement can we use for this project?
- What are the possible options to use if the water found has got salt?
- What are the possible effective curing of the concrete?
- Is there any possibility to improve the design? Specially to reduce the 40cm thickness without compromising the Employer’s requirement?
- What are the latest technologies and methodology to be applied for this type ofRigid pavement construction?
- What are the possible effective methods for curing the concrete?
- What types of Admixtures can be used in this project?
- What are the possible effective construction Machineries to be used in this project?

## Results for the challenges

### Descriptions of the Road Pavement

- Type of Pavement= Rigid Pavement/Cement Concrete Pavement ~ Notcommon in Ethiopia)
- Rigid Pavement Type = Unreinforced Jointed Rigid Pavement
- Project Length = 78.037 Km (Actual) The first practice in Ethiopia in thislength and very Hot weather.
- Pavement Thickness = 40 cm
- Concrete Class = C-35

**Required Equipment for the Project**

- Dozer -20,
- Excavator -21,
- Grader -5,
- Dump truck -45,
- Water Truck -30,
- Loader -7,
- Cement Bulk Truck -22
- Concrete Paver Machine with dowel bar inserter (Slip form) which can pave40cm properly - 02 (4meter wide each)
- Concrete Batching Plant - 03
- Crusher Plant - 03
- Sand screening plant - 03
- Water Chiller Plant - 02
- Water Treatment Plant -01

**Challenges associated with Machineries, Equipment & Plants**

Identification and procurement of Suitable equipements for the concrete operation (Paving machine, batching plants, chiller plant, treatment plant) hence there is no previous experience in this kind of project.

**Actions Taken:**

The contractor has put serious effort on the issue and has made big investment to deploy required and suitable plants and machineries for this new type of the project in Ethiopia.

**Challenges Encountered associated with Manpower Resource**

- Lack of experience in rigid pavement construction projects, as a result unavailability of experts, professionals and skilled labors for the pavement work.

**Action Taken**

- –All Technical Crew Members have been Learners at the Beginning''
- The Civil Engineers, Mechanical Engineers, and other Technical Crew Members were new for this kind of job but with extreme commitment, minor on Job Training by Trainers and majorly in Self Training in the due of the job, the Crews have coped up the required knowledge and the best experience to tackle all the challenges in the operation.

**Challenges associated with Construction Materials and actions take**

- Appropriate Cement Type ( To tackle adverse effect of the hot weather and Sulphate Resisatant )

In the context of Ethiopia, OPC cement corresponds to the Type I cement conforming to AASHTO M85. For the site condition in this project, where the maximum ambient temperature reaches 50 degree centigrade and the relative humidity of around 10%, it is not advisable to use the type I cement owing to the early age thermal cracking risk and as well the occurrence of plastic shrinkage cracks. Key parameters, in selecting the type of cement for this specific project shall then be seen from the perspective of strength requirements and risk of cracking mainly caused by early age thermal cracking or drying shrinkage. In consideration of the above performance indicators, modified cement with low generation of early age heat and low C3A content is recommended.

- Suitable sand (qualified natural sand to tackle shrinkage effects)
- Suitable water (scarcity, salinity and temperature)
- Appropriate aggregate type (reduction of surface area to tackle possible cracks

and strength optimization)

- Appropriate epoxy materials (proper adhesive property)
- Suitable curing compound materials (Replace water curing)
- Appropriate admixtures (Set retarding and Water reduction) Actions Taken to tackle those challenges with Construction Materials

- To tackle cement problems – special type of cement – Modified PPC has beenused.
- To minimize risks associated with sand problems – screened sand has beenused

**To minimize risks associated with water (salinity, temperature, scarcity)**

**Actions Taken**

- Needed to Construct Deep Wells (3 deep-wells to a depth of 500 m areconstructed each with a cost of ETB 10 Million & a Total of 30 Million
- Needed to Construct Earthen Water Reservoirs (Ponds) to collect surface water during rainy ~ 6 reservoirs are constructed each with a Capacity of 360,000 M3 that costs about 20 Million
- Needed Treatment Plant to De-saline the Saline Water
- Needed Chiller Plant to Chill/Cool the water to 1 oC

**Challenges associated with Construction Materials and Mix Design**

- To minimize risks associated with aggregate type- it has been improved the coarse aggregate nominal size to bigger size. (20 mm to 37.5 mm)
- To minimize risks associated with curing of concrete- it has been found that use of curing compound is much appropriate to tackle the rapid dehydration of the concrete during paving.
- To minimize risks with consistency and workability of the mix and to manage also suitable mix for the slip form paver (less water cement ratio) – it has beenused that set retarder and water reducer admixtures have been used.

**Challenges associated with Site Condition**

- Severe Hot Weather condition (Occurrence of Shrinkage and Thermal

Cracking on the pavement)

Mix design optimization, aggregate sprinkling, change of cement type, night time paving operation, use of admixture, use of curing compound –all these are exercised to tackle the adverse effect of the hot weather.

- Saline presence in the local water and morphology

Use of treatment plant by de-saline the saline water, use of surface water and fully coating of dowel bars and tie bars with epoxy have been solutions to counter balance risks.

- Severe temperature of ground water

Use of chiller plant that can chill up to 1oC has been used to cool the mixing water and minimize the mix temperature to the required limit.

**Concrete Mix Design**

Quantity of Constituent Materials for Trial Mix

| Sand Aggregate Ratio [by Vol.] | Cement Content [kg/m3] | Water Content [kg/m3] | Water-Cement Ratio [by Weight] | Air Content [m3/m3] | Total Aggregate [m3/m3] | 02-01 Gravel Proportion [%] |
|---|---|---|---|---|---|---|
| 0.45 | 400 | 160 | 0.40 | 0.045 | 0.66 | 50 – 50 |

Admixture – Sika NNR-2% Dosage (Water-Reducer)
Slump and Average 3rd and 7th Day Compressive Strength of Mix Trial

| Slump [mm] | Average 3Day Compressive Strength [MPa] | Standard Deviation | Average 7Day Compressive Strength [MPa] | Standard Deviation |
|---|---|---|---|---|
| 18 mm | 22.37 | 2.12 | 39.11 | 0.69 |

**Conclusions from Mix Design**

Regarding the Aggregate

- The sand from different sources should be blended by weight in equal proportion to satisfy the grading requirement

- The gravel proportion should be 50%-01 aggregate and 50%-02 aggregate
- The sand to total aggregate ratio should be 0.45 by volume; from the total aggregate 45% sand and 55% gravel should be used for the project.

Regarding the Admixture

- To efficiently and effectively control the mix, it is decided to use two different types of admixtures, separate water reducers and retarders, ASTM Type A and Type B respectively.
- Blended admixtures with both water reducing and retarding function, which is ASTM Type D and G, is not recommended for this project.

Regarding Quantity of Concrete Making Materials

- The maximum water-cement ratio is 0.40
- The cement content is limited to 400kg/m3
- The minimum total aggregate volume is 0.66m3/m3, with sand to totalaggregate ratio of 0.45.

**Challenges associated with Construction Materials, Site Condition, Mix Design and Work Methodology**

Selection of appropriate Mix Design Selection of appropriate mix design to tackle adverse effect of the hot weather .Generally, the mix design has been given serious attention in all the way that to minimize all the risks associated with any technical or workmanship problems. It has been reviewed by AAIT team as part of the Contractor’s team.

Selection of appropriate mix design that suits for SLIP FORM PAVER concrete placing

The mix design is conducted and managed all the time that it can sustain by itself without any mould during the paving time as the slip form paver is designed in this way. Thus, stiffer mix is selected by keeping the workability using water reducing admixtures.

**Challenges associated with Construction Work Methodology**

Identification of appropriate Work Methodology

- Concrete curing methods- Curing compound is used
- Texturing methods - Plastic broom is found suitable for this work
- Concrete unloading at job site- Side wastage o- side guard panels have been used concrete mix
- Night time operation management – to minimize the risks with the severe hot weather, the paving operation has been decided to be in the night. During this time, management of the whole operation has been challenging.

## 3.12. Monitoring after the Rigid Pavement is opened for Traffic: Crack Monitoring of the Concrete Pavement

- Followed by the completion of the major works of the project, the project has been provisionally handed over to the client under some corrective defects and outstanding remaining works. One of the defects identified during the site visit were cracks on the rigid pavement even though, these cracks have been occurred and noticed just in the early time almost few days after the paving activity. However, as it is noticed, until now, even after the opening of heavy traffic, the cracks are still remained non progressive.
- The photograph records annexed below showed what explained above and the status of each crack types
- Mitigation or remedial measures shall be decided later based on the actual progressive status of each crack types. However, based on the last long period observed condition, the preliminary mitigation methods expressed in the photograph records are believed to be sufficient hence the cracks are identified as minor or not structural.
- Based on the observation so far, shrinkage cracks are distributed on the surface with minimal and acceptable crack width. Whereas, transversal cracks are occurred just parallel to the designed transversal joint, this indicates also that these cracks just occurred for relief of internal stress just before the expected full depth cracks are created at the designed transversal joint and probably they may be needed for structural stability of the slabs.

Major Observations of cracks and measures

- Shrinkage cracks which can be filled with slurry mix.
- Transversal cracks which can be filled with sand mortar and filled by joint sealant material.
- Corner joint crack which can be filled by joint sealing material like bitumenafter cleaning.
- Spalling which can be repaired by removing the delaminated concrete and fillwith similar concrete using bonding agent chemical**.**

**Compressive strength of concrete**

As can be seen from the annexed data of test result, though the expected result is 35Mpa, its higher in most of the road stretches (greater than 40Mpa).

# Summary of findings Discussions

| Item No | Research/ Standard Descriptions | Findings | My Findings /Discussion. | Remarks |
|---|---|---|---|---|
| 1 | Ditchoto Galafi Junction-Ellidar-Belho Rigid Pavement Road project, Soil Materials and PavementDesign Report, By Ethiopian Roads Authority | In accordance with ERA 2013design, concrete grade is C 35 and slab thickness 400mm, | After reviewing the ERA 2013 design, the Concrete grade can be C40 and slab thickness can minimize to 350mm | The Concrete grade can be achieved by using high quality materials and reduction in thickness can reduce cost and will make the paving process easier. |
| 2 | AASHTO 1993 doesn't explicitly states as to dowels diameter. | AASHTO 2008 however states that small diameter (1in or less) dowels are relatively inefficient in preventing joint faulting, while large diameter (e.g., 1.5in) dowels are highly effective | It's acceptable to use Diam 25mm Dowel bar with 300mm spacing. However to control tensile stress due to temperature variation diam 8mm with 300mm spacing both ways is recommended. | As per Design of Dowel bars, Publication No FHWA-HRT-06-106 (Sep 2009), Both 3.81-cm (1.5-inch)-diameter and 2.54-cm diameter dowel bars with spacing varying from 30.48 to 15.24 cm provided very good LTE (Load Trasfer Value) (81 percent and higher) |
| | FHWA 1990 recommended that the minimum dowel diameter be D/8, where D is the thickness of the pavement. | However, the dowel diameter should not be less than [32 mm] 1 1/4 inches. It is also recommended that [450 mm] 18-inch long dowels be used at [300 mm] 12-inch spacing. | | |
| | ACI 325 recommends a different approach to dowel bar diameter selection for highways. | Based on the traffic level. For >90million ESAL, dowel diameter of 41mm, 450mm length and 300mm spacing is recommended<br>ACPA 1991 recommend similar to ACI except that the diameter of the bar is 38mm for slab >250mm thick. | | |

| Item No | Research/ Standard Descriptions | Findings | My Findings /Discussion. | Remarks |
|---|---|---|---|---|
| | ERA 2002 and ERA 2013 rigid pavement design manuals however recommend the least among referenced guides. | They state that the dowel bars shall be 20 mm in diameter at 300 mm spacing, 400 mm long for slabs up to 239 mm thick, and 25 mm in diameter, keeping the length and spacing, for slabs 240 mm thick or more. | | |
| 3 | Kristina Bayraktarova, Characterization of the climatic temperature variations in the design of rigid pavements.(2021) https://doi.org/10.1080/10298436.2021.1887486 | A new mechanistic-empirical pavement design method for rigid pavements (MEPDR) has been developed. The main finding from the demonstrated design example is that the more detailed the characterization of climatic boundary conditions is, the more accurate is the prediction of the design life. | The Design Life of Rigid pavement is mainly dependat on the cummulative number of vehicles (T) expressed as cumulative No of equivalent standard axles, The temperature stress can be handled by the horizontal joints. | |
| 4 | Anton K. Schindler (2002), Importance of Concrete Temperature Control During Concrete Pavement Construction in Hot Weather Conditions. https://doi.org/10.3141/1813-01 | To provide improved performance for sections paved under hot weather conditions, it is proposed that the continuously reinforced concrete pavement reinforcement standards be redesigned to provide steel quantities for specific use during hot weather conditions and that an end-result specification that limits the maximum in-place concrete temperature during hydration be implemented. | To be economical we can choose JUCP and the heat generated from hydration process can be limited by modifying the PPC cement with minimum amount of $C_3A$ and maximum amount of $C_2S$. | We can use full width paver to overcome late strength development of PPC. |

| Item No | Research/ Standard Descriptions | Findings | My Findings /Discussion. | Remarks |
|---|---|---|---|---|
| 5 | Hamad I. Al-abdul Wahhab , TEMPERATURE IMPACT ON PAVEMENT STRUCTURES IN HOT ARID ENVIRONMENT, **Research Institute** King Fahd University **of Petroleum and Minerals** Dhahran 31261, Saudi Arabia | For the rigid pavements, load stresses only without considering the temperature curling effect cannot predict the actual behavior of PCC slabs. Results showed that the combined stresses are higher than those obtained from simple addition. Increasing slab size from 5.0x5.0 m to 7.5x7.5 m will result in early fatigue failure due to the interaction between curling and load stresses. | The JURP slab size is 3.5*5m so early fatigue failure will not happen also horizontal joints are provided to care for Curling effect. | |
| 6 | As per ERA design Manual 2013, Capping and subbase The subbase layer is only necessary when the subgrade material does not meet the criteria for a subbase (CBR is less than 30%), but it is virtually always utilized to make it easier to obtain surface levels that are within the necessary tolerances. So 150mm subbase layer is recommended. | American Concrete Pavement Association, ConcretePaving Technology, 1995, Concrete pavements do not require strong foundation support, performance survey on pavements without subase were still on excellent condition. | The subgrade class is S4 with CBR 8-14% and it's supported by 200mm thick capping layer so provision of 150mm subbase is not required as the subgrade soil is not expansive and mud pumping is not a problem. | |
| 7 | Methodology of Rigid pavement project, Placing of Concrete in hot weather condition by Dr Essayas G/Yuhannes | Use night time for placing concrete to minimize the effect of temperature. Use Chiller machine to cool down hot water and sprinkle the aggregates with water before mixing. | Keep an evaporative retarder as the temperature gets hotter and water is rapidly evaporating. use liquid nitrogen to cool the concrete. Reduce the mixing time once the water has been added to the mix ( Use Dump Trucks for transport) | |
| 8 | Construction of Rigid pavement with a length of 80kms was new practice in Ethiopia. | The methodology of work and manpower skill and performance was a challenge for quality, cost and time of construction. | This study can be used to assist in drafting the works methodology for similar projects. Manpower training is very important aspect to meet the contract responsibilities of Rigid pavements before commencement of construction. | |

# CHAPTER FOUR

## 4. CONCLUSIONS AND RECOMMENDETIONS

### 4.1. CONCLUSION

The project area, Afar, is characterized by an arid and semi-arid climate with low and erratic rainfall. According to the Meteorological Map of Ethiopia, the project area receives a mean annual rain fall of 95mm – 500mm. The project area is very hot and the temperature may range up to 50oC for the rainy season in the months of June to September.

The high temperature, strong sunshine and intense wind makes the project area challenging for the concrete works. Particularly, the hydration heat induced cracking poses a great risk to our 400mm thick concrete rigid pavement.

The construction of the 400mm rigid concrete pavement poses ultimate challenges with regard to concreting works. The main challenges include;

i. Hot weather – the high temperature in the project area will create ultimate challenges for the concrete works. This is because there will be an Increased water demand, accelerated slump loss, Increased rate of setting, Increased tendency of plastic shrinkage cracking and critical need for prompt earlycuring.

ii. The heat generated from cement hydration together with the hot weather will lead to high early age thermal stresses. If the thermal stresses exceed the early age tensile strength, cracks will be induced endangering the longevity of the pavement performance. In addition to the high ambient temperature and sunshine, significant amount of energy is released from the cement hydration process at the early age. The effects of temperature and moisture early in the life of concrete strongly influence early strength development and long-term durability. Research findings from the Center for Transportation Research demonstrated that the concrete temperature development during the first 24 to 72 hours after placement has a major impact on long-term pavement performance (Hankins et al.,1991; Dossey et.al., 1994; and McCullough et al., 1998).

iii. High initial concrete temperatures has significant effect on compressive strength. This is because rapid hydration has adverse effect on the development of compressive strength.

iv. The project area suffers from critical shortage of water- demanding the concrete design to use less water and less curing. This is in contradiction with increased water demand for hot weather concreting.
v. The presence of salt and sulphate along the route – this aspect demands low Permeability concrete.
vi. The nature of the coarse aggregates is vesicular – this will increase the cement demand aggravating the early age thermal cracking risk.
vii. Environment Impact – As is required in all construction projects, the project is expected to have a reduced carbon foot print.

## 4.2. RECOMMENDATION

- Slab layer thickness found by ERA 2013 Rigid pavement Design Manual (428mm) is greater than the AASHTO method (395mm) therefore to take 400mm thick Concrete as per the Employer Requirement has been acceptable.
- Admixtures like set retarder and water reducer has been used to keep the quality of concrete with long hauling distance from the Batching Plant and hotweather.
- Curing Compound has been used instead of scarce water source.
- Modified Cement has been used to withstand the effect of hot weather andhigh heat of hydration.
- Screened and qualified sand, meeting the quality requirements has been usedto withstand the drying shrinkage effect.
- Successive mix designs have been made to keep the required quality requirement of the Concrete in this hot weather climate.
- Special Construction methodology like night time concrete paving has been implemented to minimize the effect of hot weather on concrete.
- Construction equipment's like Chiller machine, Water treatment Plant, 40cm thick paver, Drilling Rigs, Large Batching plants has been introduced to meet the project challenges.
- Treatments plant has been used to De-saline the salty water to an acceptable quality water.
- Reduction of Surface area for Aggregates to tackle possible crack and strength optimization (20mm to 37.5mm)
- Deep water wells are constructed to extract water from 500m depth. However,since it's very hot to use, Chiller machine has been used to cool it down to 1degree centigrade.
- This study can be used for other similar projects as Rigid pavement Roads arenew for our country. We can save foreign currency by using local cement instead of importing Bitumen.

## *Appendix – A*

Pictorial description

**Some Photos of cracks after service**

**Photos of New Plants and Equipment**

Some of the site visit pictures are described below

Station – 3+444 – 3+650 *Crack Type – shrinkage crack

- Length – 200 m
- Direction – RHS of the RW
- Max. Opening size - about 2 mm
- Mitigation – If it remained like this filling the crack with mortar slurry mix

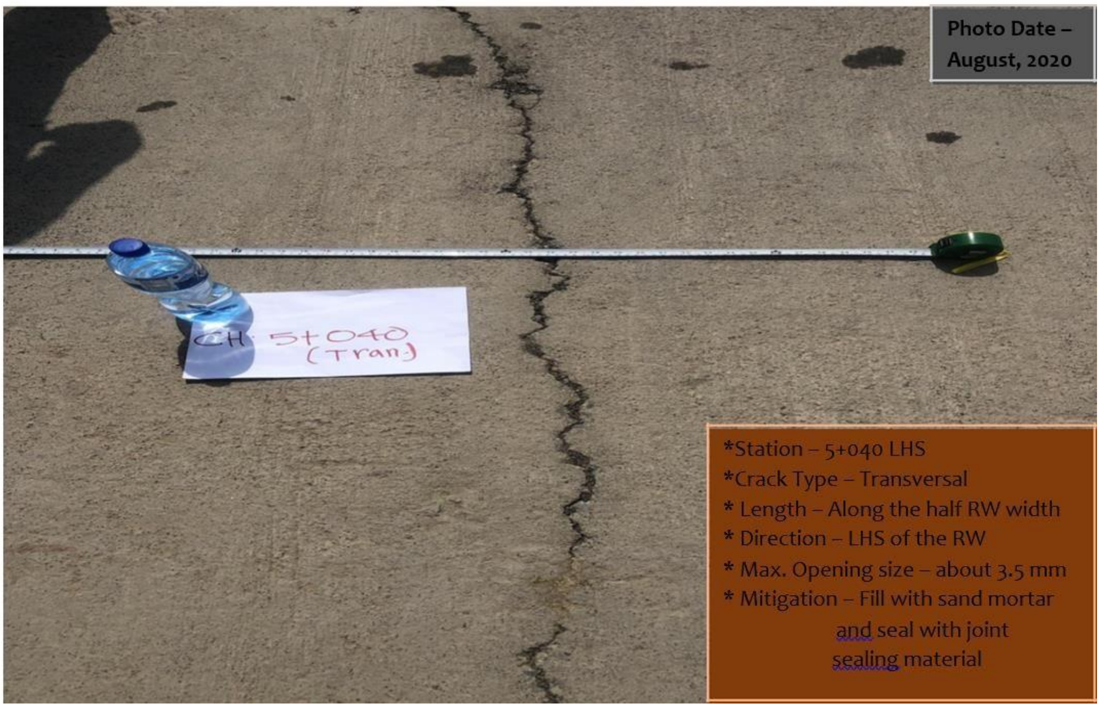


Photo Date – August, 2020
CH. 5+040 (Tran.)
*Station – 5+040 LHS
*Crack Type – Transversal
* Length – Along the half RW width
* Direction – LHS of the RW
* Max. Opening size – about 3.5 mm
* Mitigation – Fill with sand mortar and seal with joint sealing material

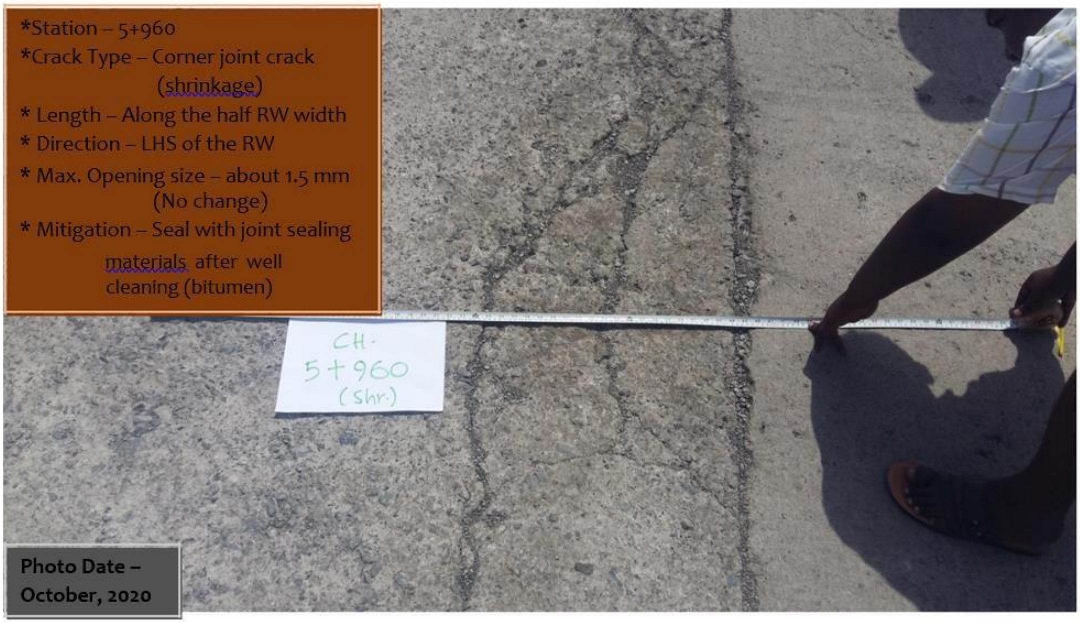

*Station – 5+960
*Crack Type – Corner joint crack (shrinkage)
* Length – Along the half RW width
* Direction – LHS of the RW
* Max. Opening size – about 1.5 mm (No change)
* Mitigation – Seal with joint sealing materials after well cleaning (bitumen)
CH. 5+960 (Shr.)
Photo Date – October, 2020


Photo Date –
October, 2020
* Station – 10+927 LHS
*Crack Type – Spalling
* Length – Along the half RW width
* Direction – LHS of the RW
* Max. Opening size – No change
* Mitigation – Remove the delaminated concrete and fill with similar concrete using boding agent chemical.
CH.
10+927
(Shr. & spall)

Concrete Paver cap. Av. 2.5 m/min.


Chiller plant  cap. 100,000  lit ~ up to 1 oC

Batching Plant ~ Av. 60 M3/hr

Water Treatment Plant ~ Cap. 1200 lit/hr

**Sand Screening**

**Water sources 500m (Deep Wells and Reservoirs)**

**Traverse oriented surface texturing using wire or plastic broom**

Concrete Curing using Curing Compound Chemical by spray

**Joint Cutting Activity**

**Mix design consistency ~ Mix Quality, Mix Temperature, Slump and the likes**

**10 hrs. Working Time only 15 m paved (Half lane)**

**With the presence of the Expertise from the Supplier Company**

2nd Paving became 25 m

3rd Paving became 42 m

4th paving became 72m

- **About a Month later = 80 m (half lane /3.5 m width)**
- **This was the maximum possible performance with the help of the Germany's Expert)**

**If this was the maximum performance remained, the completion of the paving could take about 8 Years**

**But with substantial effort of our Paving crew (Locals) = 512 m half width was recorded to be the Best Performance** .

# *Appendix – B*

Test Results

School of Civil & Environmental Engineering

**Date:-** October 24, 2017

**CONSTRUCTION MATERIALS TESTING LABORATORY**

| | |
|---|---|
| **Client:-** | ERA |
| **Consultant:-** | Zewde Eskinder |
| **Contractor:-** | DCE |
| **Project:-** | Dicheto Galafi Junction to Elidar Road Project |
| **Test required:-** | Absorbtion Capacity & Specific Gravity of Coarse Aggregate |
| **Location** | 28+000 |

**SUMMARY OF TEST RESULTS (03 Agg.)**

| **Initial dray mass (g)=5000** | | | |
|---|---|---|---|
| **Test Number** | **Sample 1** | **Sample 2** | **Mean** |
| weight of oven-dry sample in air,(g) (A) | 4916.5 | 4953.2 | 4956.30 |
| weight of SSD sample in air,(g) (B) | 5000 | 5000 | 5000.00 |
| weight of saturated sample in water,(g) (C) | 3256.3 | 3279 | 3521.40 |
| Bulk spesfic Gravity = A/(B-C)= | 2.82 | 2.88 | 2.85 |
| Bulk spesfic Gravity (SSD basis)=B/(B-C)= | 2.87 | 2.91 | 2.89 |
| Apparent spesfic Gravity =A/(A-C)= | 2.96 | 2.96 | 2.96 |
| Absorbtion capacity(%)=(B-A)*100/A = | 1.70 | 0.94 | 1.32 |

Addis Ababa Institute of Technology
Addis Ababa University

School of Civil & Environmental Engineering

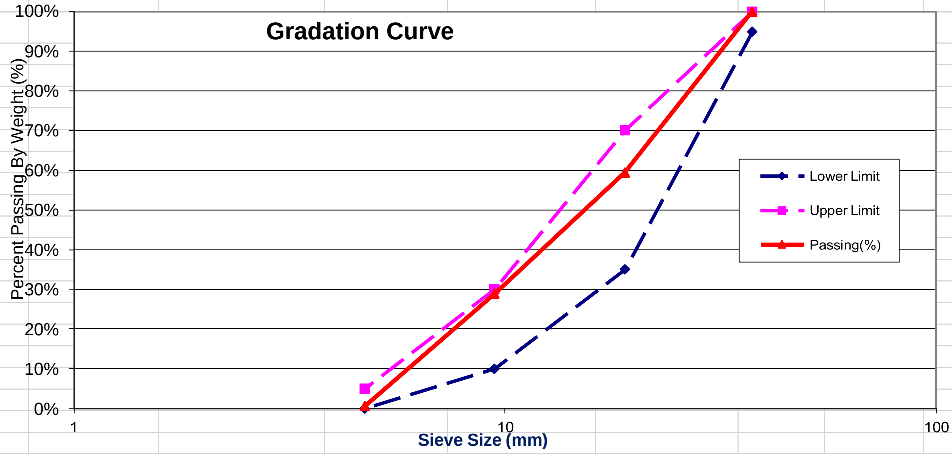
**Date:-** October 24, 2017

**CONSTRUCTION MATERIALS TESTING LABORATORY**

**Client:-** ERA
**Consultant:-** Zewde Eskinder
**Contractor:-** DCE
**Project:-** Dicheto Galafi Junction to Elidar Road Project
**Test required:-** Gradation of Coarse Aggregate
**Location** 28+000

**SUMMARY OF TEST RESULTS**

| Sieve Size [mm] | Weight Retained [gm] | % Retained | Cummulative Courser [%] | Cummulative Passing [%] |
|---|---|---|---|---|
| 37.50 | 0.00 | 0.00 | 0.00 | 100.00 |
| 19.00 | 2910.00 | 40.59 | 40.59 | 59.41 |
| 9.50 | 2178.70 | 30.39 | 70.97 | 29.03 |
| 4.75 | 2032.30 | 28.34 | 99.32 | 0.68 |
| Pan | 49.00 | 0.68 | 100.00 | 0.00 |
| **Sum** | **7170.0** | | | |



School of Civil & Environmental Engineering

| | |
|---|---|
| | **Date**:- October 24, 2017 |

**CONSTRUCTION MATERIALS TESTING LABORATORY**

| | |
|---|---|
| **Client:-** | ERA |
| **Consultant:-** | Zewde Eskinder |
| **Contractor:-** | DCE |
| **Project:-** | Dicheto Galafi Junction to Elidar Road Project |
| **Test required:-** | Aggrgate Crushing Value |
| **Location** | 28+000 |

## SUMMARY OF TEST RESULTS

| Fraction tested | Separating sieve |
|---|---|
| 14-10mm | 2.36mm |

| Specimen identification No. | Sample -01 | Sample -02 | Sample -03 |
|---|---|---|---|
| Mass of original test specimen (g)(M1) | 2643 | 2653 | 2665 |
| Mass of material passing sieve size 2.36mm (g)(M2) | 430 | 402 | 508.7 |
| Mass of material retained on sieve size 2.36mm (g)( M3) | 2213 | 2251 | 2156.3 |
| Aggregate Crushing value (% )(M2*100)/M3) | **16.27** | **15.15** | **19.09** |
| ACV mean value (% ) | **16.84** | | |

School of Civil & Environmental Engineering

| | | |
|---|---|---|
| | Date:- | October 24, 2017 |

**CONSTRUCTION MATERIALS TESTING LABORATORY**

| | |
|---|---|
| **Client:-** | ERA |
| **Consultant:-** | Zewde Eskinder |
| **Contractor:-** | DCE |
| **Project:-** | Dicheto Galafi Junction to Elidar Road Project |
| **Test required:-** | Abrasion Test |
| **Location** | 28+000 |

**SUMMARY OF TEST RESULTS**

| Sieve Size (mm) | | Mass of Indicated sizes | | | |
|---|---|---|---|---|---|
| passing | Retained on | Grading | | | |
| | | 12 | 11 | 8 | 6 |
| | | A | B | C | D |
| 37.5 | 25 | 1250 | | | |
| 25 | 19 | 1250 | | | |
| 19 | 12.5 | 1250 | | | |
| 12.5 | 9.5 | 1250 | | | |
| 9.5 | 6.3 | | | | |
| 6.3 | 4.75 | | | | |
| 4.75 | 2.36 | | | | |
| Total | | 5000 | | | |

| Specimen identification No. | Sample -01 | Sample -02 |
|---|---|---|
| Mass of sample before test (M1) | 5000 | 5000 |
| Mass retained on sieve sieze 1.70mm (M2) | 4315 | 4512 |
| Mass passing sieve size 1.70mm (M1-M2) | 685 | 488 |
| LAA Value (%) | **13.7** | **9.76** |

AAiT
Addis Ababa Institute of Technology
አዲስ አበባ ቴክኖሎጂ ኢንስቲትዩት
Addis Ababa University
አዲስ አበባ ዩኒቨርሲቲ

School of Civil & Environmental Engineering

Date:- ######

CONSTRUCTION MATERIALS TESTING LABORATORY

| | |
|---|---|
| **Client:-** | ERA |
| **Consultant:-** | Zewde Eskinder |
| **Contractor:-** | DCE |
| **Project:-** | Dicheto Galafi Junction to Elidar Road Project |
| **Test required:-** | Flakiness Index |
| **Location** | 28+000 |

## SUMMARY OF TEST RESULTS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Passing sieve (mm) | 63 | 50 | 37.5 | 28 | 20 | 14 | 10 |
| Retained on sieve (mm) | 50 | 37.5 | 28 | 20 | 14 | 10 | 6.3 |
| Slots width (mm) | 33.9 | 26.3 | 19.7 | 14.4 | 10.2 | 7.2 | 4.9 |
| **Before Gauging** | | | | | | | |
| Mass of aggregate fraction (Mo)(g) | 0 | 56 | 752 | 1291 | 869 | 874 | 1111 |
| Individual percentage | 0 | 1.13 | 15.18 | 26.07 | 17.54 | 17.65 | 22.43 |
| **Sum of aggregate mass (M1),(g)** | **4953.00** | | | | | | |
| **Sum of fraction less than 5% of M1(g)** | **56.00** | | | | | | |
| **Remaining sum of aggregate mass (M2)(g)** | **4897.00** | | | | | | |

| | |
|---|---|
| **After Guaging** | |
| Sum of Aggregate mass passing slots (M3)(g) | **688** |
| **Flakiness Index (EI)= (M3/M2 )x100 ,(g)** | **14.05** |

School of Civil & Environmental Engineering
¾c=y=M ˆ“ ›=”zÃaS”¬M
UI”Ée“ ƒ/¡õM

Date:-May. 14, 2020

## CONSTRUCTION MATERIALS TESTING LABORATORY

**Client:-** ERA

**Consultant:-** Engineer Zewide Eskinder and co.plc

**Date Received:-** May. 06 , 2020

**Contractor:-** DCE

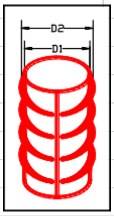
**Date Tested:-** May. 13 , 2020

**Project:-** Dicheto Galafi Junction to Elidar Belho Design and Build Road Project

**Suplier**

**Test required:-**

- Tensile strength X
- Yield strength X
- Elongation X
- Diameter X
- Mass per length X




## SUMMARY OF TEST RESULTS

| Specimen No | Diameter D1, [mm] | D2, [mm] | Yield load [kN] | Yield Stress 1*, [MPa] | 2*, [MPa] | Failure Load [kN] | Failure Stress 1*, [MPa] | 2*, [MPa] | Elongation [%] | Mass/length kg/m |
|---|---|---|---|---|---|---|---|---|---|---|
| 24-1 | 23.52 | 25.60 | 262.30 | 603.72 | 509.60 | 294.60 | 678.06 | 572.35 | 14.50 | 3.444 |
| 24-2 | 23.57 | 25.20 | 256.30 | 587.41 | 513.88 | 296.80 | 680.23 | 595.08 | 14.00 | 3.439 |
| 24-3 | 23.55 | 25.30 | 264.80 | 607.92 | 526.73 | 295.60 | 678.63 | 587.99 | 13.50 | 3.407 |

*1* Stress computed based on diameter D1*

*2* Stress computed based on diameter D2*

School of Civil & Environmenta Engineering

**Date:** November 9, 2020

**CONSTRUCTION MATERIALS TESTING LABORATORY**

**Client:-** ERA
**Consulta**Zewde Eskinder
**Consulta**DCE
**Project:-**Dicheto Galafi Junction to Elidar Road Project
**Test Req**Compressive Strength of concrete core Samples (Cylinders)

**SUMMARY OF TEST RESULTS**

| No. | Sampling Chainage | Offset | Samlple Tag | Dimensions [cm] D | H | H/D | Area [cm$^2$] | Failure Load [kN] | Cylinderical Compressive Strength [Mpa] | Equivalent Cubic Strength [Mpa] |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0+000 | LHS | 1 | 9.900 | 19.40 | 1.96 | 76.94 | 258.30 | 33.6 | 42.0 |
| 2 | 0+500 | LHS | 2 | 9.960 | 19.60 | 1.97 | 77.87 | 239.00 | 30.7 | 38.4 |
| 3 | 1+000 | CL | 3 | 9.500 | 19.60 | 2.06 | 70.85 | 238.60 | 33.7 | 42.1 |
| 4 | 1+500 | RHS | 4 | 9.600 | 19.40 | 2.02 | 72.35 | 251.90 | 34.8 | 43.5 |
| 5 | 2+000 | LHS | 5 | 9.800 | 20.00 | 2.04 | 75.39 | 266.80 | 35.4 | 44.2 |
| 6 | 2+500 | CL | 6 | 9.900 | 20.00 | 2.02 | 76.94 | 258.90 | 33.7 | 42.1 |
| 7 | 3+000 | RHS | 7 | 9.800 | 19.70 | 2.01 | 75.39 | 246.70 | 32.7 | 40.9 |
| 8 | 3+500 | RHS | 8 | 9.800 | 19.70 | 2.01 | 75.39 | 241.90 | 32.1 | 40.1 |
| 9 | 4+000 | CL | 9 | 9.800 | 19.90 | 2.03 | 75.39 | 294.20 | 39.0 | 48.8 |
| 10 | 4+500 | LHS | 10 | 9.800 | 19.90 | 2.03 | 75.39 | 286.70 | 38.0 | 47.5 |
| 11 | 5+000 | LHS | 11 | 9.800 | 19.70 | 2.01 | 75.39 | 256.90 | 34.1 | 42.6 |
| 12 | 5+500 | CL | 12 | 9.400 | 19.30 | 2.05 | 69.36 | 205.70 | 29.7 | 37.1 |
| 13 | 6+000 | RHS | 13 | 9.500 | 19.50 | 2.05 | 70.85 | 256.00 | 36.1 | 45.2 |
| 14 | 6+500 | LHS | 14 | 9.600 | 19.50 | 2.03 | 72.35 | 235.10 | 32.5 | 40.6 |
| 15 | 7+000 | CL | 15 | 9.700 | 19.70 | 2.03 | 73.86 | 236.40 | 32.0 | 40.0 |
| 16 | 7+500 | RHS | 16 | 9.600 | 19.50 | 2.03 | 72.35 | 218.40 | 30.2 | 37.7 |
| 17 | 8+000 | LHS | 17 | 9.700 | 19.20 | 1.98 | 73.86 | 241.80 | 32.7 | 40.9 |
| 18 | 8+500 | CL | 18 | 9.600 | 19.40 | 2.02 | 72.35 | 212.60 | 29.4 | 36.7 |
| 19 | 9+000 | RHS | 19 | 9.500 | 19.80 | 2.08 | 70.85 | 217.30 | 30.7 | 38.3 |
| 20 | 9+500 | LHS | 20 | 9.800 | 19.60 | 2.00 | 75.39 | 219.80 | 29.2 | 36.4 |
| 21 | 10+000 | CL | 21 | 9.600 | 19.80 | 2.06 | 72.35 | 247.70 | 34.2 | 42.8 |
| 22 | 10+500 | RHS | 22 | 9.950 | 20.00 | 2.01 | 77.72 | 308.10 | 39.6 | 49.6 |
| 23 | 11+000 | LHS | 23 | 9.800 | 19.60 | 2.00 | 75.39 | 239.10 | 31.7 | 39.6 |
| 24 | 11+500 | RHS | 24 | 9.700 | 19.80 | 2.04 | 73.86 | 223.60 | 30.3 | 37.8 |
| 25 | 78+800 | LHS | 1 | 9.900 | 19.80 | 2.00 | 76.94 | 279.80 | 36.4 | 45.5 |
| 26 | 78+300 | RHS | 2 | 9.700 | 19.80 | 2.04 | 73.86 | 286.20 | 38.7 | 48.4 |
| 27 | 77+800 | CL | 3 | 9.800 | 19.90 | 2.03 | 75.39 | 269.70 | 35.8 | 44.7 |
| 28 | 77+300 | LHS | 4 | 9.600 | 19.50 | 2.03 | 72.35 | 207.90 | 28.7 | 35.9 |
| 29 | 76+800 | RHS | 5 | 9.600 | 19.70 | 2.05 | 72.35 | 219.80 | 30.4 | 38.0 |
| 30 | 76+300 | CL | 6 | 9.700 | 19.40 | 2.00 | 73.86 | 218.10 | 29.5 | 36.9 |
| 31 | 75+800 | RHS | 7 | 9.700 | 19.60 | 2.02 | 73.86 | 335.80 | 45.5 | 56.8 |
| 32 | 75+300 | RHS | 8 | 9.800 | 19.60 | 2.00 | 75.39 | 268.90 | 35.7 | 44.6 |
| 33 | 74+800 | CL | 9 | 9.900 | 20.00 | 2.02 | 76.94 | 216.40 | 28.1 | 35.2 |
| 34 | 74+300 | LHS | 10 | 9.800 | 19.60 | 2.00 | 75.39 | 258.30 | 34.3 | 42.8 |
| 35 | 73+800 | RHS | 11 | 9.800 | 19.60 | 2.00 | 75.39 | 239.20 | 31.7 | 39.7 |
| 36 | 73+300 | CL | 12 | 9.800 | 19.40 | 1.98 | 75.39 | 225.30 | 29.9 | 37.4 |
| 37 | 72+800 | LHS | 13 | 9.400 | 19.60 | 2.09 | 69.36 | 230.20 | 33.2 | 41.5 |
| 38 | 72+300 | RHS | 14 | 9.600 | 19.40 | 2.02 | 72.35 | 216.50 | 29.9 | 37.4 |
| 39 | 71+800 | CL | 15 | 9.900 | 19.80 | 2.00 | 76.94 | 216.90 | 28.2 | 35.2 |
| 40 | 71+300 | LHS | 16 | 9.400 | 19.30 | 2.05 | 69.36 | 245.30 | 35.4 | 44.2 |
| 41 | 70+800 | RHS | 17 | 9.700 | 19.60 | 2.02 | 73.86 | 261.10 | 35.4 | 44.2 |
| 42 | 70+300 | CL | 18 | 9.900 | 20.00 | 2.02 | 76.94 | 270.20 | 35.1 | 43.9 |
| 43 | 69+800 | LHS | 19 | 9.600 | 19.40 | 2.02 | 72.35 | 268.30 | 37.1 | 46.4 |
| 44 | 69+300 | RHS | 20 | 9.300 | 19.90 | 2.14 | 67.89 | 213.40 | 31.4 | 39.3 |
| 45 | 68+800 | CL | 21 | 9.800 | 19.80 | 2.02 | 75.39 | 239.20 | 31.7 | 39.7 |
| 46 | 68+300 | LHS | 22 | 9.800 | 19.60 | 2.00 | 75.39 | 346.70 | 46.0 | 57.5 |
| 47 | 67+800 | RHS | 23 | 9.800 | 20.00 | 2.04 | 75.39 | 222.90 | 29.6 | 37.0 |
| 48 | 67+300 | CL | 24 | 9.800 | 19.60 | 2.00 | 75.39 | 317.00 | 42.0 | 52.6 |
| 49 | 66+800 | LHS | 25 | 9.600 | 19.70 | 2.05 | 72.35 | 258.50 | 35.7 | 44.7 |
| 50 | 66+300 | RHS | 26 | 9.800 | 19.70 | 2.01 | 75.39 | 267.70 | 35.5 | 44.4 |
| 51 | 65+800 | CL | 27 | 9.600 | 19.50 | 2.03 | 72.35 | 383.60 | 53.0 | 66.3 |
| 52 | 65+300 | LHS | 28 | 9.800 | 19.40 | 1.98 | 75.39 | 343.20 | 45.5 | 56.9 |
| 53 | 64+600 | RHS | 29 | 9.700 | 19.50 | 2.01 | 73.86 | 400.10 | 54.2 | 67.7 |
| 54 | 64+200 | CL | 30 | 9.600 | 19.40 | 2.02 | 72.35 | 205.70 | 28.4 | 35.5 |
| 55 | 63+700 | LHS | 31 | 9.600 | 19.70 | 2.05 | 72.35 | 221.00 | 30.5 | 38.2 |
| 56 | 43+900 | RHS | 1 | 9.200 | 19.40 | 2.11 | 66.44 | 248.20 | 37.4 | 46.7 |
| 57 | 44+400 | LHS | 2 | 9.900 | 19.80 | 2.00 | 76.94 | 238.30 | 31.0 | 38.7 |
| 58 | 44+900 | CL | 3 | 9.700 | 19.60 | 2.02 | 73.86 | 230.70 | 31.2 | 39.0 |
| 59 | 45+400 | RHS | 4 | 9.600 | 19.70 | 2.05 | 72.35 | 312.00 | 43.1 | 53.9 |
| 60 | 45+900 | LHS | 5 | 9.900 | 19.80 | 2.00 | 76.94 | 243.20 | 31.6 | 39.5 |
| 61 | 46+400 | RHS | 6 | 9.800 | 19.60 | 2.00 | 75.39 | 172.40 | 22.9 | 28.6 |
| 62 | 46+900 | LHS | 7 | 9.700 | 19.80 | 2.04 | 73.86 | 255.10 | 34.5 | 43.2 |
| 63 | 47+300 | RHS | 8 | 9.800 | 19.80 | 2.02 | 75.39 | 236.80 | 31.4 | 39.3 |
| 64 | 47+800 | LHS | 9 | 9.800 | 19.90 | 2.03 | 75.39 | 234.30 | 31.1 | 38.8 |
| 65 | 47+801 | LHS | 1 | 9.800 | 19.90 | 2.03 | 75.39 | 235.30 | 31.2 | 39.0 |

***Note:** Loading rate=0.28 MPa/S

# *References*

AASHTO. (1993). AASHTO Guide for Design of Pavement Structures, Association of State Highway and Transporation Officials.

Donald, G. (2003). "Benefits of Composite Pavements." ARRB Transportation Research, SMEC International.

ERA. (2013). ERA Pavement Design Manual,Ethiopian Road Authority.

Abebe Eshetu (2005); Concrete Production And Quality Control In Building Construction Industry Of Ethiopia, Addis Ababa University School Of Graduates.

Composition and properties of Concrete, Troxell, George Earl, 1968.

Ditchoto Galafi Junction-Ellidar-Belho Rigid Pavement Road project, Soil Materials and Pavement Design Report, By Ethiopian Roads Authority.

M.L Gambhir (2nd edition, 2002); Concrete Technology, MC Grawhill Book