


**ADDIS ABABA INSTITUTE OF TECHNOLOGY**

**SCHOOL OF GRADUATE STUDIES**

**DEPARTMENT OF CIVIL ENGINEERING**

**ADDIS ABABA UNIVERSITY**



**COMPARATIVE STUDY OF STONE MASONRY  
V  
REINFORCED CONCRETE ARCH BRIDGES**

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**COMPARATIVE STUDY OF STONE MASONRY V REINFORCED CONCRETE  
ARCH BRIDGES**

**A THESIS**

*Submitted in partial fulfillment of the  
requirements for the award of the degree*

*of*

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*In*

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**(With Specialization in Structural Engineering)**

By

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I would like to thank my family and all my friends who support me and encourage me through my work.

## **ABSTRACT**

Bridge structures play a vital role in the development of one country by providing access to cross valley and/or river. Especially for our country Ethiopia, where the geographic condition obligates to construct bridge in most area of the country. There are many bridge types; Arch Bridge is one of the oldest types which are suitable for long span bridge and for area: valley, river, and very deep gorges in addition arch bridge is very attractive in Architectural value.

Arch bridge can be constructed by stone, which is the oldest construction material or by concrete. Stone masonry arch bridge and concrete Arch bridge is very dominant in Ethiopia so the comparison of this two material for Arch bridge on the basis of design, structural, architectural, economical and their inspection in line with restoration strategy is very important to improve the existing Arch bridge and also to design the new Arch bridges.

And also the results will increase awareness among professionals and the responsible persons to give attention to the damaged masonry arch bridges in Ethiopia. The Design and cost comparison of concrete and masonry Arch Bridge in Ethiopia practice helps to select the most suitable material.

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# 1. Introduction

## 1.1 Background

Bridges structures play vital role in the construction of roads by providing access to cross valley and/or river, which in turn contributes a lot in the transport sector and development of one country. The most important feature of these bridges is that they are largely compressive members and constructed from stone or brick. When the spans are large and where line of load thrust does not coincide with axis of the arch, flexural stresses are exhibited and hence use of reinforced concrete become evident.

It is known that considerable modern road construction has been introduced in Ethiopia during the Italian occupation, between the year 1935 and 1941, [3] and almost all bridges constructed are made using stone masonry. These bridges have been serving so long that most are damaged due to:

- Aging, since they have lasted more than 70 years,
- Introduction of new vehicular system, leading to over loading ,
- Accidents and illegal traffic practices,
- Overlay of finishing materials ,which produce additional dead loads ,

Nevertheless, these bridges are aesthetically graceful and are having the most pleasant appearance. In this regard, a need to assess the performance of these type bridges and come up with proposal of similar design using stone masonry and reinforced concrete is necessary.

## **1.2 Objectives of the Thesis**

The objective of the thesis is performance assessment of existing stone masonry arch bridge in view of utilizing restoration strategy wherever the need arises. Moreover, Design of stone masonry and Reinforced Concrete of selected span shall be carried. Further cost comparison in view of the current bridge practices shall be considered.

## **1.3 What is in the Thesis?**

In this thesis six chapters are covered, which includes:

- The first chapter aims at introducing the background and objectives of the study and is made to include what is in the thesis.
- Second chapter deals with brief review of arch bridges. It is made to include historical development, Material type and properties, construction aspects of arch bridges is covered. And also the history of Arch bridges with its existing situation in Ethiopia will be viewed.
- Third chapter addresses the methodology on evaluation of existing arch bridges, and is made to include inspection and inventory of arch bridges, strength evaluation of arch bridges in accordance with the national and international standards. Some features of inspected arch Bridges in Ethiopia are also covered.
- Fourth chapter is devoted to design consideration of Stone Masonry and Reinforced Concrete Arch Bridges.
- Fifth chapter is all about comparison of Stone Masonry Vs Reinforced concrete Arch Bridges, which also covers cost analysis and comparison of designed Stone Masonry and RC Arch bridges of single span.
- Sixth chapter is made for Conclusion and Recommendation of the study

## 2. Brief Review of Arch Bridges

### 2.1 Historical Development of Arch Bridges

Nature has exhibited bridges very easily without human involvement. It has been recorded that Bridges already existed four million of years backs created from geological formation by wind and water. Later human had started different methods to use as a bridge to cross fast moving streams and natural obstacles. For instance, the first accomplishment was by means of steeping stones and later by using failed tree trunks that either supported by stones in the stream or spanned the entire distance between showers, [1].

These all lead to the modern construction of bridges. For example, the suspension bridges we know today were developed from primitive suspension bridge with cables of vines or bamboo strips twisted in to ropes. Arch bridge came much later as applied to bridge buildings.

The first construction of the reinforced concrete arch was introduced to the world by Eugene Fryssinest after World War I. He employed hydraulic jacks to lift the completed arch from its false work by applying an internal thrust at its crown, [1]. This opened the door to modern arch construction techniques that do not rely on false work and also presented the opportunity to reduce the bending moments in the arch by eliminating the dead load bending association with axial shortening of the ribs, [1].

After human discovered the advantage of the arch shape and its construction, they began to construct arch entrance ways and small arch bridges with their sun baked bricks. And this continues in other area with access to stone elements. By the time of the Romans, bridges were constructed using stone which is called masonry arches. Most are still standing, which shows masonry arch bridges are efficient and most durable.

In 1779 the first cast iron bridge was constructed at Coalbrookble, England to span the Seven Power, It is a semicircular Arch spanning 43 m. By the year 1800 there were very few long span masonry Arch Bridges, because they were not competitive with this new materials, [4].

Concrete bridge began to be constructed at the end of the 19<sup>th</sup> centuries. Roman Engineers were first and until the industrial revolution the only ones to construct bridges with concrete, which they called Opus Caemential. The outside was usually covered with brick. The introduction of these new materials allow arch bridges to be longer with lower spans and when line of load thrust does not coincide with axis of the arch, flexural stresses are exhibited and hence use of reinforced concrete become very important.

## **2.2 Material Type and Properties of Arch Bridges**

An arch bridge is a curved shaped bridge in which the load is carried out ward along the curve of the arch to the supports at each end, instead of pushing straight down. The weight is transferred to the supports at either end. These supports called the abutments carry the load and keep the ends of the bridge from spreading out. The inclined faces of the curved members of the arch bridges which are called skewbacks come in contact with the abutment.

The strength of the arch is derived from its shape. As the arch presses down ward from its top, the ground pushes upward with and equal force; for this reason, the arch is always under compression, causing it to become rigid and maintain its strength. To be able to withstand the strong compression force that help the bridge keep its shape, the arch bridge must be built out of materials that can handle such compression.

Stone and brick are strong in compression and somewhat so in shear but cannot resist much force in tension. As a result, masonry arch bridges are designed to be constantly under compression. The more weight that was put onto the bridge, the stronger its structure becomes. Masonry arch bridges use quantity of fill material above the arch in order to increase this dead weight on the bridge end, and this prevents tension from occurring in the arch ring, as loads move across the bridge. Modern materials such as steel and poured concrete which can be more easily shaped are now also being used for Arch bridge construction.

The final top stone which is called keystone is the most important stone in an arch bridge. Without which the arch would have collapsed. The keystone holds the arch together. The load at the keystone makes each stone on the arch of the bridge press on the one next to it. This happens

until the push is applied to the end supports or abutments which are embedded in the ground as shown in Figure 2.1 below.

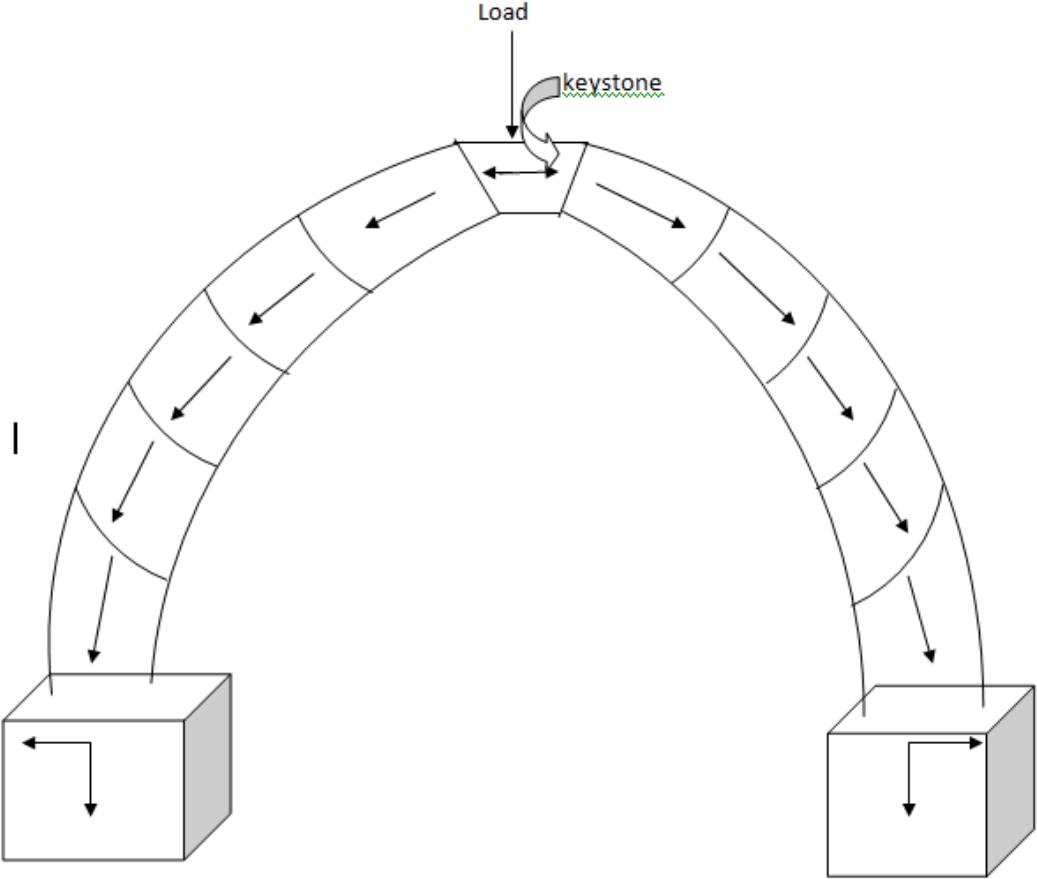


Figure 2.1 Action of the load on the arch

The ground around the abutments is squeezed and pushes back on the abutments. For every action there is an equal and opposite reaction. The ground which pushes back the abutments creates a resistance which is passed from stone to stone until it is eventually pushing the keystone which is supporting the load.

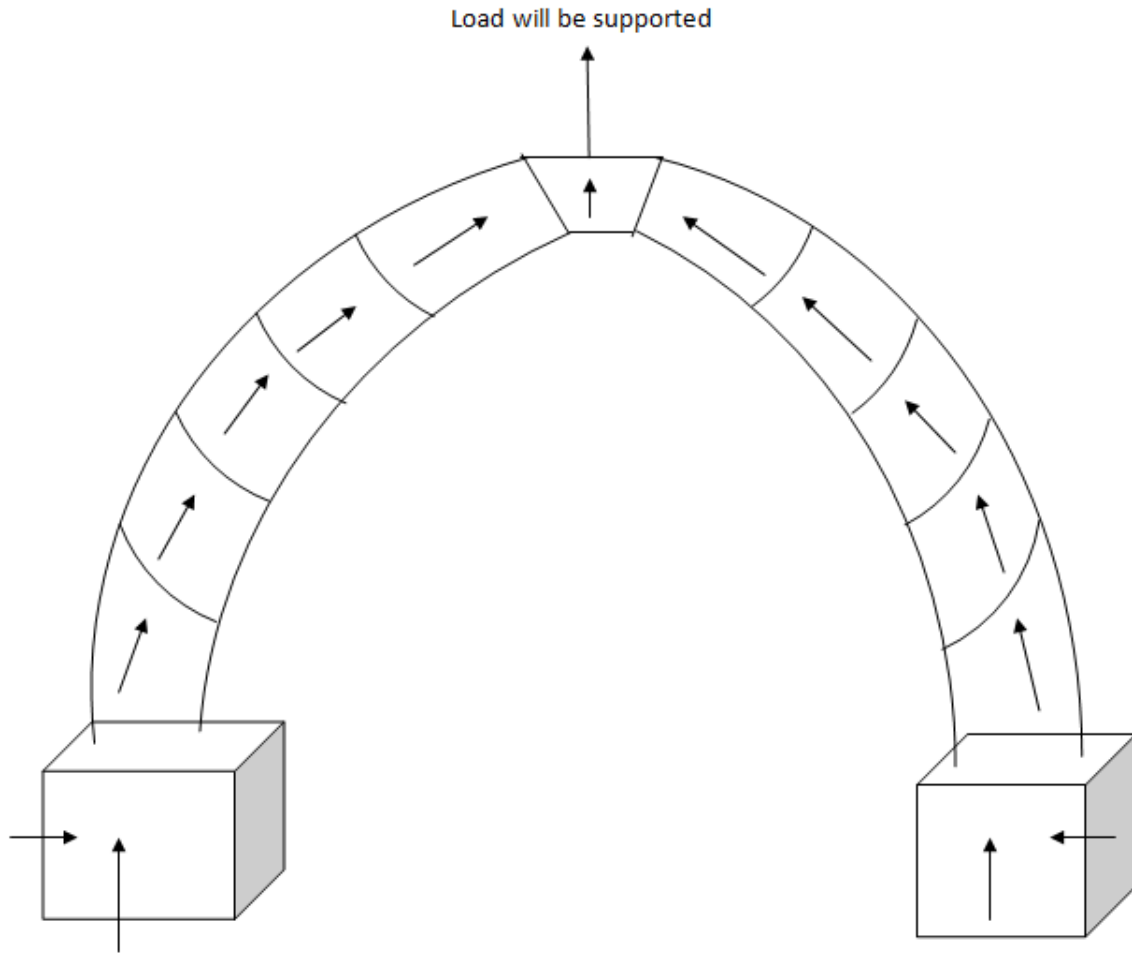


Figure 2.2 Reaction of the ground to support the load

True or perfect arch, theoretically is one in which only compressive forces acts at the centroid of each element of the arch. It is practically impossible to have a true arch bridge except for one loading condition. The arch bridge is usually subject to multiple loadings dead load, live load, temperature, etc, which will produce flexural stresses in the arch that are generally small compared with the axial compressive stresses.

No matter what the design procedure, all arch bridges share one common thing, i.e, the ability to support a great amount of weight. What allow the arch bridge to support such large amount of weight are its structural and geometric properties.

## 2.3 Construction Aspects of Arch Bridges

Since Arch Bridge cannot stand until the last stone, the keystone, is in place, it is constructed around a wooden form that help to maintain its arch shape during construction. The frame is then removed after all the stones are in position. Stone arch bridge relied on keystone to be put into place for the bridge to experience the compression that would make it strong. When cut stone is used the faces are cut to minimize shear forces. Where random uncut and unprepared stones are used, they are mortared together and the mortar is allowed to set before the false work is removed.

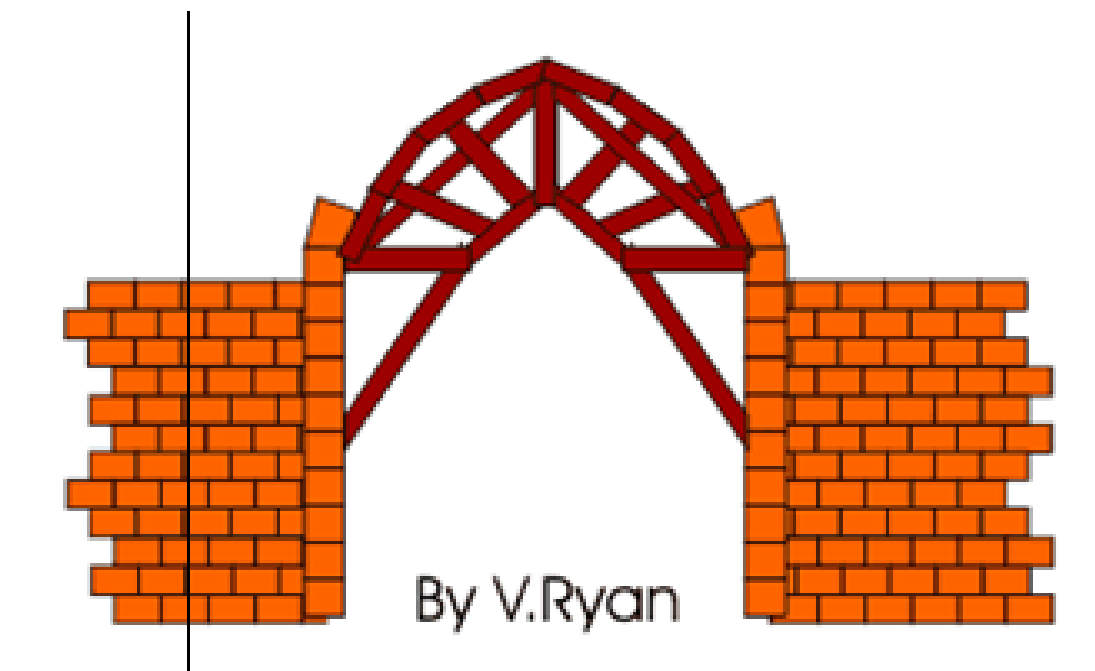


Figure 2.3 Wooden frames for construction of masonry arch

Reinforced concrete arch bridges can have their temporary wooden form removed once the concrete has sufficiently set. It is also possible to construct a reinforced concrete arch from precast concrete. Where the arch is built in two halves which are then leaned against each other.

Construction consideration

1. Structural arches must be properly supported throughout construction

2. Premature removal of the temporary support for structural arch may result in a collapse of the arch. This most often due to the introduction of lateral thrust on the abutment before proper curing has occurred.
3. Out of plane bracing is required for all arches.
4. Arches that are not laterally braced may require increased masonry thickness or reinforcements to carry loads perpendicular to the arch plane.

#### General Construction Sequence of Arch Bridge

1. The water is diverted and the gravels excavated to a good footing, the foundation piers are raised to the base of the arches, a point known as the springing.
2. The basic arch barrel will be constructed from the false work. The false work, fabricated from timber and Boards.
3. The Arches are stabilized with infill masonry between the arches and also in filled with loose material and rubble.
4. The road is paved and parapet walls protectively confine traffic to the bridge.

The typical terminology for masonry arch bridge is shown in figure 2.4

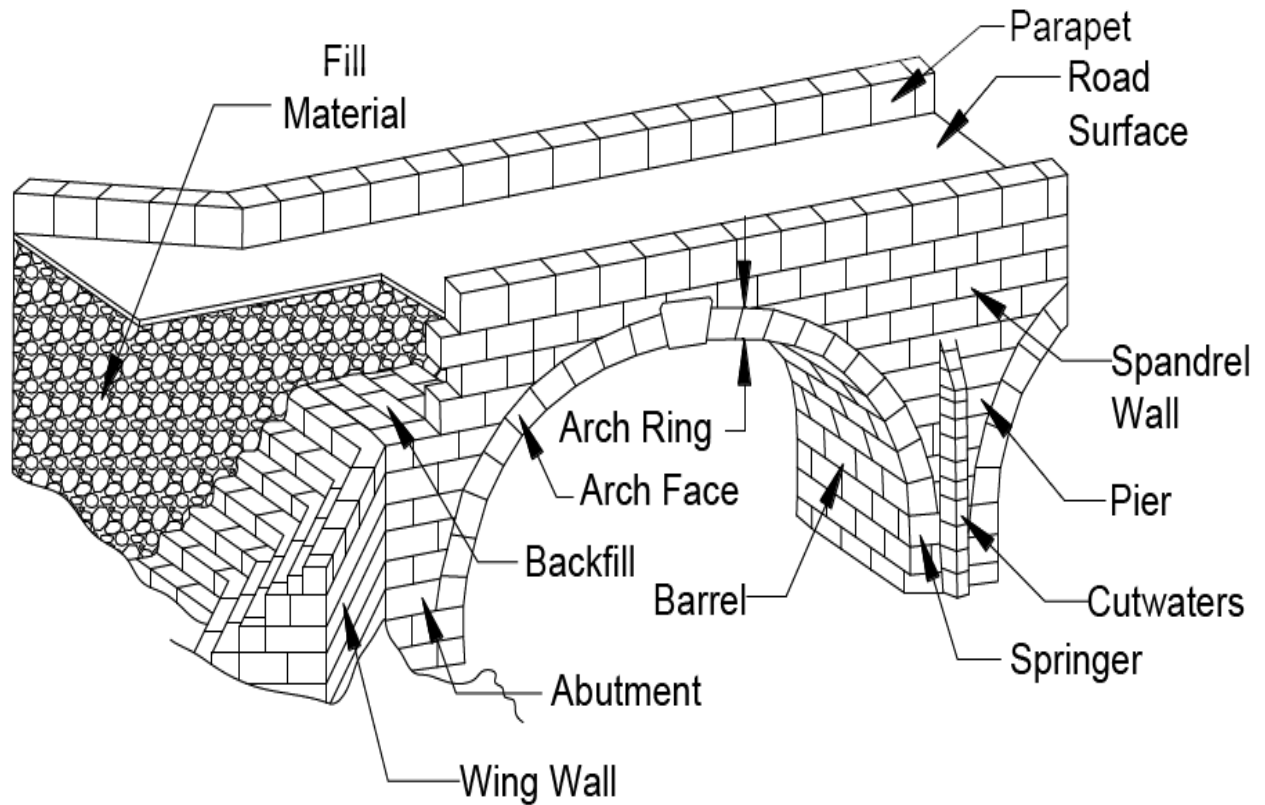


Figure 2.4 Terminology in stone masonry arch bridge

Arched bridge has two main components: the arched member which supports the loads, and the abutments or piers at either end supporting the arch ring. The lower surface of the arch ring is called the intrados, while the upper surface is termed the extrados. Rising from the extrados are spandrel walls or columns which hold the fill, loose material in the gap between the extrados and the road surface, or support the deck upon which vehicles travel.

## 2.4 Arch Bridges in Ethiopia

Bridge building in Ethiopia has begun in the 17<sup>th</sup> century with the help of the Portuguese. The 2<sup>nd</sup> Portuguese Bridge called “Sebara Dildi” is approximately 360 years old, built during the reign of Ethiopian Emperor Fasildes, 1632-67 and according to the history oratories it is built of stone sand, lime and eggs. The eggs acted as an early elastomeric adhesive can be one of an example.

In the 18<sup>th</sup> century, those built by the Portuguese were destroyed and damaged by war in Ethiopia. But several stone arch bridges made over many years ago are still standing today even without the use of mortar resisting aging war and different cause of damages.

Modern Road Construction in Ethiopia has been introduced during the Italian occupation between the year 1935 and 1941, [2]. During this moment, many stone arch bridge were constructed. For instance, the Abay No 1 RC Arch bridge, main length of 204m, found between towns of Goha Tsion and Dejen, 213 km away from Addis Ababa was constructed by Italian in 1947. It is one of the top 12 long Bridges in Ethiopia in accordance with Ethiopia Roads Authority classification. The summarized census of Arch Bridges in Ethiopia under the various ERA districts is shown in Table 2.1 below. Details of these Arch Bridges showing Name, Construction year, Length for reference is provided in Appendix A1.

Hence a total of 551 Masonry Arch Bridges and 16 RC Arch Bridges are exhibited in the Federal State of the Country.

Table 2.1 Summarized Censuses of Arch Bridges in Ethiopia

Number of RC Arch Bridges	Number of Masonry Arch Bridges	Administrative Name of District
2	156	Alemgena
-	67	Nekempt
6	52	Gonder
2	194	Combolcha
1	33	Adigrat
4	15	Deber-Markos
1	2	Dire-Dawa

-	4	Shashemene
-	23	Jimma
-	4	Amhara- Region
-	1	Oromia
16	551	TOTAL

From the record, it is observed that Stone masonry arch bridges are dominant against RC Arch Bridges. The Stone Arch Bridge mostly use granite, while for medium sized bridges use of basalt stone, sandstone and limestone has been made. Per the ERA's document [3], Granite can be found in West of Nakemte, Tigray, Southwestern Regions and South of Dodola whereas; Sandstone and limestone are found abundantly nearly in every region of the country. So these show that almost the whole country has the capacity to use stone for construction of masonry Bridges.

Many stone masonry arch bridges found in Ethiopia have been damaged due to

- Aging since they have lasted more than 60 years where defects observed include:
  - Arch ring separation
  - Diagonal cracking and hinging of the arch ring
  - Cracks in the abutments and piers
  - Leaning and bulging wing walls and spandrel walls
  - Spandrel wall separation
  - Leached mortar joints and frost damage of the masonry units
- Introduction of new vehicular system heading to over loading.
- Accidents and illegal traffic practices.
- Overlay of finishing materials produce additional dead loads

These bridges are actually graceful and are having the most pleasant appearance. A need for consideration of the original architectural aspect and restoration to their original load carrying

capacity by carrying out fairly straight forward maintenance is necessary. In view of the effects of time of construction and increasing needs of modern transportation, strengthening of the old masonry arch bridges using modern materials is necessary. Moreover, RC Arch bridges for large span Bridges are also an option to be considered. For restoration of an existing bridge, evaluation with respect to strength, serviceability and stiffness is the primary task to be carried.

### **3. Evaluation of Existing Arch Bridges**

#### **3.1 Background**

The life of a bridge depends on the fatigue life or serviceability limits of bridge materials. Higher frequent loading & unloading may affect the fatigue life or serviceability of a bridge component and which together contribute to the life of the bridge. There are also other causes which the bridge life depends on. The most common causes of damages & failures found in arch Bridges include the following.

##### **I. External Causes of Damage and Failures**

1. Damage due to floods on the Arch Bridges. This may cause breaking of stones off the bridges and erodes mortar.
2. Damages due to Earthquakes: These usually occur at mid span of the main arches as cracking and the separation of the roadways.
3. Insufficient Coverings & drainages: Insufficient coverings & damages may eventually lead to decreases in load capacity.
4. Increased Loadings: Introduction of new vehicular system produce over loading affecting the bridge load.
5. War: Causes a great damage to extent difficult to restore.
6. Vegetation: Where no regular maintenance made, vegetation can grow on the bridge which can affect both the appearance and stability of the bridge.
7. Accidents and illegal Traffic Practices: cause damage on different part of the bridge if it doesn't get a proper maintenance on time.

8. Aging: if well evolution and maintenance is not given Aging of the Bridge affect the strength and appearance of the bridge.

## **II. Internal causes of Damages & Failures**

1. Support Settlements: when settlement of sub structure (on piers and/or abutments occur large cracks results on the span of the arch .Such effect can be manifested by movements throughout the structure which can be visually inspected.
2. Scour: It is the erosion of the stream bed around and from under the foundations of a bridge. It may be difficult to detect at an earlier stage, because it is likely to occur when the river is in its worst flood conditions and access to the underwater foundation is impossible.
3. Damages from abutment movements: Diagonal cracks results when one abutment tilts relative to its adjacent. In this cases the crack will typically start at a springing near one side of the arch and propagate towards the center of the crown.
4. Ring Separation: It occurs due to chemical deterioration of mortar which significantly affect the load carrying capacity of the bridge
5. Deterioration of Masonry Materials: Mostly caused by environment like moisture content and salt attack. This affects the expected level of strength and stiffness.
6. Splitting Beneath Spandrel Walls: failure result from the restrained deformation of the spandrel walls.

While sustain loads over a period of time, different causes of damage result in various types of failures mentioned above, with which the strength of Arch Bridge gets affected. So after a bridge is constructed and left open to traffic, it must be continuously evaluated in order to ensure public safety. For arch bridge, safety will be assured on the basis of the general shape of the arch and the overall geometry configuration. This is because the strength of masonry arches is highly dependent on the geometry and support conditions. The strength of the materials on arch bridge is a secondary influence.

Evaluation of existing Arch Bridges includes provision of the necessary information for repair, rehabilitation, and the basis of which shall post to close or replace the existing bridge, to ensure the safety of the public. Generally the evaluation of a structure is based on simple principle that

the available capacity of a structure to carry loads must exceed the required capacity to support the applied loadings. Details of evaluation process of Arch Bridges are discussed in subsequent sub-section.

### **3.2 Inspection and Inventory of Arch Bridges**

Bridge inspection is the condition inspection and evaluation of the in-service bridges which determine the physical and functional condition of a bridge and identify the basis for the evaluation and take preventive and maintenance actions. Whereas, Bridge inventory provides certain standard information about each bridge and how it related to the route it serve. The bridge inventory information may be evaluated and updated through the bridge's service life.

The primary purpose of bridge inspection is to maintain the public safety, confidence and investment in bridge. The information obtained during inspection includes:-

- Whether the bridge needs maintenance & repairs,
- Determine the extent of damages so that prioritization for rehabilitation and/or replacements can be considered.
- Enables to evaluate & make improvements to design of new bridges and
- A detailed inspection of the body of the arch bridge enables a decision on the strengthening feasibility through the extrados.

Bridge inventory and inspection needs proper planning, adequate equipment professional experience and development of technique and procedures. Arch bridge inspection includes investigation and testing. The primary investigation that must come first is that understanding the structure, how it was built, condition of the materials, past interventions, structural behavior and loading conditions. The first task in understanding the bridge is to study, past documents, photos, and inspect drawings. Next, a physical inspection of the bridge shall be carried on site with possibility of carrying non-destructive testing.

Visual inspection that shall be carried include, cracks, spalling, displacements, slinging bulging missing mortar and where signs of damage are recorded during visually inspection the arch, parapet, wing & Spandrel walls, piers, abutments fill and road surface are also visually inspected.

After, visual inspection non destructive and destructive tests may be used if further materials properties are needed. Non destructive tests like:

- Rebound Hammer
- Load testing
- Sampling and coring
- Flat jack
- Ultrasonic pulse Velocity test
- Infra-red thermograph
- Strain gage
- Radon test

Destructive test is a test requires parts of the structure to be removed, maintain the integrity of the sample, and tested in a laboratory. Destructive test may be used to determine some mechanical properties such as compressive strength, tensile strength modulus of elasticity and shear strength.

The relevant dimensions parameters of arch bridge for inventory and inspection are shown in Figure 3.1, below.

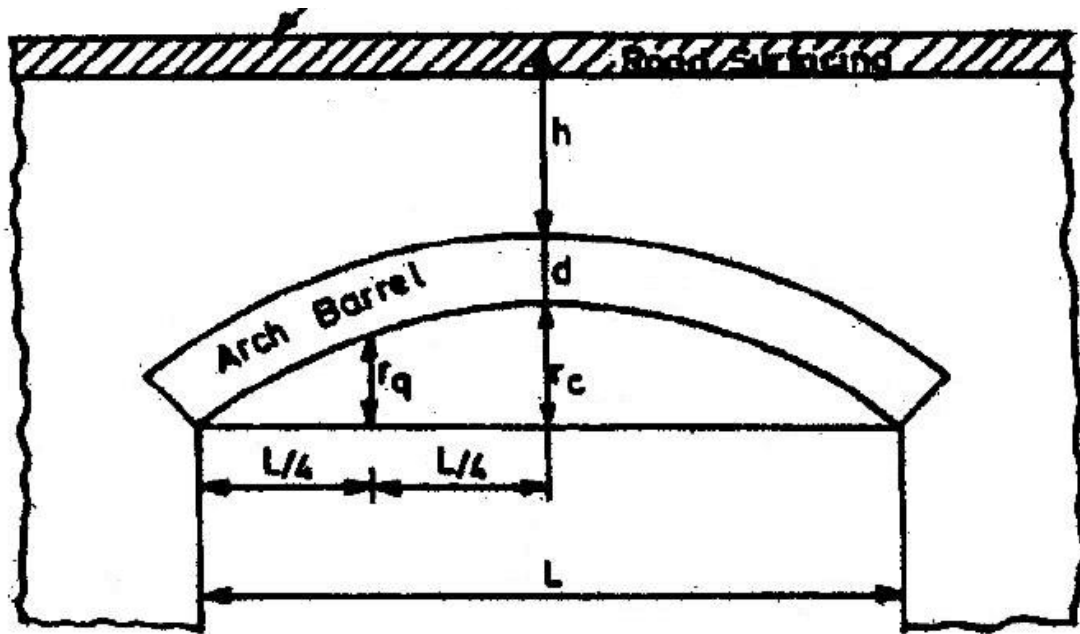


Figure 3.1 Arch dimensions [3]

In the figure,

$L$  = span in M

$r_c$  = the rise of the arch barrel at the crown in M

$r_q$  = the rise of the arch barrel at the quarter points in M

$d$  = the thickness of the arch barrel adjacent to the keystone in M

$h$  = the average depth of fill, at the quarter points of the transverse road profile between the road

surface and the arch barrel at the crown including road surfacing in M.

There are five main inspection types [5]

1. **Inventory (Initial) Inspection:** Provide structural inventory and appraisal (SI &A) data along with bridge element information and base line structural conditions. Inventory

inspections usually begin in the office with the construction plans and route information then proceed the field for verification of the as –built conditions

2. **Routine Inspection:** Identify the current structural and hydraulic adequacy and condition of the bridges. Other inspection, damage inspection which are not usually performed on a set frequently but are performed as needed to provide added information and detail to the routine bridge inspection.
3. **Fracture Critical members inspection:** Identify the location of critically fractured member and describe the inspection requirements.
4. **Underwater inspection:** Identify, locate and describe underwater elements for each bridge requiring underwater inspection.
5. **Special Feature Inspection of Complex Bridge:** This required on complex bridges that have unique or special features requiring additional attention.

The above five types of inspection are the most common and basic whereas other aspects of inspection include damage, scour, in depth inspections which are usually performed as needed.

The type of inspections used depends on the design & construction of

- the bridge
- age condition
- Factors that can affect the serviceability of the bridge.

Generally Inspection and inventory of bridge includes:

- load rating of bridge
- analysis for overload permit applications
- Initiation of maintenance actions
- Provide a continuous record of bridge condition & rate of deterioration
- Establish priorities for repair and rehabilitation programs.

Load rating is a method to know the strength of an existing bridge to carry current traffic loads.

There are two levels of rating for bridges inventory rating and operating rating. Operating rating is the absolute maximum permissible load that can be safely carried by a bridge. On the other hand, inventory rating is the load what can be safely carried by a bridge for indefinite period. In order to maintain a bridge for an indefinite period, live-load-carrying capacity, which determines

the serviceability of a bridge component and the life of the bridge, available for frequently passing vehicles needs to be estimated at service which is called inventory rating. The procedure for rating existing bridge requires knowledge of the physical condition of the bridge and the applied loadings in addition to further knowledge of traffic conditions.

Rating principle can simply expressed as the resistance of structure should be greater than the demand which is [1]

$$R \geq Q_d + Q_e + Q_i$$

Where  $R$  = resistance of structure member

$Q_d$  = effect of dead load

$Q_e$  = effect of live load

$Q_i$  = effect of load  $i$

Here thermal, wind and hydraulic loads may be neglected in the evaluation process because their occurrence is small. Thus only the effects of the dead & live loads are considered in the evaluation process. Rating of existing bridge must be a continuous activity to ensure the safety of the public.

### **3.3 Strength Evaluation of Arch Bridges**

#### **3.3.1 ERA Standards**

The ERA standards which are mainly based on AASHTO, aim to provide a comprehensive yet flexible methodology for evaluating existing bridge, consistent with today's high standards of safety.

##### **1. Substructures, foundation & retaining Walls**

Dry-stone walls, retaining walls, spandrel walls of arches, sub-structure and foundations cannot be assessed by mathematical means because of the number of unknown parameters

involved and their complex behavior. Thus, ERA standard has set a qualitative method of assessments.

### **i. Spandrel walls and dry stone walls**

The adequacy of spandrel walls and dry stone walls be assessed qualitatively and be based on the results of visual inspection of the structure. Spandrel wall failures include Tilting of the spandrel wall, bulging of the spandrel wall, sliding and cracked arch rings. These are the most common which have resulted from exposed masonry, weather, loss of pointing in the joints, direct vehicular impact which naturally causes some outward movement. Lateral forces may cause the wall to rotate outward from the arch barrel or to slide on the arch barrel or to be displaced bodily outwards, whilst taking part of the arch ring with it or force to bulge.

Inspection of dry stone walls must be based on their method of construction because the behavior of dry-stone walls is function of their method of construction. The assessment of dry-stone walls consists of regular visual inspection and comparison with adjacent structures, concerning stability regular monitoring should be introduced.

### **ii. Substructure, foundations and Retaining Walls**

The adequacy is determined from a qualitative assessment of the general condition of the structure. During assessment, attention should be paid for the following:-

- Dimensional checks are required on the sub-structure foundations or retaining wall. This is done using excavation or probing to determine depth and the extent of the sub-structure and foundation or when an exploratory excavation is not necessary prior to assessments using visual evidence.
- The existence and efficiency of the bearings should be established
- Tilting or rotation in any direction of retaining walls and abutments shall be determined, using normal survey techniques.
- Flow of water can cause leaching and scour hence any sight of unexpected or unintended water. Flows should be investigated.

## **2. Modified MEXE Method of Arch Assessment**

Modified MEXE method of Arch assessment is comprehensive method for determining the carrying capacity of single span stone and masonry arches in terms of allowable axle weights. It concerned solely with the strength of the arch barrel and tables account of the materials, various defect and geometric proportions which affect the strength of the arch.

The long term strength of a stone or masonry arch is almost impossible to calculate accurately. Therefore empirical formulas based on the arch dimensions are made.

Here the arch is assumed

- Parabolic is shape with span/rise ration of 4
- Soundly built in good quality stone work
- With well pointed in joints, to be free cracks and to have adequate abutment.

The modified MEXE shall be used to estimate the carrying capacity of Arches span up to 18m, but, for span over 12m, it becomes increasingly conservative. In addition, the method should not be used where the arch is flat or deformed.

The modified MEXE is given by the formation:

$$\text{Modified Axle load} = F_{sr} * F_p * F_M * F_j * F_c * P_{AL}$$

Where,  $P_{AL}$  = Provisional axle loading

$F_{sr}$  = Span/rise factor

$F_p$  = Profile factory

$F_M$  = Material factor

$F_j$  = joints factor

$F_c$  = condition factor

- Provisional Axle loading /PAL: The provisional axle loading can be obtained from the nomogram (Figure 3.2) by mark the arch span L on column A and the total crown thickness (d+h) (barrel and fill) on column B. Line through these points to column C, and

read off the provisional axle loading assessment in tones or by expression given below which has been derived from the Nomogram & it should only be used within the limits given in the Nomogram.

PAL is the lesser of the following

$$\text{PAL} = 740 (d+h) / L^3, \text{ or } 70$$

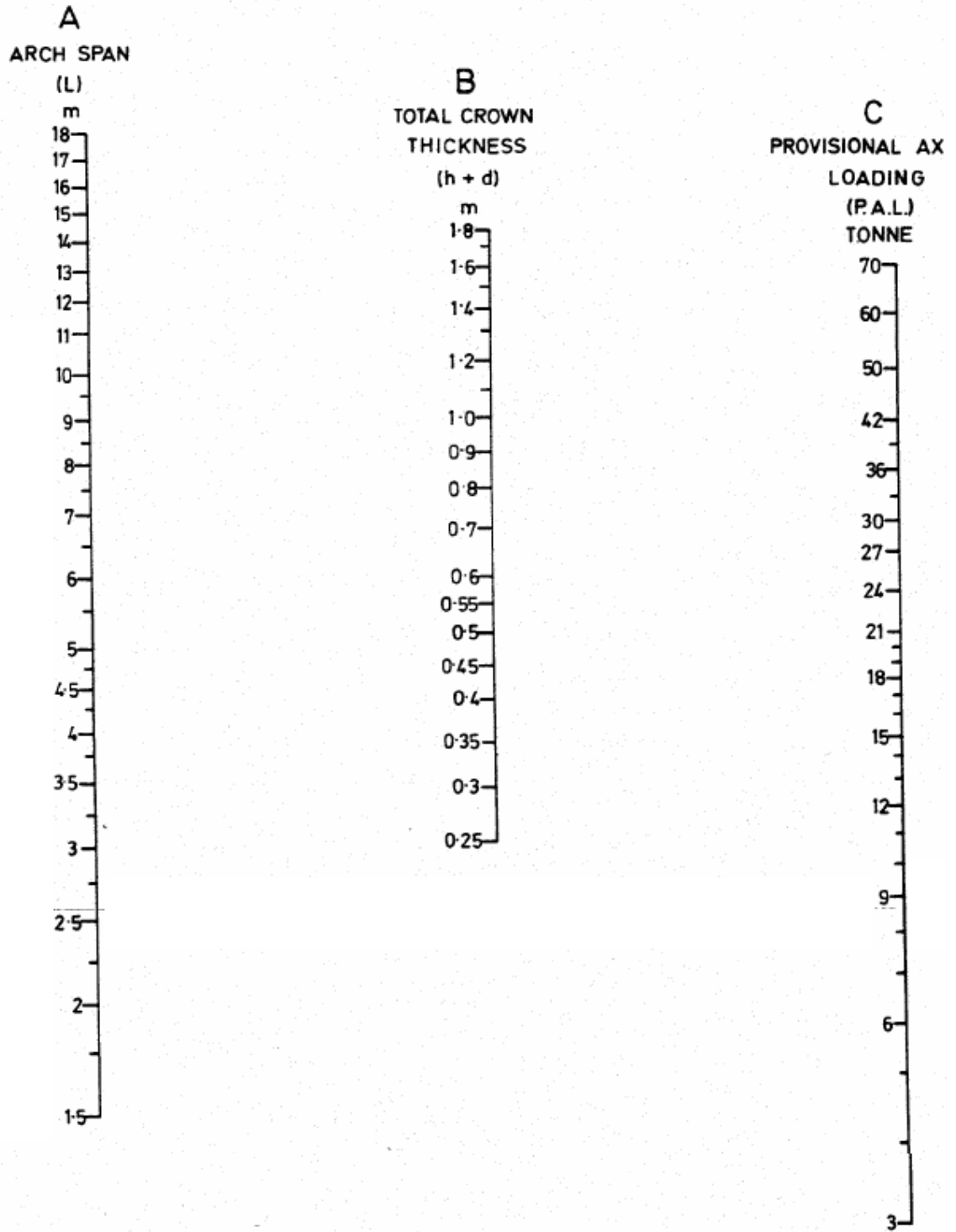


Figure 3.2 Nomogram [3]

### 3. Modifying Factor

i. **Span/Rise factor:** A span/rise ratio of 4 and less is assumed to give optimum strength and has a factor of 1. When the span/rise ratio is greater than 4, reference should be made to the nomogram given in the figure.

ii. **Profile Factor:** The profile factor  $F_p$  for ratios of  $r_q/r_c$  less than or equal to 0.75 should be taken to be unity and for ratios greater than 0.75 should be calculated from the expression

$$F_p = 2.3 [(r_c - r_q)/r_c]^{0.6}$$

Where  $r_q$  = The rise at the quarter points

$$r_q = 0.75 r_c$$

$r_c$  = is the rise at the crown

iii. **Material factor:** Materials factor can be obtained from the formula

$$F_m = [(F_b \times d) + (F_f \times r)] / (d+h)$$

Where  $F_b$  = barrel factor

$F_f$  = fill factor

The values of barrel and fill factor,  $F_b$  &  $F_s$ , can be obtained from Tables 3.1 and 3.2, respectively.

**Table 3.1: Barrel factor  $F_b$  [3]**

Arch Barrel	Barrel Factor
Granite whether random or coursed and all built-in-course masonry except limestone, all with large shaped stones	1.5
Concrete or engineering bricks and similar sized masonry (not limestone)*	1.2
Limestone, whether random or coursed, good random masonry and building bricks, all in good condition.	1.0
Masonry of any kind in poor condition (many stones flaking or badly spelling, shearing etc). some discretion is permitted if the dilapidation is only moderate.	0.7

\*Concrete arches will normally be of relatively recent construction and their assessment should be based on the design calculations if these are available.

**Table 3.2: Fill factor Fr [3]**

Filling	Fill factor (Fr)
Concrete**	1.0
Grouted materials (other than those with a clay content)	0.9
Well compacted materials	0.7
Weak materials evidenced by tracking of the carriageway surface	0.5

\*\*The fill factor for concrete is less than the barrel factor to allow for possible lack of bond to the arch.

iv. **Joint Factor (Fj):** The joint factor Fj is obtained from the following formula

$$F_j = F_w * F_d * F_{mo}$$

Values for Fw and Fmo can be obtained from Table 3.3 and 3.4, respectively.

Fd= the depth factor shall be taken as 1 for pointed joints in good condition, if not taken from table 3.5

**Table 3.3 Width factor Fw [3]**

Width of joint	Width factor (Fw)
Joints with widths up to 6mm	1.0
Joints widths between 6mm and 12.5mm	0.9
Joints with widths over 12.5mm	0.8

**Table 3.4 Mortar factor Fmo [3]**

Condition of joint	Mortar factor (Fmo)
Mortar in good condition	1.0
Loose or friable mortar	0.9

**Table 3.5 Depth factor Fd [3]**

Construction of joint	Depth factor (Fd)
Unpainted joints, pointing in poor condition and joints with up to 12.5mm from the edge insufficiently filled	0.9
Joints with from 12.5mm to one tenth of the thickness of the barrel insufficiently filled	0.8
Joints insufficiently filled for more than one tenth the thickness of the barrel	At the engineer's discretion

## **V. Condition Factor**

The value of condition factor  $F_c$  should be made by the Engineer between 0 and 1. Low factor should be taken for a bridge in poor condition, while 1 shall be the value taken for arch barrel in good condition, with no defects. Where the condition factor is less than 0.4, immediate consideration should be given to repair or reconstruction of the bridge.

The modified Axle load given above represents the allowable loading on the arch from a double axle truck configuration, with no "lift-off" from any axle. The unrounded value of the line modified axle load should be multiplied by the appropriate axle factors from Figure 3.3 to give the allowable axle loads for single & multiple axles.

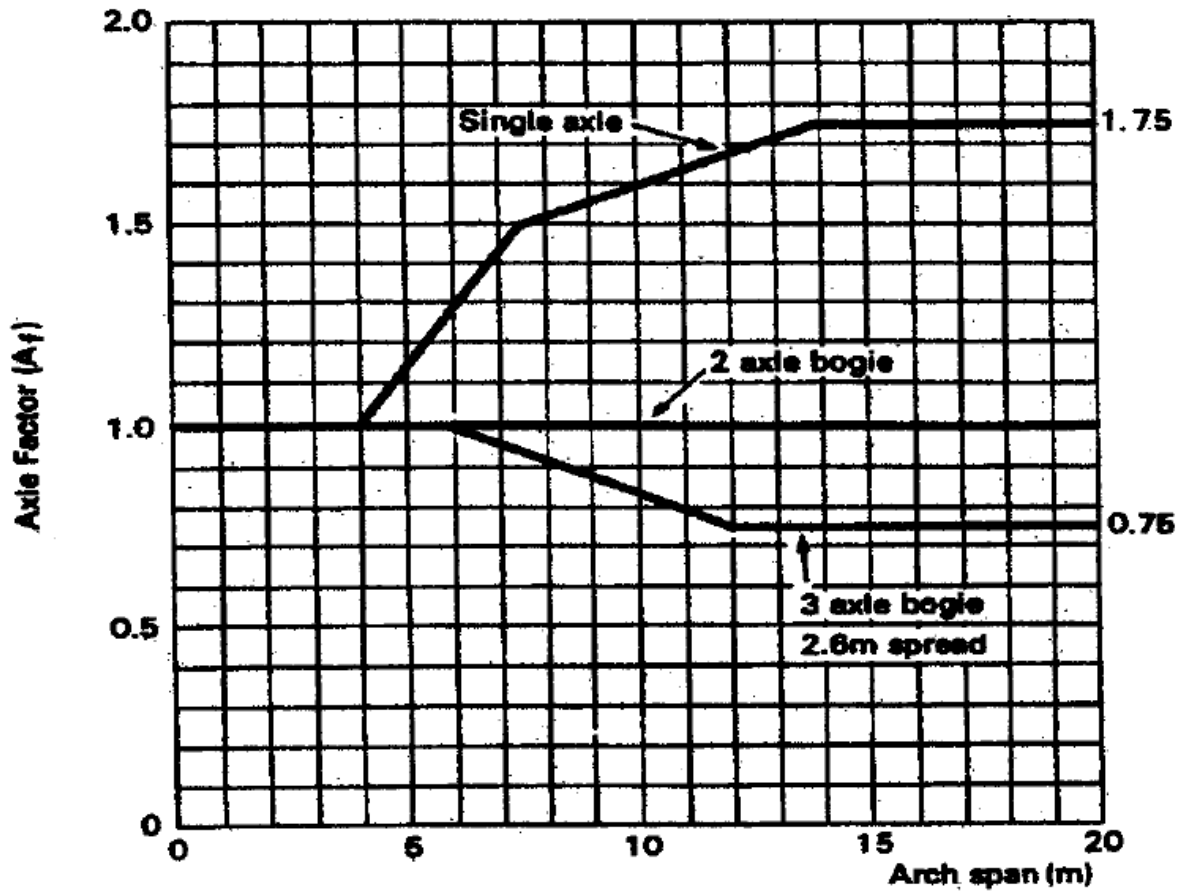


Figure 3.3 a): No axle lift-off

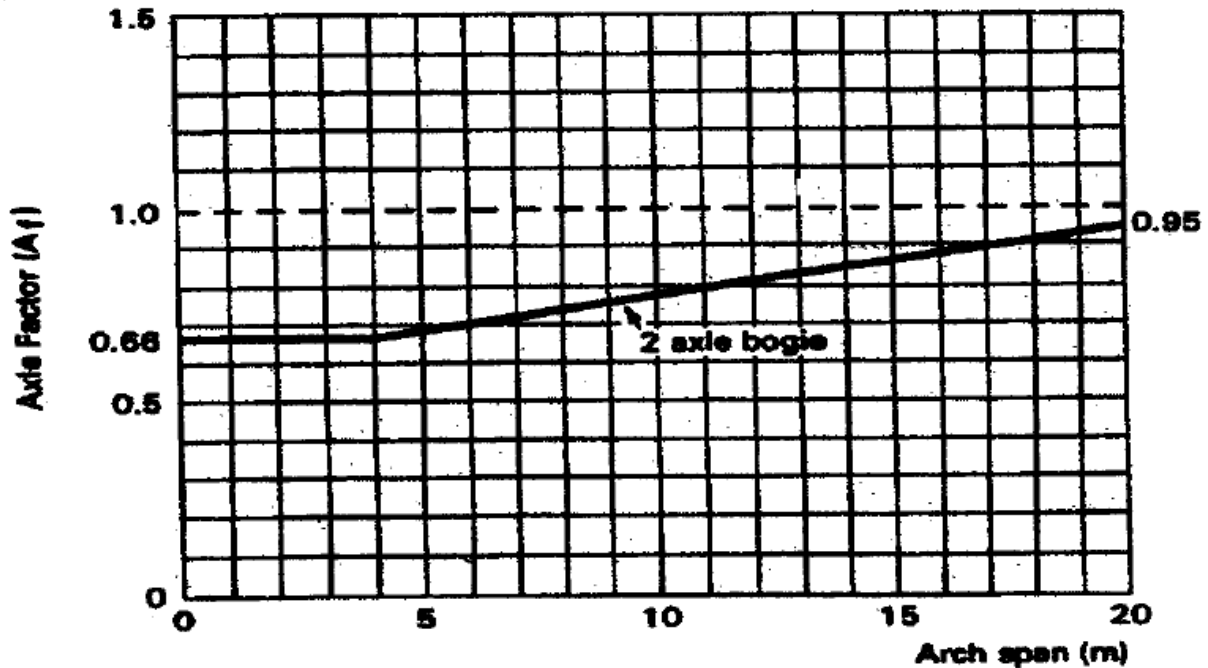


Figure 3.2 b): With axle lift-off

Figure 3.3 Conversion of modified axle loads to single double and triple axles

The capacity of arches shall be determined in terms of gross vehicle weights from Table 3.6; Accordingly, First it is rounded off to the nearest 0.5 tonnes. The maximum gross weight of the vehicles which the arch can carry is then found from Table 3.6. It is the maximum weight for which both the single and, where applicable, the double axial load calculated for the arch are satisfied.

**Table 3.6: gross vehicle weights [3]**

Allowable axle load (tonnes)			Max gross vehicle weight(gvw)(tonnes)	Weight restriction (tonnes)	Type of vehicle
Single	double	triple			
11.5	10	8*	40	N/A	5 axles
10.5	9.5	-	32.5	33	4 axles

10.5	9	-	24.5	25	3 axles
10.5	-	-	17	17	2 axles
5.5	-	-	7.5	7.5	4 WD

Allowable axle load found above may not represent the strength of the bridge as a whole. Because the strength of the bridge shall be affected by the strength of spandrel walls, wing walls, foundations etc. So strength of any of the above is assessed as being lower than the barrel strength, then the lowest value should be taken as the strength of the bridge as a whole.

### 3.3.2 Some Features of Inspected Arch Bridges in Ethiopia

Observing the damage or deterioration, ERA categorized Arch Bridges inspected into three ranks

Rating A –if the damage rating lies here, it needs urgent repairs to avoid major damage

Rating B- shows repairs are necessary but not urgent

Rating C-shows the damage, is minor

The table below indicates how the ranks are categorized

Table3.7 Sample of Damage Rating [3]

Damage Item	Rank ‘A’	Rank ‘B’	Rank ‘C’
<b>Cracking</b>	Single crack width of more than 5 mm or multiple cracks of width more than 3 mm, together with water leakage, free lime or salt. In bearing area, single crack of more than 3 mm and multiple crack width of 1mm	Single crack width of more than 3 mm or multiple cracks of width more than 1 mm, together with slight water leakage. In bearing area, single crack width of more than 1mm and multiple crack	Single crack width of more than 1 mm or multiple crack of width less than 1 mm in bearing area single crack width of less than 1 mm with no water leakage.

	which causes reduction in loading capacity.	of width less than 1 mm, which causes reduction in durability.	
--	---	--	--

Since many arch bridges in Ethiopia are constructed over 70 years ago, they are almost all damaged or deteriorated. The existing arch bridge inspected by ERA and set the inspection damage percentage is shown in detail in Appendix A2.

After the inspection damage percentage is determined, the inspection recommendation is provided in accordance with the inspection damage percentage and the inspector site investigation. The recommendation for instance can be:

- Regular inspection: which needs regular inspection so that it may not get critical condition, showing the Interval in which the inspection is done must be less.
- Rehabilitation: this needs maintenance in order to make sure public safety and the strength of the Bridge.
- Replacement: in this case, determination if the superstructures need replacement is considered. The new superstructure should be designed according to the necessary criteria set by ERA design manual, for such superstructure design.

### **Example 3.1: Strength Evaluation of Angereb Arch Bridge**

Angereb Bridge is located at km 4 + 888, which is within 5 km, stretch to Gondar Town. Recommendation given by the supervision consultant is, the top 3 course of stone masonry above the barrel require mortar grouting and pointing. The structure bed is rock and overall condition is good. The Bridge relevant Dimension of the existing Angereb Arch Bridge is given as below.

- The width of the bridge is 8.3 m,
- The clear span of the bridge is 20m
- Arch thickness “d” = 0.9m
- Average depth of fill including pavement = 1.7m
- Width between parapet wall “w” = 8.2

- The distance between the river side face of the abutment to the start of the wing wall is = 4.5



Figure 3.4 Angereb River Bridge

\* The modified MEXE shall be used to estimate the carrying capacity of Arch.

$$\text{Modified Axle load} = F_{sr} * F_p * F_M * F_j * F_c * P_{AL}$$

$$PAL = 740 (d+h) / L^3, \text{ or } 70$$

$$= 740(0.9+7) / 20^3 = 73, \text{ PAL} = 70$$

$$\text{Span /rise} = 2.8 < 4, \text{ Fsr} = 1$$

$$\text{Profile Factor} = r_q / r_c = 0.75 \text{ Fp} = 1$$

$$\text{Material factor} = F_m = [ (F_b \times d) + (F_f \times r) ] / (d+h) = 0.74$$

Where  $F_b = 1.5$  from Table 3.1

$F_f = 0.7$  from Table 3.2

Joint Factor =  $F_j = F_w * F_d * F_{mo} = 0.9$

Where,  $F_w = 0.9$  from Table 3.3

$F_{mo} = 1$  from Table 3.4

$F_d = 1$  For good condition

Condition Factor = 1, Arch barrel is in good condition

Modified Axle load =  $1 * 1 * 0.74 * 0.9 * 1 * 70 = 70$

Hence, the state of the bridge is satisfactory with minor maintenance, no requirements of remedial measure. The recommendation given is the top 3 course of stone masonry above the barrel requires mortar grouting and pointing. The structure bed is rock and overall condition is good.

Amoragedal, Alem River Arch Bridge and Golina Bridge can be another example. The existing major structures have been constructed about 70 years ago.



Figure 3.5 Amorageal River Arch Bridge

Amorageal Arch Bridge is a masonry Arch bridge located in Gonder district. The width of the bridge is 11m, is located in a very deep gorge having sharp curve. The inspection indicates the edges of the barrel on both sides are damaged. There is a continuous longitudinal crack at its carriage way.

Hence, considerable maintenance measure on its underside and also on the masonry walls of the wing walls and its abutment is necessary.



Figure 3.6 Alem Watch River Bridge

Alem Watch Bridge is located at Gonder district near to Dabat town. The width of the bridge is 8.2m, having deep gorge. Inspection indicates the bridge is generally in good condition but there are certain cracks on its wing walls. Hence, the bridge needs minor maintenance and scour protection works.

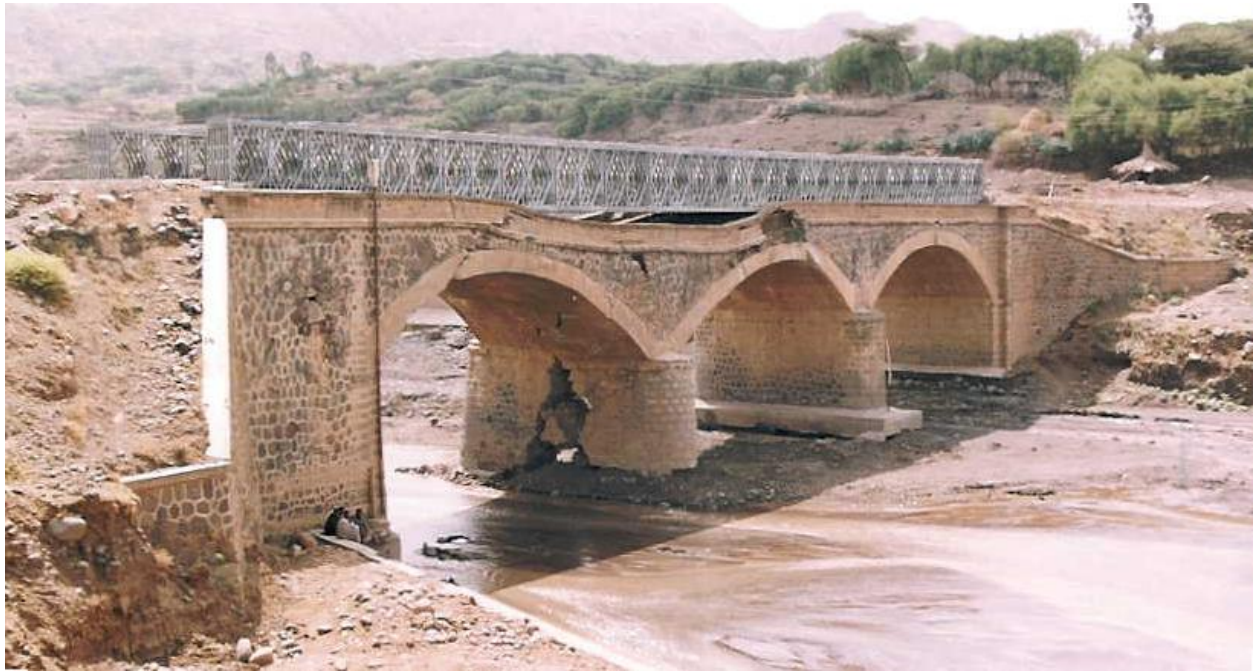


Figure 3.5 Golina Bridge

Goline Bridge is located along the road from Woldi to Mekele. As the picture and the inspection shows the damage was high which indicates it needs urgent repairs. Currently replaced and repaired.

## 4. Design Consideration of Arch Bridges

### 4.1 General approach of design

The design of the bridge starts with development of a series of possible alternatives. Comparing the different alternatives by considering various condition consisting of technical and economic aspects shall be used to obtain the final site specific solution. Generally, the design process of bridges consists of two major parts

- **Preliminary Design**- this stage consists of a comprehensive search of current practical and analytical applications of old and new method in structural bridge engineering. Preliminary design provides means to determine the exact values of parameters and their quality indexes. Here, the problem of preliminary design cannot be solved in pure mathematics and also the quality indexes cannot be expressed by algebraic functions
- **Final Design Phase**- this stage requires a detailed study and analysis of structural behavior and stability, and consists of complete treatments of a new project in all of its aspects.

### Basic Assumptions of Design

- To ensure safety of the public, it is very important that the bridge engineering determine the carrying capacity of the bridge assuming the maximum value of the temporary vertical load which the bridge can carry.
- To avoid interruption in traffic flow, it shall be should assumed in the calculation that maximum numbers of vehicles pass in a given time, and
- It is necessary for the width of the bridge to be greater than that required by the calculated carrying capacity to avoid interruption in traffic flow.

### Basic Requirement of Design

- **Safety**:-This refers to provision of safety to the public in view of strength requirements so that the bridges designed shall have their carrying and passing capacities can accommodate the required load with safety.

- **Aesthetic**:-This shall not be ignored because of economic and technical requirements. The first reason is that aesthetics are viewed in a historical perspective and the other reason is that they give great beauty to Cities and towns wherever are located.
- **Serviceability** :- includes:
  - ✓ Durability – concerned with the quality of the materials used,
  - ✓ Maintainability- structural systems whose maintenance is expected to be difficult should be avoided.
  - ✓ Ride ability- the deck of the bridge shall be designed to permit the smooth movement of traffic.
  - ✓ Utilities- provisions shall be made to support and maintain the conveyance for utilities.
- **Constructability**: - bridges should be designed in a manner such that fabrication and erection can be performed without in due difficulty or distress and that locked in construction force effects are within tolerable limits.
- **Economy**:- structural types, span lengths and materials shall be selected with due consideration of project cost. An economic design is achieved by the expedient distribution of materials, choice of the most economic system, cross sections of the members and considering working conditions and the use of proper material.

Generally, a proper design method shall meet this requirement in order to provide safe, long life and aesthetically beautiful bridge to the public. In the sub-section to follow Design of Stone Masonry and Reinforced Concrete arch bridges shall be considered.

## 4.2 Stone Masonry Arch Bridges

The first important consideration when designing a masonry arch is whether the arch is structural or non-structural that means the designer should ask what the arch is required

to transfer vertical loads to abutments or will it be fully supported by a steel angle. This question can be answered by considering the two structural requirements necessary for a masonry arch to adequately carry vertical loads. First vertical loads must be carried by the arch and transferred to the abutments. Second vertical load and lateral thrust from the arch must be resisted by the abutment. If either the arch or the abutment is deficient, the arch must be considered as nonstructural and the arch must be fully supported by a steel angle or plates. The most necessary assumptions that must be made for masonry arch during design is that

- It has no tensile strength
- It has virtually strong compressive strength
- Slip does not occur between components of the structure

Relevant steps to be followed for masonry arch bridge design [2]

- Choose the most optimal shape of the arch and estimate the thickness of the arch barrel. In this regard minimization of texture under arch barrel should be noticed. Here if the spans are less than 25 m the arch should preferably be a multiple circular curve.
- Fix the relevant dimensions and calculate the dead loads.
- Place the live load on half of the arch and check compression at point where it is most critical in respect of compression strength
- The abutments should be checked for the position of the compression time, which should be within the core. If not the shape of the arch should be changed.
- Check for shear on the abutments.
- Compute all forces on the superstructure

Some consideration that should be taken during design

- The quality of stones that can be obtained at the bridge site must be determined using the compressive strength
- Choosing the right location is crucial for designing and planning an arch bridge

- In the value of historical perspectives, the Aesthetic requirements of Arch bridges must be considered during design. It should not have to be ignored because of economic requirements.
- Since the curved rib of the arch bridges is subject to high axial force, the chance of a failure due to bucking of the rib cannot be ignored and must be accounted for design consideration.
- Crushing will occur when compressive stresses in the arch exceed the compressive strength of the masonry. If compressive stresses in the arch are too large, the arch must be redesigned with a shorter span or a greater arch depth.

### Example 4.1: Stone Masonry Arch Bridge

The dimension of the existing Angereb Arch Bridge is considered.

- The width of the bridge is 8.3 m,
- The clear span of the bridge is 20m
- Arch thickness “d” = 0.9m
- Average depth of fill including pavement = 1.7m
- Width between parapet wall “w” = 8.2
- The distance between the river side face of the abutment to the start of the wing wall is = 4.5

Loading

$$q_{EH} = K_o * \gamma_{ss} * (Z_{top} - Z_{CG}) \quad \text{Horizontal Earth Pressure}$$

$$q_{EV} = \gamma_{RG} * (Z_{top} - Z_{EA}) \quad \text{Vertical Earth fill}$$

$$K_o = 0.45 \text{ ----- loose sand}$$

$$\gamma_{LS} = (8k/m^2) \text{ ----- loose gravel}$$

$$\gamma_{RG} = 22.25 \text{ ----- rolled gravel}$$

$\gamma_{SM} = 27.3 \text{ m}$ ----- stone masonry (sand stone)

Max dead load

$$q_{EH} = 0.45 * 18 * 7 = 56.7 \text{ KN/M}^2$$

$$q_{EV} = 22.5 * 7 = 157.5 \text{ KN/M}^2$$

$$q_{DC} = 27.3 * 0.9 = 24.5 \text{ KN/M}^2$$

$$I = 0.9^3 / 12 = 0.6075$$

Live load

Lane load:  $q_{LL} = 9.3 * 2 / W = 2.24 \text{ kN/m}^2$  uniformly lane load /m

Design truck:  $\epsilon = 1.33$

The Dynamic Factor

$$l_{Tire} = 0.2 \text{ m}$$

Tire Contact Area

$$Z_{filling} = 1.7 \text{ m}$$

$$P_{Truck1} = 35 \text{ kN}$$

$$P_{Truck2} = 145 \text{ kN}$$

$$P_{Truck1} = [2 * 35 * \epsilon / (l_{Tire} + 2 * Z_{filling})] / W = 3.1 \text{ kN/m}^2$$

$$P_{Truck2} = [2 * 145 * \epsilon / (l_{Tire} + 2 * Z_{filling})] / W = 12.9 \text{ kN/m}^2$$

Check the compression line shall be within the core limit

$$e = M/N < d/6$$

$$0.104 < 0.15 \quad \text{ok}$$

### 4.3 Reinforced Concrete Arch Bridges

The use of concrete permits more variation in arch design beside its structural use. Reinforced concrete is a particular type of concrete with the addition of reinforcing steel

bars to make the structure more ductile or less brittle, which shall obviously increase the load carrying capacity of the bridge. Therefore, a bridge designed with reinforced concrete can endure the load capacity of larger truck loads without the risk of collapsing versus the same bridge that did not implement reinforcing bars into its concrete design.

### Design\_Consideration

- Proper number of reinforcement shall be added to avoid sliding at the skewback, as the reinforcement acts as a shear key
- Concrete arch bridges preferably be designed with 3 hinges (joints) to minimize stresses in the arch barrel.
- Rotation occurs when tension develops in the arch. Hence tension can be reduced by increasing the depth or rise of the arch.
- In the reinforced concrete arch bridge design, the need to reduce self weight is important for larger spans but for small to medium where extra dead weight helps to pre-compress the arch thus enhances its performance as an arch.

### Example 4.2: Concrete arch bridge design

The same dimension in example 4.1 used for comparison reason

- The width of the bridge is 8.3 m,
- The clear span of the bridge is 20m
- Arch thickness “d” = 0.9m
- Average depth of fill including pavement = 1.7m
- Width between parapet wall “w” = 8.2

Loading at --

- Arch ring =  $0.9 \times 2400 \text{ kg/m} = 2160 \text{ kg/m}$
  - Earth filling =  $1600 \text{ kg/m} \times 1.7 \text{ m} = 2720 \text{ kg/m}$
- Total =  $4880 \text{ kg m}$

Taking max bending moment (M) and Thrust (H)

$$e = M/H = 16 \text{ cm}$$

$$\text{Average stress} = p / BD \times 100 = 32\%$$

- 6% reinforcement can be provided with effective cover provided to reinforcement is at top and bottom is 5.5 cm

$$A_s = 6 / 100 \times 100 \times 90 = 54 \text{ cm}^2$$

### Example 4.3 Design of long span RC Arch Bridge

Design a filled spandrel arch for a span of 50 meters. It carries an effective width of road ways 8 meters rise of the arch is 7 meters. Cement concrete wearing coat is of 8 cm average thickines. The design is for the arch to carry 2 lanes loading. Temperature variation of  $\pm 24^0\text{c}$  is considered for the designs of arch. Coefficient of linear expansion for concrete is  $11.7 \times 10^{-6} \text{ c}$ . Unit weight of earth used for filling is 1600kg/m<sup>3</sup>. Permissible stresses are as follows:

Proportioning at crown- 80mm wearing coat 700 mm fill 600 mm arch ring, RC:-

$$\text{Compression in concrete} = 70 \text{ kg/cm}^2 = 70 \times 10\text{N}/100\text{mm} = 7\text{mMa}$$

$$\text{Tension in steel} = 1400\text{kg/cm}^2 = 140 \text{ Mpa}$$

$$\text{Modular ration } m = 13$$

#### Step-1 Dead Load Calculations

##### I. Dead Load at Crown

- Wearing coat =  $0.08 \times 22 = 1.76 \text{ KN/m}^2$
- Arch ring =  $0.6 \times 24 = 14.40\text{KN/m}^2$
- Earth filling =  $0.7 \times 16 = \underline{11.2\text{KN/m}^2}$

$$\text{Total} \text{-----} 2.736$$

##### II. Dead load at springing

- Wearing coat =  $0.08 \times 22 = 1.76 \text{ KN/m}^2$
  - Arch ring =  $1.31 \times 0.9 \times 24 = 28.30 \text{ KN/m}^2$
  - Earth filling =  $7.1 \times 1600 = 113.60 \text{ KN/m}^2$
- Total-----  $14.366 \text{ kNw/m}^2$

Ratio  $g = w_s / W_c = 14366/2736 \approx 5.25 \approx 5$

Step 2- Moment of Inertia

i. Moment inertia at crown

$$I_c = 1(t)^3/12 = 1 (.60)^3/12 = 0.018 \text{ m}^4$$

ii. Moment of Inertia at springing

$$I_s = 1(0.9)^3/12 = 0.06075 \text{ m}^4$$

$$r = I_c / I_s \cos \phi_s = 0.018 / 0.06075 \times 0.7649 = 0.3$$

Step-3 Arch ordinate and depths of Various Sections

For  $g=5$  end  $r=0.3$

$$Y = \alpha * h, \quad \tan \phi = \beta h/L = \beta * 0.14$$

**Table 4.1 Arch ordinate and depths of various sections**

coordinates at	X	Y	$\tan \phi$	$\cos \phi$	$\sec \phi$	$(\sec \phi)^{1/3}$ a	$[1-(1-r)4x^2/L^2]^{1/3}$ b	Radial depth $d_c = a/b$ (cm)	Vertical depth $d_{\sec \phi}$ (cm)
0.1	2.5	6.9538	0.0371	0.9993	1.001	1.00	0.9977	60.14	60.20
0.2	5	6.8131	0.0762	0.9971	1.002	1.001	0.9906	60.63	60.75
0.3	7.5	6.5695	0.1193	0.9929	1.007	1.002	0.9786	61.44	61.87
0.4	10	6.2111	0.1687	0.9861	1.014	1.005	0.9612	62.73	63.61
0.5	12.5	5.719	0.2269	0.9752	1.025	1.008	0.9379	64.48	66.09

0.6	15	5.0666	0.2972	0.9586	1.043	1.014	0.9078	67.02	69.90
0.7	17.5	4.2196	0.3832	0.9338	1.071	1.023	0.8693	70.61	75.62
0.8	20	3.1359	0.4893	0.8982	1.113	1.036	0.8203	75.78	84.34
0.9	22.5	1.7521	0.6213	0.8494	1.177	1.056	0.7565	83.75	98.57
1	25	0	0.786	0.786	1.272	1.084	0.6694	90.00	114.48

Step-4 Influence line Ordinates for horizontal Thrust

The coefficient is for  $a=5$   $r=0.3$   $L=50m$   $h=7m$

**Table 4.2 influence line ordinates for horizontal thrust**

Load at	Influence line coefficient	Influence line ordinate = $L/10h$ *coefficient
0	2.6502	1.893
0.1	2.5902	1.850
0.2	2.4161	1.726
0.3	2.1403	1.529
0.4	1.7864	1.276
0.5	1.3837	0.988
0.6	0.9700	0.693
0.7	0.5857	0.418
0.8	0.2726	0.195
0.9	0.0687	0.049
1.0	0	0

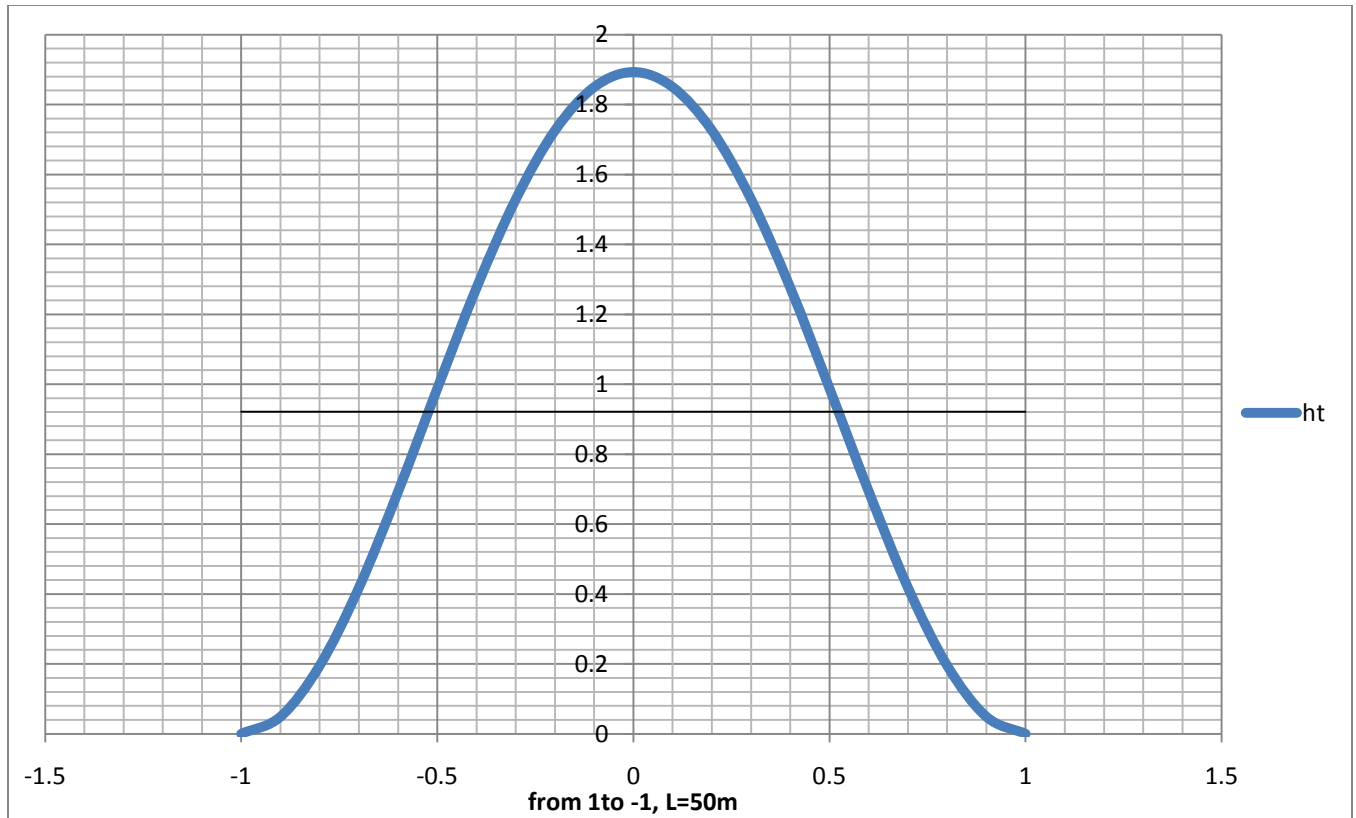


Fig 4.1 Influence line for horizontal thrust

Step5- Influence lines ordinates for bending moment at crown, springing and quarter point

For corresponding  $g=5$   $r=0.3$   $L=50$   $h=7$

**Table 4.3 Influence lines ordinates for bending moment at crown, springing and quarter point**

Load point	Crown		Quarter point		Springing	
	I.L coeff.	I.L ordinate $=L/100*\text{coeff}$	I.L coeff	I.L ordinate $=L/100*\text{coeff}$	I.L cof	I.L ordinate $L/100$
1.0	0	0	0	0	0	0
0.9	-0.087	-4.35	0.147	7.35	-4.185	-209.25
0.8	-0.313	-15.65	0.651	32.55	-6.656	-332.8
0.7	-0.587	-29.35	1.592	79.6	-7.517	-375.85

0.6	-0.794	-39.7	3.023	151.15	-7.007	-350.35
0.5	-0.820	-41.0	4.932	246.6	-5.444	-272.2
0.4	-0.554	-27.7	2.477	123.85	-3.168	-158.4
0.3	0.103	5.15	0.502	25.1	-0.531	26.55
0.2	1.227	61.35	-0.968	-48.4	2.154	107.7
0.1	2.879	143.95	-1.971	-98.55	4.603	230.15
0.0	5.092	254.6	-2.558	-127.9	6.594	329.7
0.1	2.879	143.95	-2.790	-139.5	7.965	398.25
0.2	1.227	61.35	-2.734	-136.7	8.622	431.1
0.3	0.103	5.15	-2.462	-123.1	8.543	427.15
0.4	-0.554	-27.7	-2.046	-102.3	7.788	389.4
0.5	-0.820	-41	-1.557	-77.85	6.478	323.9
0.6	-0.794	-39.7	-1.067	-53.35	4.819	240.95
0.7	-0.587	-29.35	-0.622	-31.1	3.057	152.85
0.8	-0.313	-15.65	-0.280	-14	1.482	74.05
0.9	-0.087	-4.35	-0.069	-3.45	0.385	19.25
1	0	0	0	0	0	0

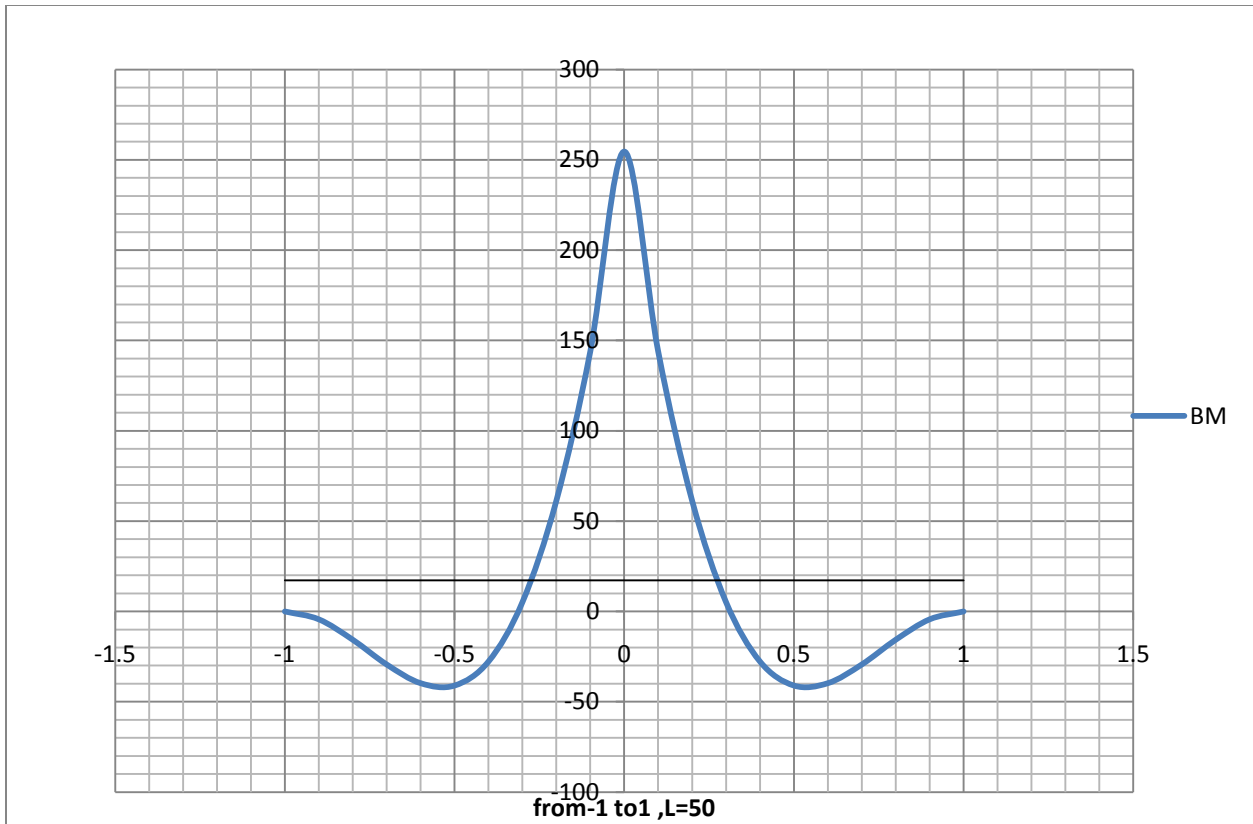


Fig 4.2 Influence line for bending moment at crown

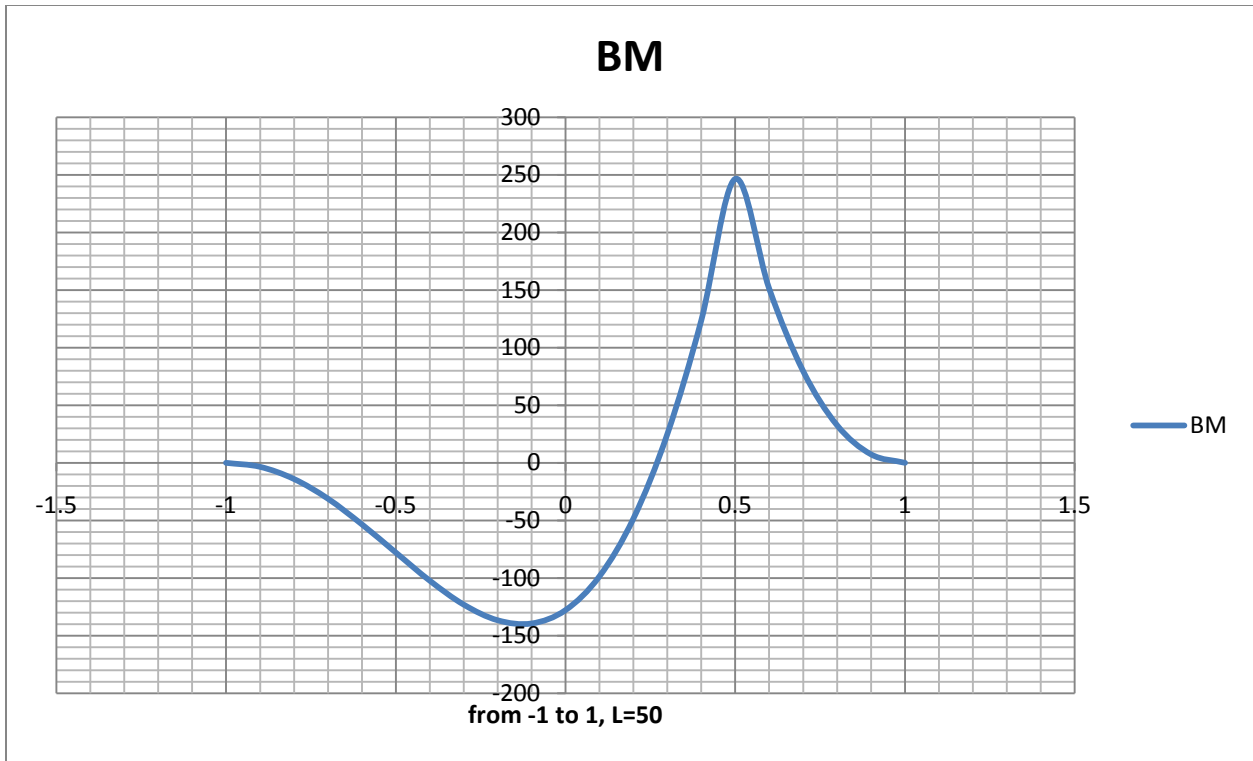


Fig 4.3 Influence line for moment at quarter point

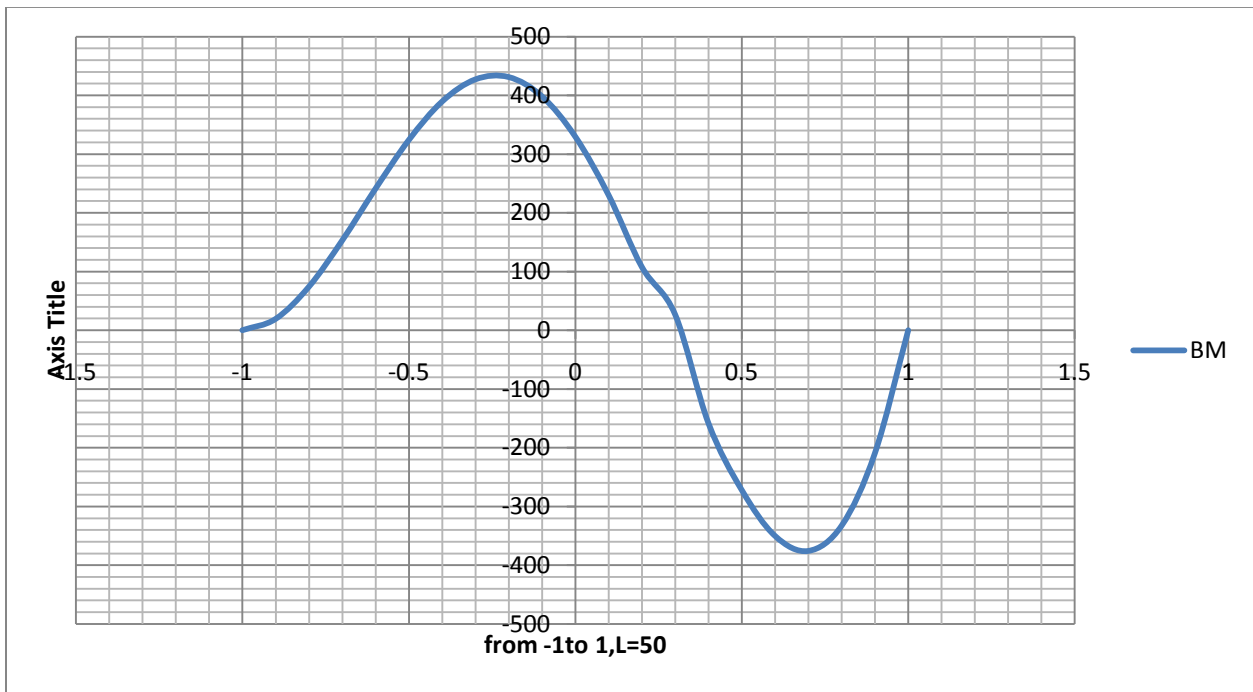


Fig 4.4 Influence line for bending moment at springing

### Step-6 Calculation of Bending moment and thrust

Note- in filled spandrel arches the wheel load shall be assumed to be dispersed at  $45^\circ$  in both direction (along span and perpendicular to span)

Let be the axle load on the road

$$145+145+35=325+\text{lane load, } 2*9.3*50$$

Maximum area of influence line diagram covered by trial error

Loading intensity: 1. Axle 145, 2. Axle 145 3. Axle 35

$$\text{Max} = 1, 098.300 \text{ KN.m/m wider}$$

Corresponding thrust from influence line for horizontal thrust

$$=700 \times 163 = 11410$$

$$= 550 \times 12.5 = 6875$$

$$= 425 \times 5.7 = 2422.5$$

$$\text{Total} = 20, 707.5\text{kg}$$

### Step7 Effect of temperature variation & Rib shortening

i. Net temperature variation in concrete =  $2/3 \times 24 = 16^\circ\text{c}$

$$M_{cT} = -(t-t_0) \epsilon E * ((g-1)/h) * I_C. \alpha_2/\beta_2$$

$$= 16 \times 11.7 \times 10^{-6} (2.1 \times 10^4) / 13 * (5-1)/7 * 0.018 \times (100)^4 \times 0.6371/0.5303$$

$$= \underline{3,73645}$$

$$H_T = (t-t_0) \epsilon E (g-1)^2 / h^2 I_C. \alpha/\beta_2$$

$$= -16 \times 11.7 \times 10^6 (2.1 \times 10^4) / 13 * (5-1)^2 / (700)^2 \times 0.018 (100)^4 \times 0.7662/0.5302$$

$$= -2570.5 \text{ kg}$$

ii. Bending Moment to rib shortening

$$M_{cs} = H (g-1) / h * [ I_c^2 / 12 b^2 ]^{1/3} * \eta \alpha_2 / \beta_2$$

Where H= is thrust due to dead load

$$= WcL^2 / 10 h$$

$$= 1.9029 \times 2736 \times 50^2 / 10 \times 7$$

$$= 185940.5 \text{ kg}$$

$$\eta = [ 1 + 16/9 (h/L)^2 - (1-r) * \{ 1/9 + 16/15 * (h/L)^2 \} ]$$

$$= 1 + 16/9 * (7/50)^2 - (1-0.3) * \{ 1/9 + 16/15 * (7/50)^2 \}$$

$$= 0.9424$$

Using the values  $M_{CS}$

$$M_{CS} = 360,961.07$$

Horizontal thrust due to rib shortening

$$H_s = -H [ (g-1) / h ]^2 * (I_c^2 / 12 b^2)^{1/3} * \eta \alpha / \beta_2$$

$$= 185940.5 [ (5-1) / 700 ]^2 * [ (0.018)^2 * (100)^8 / 12 * 100^2 ]^{1/3} * 0.9424 \times 0.7667 / 0.5302$$

$$= \underline{\underline{-2482.2 \text{ kg}}}$$

Total Bending Moment in kg. cm

$$= 1,098,300 + 3,736,45 + 360,961.07 + \frac{1}{2} 373,645$$

$$= 2,019,728.57 \text{ kg.cm} = 2,019.73 \text{ KNm}$$

Total Thrust in kg

Dead load + live load + Temperature + Rib Shortening + slub

$$= 1,39,536 + 20,707.5 + (.2570.5) + (-2482.2) + (\frac{1}{2} .2570.5)$$

$$= 153905.55 = 1539.05 \text{ KN}$$

Step -8 Design of Section

Crown Section D= 60cm depth was provided

$$\text{Electricity} = e = M/H = 20, 19728.57/153.905.55 = 13.12 \text{ cm}$$

$$e/D = 13.12/60 = 0.2187$$

$$\% \text{ average stress} = P/BD \times 100/C$$

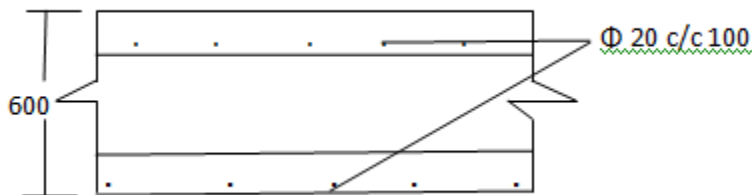
$$= 153905.55/100 \times 60 \times 100/70 = 36.64 \%$$

Considering the above average stress 36% and e/d ratio 0.2187

Provide 5% reinforcement

$$A_C = 5/100 \times 100 \times 60 = 30.0 \text{ cm}^2$$

$$= 314 \times 100/30.00 = 104 \text{ proved } \Phi 20 \text{ c/c } 100, \text{ at crown}$$



Note: The design of the spring & quarter point can be done in the same way by using the influence line for spring and quarter points drawn above in fig.

## **5. Comparison of Stone Masonry Vs Reinforced Concrete Arch Bridges**

### **5.1 Basis of Comparison**

Stone masonry and reinforced concrete are both suitable for the construction of Arch Bridge. Stone Masonry Arch is an older construction. As development progress mankind carried research and developed a new material called Reinforced Concrete to cover shortcoming of stone masonry. It is obvious the two construction Materials have different properties and have their own advantages. The need of comparison is necessary to get a clear understanding and technical knowledge to choose which one is suitable for construction of Arch Bridge

The comparison is based on the materials, structural properties, their aesthetic value and their economy. For instance regarding structural properties, which have been discussed , when the spans are larger and where line of load thrust doesn't coincide with axis of the arch, flexural stresses are exhibited, hence the use of Reinforced concrete is out of question compared with those of stone masonry.

Concerning Aesthetic value it is clear that for bridge over deep valleys arch bridges have no competitors as far as Aesthetics is concerned. Even though both Stone Masonry and Reinforced Concrete Arch Bridge are beautiful, their comparison based on other criteria and situation becomes necessary.

When comparison based on economy is to be considered, economy of the bridge mainly depends on the span of the bridge and Material used.

### **5.2 Cost Analysis and Comparison**

The material usage is compared based on the unit price derived from local market and data obtained from different bodies involved in this area and it include the material cost, labor, equipment and management. The quantity for comparison in each case is taken from design example presented in chapter 4.

**i. For stone Masonry Arch Bridge**

**Table 5.1 Cost analysis for Masonry Arch Bridge**

Sr no	Item description	Unit	Quantities	Rate Eth.Birr	Amount Eth,Birr
1	Special type of stone of barrel with 0.4 to 0.8mwidth including labor, equipment and site management	M <sup>3</sup> /length	101.5	1600	162400
2	Dressed stone including labor, equipment and management	M <sup>3</sup> /length	34.42	1112	38275.0

\*0.3 to 0.5 m thick stones in the arch barrel should be placed in some kind of bond. The length of the stones may vary b/n 0.4 to 0.8m

Cost: 200675Birr

**ii. For RC Arch Bridge**

**Table 5.2 Cost analysis for RC Arch Bridge**

Sr. no	Item description	Unit	Quantities	Rate Eth Birr	Amount Eth.Birr
1	Concrete including form work	M <sup>3</sup> /length	20.41	3800	77558
2	Reinforcement steel bars including placing	Kg/length	980	25	24500
3	Dressed stone including labor, equipment and management	M <sup>3</sup>	190	1112	211280

Cost: 313,338Birr

### **iii. Discussion**

For the above comparison which is based on material labor and equipment cost of the different components indicates that for short span arch bridge the reinforced concrete arch bridge is more expensive than stone masonry.

Especially for long span bridge, for very deep gorges area, for area which is difficult to build bridge and where line of load thrust does not coincide with axis of the arch flexural stresses are exhibited reinforced concrete is advisable. On the other side when we see regarding aesthetic purpose reinforcement concrete Arch bridge is very beautiful, pleasing appearance and graceful best to be chosen for city to make it beautiful and memorable.

### **5.3 Long span Arch Bridges**

A long bridge may be made from a series of Arches for their advantage of aesthetic value, although other more economical structures are there. For instance, if the cost is the same or only slightly higher than other type of bridge to construct over deep valleys, then from aesthetic considerations the arch bridge would be selected.

Most long beautiful ancient arch bridge are constructed from stone masonry but now a day Reinforced Concrete arch bridges are ideal to long span bridges over river valleys with a pleasant appearance.

Masonry arches are generally durable and somewhat resistant to settlement. However, relative to modern alternatives, Reinforced Concrete arch bridge, such bridges are very heavy, requiring extensive foundations for long span arch bridges.

Regarding to economy stone work has become too expensive for long span Stone Masonry Arch Bridges in addition they are also expensive to build wherever labor costs are high, So the use of Reinforced concrete become evident for large span bridges.

## **6. Conclusion and Recommendation**

### **6.1 Conclusion**

Arch bridges in Ethiopia are very dominant. A total of 551 Masonry Arch Bridges and 16 Reinforced Concrete Arch Bridges are exhibited in the Federal State of the Country. Almost all arch bridge is not in good conditions as it has been discussed above.

Many Stone Masonry Arch Bridge constructed in Ethiopia are damaged and need attention as well as concrete arch bridges. Even if bridge inspection and maintenance activity in Ethiopia has only began recently. The study of the conditions of the arch bridge and their comparison is very necessary for their improvement and construction of new arch bridges. This thesis has tried to cover the performance assessments of existing stone masonry arch bridge in line with restoration strategy and design of stone masonry and reinforced concrete arch bridges for selected span and also long span reinforced Arch Bridge. In addition, the condition and the comparison of stone masonry and reinforced concrete arch bridge on the basis of structural, economical and cost comparison has been done. This all helps to increase awareness among professionals and the responsible persons to give attention to the damaged Masonry Arch Bridges in Ethiopia and consider Reinforcement Concrete for construction and replacement of Arch Bridges.

### **6.2 Recommendation**

Existing stone masonry arch and concrete arches need maintenance and replacement damaged stone masonry arch should need maintenance as they were by careful rehabilitation and badly damaged stone masonry arch should need a complete replacement. This thesis tried to see the advantage of reinforced concrete for arch bridge so the replacement of damaged stone masonry arch bridge should be done by reinforcement concrete by keeping its cultural and Architectural heritage. In all this a well equipped, trained engineers are necessary for Arch bridge inspection and inventory for design and construction of new Arch Bridge, for maintenance and replacement.

The Stone Arch Bridge mostly use granite, while for medium sized bridges use of basalt stone, sandstone and limestone has been made. Per the ERA's document [3], Granite can be found in West of Nakemte, Tigray, Southwestern Regions and South of Dodola whereas; Sandstone and

limestone are found abundantly nearly in every region of the country, almost the whole country has the capacity to use stone for construction of masonry Bridges. So these show that by using local materials and labor it is recommended that for small spans Arch Bridges masonry arch bridges are good and durable ,ERA must consider to use locally available stone material for construction of small spans masonry Arch Bridges.

So for all who are responsible for this, professionals, practicing engineers and organizations, should have to give attention for this to bring change and to see damaged free, replaced and constructed beautiful arch bridges in our country.

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## Appendix

### Appendix A.1: Details of Arch Bridges in Ethiopia [ERA]

Bridg Name	Constr. Year	Km From Addis	Bridge Type	Bridge Length	Road Segment
Ayba	1937	686.81	Masonry Arch	16.5	Maychew-Adigudom
Unknown	1940	707.09	Masonry Arch	5	Maychew-Adigudom
Mai Hebot	1940	720.42	Masonry Arch	11.4	Maychew-Adigudom
Unknown	1940	932.79	Masonry Arch	4	Adigrat-Bizet
Unknown	1937	933.54	Masonry Arch	5.6	Adigrat-Bizet
Unknown	1937	934.85	Masonry Arch	4	Adigrat-Bizet
Mai-Maria	1939	939.5	Masonry Arch	9	Bizet - Adiabun
Unknown	1953	613.21	Masonry Arch	5.1	Waja-Maychew
Gereb haya	1953	644.23	Masonry Arch	10	Waja-Maychew
Unknown	1954	655.82	Masonry Arch	5.9	Waja-Maychew
Unknown	1938	1148.78	Masonry Arch	5.85	Tekeze-Boya River
Unknown	1939	1150.44	Masonry Arch	4	Tekeze-Boya River
Unknown	1936	1151.3	Masonry Arch	4.6	Tekeze-Boya River
Fendika	1938	1170.02	Masonry Arch	6.1	Tekeze-Boya River
Unknown	1939	990.2	Masonry Arch	4.6	Shire-Tekeze
Unknown	1940	991.06	Masonry Arch	4	Shire-Tekeze
Unknown	1939	992.72	Masonry Arch	5.85	Shire-Tekeze

MaiTimket	1939	1141.9	Masonry Arch	6.2	Shire-Tekeze
Unknown	1937	1070.3	Masonry Arch	4	Axum-Selekleka
Unknown	1937	1072.63	Masonry Arch	4	Axum-Selekleka
Unknown	1936	1072.63	Masonry Arch	4.1	Axum-Selekleka
Unknown	1940	1072.63	Masonry Arch	4.1	Axum-Selekleka
Unknown	1938	1072.97	Masonry Arch	4	Axum-Selekleka
Unknown	1940	1074.19	Masonry Arch	5.4	Selekleka - Shire
Unknown	1938	1074.68	Masonry Arch	4	Selekleka - Shire
Qulamat	1939	739.86	Masonry Arch	10	Sekota-Agbe
Unknown	1939	827.96	Masonry Arch	4	Sekota-Agbe
Denager	1940	849.92	Masonry Arch	9	Sekota-Agbe
Madjir	1940	858.23	Masonry Arch	9	Sekota-Agbe
Grazeya	1937	860.44	Masonry Arch	9	Sekota-Agbe
Mai-Tsadakalay	1938	1029.87	Masonry Arch	20.4	Adiabun-Mereb
Unknown	1938	1033.98	Masonry Arch	4.4	Adiabun-Mereb
Tsegai-Dembe	1938	1033.74	Masonry Arch	6	Adiabun-Mereb
Legetafo	1938	17.7	Masonry Arch	15	Addis - Aleltu
Dale denbel	1940	21.1	Masonry Arch	5	Addis - Aleltu
Chillalo	1937	22.53	Masonry Arch	10	Addis - Aleltu
Lege wako	1939	24.058	Masonry Arch	8.6	Addis - Aleltu
Legedade	1939	25.053	Masonry Arch	15	Addis - Aleltu
Kulit	1937	28.1	Masonry Arch	5.1	Addis - Aleltu
Sokoru No 1	1937	32.5	Masonry Arch	5	Addis - Aleltu
Lege jilla	1939	39.693	Masonry Arch	14.8	Addis - Aleltu

Beke Tributary	1938	41.642	Masonry Arch	10	Addis - Aleltu
Beke	1940	44.164	Masonry Arch	15	Addis - Aleltu
Dargie	1937	44.4	Masonry Arch	5	Addis - Aleltu
Aba Diro	1938	45.4	Masonry Arch	5.1	Addis - Aleltu
Mikawa	1940	54.451	Masonry Arch	15.1	Addis - Aleltu
Kumte	1938	57.416	Masonry Arch	10	Aleltu - Sembo
Sengabelu	1939	60.117	Masonry Arch	29.8	Aleltu - Sembo
Suke	1939	92.197	Masonry Arch	10	Sembo - DebreBerhan
Koba	1938	98.097	Masonry Arch	10	Sembo - DebreBerhan
Chacha	1938	109.097	Masonry Arch	30	Sembo - DebreBerhan
Unknown	1937	112.6	Masonry Arch	5.7	Sembo - DebreBerhan
Unknown	1938	121	Masonry Arch	5	Sembo - DebreBerhan
Bedessa	1939	126.297	Masonry Arch	30	DebreBerhan - Gudoberet
Yalecha	1938	130.597	Masonry Arch	20	DebreBerhan - Gudoberet
Unknown	1937	131.98	Masonry Arch	5	DebreBerhan - Gudoberet
Unknown	1939	135.81	Masonry Arch	5	DebreBerhan - Gudoberet
Aba Chacha	1939	139.35	Masonry Arch	14.5	DebreBerhan - Gudoberet
Unknown	1936	140.63	Masonry Arch	6	DebreBerhan - Gudoberet
Sheleko	1940	140.95	Masonry Arch	10	DebreBerhan - Gudoberet
Unknown	1938	144.76	Masonry Arch	5	DebreBerhan - Gudoberet
Unknown	1939	145.31	Masonry Arch	5.1	DebreBerhan - Gudoberet
Guna Gunit	1937	146.6	Masonry Arch	51.5	DebreBerhan - Gudoberet
Unknown	1940	147.78	Masonry Arch	5	DebreBerhan - Gudoberet
Unknown	1940	149.37	Masonry Arch	5.2	DebreBerhan - Gudoberet

Bura Tributary	1939	149.524	Masonry Arch	10	DebreBerhan - Gudoberet
Bura	1937	150.6	Masonry Arch	19.5	DebreBerhan - Gudoberet
Werke Tributary	1940	152.238	Masonry Arch	10	DebreBerhan - Gudoberet
Werke Tvibutary	1936	152.338	Masonry Arch	9.9	DebreBerhan - Gudoberet
Bakelo	1938	153.24	Masonry Arch	5	DebreBerhan - Gudoberet
Guna Gunit	1938	153.72	Masonry Arch	5	DebreBerhan - Gudoberet
Gudoberet	1939	155.64	Masonry Arch	5	DebreBerhan - Gudoberet
Boro Ager	1938	155.938	Masonry Arch	37.3	DebreBerhan - Gudoberet
Mush	1937	156.29	Masonry Arch	5	DebreBerhan - Gudoberet
Tosign amba	1940	157.14	Masonry Arch	5	DebreBerhan - Gudoberet
Chebed Bado	1938	159.46	Masonry Arch	9.9	DebreBerhan - Gudoberet
Weyna Abich	1938	161.238	Masonry Arch	21	Gudoberet - DebreSina
Dadish Trib	1939	165.404	Masonry Arch	42.6	Gudoberet - DebreSina
Satria	1939	168.49	Masonry Arch	9.6	Gudoberet - DebreSina
Gib Washa	1940	170.547	Masonry Arch	22	Gudoberet - DebreSina
Kosso	1939	176.28	Masonry Arch	4.6	Gudoberet - DebreSina
Washa No2	1939	180.9	Masonry Arch	19.9	Gudoberet - DebreSina
Washa No2	1938	180.96	Masonry Arch	5	Gudoberet - DebreSina
Guges	1940	182.5	Masonry Arch	18.6	Gudoberet - DebreSina
Guges 2	1939	184.68	Masonry Arch	6	Gudoberet - DebreSina
Unknown	1940	188	Masonry Arch	10	Gudoberet - DebreSina
Fasile amba	1940	189.3	Masonry Arch	5	Gudoberet - DebreSina
Ajmar	1939	215.96	Masonry Arch	10	DebreSina - Robit
Wanza	1939	218.96	Masonry Arch	9.6	DebreSina - Robit

Wefkele	1937	219.28	Masonry Arch	9.5	DebreSina - Robit
Cheneku	1940	220.38	Masonry Arch	9.9	DebreSina - Robit
Ferfer	1940	220.54	Masonry Arch	9.7	DebreSina - Robit
Robit	1940	223.82	Masonry Arch	36	DebreSina - Robit
Balcha	1938	235.825	Masonry Arch	5.1	DebreSina - Robit
Jwuha	1939	237.644	Masonry Arch	21.7	Robit - Ataye
Kodoma	1938	258.02	Masonry Arch	5.7	DebreSina - Robit
Kodoma 2	1939	258.09	Masonry Arch	4.8	DebreSina - Robit
Tusu No1	1940	260.931	Masonry Arch	6	Robit - Ataye
Tusu No.2	1937	261.04	Masonry Arch	24	Robit - Ataye
Unknown	1938	263.14	Masonry Arch	6	DebreSina - Robit
Ruman	1937	263.2	Masonry Arch	32	Robit - Ataye
Unknown	1937	264.35	Masonry Arch	4	Robit - Ataye
Chefie	1936	266.1	Masonry Arch	6	Robit - Ataye
Ataye	1939	269.79	Masonry Arch	18	Robit - Ataye
Legegur	1938	100.15	Masonry Arch	51.65	Chancho - Commando
Silmi	1938	121.6	Masonry Arch	8	Commando - GebreGurach
Mushiraw Gedel	1960	188.2	Masonry Arch	14.5	GebreGurach - AbayRiver
Unknown	1941	11	Masonry Arch	6	Addis - Holeta
Holeta2	1940	40.6	Masonry Arch	10.1	Addis - Holeta
Holeta	1936	40.8	Masonry Arch	10	Addis - Holeta
Berga	1940	62.8	Masonry Arch	14.6	Holeta - Ginchi
Holuko	1940	65.8	Masonry Arch	6.5	Holeta - Ginchi
Aba Debela	1940	66.65	Masonry Arch	7.8	Holeta - Ginchi

Chinkitu1	1940	67.6	Masonry Arch	5.6	Holeta - Ginchi
Chinkitu	1940	71.42	Masonry Arch	8	Holeta - Ginchi
Kella	1939	73.96	Masonry Arch	10	Holeta - Ginchi
Jemjem	1939	77.18	Masonry Arch	8	Holeta - Ginchi
Fekere 3rd	1938	85.06	Masonry Arch	8	Holeta - Ginchi
Aba Semar	1939	88.8	Masonry Arch	8.8	Ginchi - Ambo
Awash	1940	90.2	Masonry Arch	12	Ginchi - Ambo
Boren	1939	103.36	Masonry Arch	8	Ginchi - Ambo
Derebebe	1940	105	Masonry Arch	18	Ginchi - Ambo
Bollo	1938	108.18	Masonry Arch	6	Ginchi - Ambo
Amaroo	1940	110	Masonry Arch	4	Ginchi - Ambo
Dindila	1938	111.3	Masonry Arch	10	Ginchi - Ambo
Solbe	1939	117	Masonry Arch	10	Ginchi - Ambo
Borele	1940	117.92	Masonry Arch	8	Ginchi - Ambo
Huluka	1937	125.08	Masonry Arch	18	Ginchi - Ambo
Teltele	1936	127.4	Masonry Arch	8	Ambo - Gedo
Horra	1940	129.93	Masonry Arch	20	Ambo - Gedo
YahaGuraua	1937	131.4	Masonry Arch	10	Ambo - Gedo
Boji	1938	132	Masonry Arch	12	Ambo - Gedo
Chancho	1940	134.2	Masonry Arch	4.1	Ambo - Gedo
Chole	1938	136.18	Masonry Arch	12.5	Ambo - Gedo
Gudertiqa	1940	136.3	Masonry Arch	4.7	Ambo - Gedo
Guder	1938	137.64	Masonry Arch	40	Ambo - Gedo
Beshi	1940	138.8	Masonry Arch	10	Ambo - Gedo

Gorfomazoria	1938	140.9	Masonry Arch	4	Ambo - Gedo
Dembi	1939	144.3	Masonry Arch	20	Ambo - Gedo
Gorfo	1940	144.4	Masonry Arch	10	Ambo - Gedo
Shanko	1938	146.58	Masonry Arch	10	Ambo - Gedo
Kolab	1940	147.88	Masonry Arch	20	Ambo - Gedo
Chonfa	1940	149.6	Masonry Arch	4	Ambo - Gedo
Aba Erae	1937	150.1	Masonry Arch	4.4	Ambo - Gedo
Tamaye	1941	154.2	Masonry Arch	4	Ambo - Gedo
Aba Fitte	1940	157.95	Masonry Arch	15	Ambo - Gedo
Aba Ararse	1939	158.48	Masonry Arch	6	Ambo - Gedo
Kono	1936	159.06	Masonry Arch	8.6	Ambo - Gedo
Walle	1938	161.3	Masonry Arch	4	Ambo - Gedo
Kille	1939	161.42	Masonry Arch	13	Ambo - Gedo
Meliyu	1939	164.86	Masonry Arch	10	Ambo - Gedo
Kawe	1938	165.84	Masonry Arch	10	Ambo - Gedo
Wosene	1937	166.32	Masonry Arch	7.4	Ambo - Gedo
Meti	1938	166.65	Masonry Arch	11	Ambo - Gedo
Erensa 2nd	1940	170.82	Masonry Arch	10	Ambo - Gedo
Bicha	1939	172.5	Masonry Arch	4	Ambo - Gedo
Waboo	1938	172.9	Masonry Arch	4	Ambo - Gedo
Bitte	1937	173.82	Masonry Arch	6	Ambo - Gedo
Metarba	1939	174.27	Masonry Arch	11	Ambo - Gedo
Lemicho	1938	177.59	Masonry Arch	8	Ambo - Gedo
Doke	1939	179.93	Masonry Arch	8	Ambo - Gedo

Loko	1940	180.84	Masonry Arch	14	Ambo - Gedo
Wolene	1939	148.38	Masonry Arch	8	Ambo - Gedo
Belesa	1939	188.4	Masonry Arch	10	Ambo - Gedo
Gashaba	1940	188.4	Masonry Arch	4	Ambo - Gedo
Sambo	1936	188.75	Masonry Arch	11.6	Ambo - Gedo
Urgaha	1937	189.33	Masonry Arch	36	Ambo - Gedo
Tsebele 1	1940	190.24	Masonry Arch	10	Ambo - Gedo
Tsebele 2	1936	190.39	Masonry Arch	10	Ambo - Gedo
Ebaboye	1940	191.25	Masonry Arch	6	Ambo - Gedo
Metri	1938	191.68	Masonry Arch	10	Ambo - Gedo
Medhane Alem	1939	191.92	Masonry Arch	10	Ambo - Gedo
Aba Woya	1940	192.42	Masonry Arch	10	Ambo - Gedo
Aba Kassa	1938	193.3	Masonry Arch	6	Ambo - Gedo
Gerado	1937	19.646	Masonry Arch	4.2	Addis - Tulubolo
Kecha dimma	1940	20.687	Masonry Arch	6.4	Addis - Tulubolo
Afeder	1937	20.7	Masonry Arch	6	Addis - Tulubolo
Gobye Mazoria	1940	21.347	Masonry Arch	4.8	Addis - Tulubolo
Unknown	1938	22.039	Masonry Arch	4	Addis - Tulubolo
Koshie	1940	22.5	Masonry Arch	8	Addis - Tulubolo
Arbo Deno	1939	23.175	Masonry Arch	5.1	Addis - Tulubolo
Entotehish	1940	26	Masonry Arch	9	Addis - Tulubolo
Dima	1940	27.8	Masonry Arch	10	Addis - Tulubolo
Kora	1939	93.5	Masonry Arch	7	Tulubolo - Weliso
Yebcha	1940	148.2	Masonry Arch	8	Weliso - Welkite

Unknown	1939	176.6	Masonry Arch	4	Welkite - Gibe River
Sertie	1938	178	Masonry Arch	6	Welkite - Gibe River
Gibea Eabare	1939	183.237	Masonry Arch	5.9	Welkite - Gibe River
KULUMSA	1938	157	Masonry Arch	8.2	Iteya - Assela
Unknown	1936	411.8	Masonry Arch	4	Dessie-Kutaber
Argode	1936	419.1	Masonry Arch	4	Dessie-Kutaber
Unknown	1936	419.8	Masonry Arch	4	Dessie-Kutaber
Unknown	1936	419.9	Masonry Arch	4	Dessie-Kutaber
Amayad	1938	665.89	Masonry Arch	8	Ditcheto-Elidar
Melkalemi	1940	666.97	Masonry Arch	5	Ditcheto-Elidar
Ambedom	1939	674.1	Masonry Arch	8	Ditcheto-Elidar
Lumma	1937	681.54	Masonry Arch	6	Ditcheto-Elidar
Unknown	1937	682.18	Masonry Arch	5	Ditcheto-Elidar
Guma	1970	688.987	Masonry Arch	24	Ditcheto-Elidar
Alakel	1940	693.277	Masonry Arch	9	Ditcheto-Elidar
Liadu-1	1940	697.027	Masonry Arch	9	Ditcheto-Elidar
Elideare	1938	712.504	Masonry Arch	17	Elidaar-Manda
Lefeflae-2	1937	722.289	Masonry Arch	9	Elidaar-Manda
Beli-Etu-1	1940	730.8	Masonry Arch	4.9	Elidaar-Manda
Gewaha-1	1937	734.74	Masonry Arch	5.1	Elidaar-Manda
Gewaha-2	1939	735.43	Masonry Arch	15	Elidaar-Manda
Gewaha-5	1937	737.08	Masonry Arch	5	Elidaar-Manda
Sola	1939	739.72	Masonry Arch	20	Elidaar-Manda
Regidneba-1	1937	747.05	Masonry Arch	9	Elidaar-Manda

Su-oulidaba-2	1938	749.55	Masonry Arch	5	Elidaar-Manda
Su-oulidaba-4	1938	751.24	Masonry Arch	5	Elidaar-Manda
Kaylea-2	1939	757.69	Masonry Arch	20	Elidaar-Manda
Kaylea-3	1940	759.11	Masonry Arch	15	Elidaar-Manda
Diweyta	1939	762.94	Masonry Arch	5	Elidaar-Manda
Bododa	1939	790.66	Masonry Arch	5	Manda-Burie
Dog-eyyo	1938	791.6	Masonry Arch	9	Manda-Burie
Hiraygefur-1	1938	794.12	Masonry Arch	9	Manda-Burie
dear Bure	1939	794.88	Masonry Arch	24	Manda-Burie
Hiraygefur-2	1939	795	Masonry Arch	9	Manda-Burie
Unda Absinum	1942	518.566	Masonry Arch	20	Mille-Semera
Mille No1	1940	519.316	Masonry Arch	5	Mille-Semera
Mille No2	1941	520.958	Masonry Arch	5	Mille-Semera
Gedita	1939	524.366	Masonry Arch	8	Mille-Semera
Gudiyatu-1	1942	528.606	Masonry Arch	5	Mille-Semera
Bekel Dear-1	1938	528.096	Masonry Arch	22	Mille-Semera
Bekel Dear-2	1940	528.196	Masonry Arch	8	Mille-Semera
Defura-1	1942	529.826	Masonry Arch	12	Mille-Semera
Defura-2	1940	532.636	Masonry Arch	5	Mille-Semera
Defura-2	1941	532.426	Masonry Arch	22	Mille-Semera
Seraytu	1940	538.526	Masonry Arch	18	Mille-Semera
Gitta	1939	540.796	Masonry Arch	12	Mille-Semera
Alia	1940	542.596	Masonry Arch	20	Mille-Semera
Amestegna	1938	546.519	Masonry Arch	5	Mille-Semera

Dehara	1941	547.679	Masonry Arch	20	Mille-Semera
Arsis No.1	1937	550.219	Masonry Arch	6	Mille-Semera
Arsis No.2	1937	550.629	Masonry Arch	46	Mille-Semera
Mesgid-dar	1940	553.409	Masonry Arch	5	Mille-Semera
Weya neta	1940	570.502	Masonry Arch	18	Mille-Semera
Adedira-3	1942	573.416	Masonry Arch	5	Mille-Semera
Wea	1939	575.712	Masonry Arch	60	Mille-Semera
Kurubmeda	1940	585.77	Masonry Arch	5	Semera-Serdo
Serdo	1940	621.77	Masonry Arch	24	Semera-Serdo
Serdo-2	1942	622.45	Masonry Arch	5	Semera-Serdo
Dere Alie	1940	623.29	Masonry Arch	8	Semera-Serdo
Uper Dichoto	1937	654.678	Masonry Arch	8	Serdo-Hanef
Gunto	1938	282.1	Masonry Arch	6.1	Attaye - Chefa Robit
Kukube	1939	282.97	Masonry Arch	6.1	Attaye - Chefa Robit
Gamilo	1938	292.54	Masonry Arch	5	Attaye - Chefa Robit
Mereray	1940	292.68	Masonry Arch	20	Attaye - Chefa Robit
Jara	1937	298.08	Masonry Arch	12	Attaye - Chefa Robit
Borkena	1937	314.72	Masonry Arch	20.2	Chefa robit - Harbu
Unknown	1938	361.36	Masonry Arch	4	Harbu - Combolcha
Churufti-1	1939	368.7	Masonry Arch	5	Harbu - Combolcha
Churufti-2	1939	368.94	Masonry Arch	5	Harbu - Combolcha
Chefea mesendi-1	1939	371.47	Masonry Arch	5.9	Harbu - Combolcha
Chefeamesendi-2	1939	371.84	Masonry Arch	5.1	Harbu - Combolcha
Unknown	1939	376.8	Masonry Arch	4	Harbu - Combolcha

Galeasa	1954	382.58	Masonry Arch	4.1	Combolcha-Dessie
Hisawwa	1955	383.35	Masonry Arch	5.85	Combolcha-Dessie
Harego-1	1953	388.54	Masonry Arch	4.3	Combolcha-Dessie
Hareso	1954	390.95	Masonry Arch	15	Combolcha-Dessie
Jesso-1	1954	403.52	Masonry Arch	5	Dessie-Haik
Unknown	1955	409.23	Masonry Arch	4	Dessie-Haik
Unknown	1953	419.82	Masonry Arch	4	Dessie-Haik
Kechenea	1953	423.9	Masonry Arch	5	Dessie-Haik
Ketae	1954	427.5	Masonry Arch	15.25	Dessie-Haik
Grar wenz	1955	434.89	Masonry Arch	5	Dessie-Haik
Basso mille	1953	436.21	Masonry Arch	4.3	Dessie-Haik
Berkit	1954	437.74	Masonry Arch	5	Dessie-Haik
Amistginbe	1955	439.08	Masonry Arch	50	Haik- Wuchale
Aba Senkar	1954	442.38	Masonry Arch	4.9	Haik- Wuchale
Aba Yemer No1	1955	443.15	Masonry Arch	5	Haik- Wuchale
Aba Yemer No2	1953	448.31	Masonry Arch	10.1	Haik- Wuchale
Weletie	1954	449.22	Masonry Arch	10	Haik- Wuchale
Ajuha	1955	451.86	Masonry Arch	30	Haik- Wuchale
Wulukue	1953	456.41	Masonry Arch	7	Haik- Wuchale
Unknown	1953	466.32	Masonry Arch	4	Wuchale-Mersa
derek Wuha	1955	476.46	Masonry Arch	9.95	Wuchale-Mersa
Yeba	1955	486.47	Masonry Arch	10	Wuchale-Mersa
Berbisa	1953	488.27	Masonry Arch	10	Wuchale-Mersa
Mersa Wuha	1954	490.93	Masonry Arch	22.5	Mersa - Woldia

Kobbo	1955	492.72	Masonry Arch	4.2	Mersa - Woldia
Awarae	1954	492.45	Masonry Arch	10	Mersa - Woldia
Unknown	1954	495.02	Masonry Arch	4.2	Mersa - Woldia
Mermasa	1954	498.36	Masonry Arch	10	Mersa - Woldia
Unknown	1954	505.42	Masonry Arch	4	Mersa - Woldia
Sirinka	1954	507.62	Masonry Arch	20	Mersa - Woldia
Sembo	1954	510.09	Masonry Arch	6.05	Mersa - Woldia
Tenfath	1954	517.43	Masonry Arch	6	Mersa - Woldia
Shelae	1954	524.41	Masonry Arch	6	Woldia-Robit
Fencha	1954	527.27	Masonry Arch	10	Woldia-Robit
Kelee Feta	1954	528.23	Masonry Arch	7	Woldia-Robit
Shelea-6	1953	529.59	Masonry Arch	5.2	Woldia-Robit
Ala Wuha	1954	535.22	Masonry Arch	89.4	Woldia-Robit
Mekerecha	1953	545.67	Masonry Arch	10	Woldia-Robit
Hamid wuha	1954	547.41	Masonry Arch	13	Woldia-Robit
Weylet	1953	551.78	Masonry Arch	4.8	Woldia-Robit
Unknown	1938	418.88	Masonry Arch	4	Eliwuha-Bati
Lege Shenbeko	1939	420.07	Masonry Arch	5.3	Eliwuha-Bati
Upper Legetemira	1936	420.81	Masonry Arch	6	Eliwuha-Bati
Legetemira	1941	420.97	Masonry Arch	8	Eliwuha-Bati
Legetemira-2	1938	421.02	Masonry Arch	4.5	Eliwuha-Bati
Legetemira-4	1940	421.75	Masonry Arch	5.1	Eliwuha-Bati
Legetemira-5	1941	422.07	Masonry Arch	4.7	Eliwuha-Bati
Lagakemelae	1938	422.21	Masonry Arch	10	Eliwuha-Bati

Laga Messa	1939	422.33	Masonry Arch	8	Eliwuha-Bati
Gora Kemelae	1937	422.95	Masonry Arch	10	Eliwuha-Bati
Gora Kemelea-2	1941	423.05	Masonry Arch	5.9	Eliwuha-Bati
Gora Kemelea-3	1939	423.36	Masonry Arch	5.2	Eliwuha-Bati
Laga Titu	1942	423.53	Masonry Arch	12	Eliwuha-Bati
Odie	1939	424.2	Masonry Arch	22.5	Eliwuha-Bati
Enkisaie	1941	424.95	Masonry Arch	10.1	Eliwuha-Bati
Nasa Kenesa	1938	425.51	Masonry Arch	8	Eliwuha-Bati
Lazadugo	1942	426.04	Masonry Arch	5.9	Eliwuha-Bati
Unknown	1938	426.75	Masonry Arch	5.85	Eliwuha-Bati
Etebewa	1941	427.72	Masonry Arch	12	Eliwuha-Bati
Chachatu	1937	429.32	Masonry Arch	6	Eliwuha-Bati
Simandi	1942	435.94	Masonry Arch	12	Eliwuha-Bati
Unknown	1939	437.295	Masonry Arch	5.9	Eliwuha-Bati
dehan	1940	448.715	Masonry Arch	12	Eliwuha-Bati
Fursa-1	1942	449.26	Masonry Arch	5.9	Eliwuha-Bati
Fursa-3	1941	450.41	Masonry Arch	4.95	Eliwuha-Bati
Fursa-4	1938	451.12	Masonry Arch	4.9	Eliwuha-Bati
Dalifoe	1942	451.765	Masonry Arch	6.1	Eliwuha-Bati
Cobbo-0	1938	452.09	Masonry Arch	5	Eliwuha-Bati
Fursa-5	1941	452.96	Masonry Arch	5.1	Eliwuha-Bati
Holo Holo	1937	452.665	Masonry Arch	6	Eliwuha-Bati
Fursa	1938	452.915	Masonry Arch	23.5	Eliwuha-Bati
Sebutol	1942	453.415	Masonry Arch	8	Eliwuha-Bati

Zingero Gedel	1940	453.765	Masonry Arch	6	Eliwuha-Bati
Adedero	1941	453.965	Masonry Arch	10	Eliwuha-Bati
Dubula	1940	454.565	Masonry Arch	12	Eliwuha-Bati
Unknown	1942	455.23	Masonry Arch	4	Eliwuha-Bati
Unknown	1940	463.09	Masonry Arch	4	Eliwuha-Bati
Unknown	1941	470.303	Masonry Arch	4	Weranso-Eliwuha
Galeha	1940	470.208	Masonry Arch	24	Weranso-Eliwuha
Garduli	1942	479.998	Masonry Arch	24	Weranso-Eliwuha
Unknown	1937	480.988	Masonry Arch	4	Weranso-Eliwuha
Beddena-1	1942	503.902	Masonry Arch	5.05	Mile-Weranso
Hol hol-1	1941	503.817	Masonry Arch	8	Mile-Weranso
Hol hol-2	1939	504.007	Masonry Arch	29.3	Mile-Weranso
Koda-Foyita	1942	506.327	Masonry Arch	7.8	Mile-Weranso
Weranso	1938	506.527	Masonry Arch	37	Mile-Weranso
Meshesha Gilhe	1938	378.95	Masonry Arch	6	Bati-Combolcha
Unknown	1939	380.89	Masonry Arch	4	Bati-Combolcha
Unknown	1939	381.72	Masonry Arch	4	Bati-Combolcha
Shebele	1941	382.81	Masonry Arch	12	Bati-Combolcha
Shebele Megatemia	1938	382.96	Masonry Arch	12	Bati-Combolcha
Unknown	1939	383.32	Masonry Arch	4	Bati-Combolcha
Kurkur	1938	383.5	Masonry Arch	20	Bati-Combolcha
Mayoch	1941	383.94	Masonry Arch	10	Bati-Combolcha
Afeshashe Wuha	1938	384.3	Masonry Arch	8	Bati-Combolcha
Gelana - 1	1939	384.85	Masonry Arch	26.1	Bati-Combolcha

Buni Wuha	1938	385.08	Masonry Arch	12	Bati-Combolcha
Terkeso	1941	386.13	Masonry Arch	10	Bati-Combolcha
Gelana Melka	1939	386.88	Masonry Arch	10.1	Bati-Combolcha
Kerkeso	1942	387.95	Masonry Arch	6	Bati-Combolcha
Unknown	1940	388.27	Masonry Arch	4	Bati-Combolcha
Gelana-2	1941	390.16	Masonry Arch	4.1	Bati-Combolcha
Gelana -2	1937	390.03	Masonry Arch	20	Bati-Combolcha
Sostafe Ginbe	1942	390.21	Masonry Arch	23.5	Bati-Combolcha
Dildilu	1936	390.9	Masonry Arch	25	Bati-Combolcha
Arba Ginbe	1941	391.27	Masonry Arch	10	Bati-Combolcha
Megehora	1937	391.99	Masonry Arch	12	Bati-Combolcha
Tulube	1942	392.04	Masonry Arch	12	Bati-Combolcha
Etecha	1936	395.44	Masonry Arch	15.05	Bati-Combolcha
Wulawulea	1941	397.11	Masonry Arch	5	Bati-Combolcha
Asrahulet ginb	1939	398.35	Masonry Arch	5	Bati-Combolcha
Yelugn-ayl	1942	401.6	Masonry Arch	4.7	Bati-Combolcha
Unknown	1940	402.56	Masonry Arch	4	Bati-Combolcha
Damu	1941	402.96	Masonry Arch	15.2	Bati-Combolcha
Damu-2	1937	403.1	Masonry Arch	4.05	Bati-Combolcha
Unknown	1942	403.36	Masonry Arch	4	Bati-Combolcha
Abay Kosi	1939	403.99	Masonry Arch	12	Bati-Combolcha
Gerba	1941	406	Masonry Arch	8	Bati-Combolcha
Durea-1	1940	408.41	Masonry Arch	5.9	Bati-Combolcha
Burae	1938	408.01	Masonry Arch	10	Bati-Combolcha

Durae	1942	408.31	Masonry Arch	10	Bati-Combolcha
Unknown	1938	409.91	Masonry Arch	4	Bati-Combolcha
Dandegussa	1941	410.44	Masonry Arch	6	Bati-Combolcha
Gobensa-1	1940	411.91	Masonry Arch	5.7	Bati-Combolcha
Ginbe Guda	1942	411.2	Masonry Arch	6	Bati-Combolcha
Wubansa	1937	412.74	Masonry Arch	12	Bati-Combolcha
Kersa	1941	415.28	Masonry Arch	12	Bati-Combolcha
Shelae two	1982	522.43	Masonry Arch	8	Woldia - Dilb
Unknown	1981	531.31	Masonry Arch	4	Woldia - Dilb
Eribrib Wenz	1939	459.03	Masonry Arch	5	Tanta-Wegel Tena
Unknown	1941	264.74	Masonry Arch	5	Dejen-Lumame
Unknown	1940	273.31	Masonry Arch	5	Lumame-D/Markos
Unknown	1941	288.23	Masonry Arch	5	Lumame-D/Markos
Chemaga	1938	293.78	Masonry Arch	19.8	Lumame-D/Markos
Wenguan Wenz	1938	304.94	Masonry Arch	12	Dber Markos-Denbecha
Kulech Wenz	1937	317.05	Masonry Arch	0	Dber Markos-Denbecha
Gedeb Wenz	1937	321.84	Masonry Arch	20	Dber Markos-Denbecha
Densa Wenz	1938	339.69	Masonry Arch	8	Dber Markos-Denbecha
Unknown	1940	348.34	Masonry Arch	5.95	Dber Markos-Denbecha
Unknown	1940	348.55	Masonry Arch	5.95	Denbecha-Bure
Yechereka Wenz	1938	355.34	Masonry Arch	12.8	Denbecha-Bure
Kechem	1937	360.82	Masonry Arch	26.2	Denbecha-Bure
Birr Wuha	1937	364.82	Masonry Arch	66.4	Denbecha-Bure
Adefit	1938	395.95	Masonry Arch	8	Denbecha-Bure

Selala	1937	399.57	Masonry Arch	11.9	Denbecha-Bure
SHEK IBRAHEM	1940	576.7	Masonry Arch	6	Bombas - Jijiga
Unknown No6	1940	585.33	Masonry Arch	6	Bombas - Jijiga
Dimaza	1939	731.994	Masonry Arch	23	AirPort - Gonder
Shinta	1937	736.274	Masonry Arch	10	AirPort - Gonder
Unknown	1937	741.104	Masonry Arch	8	AirPort - Gonder
Keha	1940	741.239	Masonry Arch	15	AirPort - Gonder
Unknown	1960	742.029	Masonry Arch	5	AirPort - Gonder
Unknown	1960	706.12	Masonry Arch	5	Maksegnet - AirPort
Galie	1980	666.3	Masonry Arch	6	Damot- D/Tabor
Asregina	1980	667.55	Masonry Arch	6	Damot- D/Tabor
Goleye 2	1980	686	Masonry Arch	15.2	Damot- D/Tabor
Goleye	1980	686.9	Masonry Arch	15	Damot- D/Tabor
Ay wuha	1980	721.2	Masonry Arch	12	Checheho-Damot
Yiber	1980	630	Masonry Arch	10	D/Tabor- Wereta
Gomer	1980	632.75	Masonry Arch	10	D/Tabor- Wereta
Dildelie	1980	641.8	Masonry Arch	6	D/Tabor- Wereta
Ache	1980	643.4	Masonry Arch	6	D/Tabor- Wereta
Unknown	1936	721.3	Masonry Arch	4.9	Gonder - AmbaGiorgis
Unknown	1938	723.72	Masonry Arch	5.9	Gonder - AmbaGiorgis
Angereb	1939	724.97	Masonry Arch	20	Gonder - AmbaGiorgis
Unknown	1938	726.02	Masonry Arch	5	Gonder - AmbaGiorgis
Unknown	1940	728.08	Masonry Arch	4	Gonder - AmbaGiorgis
Unknown	1936	729.87	Masonry Arch	4	Gonder - AmbaGiorgis

Shembkit	1938	730.73	Masonry Arch	6	Gonder - AmbaGiorgis
Unknown	1939	731.99	Masonry Arch	5	Gonder - AmbaGiorgis
Shina	1940	733.462	Masonry Arch	8	Gonder - AmbaGiorgis
Unknown	1937	735.832	Masonry Arch	4	Gonder - AmbaGiorgis
Unknown	1938	736.022	Masonry Arch	4	Gonder - AmbaGiorgis
Maber	1939	760.295	Masonry Arch	6	Aba giorgis- Debrak
Aywesdie	1938	766.835	Masonry Arch	8	Aba giorgis- Debrak
Temamie	1941	767.165	Masonry Arch	8	Aba giorgis- Debrak
Gallo	1939	786.603	Masonry Arch	18	Aba giorgis- Debrak
Alemwach	1937	792.973	Masonry Arch	20	Aba giorgis- Debrak
Baslios	1941	794.403	Masonry Arch	10	Aba giorgis- Debrak
Unknown	1939	795.973	Masonry Arch	4	Aba giorgis- Debrak
Unknown	1938	800.703	Masonry Arch	4	Aba giorgis- Debrak
Chira	1939	803.193	Masonry Arch	8	Aba giorgis- Debrak
Unknown	1939	806.103	Masonry Arch	4	Aba giorgis- Debrak
Unknown	1938	807.843	Masonry Arch	4	Aba giorgis- Debrak
Unknown	1938	811.293	Masonry Arch	4.5	Aba giorgis- Debrak
Arbatensa	1939	811.703	Masonry Arch	8	Aba giorgis- Debrak
Kega	1941	813.393	Masonry Arch	10	Aba giorgis- Debrak
Assera	1938	817.683	Masonry Arch	20	Aba giorgis- Debrak
Unknown	1940	850.29	Masonry Arch	4	Debark-Dagusit
Unknown	1938	852.66	Masonry Arch	4	Debark-Dagusit
Adagusa	1939	855.7	Masonry Arch	6	Dagusit -Unzo River
Umbre	1940	857.09	Masonry Arch	6	Dagusit -Unzo River

Unknown	1936	859.59	Masonry Arch	4	Debark-Dagusit
Mai Nebra	1938	860.12	Masonry Arch	8	Dagusit -Unzo River
Unknown	1940	885.17	Masonry Arch	4	Dagusit -Unzo River
Unknown	1940	890.406	Masonry Arch	4	Dagusit -Unzo River
Biduet	1939	891.446	Masonry Arch	50	Unzo River - Adi Arkay
Dirma	1937	745.51	Masonry Arch	16	Azezo- Gorgora
Unknown	1940	770.92	Masonry Arch	5	Azezo- Gorgora
SHANKELLA	1937	186.26	Masonry Arch	27	Gibe River -Saja
Unknown	1941	191.47	Masonry Arch	5.1	Gibe River -Saja
Getta	1940	220.9	Masonry Arch	5	Gibe River -Saja
GETA	1938	220.99	Masonry Arch	7	Gibe River -Saja
CHORA	1939	223.66	Masonry Arch	7	Gibe River -Saja
Unta	1939	226.76	Masonry Arch	5	Gibe River -Saja
DOMA	1940	231.47	Masonry Arch	9	Gibe River -Saja
Kojo	1940	242.216	Masonry Arch	8	Saja-Asendabo
Bekere	1939	246.166	Masonry Arch	6	Saja-Asendabo
Simini	1938	247.766	Masonry Arch	15	Saja-Asendabo
Yaerbe	1939	248.56	Masonry Arch	9	Saja-Asendabo
Hora	1939	249.4	Masonry Arch	4	Saja-Asendabo
Kore	1940	256.666	Masonry Arch	6	Saja-Asendabo
Deneba	1938	262.266	Masonry Arch	9	Saja-Asendabo
Deneba Beke	1940	263.666	Masonry Arch	6	Saja-Asendabo
Chilelelo	1938	268.75	Masonry Arch	13	Saja-Asendabo
Gibe	1940	290.3	Masonry Arch	50.6	Assendabo-Jimma

Bulbul	1940	304.8	Masonry Arch	26	Assendabo-Jimma
Kito	1937	339	Masonry Arch	8	Jimma - Belete chaka
Feki	1939	343.72	Masonry Arch	6	Jimma - Belete chaka
Kechema	1940	365.01	Masonry Arch	4	Jimma - Belete chaka
Sedecha	1940	366.44	Masonry Arch	4.1	Jimma - Belete chaka
Gulufa	1938	380.41	Masonry Arch	7	Jimma - Belete chaka
Unknown	1941	196.45	Masonry Arch	4	Gedo - Bako
Leku	1938	197.58	Masonry Arch	10	Gedo - Bako
Gura	1938	198.15	Masonry Arch	6	Gedo - Bako
Unknown	1938	199.89	Masonry Arch	4	Gedo - Bako
Feker - 1	1939	202.53	Masonry Arch	6	Gedo - Bako
Feker - 2	1939	203.89	Masonry Arch	8	Gedo - Bako
Unknown	1940	205.24	Masonry Arch	7	Gedo - Bako
Unknown	1940	209.74	Masonry Arch	5.4	Gedo - Bako
Horba	1938	209.37	Masonry Arch	10	Gedo - Bako
Unknown	1940	210.19	Masonry Arch	5	Gedo - Bako
Filinchir	1939	210.44	Masonry Arch	6	Gedo - Bako
Awaso	1940	212.14	Masonry Arch	6	Gedo - Bako
Unknown	1938	213.3	Masonry Arch	4	Gedo - Bako
Unknown	1938	214.23	Masonry Arch	5.7	Gedo - Bako
Rassa	1940	216.28	Masonry Arch	6	Gedo - Bako
Washemo	1937	217.7	Masonry Arch	6	Gedo - Bako
Bildima	1939	219.41	Masonry Arch	8	Gedo - Bako
Unknown	1939	220.58	Masonry Arch	4	Gedo - Bako

Kerse	1939	222.18	Masonry Arch	10	Gedo - Bako
Ketie	1937	223.57	Masonry Arch	6	Gedo - Bako
Jarra	1938	223.82	Masonry Arch	6	Gedo - Bako
Roha	1938	224.11	Masonry Arch	6	Gedo - Bako
Dessa	1939	225.89	Masonry Arch	6	Gedo - Bako
Obda	1939	226.42	Masonry Arch	6	Gedo - Bako
Udie	1940	227.19	Masonry Arch	6	Gedo - Bako
Gnaro	1940	227.55	Masonry Arch	6	Gedo - Bako
Bechekie	1937	228.35	Masonry Arch	6	Gedo - Bako
Birbirs	1937	228.88	Masonry Arch	6	Gedo - Bako
Meda	1940	233.84	Masonry Arch	8	Gedo - Bako
Dokie	1940	236.96	Masonry Arch	8	Gedo - Bako
Melka Bella	1937	240.78	Masonry Arch	8	Gedo - Bako
Mara	1937	242.84	Masonry Arch	8	Gedo - Bako
Sheboka	1940	245.48	Masonry Arch	8	Gedo - Bako
Hida	1939	245.99	Masonry Arch	8.5	Gedo - Bako
Abuko	1938	248.37	Masonry Arch	8	Gedo - Bako
Unknown	1940	251.55	Masonry Arch	5	Gedo - Bako
Unknown	1937	251.91	Masonry Arch	5	Gedo - Bako
Unknown	1937	254.14	Masonry Arch	5	Gedo - Bako
Antutu	1938	261.59	Masonry Arch	8	Bako - Nekempt
Meki	1937	262.49	Masonry Arch	7	Bako - Nekempt
Dokonu	1937	265.38	Masonry Arch	7	Bako - Nekempt
Chobii	1938	267.51	Masonry Arch	7	Bako - Nekempt

Akabo	1938	269.59	Masonry Arch	7	Bako - Nekempt
Kela	1939	271.52	Masonry Arch	7	Bako - Nekempt
Chekorssa	1939	272.12	Masonry Arch	8.5	Bako - Nekempt
Feker	1939	273.23	Masonry Arch	7	Bako - Nekempt
Unknown	1938	274.86	Masonry Arch	5	Bako - Nekempt
Kemisie	1940	274.07	Masonry Arch	7	Bako - Nekempt
Unknown	1938	275.27	Masonry Arch	5	Bako - Nekempt
Chalte	1940	275.51	Masonry Arch	7	Bako - Nekempt
Gewisso	1939	276.93	Masonry Arch	10	Bako - Nekempt
Unknown	1937	277.4	Masonry Arch	4.2	Bako - Nekempt
Chorie	1937	277.89	Masonry Arch	7	Bako - Nekempt
Leku	1940	279.69	Masonry Arch	10	Bako - Nekempt
Gindo	1937	281.26	Masonry Arch	7	Bako - Nekempt
Aba Mukel	1940	283.31	Masonry Arch	10	Bako - Nekempt
Supie	1953	299.23	Masonry Arch	7	Bako - Nekempt
Mechara	1953	300.67	Masonry Arch	10	Bako - Nekempt
Ekamssa	1953	303.27	Masonry Arch	10	Bako - Nekempt
Ashkole	1937	308.27	Masonry Arch	10	Bako - Nekempt
Gulisso	1937	308.42	Masonry Arch	10	Bako - Nekempt
Unknown	1938	311.35	Masonry Arch	4.6	Bako - Nekempt
Unknown	1939	312.46	Masonry Arch	5	Bako - Nekempt
Hurri	1938	314.4	Masonry Arch	10	Bako - Nekempt
Unknown	1939	316.53	Masonry Arch	14.1	Bako - Nekempt
Chorie	1938	324.26	Masonry Arch	10	Bako - Nekempt

Adiya	1939	325.4	Masonry Arch	10	Bako - Nekempt
Dawe	1937	512.94	Masonry Arch	6	Adele - Girawa
Dosha	1974	431.6	Masonry Arch	4.1	Asella - Bekoji
Digessa	1938	346.2	Masonry Arch	9	Wondo - Dilla
Unknown	1939	595.9	Masonry Arch	4	Negele - AwreGebeya
Unknown	1940	625.88	Masonry Arch	5	Filtu - AwreGebeya

Boya	1941	1203.49	RC Arch	26	Tekeze-Boya River
Rebu	1938	146	RC Arch	19.5	Weliso - Welkite
Awash	1963	49.3	RC Arch	91.96	Alemgena - Lemen
Ginbora	1981	539.11	RC Arch	26	Woldia - Dilb
Kurakura	1980	540.92	RC Arch	24.9	Woldia - Dilb
Beket	1945	246.25	RC Arch	30	Dejen-Lumame
Aba Adem	1945	254.02	RC Arch	12	Dejen-Lumame
Lah Wenz	1945	380.54	RC Arch	23.9	Denbecha-Bure
Arera Wenz	1945	382.73	RC Arch	11.9	Denbecha-Bure
BOMBAS	1940	569.56	RC Arch	42	Bombas - Jijiga
Kentie	1980	671.45	RC Arch	15	Damot- D/Tabor
Rib	1980	672.75	RC Arch	33	Damot- D/Tabor

Meher	1980	678.55	RC Arch	15	Damot- D/Tabor
Zarima	1941	858.63	RC Arch	50	Dagusit -Unzo River
Ensita	1938	891.096	RC Arch	75	Unzo River - Adi Arkay
Jama	1937	902.626	RC Arch	21	Adi Arkay- Buya River
Abay No 6	2008	213	RC Arch main	204.45	Abay River - Degen
Wabeshebele	1936	1418	RC Arch main	42	Kelafo - Mustahil

## Appendix A.2: Arch bridges in Ethiopia with inspection damages percentage [ERA]

Bridge Name	Constr. Year	Km From Addis	Bridge Type	Bridge Length	Inspection Dmg %
Ayba	1937	686.81	Masonry Arch	16.5	0.66
Unknown	1940	707.09	Masonry Arch	5	0.66
Mai Hebot	1940	720.42	Masonry Arch	11.4	2.01
Unknown	1940	932.79	Masonry Arch	4	0.66
Unknown	1937	933.54	Masonry Arch	5.6	0.66
Unknown	1937	934.85	Masonry Arch	4	0.66
Mai-Maria	1939	939.5	Masonry Arch	9	6.66
Unknown	1953	613.21	Masonry Arch	5.1	0.66
Gereb haya	1953	644.23	Masonry Arch	10	3.96
Unknown	1954	655.82	Masonry Arch	5.9	0.66
Unknown	1938	1148.78	Masonry Arch	5.85	0.66
Unknown	1939	1150.44	Masonry Arch	4	0.66
Unknown	1936	1151.3	Masonry Arch	4.6	0.66
Fendika	1938	1170.02	Masonry Arch	6.1	2.01
Unknown	1939	990.2	Masonry Arch	4.6	0.66
Unknown	1940	991.06	Masonry Arch	4	0.66
Unknown	1939	992.72	Masonry Arch	5.85	0.66
MaiTimket	1939	1141.9	Masonry Arch	6.2	4.65
Unknown	1937	1070.3	Masonry Arch	4	0.66
Unknown	1937	1072.63	Masonry Arch	4	0.66
Unknown	1936	1072.63	Masonry Arch	4.1	0.66

Unknown	1940	1072.63	Masonry Arch	4.1	0.66
Unknown	1938	1072.97	Masonry Arch	4	0.66
Unknown	1940	1074.19	Masonry Arch	5.4	0.66
Unknown	1938	1074.68	Masonry Arch	4	0.66
Qulamat	1939	739.86	Masonry Arch	10	0.99
Unknown	1939	827.96	Masonry Arch	4	0.66
Denager	1940	849.92	Masonry Arch	9	0.53
Madjir	1940	858.23	Masonry Arch	9	2.64
Grazeya	1937	860.44	Masonry Arch	9	4.95
Mai-Tsadakalay	1938	1029.87	Masonry Arch	20.4	8.04
Unknown	1938	1033.98	Masonry Arch	4.4	0.66
Tsegai-Dembe	1938	1033.74	Masonry Arch	6	2.01
Legetafo	1938	17.7	Masonry Arch	15	25.44
Dale denbel	1940	21.1	Masonry Arch	5	0.66
Chillalo	1937	22.53	Masonry Arch	10	18.47
Lege wako	1939	24.058	Masonry Arch	8.6	16
Legedade	1939	25.053	Masonry Arch	15	14.7
Kulit	1937	28.1	Masonry Arch	5.1	0.66
Sokoru No 1	1937	32.5	Masonry Arch	5	0.66
Lege jilla	1939	39.693	Masonry Arch	14.8	25.25
Beke Tributary	1938	41.642	Masonry Arch	10	21.78
Beke	1940	44.164	Masonry Arch	15	10.22
Dargie	1937	44.4	Masonry Arch	5	0.66
Aba Diro	1938	45.4	Masonry Arch	5.1	0.66
Mikawa	1940	54.451	Masonry Arch	15.1	18.78
Kumte	1938	57.416	Masonry Arch	10	4.23
Sengabelu	1939	60.117	Masonry Arch	29.8	21.61
Suke	1939	92.197	Masonry Arch	10	24.75
Koba	1938	98.097	Masonry Arch	10	20
Chacha	1938	109.097	Masonry Arch	30	8.89
Unknown	1937	112.6	Masonry Arch	5.7	0.66
Unknown	1938	121	Masonry Arch	5	0.66
Bedessa	1939	126.297	Masonry Arch	30	14.7
Yalecha	1938	130.597	Masonry Arch	20	24.12
Unknown	1937	131.98	Masonry Arch	5	0.66
Unknown	1939	135.81	Masonry Arch	5	0.66
Aba Chacha	1939	139.35	Masonry Arch	14.5	21.11
Unknown	1936	140.63	Masonry Arch	6	0.66
Sheleko	1940	140.95	Masonry Arch	10	9.33

Unknown	1938	144.76	Masonry Arch	5	0.66
Unknown	1939	145.31	Masonry Arch	5.1	0.66
Guna Gunit	1937	146.6	Masonry Arch	51.5	9.56
Unknown	1940	147.78	Masonry Arch	5	0.66
Unknown	1940	149.37	Masonry Arch	5.2	0.66
Bura Tributary	1939	149.524	Masonry Arch	10	10
Bura	1937	150.6	Masonry Arch	19.5	8
Werke					
Tributary	1940	152.238	Masonry Arch	10	10.22
Werke					
Tvibutary	1936	152.338	Masonry Arch	9.9	11.78
Bakelo	1938	153.24	Masonry Arch	5	0.66
Guna Gunit	1938	153.72	Masonry Arch	5	0.66
Gudoberet	1939	155.64	Masonry Arch	5	0.66
Boro Ager	1938	155.938	Masonry Arch	37.3	10.22
Mush	1937	156.29	Masonry Arch	5	0.66
Tosign amba	1940	157.14	Masonry Arch	5	0.66
Chebed Bado	1938	159.46	Masonry Arch	9.9	8.89
Weyna Abich	1938	161.238	Masonry Arch	21	14.27
Dadish Trib	1939	165.404	Masonry Arch	42.6	15.11
Satria	1939	168.49	Masonry Arch	9.6	19.6
Gib Washa	1940	170.547	Masonry Arch	22	10.63
Kosso	1939	176.28	Masonry Arch	4.6	0.66
Washa No2	1939	180.9	Masonry Arch	19.9	7.33
Washa No2	1938	180.96	Masonry Arch	5	0.66
Guges	1940	182.5	Masonry Arch	18.6	6
Guges 2	1939	184.68	Masonry Arch	6	0.66
Unknown	1940	188	Masonry Arch	10	0.22
Fasile amba	1940	189.3	Masonry Arch	5	0.66
Ajmar	1939	215.96	Masonry Arch	10	0.22
Wanza	1939	218.96	Masonry Arch	9.6	0.22
Wefkele	1937	219.28	Masonry Arch	9.5	0.22
Cheneku	1940	220.38	Masonry Arch	9.9	45.23
Ferfer	1940	220.54	Masonry Arch	9.7	0.22
Robit	1940	223.82	Masonry Arch	36	14.66
Balcha	1938	235.825	Masonry Arch	5.1	0.66
Jwuha	1939	237.644	Masonry Arch	21.7	8.89
Kodoma	1938	258.02	Masonry Arch	5.7	0.66
Kodoma 2	1939	258.09	Masonry Arch	4.8	0.66

Tusu No1	1940	260.931	Masonry Arch	6	8.89
Tusu No.2	1937	261.04	Masonry Arch	24	8.04
Unknown	1938	263.14	Masonry Arch	6	0.66
Ruman	1937	263.2	Masonry Arch	32	8
Unknown	1937	264.35	Masonry Arch	4	0.66
Chefie	1936	266.1	Masonry Arch	6	8.89
Ataye	1939	269.79	Masonry Arch	18	14.07
Legegur	1938	100.15	Masonry Arch	51.65	17.09
Silmi	1938	121.6	Masonry Arch	8	11.78
Mushiraw					
Gedel	1960	188.2	Masonry Arch	14.5	5.78
Unknown	1941	11	Masonry Arch	6	0.66
Holeta2	1940	40.6	Masonry Arch	10.1	0.66
Holeta	1936	40.8	Masonry Arch	10	6.22
Berga	1940	62.8	Masonry Arch	14.6	15.45
Holuko	1940	65.8	Masonry Arch	6.5	7.29
Aba Debela	1940	66.65	Masonry Arch	7.8	8.42
Chinkitu1	1940	67.6	Masonry Arch	5.6	0.66
Chinkitu	1940	71.42	Masonry Arch	8	8.92
Kella	1939	73.96	Masonry Arch	10	9.05
Jemjem	1939	77.18	Masonry Arch	8	9.55
Fekere 3rd	1938	85.06	Masonry Arch	8	10
Aba Semar	1939	88.8	Masonry Arch	8.8	2.97
Awash	1940	90.2	Masonry Arch	12	8.89
Boren	1939	103.36	Masonry Arch	8	0.67
Derebebe	1940	105	Masonry Arch	18	5.78
Bollo	1938	108.18	Masonry Arch	6	7.79
Amaroo	1940	110	Masonry Arch	4	0.66
Dindila	1938	111.3	Masonry Arch	10	19.6
Solbe	1939	117	Masonry Arch	10	8.22
Borele	1940	117.92	Masonry Arch	8	8.22
Huluka	1937	125.08	Masonry Arch	18	6.41
Teltele	1936	127.4	Masonry Arch	8	13.89
Horra	1940	129.93	Masonry Arch	20	9.55
YahaGuraua	1937	131.4	Masonry Arch	10	9.55
Boji	1938	132	Masonry Arch	12	9.55
Chancho	1940	134.2	Masonry Arch	4.1	0.66
Chole	1938	136.18	Masonry Arch	12.5	5.15
Gudertiqa	1940	136.3	Masonry Arch	4.7	0.66

Guder	1938	137.64	Masonry Arch	40	9.55
Beshi	1940	138.8	Masonry Arch	10	18.72
Gorfomazoria	1938	140.9	Masonry Arch	4	0.66
Dembi	1939	144.3	Masonry Arch	20	9.55
Gorfo	1940	144.4	Masonry Arch	10	19.6
Shanko	1938	146.58	Masonry Arch	10	10
Kolab	1940	147.88	Masonry Arch	20	7.29
Chonfa	1940	149.6	Masonry Arch	4	0.66
Aba Erae	1937	150.1	Masonry Arch	4.4	0.66
Tamaye	1941	154.2	Masonry Arch	4	0.66
Aba Fitte	1940	157.95	Masonry Arch	15	5.78
Aba Ararse	1939	158.48	Masonry Arch	6	10.43
Kono	1936	159.06	Masonry Arch	8.6	19.6
Walle	1938	161.3	Masonry Arch	4	0.66
Kille	1939	161.42	Masonry Arch	13	19.6
Meliyu	1939	164.86	Masonry Arch	10	18.97
Kawe	1938	165.84	Masonry Arch	10	8.89
Wosene	1937	166.32	Masonry Arch	7.4	9.55
Meti	1938	166.65	Masonry Arch	11	19.6
Erensa 2nd	1940	170.82	Masonry Arch	10	9.55
Bicha	1939	172.5	Masonry Arch	4	0.66
Waboo	1938	172.9	Masonry Arch	4	0.66
Bitte	1937	173.82	Masonry Arch	6	9.55
Metarba	1939	174.27	Masonry Arch	11	9.55
Lemicho	1938	177.59	Masonry Arch	8	9.55
Doke	1939	179.93	Masonry Arch	8	9.55
Loko	1940	180.84	Masonry Arch	14	9.55
Wolene	1939	148.38	Masonry Arch	8	9.55
Belesa	1939	188.4	Masonry Arch	10	19.6
Gashaba	1940	188.4	Masonry Arch	4	0.66
Sambo	1936	188.75	Masonry Arch	11.6	11.67
Urgaha	1937	189.33	Masonry Arch	36	13.33
Tsebele 1	1940	190.24	Masonry Arch	10	7.29
Tsebele 2	1936	190.39	Masonry Arch	10	17.34
Ebaboye	1940	191.25	Masonry Arch	6	7.29
Metri	1938	191.68	Masonry Arch	10	11.31
Medhane Alem	1939	191.92	Masonry Arch	10	7.29
Aba Woya	1940	192.42	Masonry Arch	10	7.29
Aba Kassa	1938	193.3	Masonry Arch	6	0.66

Gerado	1937	19.646	Masonry Arch	4.2	0.66
Kecha dimma	1940	20.687	Masonry Arch	6.4	0.66
Afeder	1937	20.7	Masonry Arch	6	14.07
Gobye Mazoria	1940	21.347	Masonry Arch	4.8	0.66
Unknown	1938	22.039	Masonry Arch	4	0.66
Koshie	1940	22.5	Masonry Arch	8	5.42
Arbo Deno	1939	23.175	Masonry Arch	5.1	0.66
Entotehish	1940	26	Masonry Arch	9	6.21
Dima	1940	27.8	Masonry Arch	10	5.42
Kora	1939	93.5	Masonry Arch	7	7.91
Yebcha	1940	148.2	Masonry Arch	8	5.42
Unknown	1939	176.6	Masonry Arch	4	0.66
Sertie	1938	178	Masonry Arch	6	9.8
Gibea Eabare	1939	183.237	Masonry Arch	5.9	0.66
KULUMSA	1938	157	Masonry Arch	8.2	15.83
Unknown	1936	411.8	Masonry Arch	4	0.89
Argode	1936	419.1	Masonry Arch	4	0.89
Unknown	1936	419.8	Masonry Arch	4	0.89
Unknown	1936	419.9	Masonry Arch	4	0.89
Amayad	1938	665.89	Masonry Arch	8	9.42
Melkalemi	1940	666.97	Masonry Arch	5	0.66
Ambedom	1939	674.1	Masonry Arch	8	24.62
Lumma	1937	681.54	Masonry Arch	6	0.66
Unknown	1937	682.18	Masonry Arch	5	0.66
Guma	1970	688.987	Masonry Arch	24	8.29
Alakel	1940	693.277	Masonry Arch	9	0.66
Liadu-1	1940	697.027	Masonry Arch	9	0.66
Elideare	1938	712.504	Masonry Arch	17	12.22
Lefeflae-2	1937	722.289	Masonry Arch	9	0.66
Beli-Etu-1	1940	730.8	Masonry Arch	4.9	0.66
Gewaha-1	1937	734.74	Masonry Arch	5.1	0.66
Gewaha-2	1939	735.43	Masonry Arch	15	0.66
Gewaha-5	1937	737.08	Masonry Arch	5	0.66
Sola	1939	739.72	Masonry Arch	20	8.67
Regidneba-1	1937	747.05	Masonry Arch	9	0.66
Su-oulidaba-2	1938	749.55	Masonry Arch	5	0.66
Su-oulidaba-4	1938	751.24	Masonry Arch	5	0.66
Kaylea-2	1939	757.69	Masonry Arch	20	0.66
Kaylea-3	1940	759.11	Masonry Arch	15	0.66

Diweyta	1939	762.94	Masonry Arch	5	0.66
Bododa	1939	790.66	Masonry Arch	5	0.66
Dog-eyyo	1938	791.6	Masonry Arch	9	0.66
Hiraygefur-1	1938	794.12	Masonry Arch	9	0.66
dear Bure	1939	794.88	Masonry Arch	24	32.67
Hiraygefur-2	1939	795	Masonry Arch	9	0.66
Unda Absinum	1942	518.566	Masonry Arch	20	3.39
Mille No1	1940	519.316	Masonry Arch	5	0.66
Mille No2	1941	520.958	Masonry Arch	5	0.66
Gedita	1939	524.366	Masonry Arch	8	21.48
Gudiyatu-1	1942	528.606	Masonry Arch	5	0.66
Bekel Dear-1	1938	528.096	Masonry Arch	22	18.84
Bekel Dear-2	1940	528.196	Masonry Arch	8	9.42
Defura-1	1942	529.826	Masonry Arch	12	8.67
Defura-2	1940	532.636	Masonry Arch	5	0.66
Defura-2	1941	532.426	Masonry Arch	22	3.39
Seraytu	1940	538.526	Masonry Arch	18	20.1
Gitta	1939	540.796	Masonry Arch	12	20.1
Alia	1940	542.596	Masonry Arch	20	8.67
Amestegna	1938	546.519	Masonry Arch	5	0.66
Dehara	1941	547.679	Masonry Arch	20	18.09
Arsis No.1	1937	550.219	Masonry Arch	6	21.98
Arsis No.2	1937	550.629	Masonry Arch	46	6.71
Mesgid-dar	1940	553.409	Masonry Arch	5	0.66
Weya neta	1940	570.502	Masonry Arch	18	9.42
Adedira-3	1942	573.416	Masonry Arch	5	0.66
Wea	1939	575.712	Masonry Arch	60	18.72
Kurubmeda	1940	585.77	Masonry Arch	5	0.66
Serdo	1940	621.77	Masonry Arch	24	22.99
Serdo-2	1942	622.45	Masonry Arch	5	0.66
Dere Alie	1940	623.29	Masonry Arch	8	18.84
Uper Dichoto	1937	654.678	Masonry Arch	8	20.73
Gunto	1938	282.1	Masonry Arch	6.1	14.2
Kukube	1939	282.97	Masonry Arch	6.1	0.56
Gamilo	1938	292.54	Masonry Arch	5	15.83
Mereray	1940	292.68	Masonry Arch	20	4.4
Jara	1937	298.08	Masonry Arch	12	2.01
Borkena	1937	314.72	Masonry Arch	20.2	11.62
Unknown	1938	361.36	Masonry Arch	4	0.66

Churufti-1	1939	368.7	Masonry Arch	5	0.66
Churufti-2	1939	368.94	Masonry Arch	5	0.66
Chefea mesendi-	1939	371.47	Masonry Arch	5.9	0.66
Chefeamesendi- 2	1939	371.84	Masonry Arch	5.1	0.66
Unknown	1939	376.8	Masonry Arch	4	0.66
Galeasa	1954	382.58	Masonry Arch	4.1	0.66
Hisawwa	1955	383.35	Masonry Arch	5.85	0.66
Harego-1	1953	388.54	Masonry Arch	4.3	0.66
Hareso	1954	390.95	Masonry Arch	15	2.01
Jesso-1	1954	403.52	Masonry Arch	5	0.66
Unknown	1955	409.23	Masonry Arch	4	0.66
Unknown	1953	419.82	Masonry Arch	4	0.66
Kechenea	1953	423.9	Masonry Arch	5	0.66
Ketae	1954	427.5	Masonry Arch	15.25	20.73
Grar wenz	1955	434.89	Masonry Arch	5	0.66
Basso mille	1953	436.21	Masonry Arch	4.3	0.66
Berkit	1954	437.74	Masonry Arch	5	0.66
Amistginbe	1955	439.08	Masonry Arch	50	9.42
Aba Senkar	1954	442.38	Masonry Arch	4.9	0.66
Aba Yemer No1	1955	443.15	Masonry Arch	5	0.66
Aba Yemer No2	1953	448.31	Masonry Arch	10.1	9.45
Weletie	1954	449.22	Masonry Arch	10	12.06
Ajuha	1955	451.86	Masonry Arch	30	10.11
Wulukue	1953	456.41	Masonry Arch	7	3.96
Unknown	1953	466.32	Masonry Arch	4	0.66
derek Wuha	1955	476.46	Masonry Arch	9.95	6.08
Yeba	1955	486.47	Masonry Arch	10	8.29
Berbisa	1953	488.27	Masonry Arch	10	4.95
Mersa Wuha	1954	490.93	Masonry Arch	22.5	6.53
Kobbo	1955	492.72	Masonry Arch	4.2	0.66
Awarae	1954	492.45	Masonry Arch	10	3.1
Unknown	1954	495.02	Masonry Arch	4.2	0.66
Mermasa	1954	498.36	Masonry Arch	10	4.62
Unknown	1954	505.42	Masonry Arch	4	0.66
Sirinka	1954	507.62	Masonry Arch	20	5.65

Sembo	1954	510.09	Masonry Arch	6.05	7.53
Tenfath	1954	517.43	Masonry Arch	6	7.4
Shelae	1954	524.41	Masonry Arch	6	9.92
Fencha	1954	527.27	Masonry Arch	10	14.32
Kelee Feta	1954	528.23	Masonry Arch	7	6.56
Shelea-6	1953	529.59	Masonry Arch	5.2	0.66
Ala Wuha	1954	535.22	Masonry Arch	89.4	10.55
Mekerecha	1953	545.67	Masonry Arch	10	3.44
Hamid wuha	1954	547.41	Masonry Arch	13	2.01
Weylet	1953	551.78	Masonry Arch	4.8	1.88
Unknown	1938	418.88	Masonry Arch	4	0.66
Lege Shenbeko	1939	420.07	Masonry Arch	5.3	0.66
Upper					
Legetemira	1936	420.81	Masonry Arch	6	13.57
Legetemira	1941	420.97	Masonry Arch	8	8.79
Legetemira-2	1938	421.02	Masonry Arch	4.5	0.66
Legetemira-4	1940	421.75	Masonry Arch	5.1	0.66
Legetemira-5	1941	422.07	Masonry Arch	4.7	0.66
Lagakemelae	1938	422.21	Masonry Arch	10	6.54
Laga Messa	1939	422.33	Masonry Arch	8	21.48
Gora Kemelae	1937	422.95	Masonry Arch	10	21.36
Gora Kemelea-2	1941	423.05	Masonry Arch	5.9	0.66
Gora Kemelea-3	1939	423.36	Masonry Arch	5.2	0.66
Laga Titu	1942	423.53	Masonry Arch	12	22.11
Odie	1939	424.2	Masonry Arch	22.5	3.3
Enkisaie	1941	424.95	Masonry Arch	10.1	10.11
Nasa Kenesa	1938	425.51	Masonry Arch	8	6.34
Lazadugo	1942	426.04	Masonry Arch	5.9	0.66
Unknown	1938	426.75	Masonry Arch	5.85	0.66
Etebewa	1941	427.72	Masonry Arch	12	14.7
Chachatu	1937	429.32	Masonry Arch	6	1.52
Simandi	1942	435.94	Masonry Arch	12	17.71
Unknown	1939	437.295	Masonry Arch	5.9	0.66
dehan	1940	448.715	Masonry Arch	12	20.85
Fursa-1	1942	449.26	Masonry Arch	5.9	0.66
Fursa-3	1941	450.41	Masonry Arch	4.95	0.66
Fursa-4	1938	451.12	Masonry Arch	4.9	0.66

Dalifoe	1942	451.765	Masonry Arch	6.1	6.34
Cobbo-0	1938	452.09	Masonry Arch	5	0.66
Fursa-5	1941	452.96	Masonry Arch	5.1	0.66
Holo Holo	1937	452.665	Masonry Arch	6	8.04
Fursa	1938	452.915	Masonry Arch	23.5	5.48
Sebutol	1942	453.415	Masonry Arch	8	3.96
Zingero Gedel	1940	453.765	Masonry Arch	6	3.64
Adedero	1941	453.965	Masonry Arch	10	14.7
Dubula	1940	454.565	Masonry Arch	12	3.83
Unknown	1942	455.23	Masonry Arch	4	0.66
Unknown	1940	463.09	Masonry Arch	4	0.66
Unknown	1941	470.303	Masonry Arch	4	0.66
Galeha	1940	470.208	Masonry Arch	24	29.56
Garduli	1942	479.998	Masonry Arch	24	26.01
Unknown	1937	480.988	Masonry Arch	4	0.66
Beddena-1	1942	503.902	Masonry Arch	5.05	0.66
Hol hol-1	1941	503.817	Masonry Arch	8	6.53
Hol hol-2	1939	504.007	Masonry Arch	29.3	26.38
Koda-Foyita	1942	506.327	Masonry Arch	7.8	22.24
Weranso	1938	506.527	Masonry Arch	37	32.79
Meshesha Gilhe	1938	378.95	Masonry Arch	6	6.66
Unknown	1939	380.89	Masonry Arch	4	0.66
Unknown	1939	381.72	Masonry Arch	4	0.66
Shebele	1941	382.81	Masonry Arch	12	2.01
Shebele					
Megatemia	1938	382.96	Masonry Arch	12	0.11
Unknown	1939	383.32	Masonry Arch	4	0.66
Kurkur	1938	383.5	Masonry Arch	20	8.19
Mayoch	1941	383.94	Masonry Arch	10	1.72
Afeshashe					
Wuha	1938	384.3	Masonry Arch	8	2.64
Gelana - 1	1939	384.85	Masonry Arch	26.1	2.77
Buni Wuha	1938	385.08	Masonry Arch	12	20.73
Terkeso	1941	386.13	Masonry Arch	10	2.64
Gelana Melka	1939	386.88	Masonry Arch	10.1	10.67
Kerkeso	1942	387.95	Masonry Arch	6	3.96
Unknown	1940	388.27	Masonry Arch	4	0.66
Gelana-2	1941	390.16	Masonry Arch	4.1	0.66
Gelana -2	1937	390.03	Masonry Arch	20	14.95

Sostafe Ginbe	1942	390.21	Masonry Arch	23.5	12.44
Dildilu	1936	390.9	Masonry Arch	25	2.64
Arba Ginbe	1941	391.27	Masonry Arch	10	7.29
Megehora	1937	391.99	Masonry Arch	12	10.18
Tulube	1942	392.04	Masonry Arch	12	7.41
Etecha	1936	395.44	Masonry Arch	15.05	20.1
Wulawulea	1941	397.11	Masonry Arch	5	0.66
Asrahulet ginb	1939	398.35	Masonry Arch	5	0.66
Yelugn-ayl	1942	401.6	Masonry Arch	4.7	0.66
Unknown	1940	402.56	Masonry Arch	4	0.66
Damu	1941	402.96	Masonry Arch	15.2	14.82
Damu-2	1937	403.1	Masonry Arch	4.05	0.66
Unknown	1942	403.36	Masonry Arch	4	0.66
Abay Kosi	1939	403.99	Masonry Arch	12	9.42
Gerba	1941	406	Masonry Arch	8	11.56
Durea-1	1940	408.41	Masonry Arch	5.9	0.66
Burae	1938	408.01	Masonry Arch	10	2.64
Durae	1942	408.31	Masonry Arch	10	5.15
Unknown	1938	409.91	Masonry Arch	4	0.66
Dandegussa	1941	410.44	Masonry Arch	6	7.13
Gobensa-1	1940	411.91	Masonry Arch	5.7	0.66
Ginbe Guda	1942	411.2	Masonry Arch	6	6.34
Wubansa	1937	412.74	Masonry Arch	12	4.9
Kersa	1941	415.28	Masonry Arch	12	7.33
Shelae two	1982	522.43	Masonry Arch	8	11.49
Unknown	1981	531.31	Masonry Arch	4	0.66
Eribrib Wenz	1939	459.03	Masonry Arch	5	0.66
Unknown	1941	264.74	Masonry Arch	5	0.66
Unknown	1940	273.31	Masonry Arch	5	0.66
Unknown	1941	288.23	Masonry Arch	5	0.66
Chemaga	1938	293.78	Masonry Arch	19.8	0.86
Wenguan Wenz	1938	304.94	Masonry Arch	12	2.01
Kulech Wenz	1937	317.05	Masonry Arch	0	4.52
Gedeb Wenz	1937	321.84	Masonry Arch	20	2.64
Densa Wenz	1938	339.69	Masonry Arch	8	0.63
Unknown	1940	348.34	Masonry Arch	5.95	0.66
Unknown	1940	348.55	Masonry Arch	5.95	0.66
Yechereka					
Wenz	1938	355.34	Masonry Arch	12.8	6.66

Kechem	1937	360.82	Masonry Arch	26.2	1.26
Birr Wuha	1937	364.82	Masonry Arch	66.4	0.63
Adefit	1938	395.95	Masonry Arch	8	0.63
Selala	1937	399.57	Masonry Arch	11.9	2.64
SHEK					
IBRAHEM	1940	576.7	Masonry Arch	6	5.11
Unknown No6	1940	585.33	Masonry Arch	6	5.78
Dimaza	1939	731.994	Masonry Arch	23	8.98
Shinta	1937	736.274	Masonry Arch	10	1.78
Unknown	1937	741.104	Masonry Arch	8	0.66
Keha	1940	741.239	Masonry Arch	15	1.33
Unknown	1960	742.029	Masonry Arch	5	0.66
Unknown	1960	706.12	Masonry Arch	5	0.66
Galie	1980	666.3	Masonry Arch	6	0.18
Asregina	1980	667.55	Masonry Arch	6	2
Goleye 2	1980	686	Masonry Arch	15.2	5.35
Goleye	1980	686.9	Masonry Arch	15	1.62
Ay wuha	1980	721.2	Masonry Arch	12	0.53
Yiber	1980	630	Masonry Arch	10	0.73
Gomer	1980	632.75	Masonry Arch	10	0.99
Dildelie	1980	641.8	Masonry Arch	6	1.67
Ache	1980	643.4	Masonry Arch	6	5.81
Unknown	1936	721.3	Masonry Arch	4.9	0.66
Unknown	1938	723.72	Masonry Arch	5.9	0.66
Angereb	1939	724.97	Masonry Arch	20	8.17
Unknown	1938	726.02	Masonry Arch	5	0.66
Unknown	1940	728.08	Masonry Arch	4	0.66
Unknown	1936	729.87	Masonry Arch	4	0.66
Shembkit	1938	730.73	Masonry Arch	6	5.35
Unknown	1939	731.99	Masonry Arch	5	0.66
Shina	1940	733.462	Masonry Arch	8	31.16
Unknown	1937	735.832	Masonry Arch	4	0.66
Unknown	1938	736.022	Masonry Arch	4	0.66
Maber	1939	760.295	Masonry Arch	6	1.26
Aywesdie	1938	766.835	Masonry Arch	8	3.89
Temamie	1941	767.165	Masonry Arch	8	7.66
Gallo	1939	786.603	Masonry Arch	18	4.77
Alemwach	1937	792.973	Masonry Arch	20	9.3
Baslios	1941	794.403	Masonry Arch	10	6.47

Unknown	1939	795.973	Masonry Arch	4	0.66
Unknown	1938	800.703	Masonry Arch	4	0.66
Chira	1939	803.193	Masonry Arch	8	15.33
Unknown	1939	806.103	Masonry Arch	4	0.66
Unknown	1938	807.843	Masonry Arch	4	0.66
Unknown	1938	811.293	Masonry Arch	4.5	0.66
Arbatensa	1939	811.703	Masonry Arch	8	7.16
Kega	1941	813.393	Masonry Arch	10	17.96
Assera	1938	817.683	Masonry Arch	20	3.5
Unknown	1940	850.29	Masonry Arch	4	0.66
Unknown	1938	852.66	Masonry Arch	4	0.66
Adagusa	1939	855.7	Masonry Arch	6	2
Umbre	1940	857.09	Masonry Arch	6	1.19
Unknown	1936	859.59	Masonry Arch	4	0.66
Mai Nebra	1938	860.12	Masonry Arch	8	0.99
Unknown	1940	885.17	Masonry Arch	4	0.66
Unknown	1940	890.406	Masonry Arch	4	0.66
Biduet	1939	891.446	Masonry Arch	50	9.67
Dirma	1937	745.51	Masonry Arch	16	9.3
Unknown	1940	770.92	Masonry Arch	5	0.66
SHANKELLA	1937	186.26	Masonry Arch	27	1.44
Unknown	1941	191.47	Masonry Arch	5.1	0.66
Getta	1940	220.9	Masonry Arch	5	0.66
GETA	1938	220.99	Masonry Arch	7	0.67
CHORA	1939	223.66	Masonry Arch	7	1.44
Unta	1939	226.76	Masonry Arch	5	0.66
DOMA	1940	231.47	Masonry Arch	9	0.67
Kojo	1940	242.216	Masonry Arch	8	1.44
Bekere	1939	246.166	Masonry Arch	6	1.44
Simini	1938	247.766	Masonry Arch	15	1.44
Yaerbe	1939	248.56	Masonry Arch	9	1.44
Hora	1939	249.4	Masonry Arch	4	0.66
Kore	1940	256.666	Masonry Arch	6	1.44
Deneba	1938	262.266	Masonry Arch	9	1.44
Deneba Beke	1940	263.666	Masonry Arch	6	1.44
Chilelelo	1938	268.75	Masonry Arch	13	1.44
Gibe	1940	290.3	Masonry Arch	50.6	1.44
Bulbul	1940	304.8	Masonry Arch	26	1.44
Kito	1937	339	Masonry Arch	8	8.06

Feki	1939	343.72	Masonry Arch	6	6.16
Kechema	1940	365.01	Masonry Arch	4	0.66
Sedecha	1940	366.44	Masonry Arch	4.1	0.66
Gulufa	1938	380.41	Masonry Arch	7	0.66
Unknown	1941	196.45	Masonry Arch	4	0.66
Leku	1938	197.58	Masonry Arch	10	23.24
Gura	1938	198.15	Masonry Arch	6	12.69
Unknown	1938	199.89	Masonry Arch	4	0.66
Feker - 1	1939	202.53	Masonry Arch	6	2.71
Feker - 2	1939	203.89	Masonry Arch	8	18.09
Unknown	1940	205.24	Masonry Arch	7	0.66
Unknown	1940	209.74	Masonry Arch	5.4	0.66
Horba	1938	209.37	Masonry Arch	10	3.39
Unknown	1940	210.19	Masonry Arch	5	0.66
Filinchir	1939	210.44	Masonry Arch	6	5
Awaso	1940	212.14	Masonry Arch	6	6.54
Unknown	1938	213.3	Masonry Arch	4	0.66
Unknown	1938	214.23	Masonry Arch	5.7	0.66
Rassa	1940	216.28	Masonry Arch	6	4.16
Washemo	1937	217.7	Masonry Arch	6	6.33
Bildima	1939	219.41	Masonry Arch	8	2.64
Unknown	1939	220.58	Masonry Arch	4	0.66
Kerse	1939	222.18	Masonry Arch	10	3.39
Ketie	1937	223.57	Masonry Arch	6	8
Jarra	1938	223.82	Masonry Arch	6	21.98
Roha	1938	224.11	Masonry Arch	6	17.96
Dessa	1939	225.89	Masonry Arch	6	24.5
Obda	1939	226.42	Masonry Arch	6	20.98
Udie	1940	227.19	Masonry Arch	6	21.36
Gnaro	1940	227.55	Masonry Arch	6	17.21
Bechekie	1937	228.35	Masonry Arch	6	7.54
Birbirs	1937	228.88	Masonry Arch	6	13.57
Meda	1940	233.84	Masonry Arch	8	6.78
Dokie	1940	236.96	Masonry Arch	8	7.33
Melka Bella	1937	240.78	Masonry Arch	8	10.89
Mara	1937	242.84	Masonry Arch	8	9.38
Sheboka	1940	245.48	Masonry Arch	8	12.06
Hida	1939	245.99	Masonry Arch	8.5	7.33
Abuko	1938	248.37	Masonry Arch	8	5.33

Unknown	1940	251.55	Masonry Arch	5	0.66
Unknown	1937	251.91	Masonry Arch	5	0.66
Unknown	1937	254.14	Masonry Arch	5	0.66
Antutu	1938	261.59	Masonry Arch	8	6.94
Meki	1937	262.49	Masonry Arch	7	7.27
Dokonu	1937	265.38	Masonry Arch	7	3.89
Chobii	1938	267.51	Masonry Arch	7	3.7
Akabo	1938	269.59	Masonry Arch	7	3.3
Kela	1939	271.52	Masonry Arch	7	2.01
Chekorssa	1939	272.12	Masonry Arch	8.5	9.31
Feker	1939	273.23	Masonry Arch	7	2.01
Unknown	1938	274.86	Masonry Arch	5	0.66
Kemisie	1940	274.07	Masonry Arch	7	5.15
Unknown	1938	275.27	Masonry Arch	5	0.66
Chalte	1940	275.51	Masonry Arch	7	1.98
Gewisso	1939	276.93	Masonry Arch	10	6.94
Unknown	1937	277.4	Masonry Arch	4.2	0.66
Chorie	1937	277.89	Masonry Arch	7	4.29
Leku	1940	279.69	Masonry Arch	10	6.08
Gindo	1937	281.26	Masonry Arch	7	4.89
Aba Mukel	1940	283.31	Masonry Arch	10	4.02
Supie	1953	299.23	Masonry Arch	7	3.76
Mechara	1953	300.67	Masonry Arch	10	10.55
Ekamssa	1953	303.27	Masonry Arch	10	8.67
Ashkole	1937	308.27	Masonry Arch	10	9.3
Gulisso	1937	308.42	Masonry Arch	10	19.97
Unknown	1938	311.35	Masonry Arch	4.6	0.66
Unknown	1939	312.46	Masonry Arch	5	0.66
Hurri	1938	314.4	Masonry Arch	10	1.38
Unknown	1939	316.53	Masonry Arch	14.1	0.66
Chorie	1938	324.26	Masonry Arch	10	3.5
Adiya	1939	325.4	Masonry Arch	10	2.01
Dawe	1937	512.94	Masonry Arch	6	18.89
Dosha	1974	431.6	Masonry Arch	4.1	0.66
Digessa	1938	346.2	Masonry Arch	9	6.41
Unknown	1939	595.9	Masonry Arch	4	0.66
Unknown	1940	625.88	Masonry Arch	5	0.66
Abay No.5	1990	465.26	PC Box Girder	235.5	1.33
Useta	1990	297.11	PC Deck Girder	12.2	9.05

Enat Yeta	1983	422.46	PC Deck Girder	15	1.33
Gucheksi (2)	1978	470.24	PC Deck Girder	14	2.51
Awash South	1974	217	PC Deck Girder	109	13.69
Gadi	1945	256.42	PC Deck Girder	88	2.01
Boya	1941	1203.49	RC Arch	26	7.79
Rebu	1938	146	RC Arch	19.5	9.8
Awash	1963	49.3	RC Arch	91.96	18.27
Ginbora	1981	539.11	RC Arch	26	8.26
Kurakura	1980	540.92	RC Arch	24.9	5.88
Beket	1945	246.25	RC Arch	30	2.67
Aba Adem	1945	254.02	RC Arch	12	5.4
Lah Wenz	1945	380.54	RC Arch	23.9	3.89
Arera Wenz	1945	382.73	RC Arch	11.9	2.64
BOMBAS	1940	569.56	RC Arch	42	9.8
Kentie	1980	671.45	RC Arch	15	0.33
Rib	1980	672.75	RC Arch	33	0.33
Meher	1980	678.55	RC Arch	15	8.44
Zarima	1941	858.63	RC Arch	50	7.99
Ensita	1938	891.096	RC Arch	75	13.28
Jama	1937	902.626	RC Arch	21	4.16
Abay No 6	2008	213	RC Arch main	204.45	3.64
Wabeshebele	1936	1418	RC Arch main	42	9.8



## Declaration

I hereby declare that the work presented in this thesis which is entitled “Assessment of Ribbed Slab Constructions Framed Only in One Direction against Lateral Load Excitations” is my original work and has not been presented in any other University and that all sources of material used for the thesis have been properly acknowledged.

\_\_\_\_\_  
Saba Negash  
(Candidate)

\_\_\_\_\_/\_\_\_\_\_/\_\_\_\_\_  
Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

\_\_\_\_\_  
Dr. Asnake Adamu  
(Thesis Advisor)

\_\_\_\_\_/\_\_\_\_\_/\_\_\_\_\_  
Date