

FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA



ETHIOPIAN ROADS AUTHORITY



## Short Study on Ethiopian Arch Bridges

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ERA - Bridge Management Team

## Introduction

This study is the first in its kind ever made on Ethiopian Arch bridges at any level and entity. It presents general view of Masonry and RC arch bridges constructed, replaced, abandoned and steel serving in the country since 1930s.

As it is known, in Ethiopia, the first Nationwide Bridge Inventory and Inspection was conducted in 2005. Consequently the same was done in 2010 and 2013. The latest database is updated in 2016 under Bridge Management Support Service rendered to all 10 ERA branch offices by employed local engineering firms.

The study covers 585 Masonry and 17 RC type totally 602 Arch bridges in the country constructed between 1930s and 1980s. There are also about 1000 Arch type culverts opening size of which is under 4 mt and are considered as minor structure based on ERA classification.

Physical, Historical, geographical, and some engineering data of each arch bridge and arch culvert is stored as well as yearly updated service condition data is found in Bridge Management System software, which is developed by ERA bridge engineers and sustainably working since 2004.

When we see Arch bridges construction eras in Ethiopia, we find four periods.

- The first period is 17<sup>th</sup> century when Portuguese introduced stone bridge construction in Ethiopia,
- The second is during the 2<sup>nd</sup> world war , Italian invasion, when 80% of Ethiopian arch bridges were constructed,
- The 3<sup>rd</sup> period is after war and after invasion some long and economically important arch bridges are constructed by Italians, under war compensation scheme,
- The 4<sup>th</sup> period is when the Woreta - Debretabor road construction was undertaken by Chines in 1980s.

In line with the road network expansion and increasing traffic volume there is a serious concern and threat by many with regard to the need for replacement of old arch bridges before sudden collapses could be occurred.

The first nationwide bridge inventory and inspection data revealed that the concern was fair and reasonable. On top of that, the study exposed among old bridges which suddenly failed down in rainy season is those masonry arch bridges.

Therefore, the bridge management Team of ERA has prepared a sort of master plan and proposal that suggesting replacement of many of arch bridges within 10 years of time ( 2021) based on the priority list that considering mainly present service condition, age and defect level.

In this regard a number of arch bridges are being replaced by other type of bridges. For example many bridges are changed during rehabilitation of the Combolcha - Woldya

stretch and significant number of arch bridges is packaged in Combolcha-Batti-Mille road rehabilitation projects for replacement.

Unfortunately, due to lack of arch bridge design experience / refrain and less interest from local contractors' side, no one bridge is replaced by similar arch structure, despite high value of aesthetics is agreed. As evidence we can mention the project for replacement of old East Awash river Bridge found along Awash Mille road that was intended to replace by RC arch bridge designed by foreign firms in 2009. But, the construction cant proceed due to absence of interested contractors. Lately this bridge was changed to PC Box girder type and constructed by Japanese grant aid program. That is why we say that, there is no arch bridge constructed in Ethiopia after 1980s.

The Bridge Management Team of ERA is pleased to present this concise document produced after the study made on Ethiopian arch bridges to all Engineers and stakeholders working in the sector as well as to whom the issue is interesting for general knowledge and further research and study.

We would like to extend our respect to all local engineering firms assisted us in collection of bridge data from site including pictures and videos.

## General assessment

According to the first nationwide bridge Inventory done in 2005/06, in all road segments under ERA administration, except in Soddo District where no arch bridge exists, there were about 585 MABs.

Most of them are constructed during Italian invasion before 1945. These bridges are serving for more than 7 decades and currently they are not compatible and suitable to the current flow of traffic and cargos as they were not designed to it.

Combolcha District has the largest number of arch bridges than other Districts. It consists 35% of the total stock. It is obvious that because of concentrated political and administrative movement of the Italian invaders to the ports, the road network expansion was done in the Northern part of the Country. Such as Combolcha-Batti - Mille and Awash - Mille - Assab port route.

Almost all these old arch bridges can be considered as deficient. This can be explained by its long service time, visible deterioration of the bridge body, growth in current traffic volume and load, etc

Despite there are some RC Arch bridges, Masonry Arch Bridges in Ethiopia are mostly made of masonry wall from both sides and gravel back fill inside. Due to the fact that the road pavement or the surface was originally gravel type, during the rainy season water leakage was common and thus the inside part of concrete deck suffered from water leakage and decay.

It could be therefore many of the existing old MA bridges are vulnerable to sudden collapse.

Even though many think that, Ethiopian Masonry arch bridges are old enough and out of service due to age, the detail investigation exhibits that some of them looks intact and could serve for more additional years. But, until the residual bearing capacity result confirming the capacity to carry the current traffic weight this doubt remains there. Proving this fact by conducting the required test is, on the other hand, difficult for Masonry type arch bridges due to absence of common procedure. Therefore, realization of Engineers` recommendation for total replacement will continue.

In replacement process, according to BMS, priority is given to those located along sharp curves, which are prone to accident. In this case the road alignment will be improved and the old arch bridge shall be abandoned. In the reverse case, temporary traffic access shall be provided and the old one is going to be demolished before the replacement takes place to keep natural tangent line of the road.

In order to buy some time and avoid threats of collapse until realization of replacement, some arch bridges are considered under treatment program.

However significant number of arch bridges is maintained in recent years, due to the service age and the high traffic flow, they need surveillance to assure safe service and to be planned in medium term replacement program.

<b>No. Of Masonry Arch bridges By Inventory Year</b>						
<b>It. No.</b>	<b>District / RNMD</b>	<b>2006</b>	<b>2010</b>	<b>2013</b>	<b>2016</b>	<b>Reduced from the original until 2016 by %</b>
1	<b>Alemgena</b>	194	116	115	115	59
2	<b>Jimma</b>	32	26	25	18	56
3	<b>Nekempt</b>	34	16	7	5	15
4	<b>Combolcha</b>	206	188	188	143	69
5	<b>Shashemene</b>	6	5	5	4	67
6	<b>Dire Dawa</b>	3	2	2	1	33
7	<b>Adigrat</b>	35	26	26	25	71
8	<b>Debre markos</b>	15	13	13	13	87
9	<b>Gonder</b>	60	58	43	42	70
		<b>585</b>	<b>450</b>	<b>422</b>	<b>350</b>	<b>58</b>



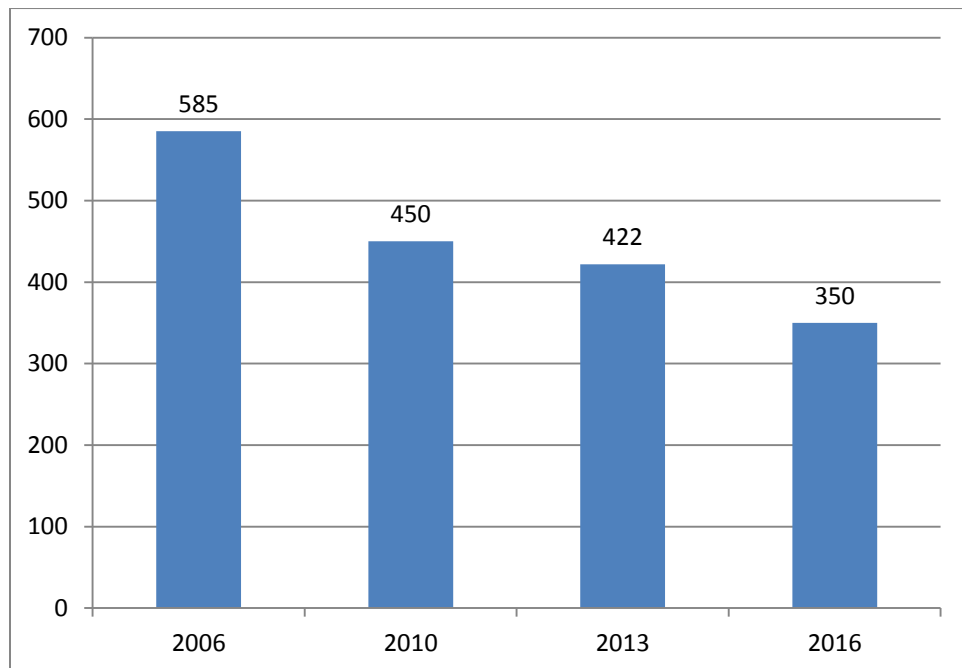
*One of replaced arch bridge, Bombas bridge , Bombas-Jijiga, A10-7-008*







*Example of bridge pictures before and after replacement.*



*Reduction of Ethiopian Old Masonry Arch bridges due to replacement*

Cases of replacement was tried to investigate in some instances. There are many reasons for replacement of theses MAB. This could be:-

- Age,
- Sever defects,
- Found along sharp curves , susceptible to frequent accident,
- Lose of bearing capacity,
- Over toping, etc

General bridge improvement data of ERA shows that ``Good`` condition is growing from 52.5% in 2011 to 74% in 2016. When we look the average improvement progress

of the existing arch bridges due to minor and major repair actions taken, the current good condition is 63% from 38% in 2006.

In general, in the past less than 10 years alone, about 41% of the arch bridge stock was replaced by new bridges and some are abandoned due to road alignment.

With regard to bridge length, many of old masonry arch bridges have short opening size. Therefore, the replaced structures are a typical standard RC bridges having 24 mt or max 36 mt long RC Box Girder. Some are replaced by RC Box Culvert and Slab Culverts. For instance, here under is presented changes achieved in 3 Districts.

It. No.	District / RNMD	1st NBI Bridge data	Changed to			Abandoned due to road alignment	Widened by Slab Culvert	In the 1st NBI wrongly registered as Masonry but it is RC Arch or missed
			Box culvert	RC Slab culvert	RCDG and composite			
1	Alemgena	194	24	13	14	28	7	19
2	Jimma	32	2	1	1	4	0	7
3	Nekempt	34	2	9	17	1	0	0
		<b>260</b>	<b>28</b>	<b>23</b>	<b>32</b>	<b>33</b>	<b>7</b>	<b>26</b>

Despite it seems that, there is good improvement in this regard, many of Masonry arch bridges still in need of total replacement. It is because:

- 1 Since many of them are constructed in 1930-40s and served for more than 70 years, no matter how they are maintained now they are not reliable to carry the current and future traffic load,
- 2 The material type, which is masonry wall and gravel fill is weathered enough in the past many years and the surface cover is wear out in many cases despite good looking asphalt pavement is now.
- 3 The current traffic volume and weight is very different from designed and intended service at that time,
- 4 By nature of the masonry arch structure ( not reinforced ) once the key stone and the central part starts collapsing, the whole structure can fall down in a moment and can't spare time to somehow provide temporary solution.

It is therefore many admit as true that, these old bridges should be set in first priority for replacement.

## Replacement campaign

Historically many of Ethiopian old masonry arch bridges were constructed in 1940s during Italian invasion. The fact is that many bridges are constructed with in few years. However there are engineering judgements are there telling that, these bridges didn't have sufficient engineering study on selection of location, size and bearing capacity. Whatever the situation was then, many agree that, these bridges are constructed just to open the road for traffic service at the time when it was critically important to control and govern the country.

In the process of replacing the old arch bridges many asked that, why not we replace them by same type of bridge due to aesthetical value of arch bridges?, why we demolish such historical bridges rather than leaving there and construct new by side?, can we have reliable bridges like the olds with regard to their long service life?, etc Despite many reservations are there, assuring safe traffic service becomes unavoidable priority and concern than comparing with worries for aesthetic.

On the other hand, dissatisfaction remains there due to the fact that many bridge designers go for easiest, common and typical bridge type in the course of design. This could be because of fear of the available local contractors less experience and interest.

In order to compromise concern of all stakeholders, demolishing of the old arch bridges is being avoided unless necessity of maintaining the existing tangent road realignment issue is major.

Therefore, as shown in the above table, there are abandoned arch bridges nearby newly constructed bridges.





*One of after replacement abandoned old masonry bridges, Mille bridge*



*One of Old Masonry Arch bridges found on sharp curve road alignment and susceptible to frequent car accident*

As the replacement is undergoing, priority should be given to those located along sharp curves and having scour problem in central piers or abutments.

Some of our recommendations are:-

- Regularly revise the priority list based on the condition survey specially where accident is frequently occurs and where traffic volume is high.
- Prepare Temporary Steel bridges at the closest area of the existing arch bridge to tackle possible traffic flow interruption in case of sudden collapse.
- Prepare design for new bridge in advance and enter into construction when the urgency arises.
- Place traffic post and sign showing weight limit.

However the bridge rehabilitation Master Plan indicates that, almost all old masonry arch bridges will be replaced with in the coming few years, the existing arch bridges need special attention as they are susceptible to sudden collapse due to defragmentation and deterioration of materials through these long years' service.

Knowing the most frequent and prevalent damage in such type of bridges is also vital to take action in short term maintenance plan.

Causes for sudden collapse could be internal or external, which means in the structure itself and in the bridge area like river channel , embankment , downstream erosion, upstream water flow obstacles, disintegration of bridge material, impact load due to car accident at narrow or curve location, etc.

As we have seen in the previous sections, significant number of arch bridges are maintained, but still there must be close follow up for their service condition as the traffic volume and weight is increasing from time to time.

As we could see in the below picture defragmentation of the superstructure, which is commonly masonry stone wall filled by gravel material is also exhibited itself as a cause for degraded bearing capacity and subsequently fall down.



In the course of preparing replacement plan, some of them can be incorporated in road rehabilitation projects as a package. But, as temporary solution, there can be either minor repair actions that require high skill and experience as well as use of common type adhesive and partial strengthening special materials.

The truth is that, replacement of all old masonry arch bridge at a time is impossible taking in to consideration that, the Design, construction and resource capacity available in the country as well as the traffic management challenge.

Therefore, as a short term plan repair works and as a medium term plan replacement is recommended.

Repair works shall be mainly focused on Scour defects. Because as replacement works can be done at any convenient time investment of much money for repair may not be wise decision. But, the repair works should be done strictly as per the ERA Specification and Manual for bridge repair.

### **Prevalent damages**

In the past few years different studies are held by ERA bridge engineers and other engineering consulting firms on identification of common and prevalent defects of bridges. For example if we take the collected bridge defect inspection data in 2006, 2010, and 2013 ( under Nationwide bridge Inspection schedule ), Cracking ; Honey Comb and voids ; Peel Off : Water Leakage and Scour takes the lion share.

For Masonry arch bridges specifically, deterioration and longitudinal cracks are common on the Decks and scour is common in Abutment and central piers.

As it was discussed many of Ethiopian arch bridges are constructed in early 1940s and 1950s when the Asphalt Concrete pavement was not yet introduced in the country's High Way.

Since the road pavement was gravel material, the water leakage problems are very common where pot holes are there. On top of this due to rutting and Waves, rain water can accumulate over the surface and segregate in to the deep of the gravel fill of superstructure. This in turn soaks the concrete cover inside and easily exposes the concrete to different deteriorations.

It. No.	MAB Structure	Damage Type	Damage counted
1	Abutment & Wing wall	Cracking	47
		Peel Off / Stone deterioration	39
		Rebar Exposure	5
		Honey comb	5
		Void	5
		Water Leakage	9
		Displacement / Bulging	4
		Scour	24
2	Concrete Arch	Cracking	88
		Peel Off	53
		Rebar Exposure	22
		Honey Comb	98
		Void	19
		Water Leakage	63

Regarding the counted Honeycomb and void defects, it can be understood that the workmanship problem that could be the cause may be expected and inconsiderable at the construction time, which was invasion and war time.

From the recent study conducted on more than 90% of the old Masonry Arch Bridges in all ERA Districts, the following representative data are obtained.  
( BMS database 2013 )



*One of the old bridges replaced due to scour problem, Washamo bridge, Gedo-Bako, ( A4-4-10)*

### **RC Arch Bridges**

Arch bridges made of Reinforced Concrete and Masonry stone are very different structurally and in bearing capacity. With regard to the bridge length, masonry arch bridges are significantly shorter than how long RC arch bridges can be.

RC Arch bridges can serve for longer years as any RC Girder Deck bridges and their defect is common to any other concrete made bridges.

There are few RC arch bridges in Ethiopia. To mention long ones, there are Abay River Bridge at the middle of GohaTSION - Dejen route and Awash River Bridge along Alemgena - Butajira route built by Italians. Aesthetically beautiful some RC arch bridges are also found along Woreta - Woldya route built by Chines in 1980s.



*The famous Abay River RC Arch Bridge, 210 mt long, (A3-4-001)*



Historically, according to the first nationwide bridge inventory database conducted in 2006, there were 585 Masonry Arch bridges and 17 RC Arch Bridges. But, as per the latest 2016 Bridge Inventory, there are 350 Masonry Arch bridges and 15 RC Arch Bridges.

It. No.	No. Of RC Arch Bridges By Inventory Year				
	District/ RNMD	2006	2010	2013	2016
1	Adigrat	1	1	1	1
2	Debremarkos	5	5	3	3
3	Gonder	6	6	6	6
4	Alemgena	3	3	3	3
5	Combolcha	2	2	2	2
	<b>Total</b>	<b>17</b>	<b>17</b>	<b>15</b>	<b>15</b>



One of the old RC Arch bridges being replaced, Lah bridge, Finoteselam,



Some RC Arch bridges are also replaced by RC girder due to serious defects, A3-





*Ginbora bridge, Woldya-Dilb route (B22-1-008)*



*One of still serving RC Arch bridges,*



*One of architecturally beautiful RC bridges , Boya River Bridge, Adiarkay - Tekeze*

***Note:-*** Any kind of detail technical information on Ethiopian Arch bridges including pictures before and after for those replaced as well as short video clip of existing bridges can be obtained in BMS database at ERA Bridge management team office.

*The Article produced by  
ERA - Bridge Management Team Leader  
Girma Worku, Bridge Engineer  
Wkgirma@gmail.com*