HISTORICAL DEVELOPMENTOF ARCH BRIDGES IN SRI LANKA

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ABSTRACT

Greeks and Romans are believed to be the first to recognize the full potential of using the arch shape for bridge construction. The early arch bridges of Sri Lanka date back to the period of the British reign. This research was conducted to explore the history of arch bridges in Sri Lanka and how the construction methods have developed from the time of stone arch bridges to modern steel and concrete arch bridges. Arch bridges can be classified based on the type of material used for the construction as stone, masonry, concrete and steel bridges. Arch bridges were built of stone initially later on masonry arch bridges were built. Concrete and steel are popular materials that are currently in use.

***Key words*:** Abutment, Span, Keystone

1. INTRODUCTION

Civil engineering defines an arch as a curved structure spanning an opening and supporting the weight of a bridge, roof or a wall above it.

Although arches have been appeared as early as the 2nd millennium B.C. they were not used for a variety of structures until Romans took advantage of their capabilities. The art of building arch structures seems to have arrived to Sri Lanka in 377 B.C during the Anuradhapura Era. Different arch structures can be found from both historical and modern times of Sri Lanka. They have been erected as bridges, gates, tunnels and roofing large interior spacing in halls and temples depicting their structural as well as architectural properties.

Examples for buildings are Guard stones, Lankathilaka viharaya, Archways in Degaldoruwa temple, Kelaniya thorana, Colombo museum, Lloyds building Colombo, All Saints church Borella, Basilica church Ragama.

Examples for Tunnels are Ramboda tunnel, No. 18 tunnel pattipola end, Demodara 41 tunnel.

Examples for bridges are Mawanella masonry bridge, Nanuoya arch bridge, Angunawala stone bridge, Demodara stone nine arch bridge, Ulapane concrete arch bridge, Pilimathalawa truss arch bridge, Peradeniya truss arch bridge, Nathupana steel tied arch bridge Belihul oya concrete arch bridge.

This paper is focused only on the arch bridges of Sri Lanka as the objective is to examine their historical development. By closely observing some of the selected arch bridges, our scope was to understand how their evolution took place, Out of the many bridges in Sri Lanka Mawanella arch bridge, Pilimathalawa Nanuoya bridge, Angunawala bridge and the truss arch bridge at Pilimathalawa were closely observed.

Figure 1: Pilimathalawa steel truss arch bridge

Figure 2: Angunawala stone arch bridge

Figure 3: Mawanella masonry arch bridge

Figure 4: Nanuoya Masonry Bridge

An arch bridge has the objective of forming a structure to span a certain gap and cross over something as any other bridge. The basic principle of an arch bridge is its curved design which does not push the load forces straight down but elegantly distribute the compression through its entire form and diverts onto its two abutments as shown in Figure 5. Conveying the forces across the arch is done via central keystone on the top of the masonry and stone arch bridges. Its weight pushes the surrounding rocks down and outwards, making the entire structure rigid and strong.

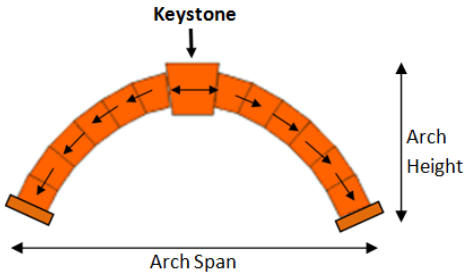


Figure 5 :Show how the load is distributed from the keystone

Tensional forces in arch bridges on the other hand is virtually negligible as the curve of the arch dissipate the force outwards.

To build arch bridges, any different materials can be used as long as they are strong in compression but the possible span length depends on the chosen material. Historic arch bridges were often made of simple materials like stone and bricks but nowadays are usually constructed from reinforced concrete and steel. In this paper, it is only considered four types of arch bridges depending on their material as masonry, stone, steel and concrete. Considering their construction periods, the evolution of arch bridges of Sri lanka took place from masonry, then stone to steel and finally concrete.

Span to height ratio is an important bridge design parameter that relates a span to bridge's girder depth. This ratio directly affects the cost

of the materials and the construction of the superstructure. For instance using a high ratio reduces the compression forces and governs the design by beam action.

2. METHODOLOGY

Out of the arch structures that were listed down in the previous chapter, the following four arch bridges were chosen to be closely examined for the purpose of the research. They are :

- PilimatalawaNanuoya Bridge
- Mawanella Arch Bridge
- Pilimatalawa Steel Arch bride
- Agunawela Bridge

The data collected at the sites were year of construction, number of spans, arch span, arch height, width, the type of arch (Concrete, Masonry, Steel or Stone) and types of supports. Table 1 summarized the all the collected at the sites.

Table 1 : shows the summary of the data for four selected arch bridges.

Bridge	Arch Span	Arch height	Types of Supports
Nanuoya (Masonry Bridge)	27.7m	2.0 m	Fixed
Angunawala (stone bridge) -Large arch -Small arch	56.3m	5.1 m 2.0 m	Fixed
Mawanalla (masonry bridge)	69 m	4.8 m	Fixed
Pilimathalawa (steel truss arch bridge)	43.2m	3.0 m	Fixed

Furthermore, heights of each arch at considerable intervals with respect to a fixed datum to plot the shape of the arch were obtained.

3. RESULTS

By closely analyzing the data, which is obtained during the field survey, following results can be observed.

4.1 Types of arch bridges

Four types of arch bridges can be identified based on the material type used in the construction. They are stone, brick, concrete and steel. Stone and masonry as materials are strong in compression but are very weak in resisting tensile forces. Therefore, masonry arch bridges are designed to be under compressive stresses. Masonry and stone arch bridges use a quantity of fill material (typically compacted rubble for stone arch and masonry infill for masonry arch bridges) above the arch in order to increase the dead-weight on the bridge and prevent tensile forces from occurring in the arch as loads move on the bridge.

Reinforced concrete uses steel bars with concrete in order to increase the capability of arches to take tensile stresses induced due to bending moment as well as compressive forces. The increased tensile strength of reinforced concrete in this manner allows engineers to develop innovative and aesthetically attractive designs of concrete bridges instead of simply replicating the form of masonry arch bridges.

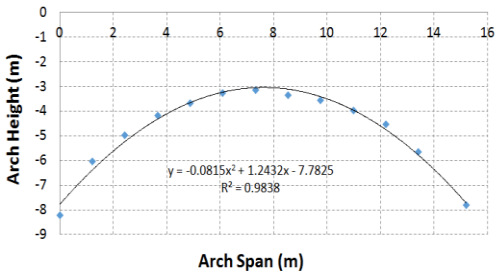
Relative to steel and concrete arch bridges, masonry and stone arch bridges are very heavy, requiring extensive foundations. They are also expensive to build and labor costs are high.

Today steel is used for arch construction. This makes the bridges much lighter as a fill is not required.

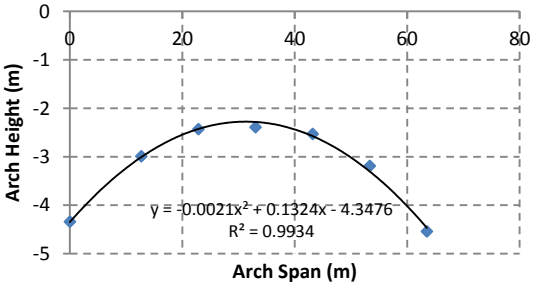
4.2 Arch shape

The shape of the arch structure plays an important role. The strength of the arch is also highly influenced by its span. Large arches produce high stresses, therefore the span to depth ratios used for the arch bridges should be considered.

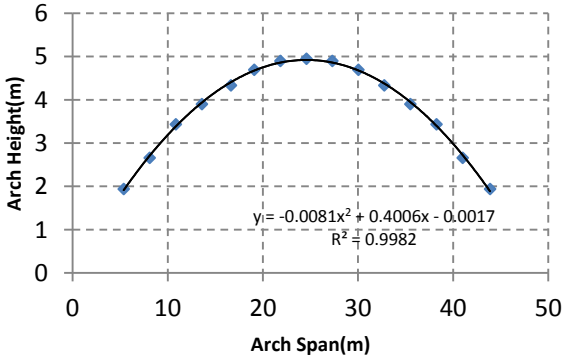
By fitting a curve to the heights measured at different intervals against the length, the shapes of the four selected arch bridges were obtained. Figure 6 illustrates the resultant shapes of the four selected arch bridges.



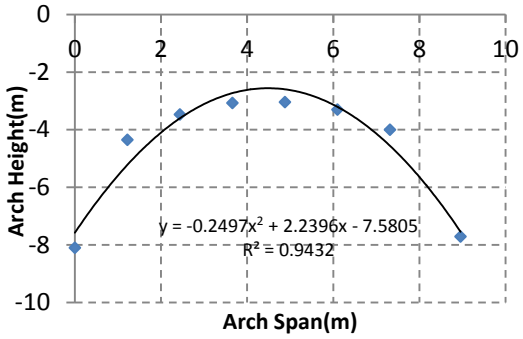
(a) Mawanella Bridge : Parabolic shape



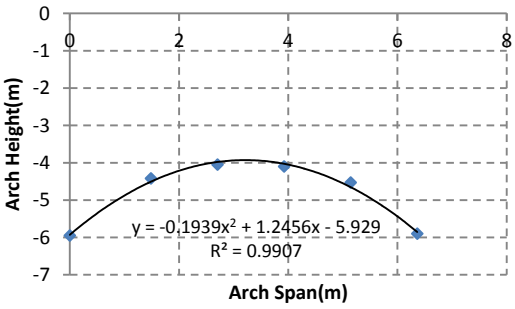
(b) Nanuoya Bridge : Parabolic shape



(c) Pilimathalawa truss-arch bridge : Parabolic shape



(d) Angunawala - Large arch : semi circular



(e) Angunawala bridge -Small arch : Parabolic

Figure 6 : illustrates the arch shapes of the four structures.

4.2 Span to depth ratio

The resultant span to depth ratios of the selected bridges are tabulated in Table 2.

Table 2: Span to depth ratios

Type of the bridge	Span to height ratio	Constructed year
Masonry		
- Mawanella	1.6	1820
- Nanuouya	6	1826
Stone		
- Angunawala	1	1926
Steel		
- Pilimathalawa (Truss- arch)	9	1890

5 CONCLUSION

Based on the results obtained from the survey of the four selected arch bridges, it can be concluded that old stone bridges built in 19th century in Sri Lanka are in semi circular shape with the span to height ratio of 1 and masonry arch bridges built in 18th century are in parabolic shape with varying span to depth ratio of 6 to 3. Modern arch steel and concrete bridges have also followed the parabolic shape with even higher ratios. This is because steel can take bending moments unlike masonry and stone as they cant take tensile forces.

During the 1st half of the 20th century, more modest steel arch bridges continued to be built. The aesthetic and the classic appeal of the arch form made the metal arches an attractive 20th century alternative. Although metal arch bridges in the modern, automotive era did not attain the general versatility and adaptability of steel girder and reinforced concrete structures, the metal arch form remains significant displaying a technological continuity of development similar to that of the more common metal truss bridges.

4. REFERENCES

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