STRUCTURAL ASSESSMENT OF MASONRY ARCH BRIDGES IN SRI LANKA

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INTRODUCTION

Masonry arch bridges are one of the oldest and most attractive structural forms of bridge construction in the world. At present, there are about 150 masonry arch bridges on roads and railway networks in Sri Lanka. Most of these bridges are more than 150 years old. The current condition of these bridges is not satisfactory and need urgent attention and maintenance. At the time of construction there was little consideration given to future sustainability. Increase in loading, high traffic frequency and age of masonry arch bridges have directly affected their structural decay. Structural decay has negatively impacted the load carrying capacity of these masonry arch bridges. Hence, it is necessary to assess the load carrying capacity of existing masonry arch bridges and check that bridges remain serviceable.

The capacity of an arch bridge cannot be determined accurately only by assessment. However, it can be assessed with a greater degree of reliability using reliable input parameters and visual inspections, which are required for calculations. Existing damages in arch bridges reduce their structural capacities. Therefore visual inspections are important to determine their capacities. Assessment of masonry arch bridges is a difficult task, because there is no widely accepted and reliable structural assessment procedure. Most of the bridges are in remote areas with limited access and some parts of the structure are hidden from view. The comprehensive evaluation of these bridges and developing an effective structural assessment methodology is critically important in maintaining these bridges in usable condition.

Assessment is a quantitative determination of the capacity of a bridge to carry static and dynamic loads. It is the combined effect of geometric form of structure, the materials used, the structural interaction of the parts and the condition of the structure.

Assessment is necessary for a number of reasons. Perhaps, most important is that bridges deteriorate with time so their capacity to withstand load also declines. The loading to which bridges are exposed also changes with time. The axle loads, numbers of axles and vehicle speeds increase with time, and in the process they might exceed known or unknown safety margins.

The structural assessment of masonry arch bridges is therefore necessary to check that bridges remain serviceable for continued use. A reliable assessment method is needed to ensure that strengthening is used only where necessary, and is as economical and efficient as possible.

METHODOLOGY

The main objective of this study is to propose a more effective assessment technique for masonry arch bridges. The study consists of three phases: (1) literary review on previous theoretical studies on masonry arch bridges; (2) assessment of current conditions of masonry arch bridges in Sri Lanka; (3) utilization of current state-of-art techniques in assessment of a few masonry arch bridges in Sri Lanka. The Military Engineering Experimental Establishment (MEXE) method is used to check the routine strength of existing masonry arch bridges in this research article.

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The MEXE method
Load carrying capacity has traditionally been evaluated using the Military Engineering Experimental Establishment (MEXE) method (or a modified version of this method) for assessment of masonry arch bridges. The MEXE method is a semi-empirical method, which was developed during the Second World War and into the 1950's because the British Ministry of Supply wanted to classify bridges according to the military loads they could carry. This method was derived by the Military Engineering Experimental Establishment based on the work done by Pippard. The method is based on some classic elastic theories and a series of experimental studies. At present, the modified MEXE method is used to find the residual strength of masonry arch bridges in developing countries. Its use in Sri Lanka is rare but in European countries, it is popularly used as a routine strength checking method.

Using the MEXE method
Analysis was carried out using the Modified MEXE method. As stated in the current bridge assessment code BA16/97 [4], the MEXE method may be used to estimate the carrying capacity of arch bridges (Highway Agency 2001).

During the field visit survey, seven arch bridges on the Colombo-Kandy (A1) road, one arch bridge on the Galle–Deniyaya-Madampe (A17) road and six arch bridges on the Colombo-Badulla Railway line were inspected. The Mawenella four span brick masonry arch bridge was selected to illustrate the analysis. A side view of the bridge is shown in Figure 2 and geometric details of the bridge are given in Table 1.

Table 1. Geometric details of the Mawenella Bridge

Geometric parameter	Value
Bridge length (L_b)	69.00 m
Clear span of an arch (L)	15.20 m
Thickness of the barrel (d)	1.00 m
Height of the compacted fill from the crest of the barrel (h)	1.33 m
Rise of the arch at mid span (r_c)	4.90 m
Rise of the arch barrel at the quarter point (r_q)	4.20 m
Number of arches (n)	4

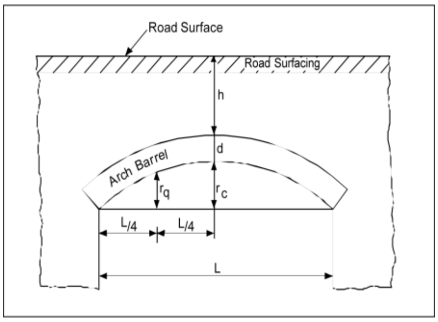

Figure 1. Arch Dimensions


Figure 2. Mawenelle Bridge

Estimation of Provisional Axle Load (PAL)

PAL of the bridge is estimated by using modified MEXE method

$$PAL = 740\frac{(d+h)^2}{L^{1.3}}$$

$$PAL = 740\frac{(1.0+1.33)^2}{15.2^{1.3}}$$

$$PAL = 116.83\ tonne$$

The following modification factors have been applied to the calculated value of PAL to generate the modified axle load. The current bridge assessment code BA16/97 was used to evaluate these modification factors.

Span rise factor F_{sr}

$L/r_c = 3.1 < 4.0$

Therefore, $F_{sr} = 1.0$

Profile factor F_p (Clause 3.12)

$r_q/r_c = 0.9 > 0.75$, (If $r_q/r_c < 0.75$, $F_p = 1.0$)

Therefore,

$$F_p = 2.3\left[\frac{r_c - r_q}{r_c}\right]^{0.6}$$

$$F_p = 2.3\left[\frac{4.9 - 4.2}{4.9}\right]^{0.6}$$

$$F_p = 0.7$$

Material factor F_m: (Clause 3.13)

Arch barrel consist of engineering bricks and similar sized masonry. Therefore,

$F_b = 1.2$ (Table 3/1)

Assumed as filling material was well compacted,

$F_f = 0.7$ (Table 3/2)

$$F_m = \frac{(F_b.d) + (F_f.h)}{d + h}$$

$$F_m = \frac{(1.2X1.0) + (0.7X1.33)}{1.0 + 1.33}$$

$$F_m = 0.91$$

Joint factor F_j: (Clause 3.16)

Width of the mortar joints were about 20mm. Therefore,

$F_w = 0.8$ (Table 3/3)

Joints were good condition of this bridge and there's not appeared missing mortar.

$F_d = 1.0$ (Clause 3.16)

Mortar was in good condition. Therefore,

$F_{mo} = 1.0$ (Table 3/4)

Joint factor (F_j) = width factor (F_w) x depth factor (F_d) x mortar factor (F_{mo})

(F_j) = 0.8 x1.0 x 1.0

(F_j) = 0.8

Condition factor F_c:

Condition of the arch was good in the Mawenella bridge. It was found that arch barrels are free of cracks. Therefore,

$F_c = 1.0$ (Clause 3.18)

Number of spans factor F_n:

In fact, this factor takes in to account the multispan effects of the arch bridge.

For outer arch, $F_n = 0.9$, (arches supported by one abutment and pier)

For inner arch, $F_n = 0.8$, (arches supported on two piers)

The modification factors are applied to the provisional axle load to generate a modified axle load as follows:

Modified axle load (MAL) = (F_{sr}) x (F_p) x (F_m) x (F_j) x (F_c) x (F_n) x PAL

For Outer Arch, MAL = 1.0 x 0.7 x 0.91 x 0.8 x 1.0 x 0.9 x 116.83

MAL = **53.58 *tonne***

For Inner Arch, **MAL** = 1.0 x 0.7 x 0.91 x 0.8 x 1.0 x 0.8 x 116.83

MAL = **47.63 *tonne***

RESULTS

The results obtained with regard to load carrying capacities of the masonry arch bridges are shown in Table 2.

Table 2. Load carrying capacities of Road & Railway masonry arch bridges

Road No.	Bridge No.	Bridge Name	No. of Spans	**PAL (tonne)**	Modification factors										MAL (tonne)	**MAL (tonne)**	
					Fsr	Fp	Fb	Ff	Fm	Fw	Fd	Fmo	Fj	Fc		Outer Arch	Inner Arch
A001	67/5	Bridge at Nelundeniya	1	**136.81**	0.96	0.50	1.20	0.70	0.91	0.80	1.00	1.00	0.80	1.00	47.85	**47.85**	
	84/2	Muadimawatta Bridge	1	**490.06**	0.79	0.89	1.20	0.70	0.80	0.80	1.00	1.00	0.80	1.00	221.54	**221.54**	
	85/1	Weragoda Bridge	1	**556.16**	0.78	0.96	1.20	0.70	0.81	0.80	1.00	1.00	0.80	1.00	270.43	**270.43**	
	88/4	Bridge at Walakadayawa	1	**191.56**	0.83	0.85	1.20	0.70	0.86	0.80	1.00	1.00	0.80	0.60	55.58	**55.58**	
	90/3	Bridge at Anwarama	1	**1113.11**	1.00	0.87	1.20	0.70	0.77	0.90	1.00	1.00	0.90	0.70	468.32	**468.32**	
	91/1	Mawenella Bridge	4	**116.83**	1.00	0.70	1.20	0.70	0.91	0.80	1.00	1.00	0.80	1.00	59.54	**53.58**	**47.63**
	99/8	Bridge at Gala widapu thena	1	**647.02**	1.00	0.84	1.20	0.70	0.83	0.80	1.00	1.00	0.80	1.00	361.62	**361.62**	
A017	64/2	Porupitiya Arch Bridge	1	**139.32**	1.00	0.91	1.50	0.70	1.06	0.80	1.00	0.90	0.72	1.00	95.93	**95.93**	

	Mileage	Name or Location of the Arch Bridge	No. of Spans	**PAL (tonne)**	Modification factors										MAL (tonne)	**MAL (tonne)**	
					Fsr	Fp	Fb	Ff	Fm	Fw	Fd	Fmo	Fj	Fc		Outer Arch	Inner Arch
MAIN LINE	168/02	Before Ella railway station	1	**156.36**	1.00	0.81	1.50	0.70	1.07	0.80	1.00	1.00	0.80	1.00	108.65	**108.65**	
	168/51	After Ella railway station	3	**45.19**	1.00	0.68	1.50	0.70	1.30	0.80	1.00	1.00	0.80	1.00	32.21	**28.99**	**25.77**
	169/58	Nine Arch Bridge	9	**51.46**	1.00	0.69	1.50	0.70	1.27	0.90	1.00	1.00	0.90	1.00	40.43	**36.39**	**32.34**
	169/63	After nine arch bridge	1	**131.83**	1.00	0.83	1.50	0.70	1.17	0.80	1.00	1.00	0.80	1.00	102.10	**102.10**	
	170/26	Before Demodara station	4	**80.41**	1.00	0.67	1.50	0.70	1.17	0.80	1.00	1.00	0.80	1.00	50.52	**45.46**	**40.41**
	171/28	Before Demodara station	2	**155.32**	1.00	0.77	1.50	0.70	1.25	0.80	1.00	1.00	0.80	1.00	119.06	**107.15**	-

CONCLUSION AND RECOMMENDATIONS

The MEXE method was used to assess present load capacities of a few masonry arch bridges in Sri Lanka. From the results, it is clear that the MEXE method can be applied in capacity assessment of these bridges. Further, present load capacities of these bridges exceed their live-load applications. Hence, it can be concluded that the above bridges are presently safe even though there is some structural decay. However, it is recommended to perform local modeling of these structural degradations to confirm the effectiveness of these bridges in their load carrying capacities.

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