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Repair and strengthening techniques for masonry arch bridges

Vlad A. Apreutesei[1], Daniel V. Oliveira[2], Paulo B. Lourenço[2]
[1] *"Gh. Asachi" Technical University, Iasi, 700050, Romania*
[2] *Universidade do Minho, Campus of Azurém, Guimarães, 4800, Portugal*

Summary

The paper presents a summary of the work undertaken by the first author in the frame of "Leonardo da Vinci" Mobility, Contract RO/2004/PL93209/S, at Universidade do Minho - Center for Civil Engineering, under the coordination of Paulo B. Lourenço, Professor of Civil Engineering, tutored by Daniel Oliveira (assistant Professor of Civil Engineering) and supervised by Irina Lungu (Associate Professor at "Gh. Asachi" Technical University, Iasi).

The most common techniques used in the process of strengthening damaged masonry arch bridges are here described, being revised the typical defects and damage for which they are applied, as well as economical issues and operation difficulties.

KEYWORDS: arch bridges, rehabilitation, strengthening techniques, environment pollution.

1. INTRODUCTION

Virtually, most of the defects observed in arch bridges can be repaired. Practicalities regarding the execution of various repair techniques have been fairly widely documented, although the philosophy behind the application of some of the techniques has sometimes been somewhat dubious, perhaps resulting from a fundamental lack of understanding of the structure under consideration.

Nowadays, a great variety of intervention techniques are available, from which it should be distinguished the following groups:

- Traditional techniques: they use materials and construction techniques similar to those used during the construction of the structure;
- Modern or innovative techniques: they try to adapt more efficient solutions than the traditional ones through the use of modern materials and equipments;

The choice among traditional or innovative solutions is controversial, but if with traditional techniques it is possible to obtain satisfactory solutions from the structural, economic and constructive points of view, its use should be preferred, not only for aesthetic and cultural reasons, but also for compatibility reasons between the new elements and the original ones. When dealing with cultural heritage bridges, the choice between "traditional" and "innovative" techniques should be determined on a case-by-case basis with preference given to those that are least invasive and most compatible with heritage values, but consistent with the need for safety and durability.

In some cases, it is not easy to repair the structural damage with the exclusive resource to traditional solutions, because original materials are no longer available, as mortars, because qualified labour doesn't exist (craftsmen) for this type of constructive techniques, or even for economical reasons. The most frequent reason to go through modern techniques is related with the need of significant increases of load bearing capacity, that are only gotten with much more efficient materials than the original ones. However, whenever possible the "interventions in masonry should be made with masonry".

Before the decision for the use of any repairing techniques or reinforcement is made, it is quite necessary to establish and to understand the causes of the found damage. On the other hand, the effect of the intervention on the behavior of the structure should be carefully evaluated, by means of in situ tests or numerical modeling.

2. IDENTIFICATION OF DEFECTS

The identification of many of the defects affecting masonry bridges (spandrel wall bulging, bowing or detachment, gross abutment movement) is straightforward, being sufficient an accurate visual inspection.

Abutment movements can be identified by the presence of a crack in the region of the crown, or by settlement of the parapet walls. Spandrel wall detachment can be identified by the presence of continuous longitudinal cracks in the arch barrel beneath the internal faces of the walls. Unfortunately, some other defects may be less evident. In these cases, either partial dismantling of the structure, coring through sections of the structure or the use of NDT (non-destructive-testing) techniques will be required. These methods would prove impractical or expensive for the majority of bridges requiring assessment, but useful for assessing a small numbers of important structures, or a sample of representative structures.

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3. STRENGTHENING TECHNIQUES

3.1 Pressure pointing and grouting

Pressure pointing and grouting is an economical strengthening technique, usually involving little traffic disruption. Grouting of the contained ground above and behind an arch can be a useful measure: with suitable receptive grounds (not high in clay or silt) and in the absence of complications such as drainage systems, the method is very effective and very economical. Furthermore, it increases the assessment factor to 0.9 and improves the arch ring condition factor by filling cracks and voids in the extrados. Grout quantities can be hard to predict and considerable variation is therefore to be expected.

Figure 1 presents the operation of repointing the joints of a masonry bridge.

Figure 1. Repointing of the joints

3.2 Tie bars

Tie bars, anchored as presented in Figure 2, are used to restrain further outward movement of spandrel walls. They consist of a bar passing through the full width of the bridge, with pattress plates at each end, generally secured by a nut and washer, to provide the restraint to the wall. If the arch ring requires strengthening at the same time a more common solution is to use a concrete saddle which will also relieve the spandrel wall of outward forces.

One of the advantages of using tie bars is that they can be inserted with little or no disruption to overtraffic. However, their effectiveness has never been scientifically proved and many engineers are worried that sections of the spandrel wall may fracture around the pattress plates or spreader beams, the walls then becoming potentially unstable. There is no scientific guidance as to suitable spacing the tie bars in a given structure.

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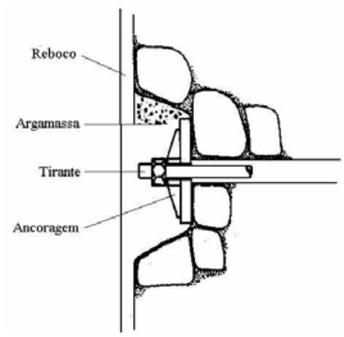
In one of the cases studied, it appeared to have been further movement of a spandrel wall since installation of the tie bars. Rusting of the exposed parts, in one severe case, was also found. The use of stainless steel bars could be considered, or even the application of cathodic protection.



a) Anchorage system

b) Anchorage plates

Figure 2.

3.3 Rebuilding bulging spandrel/wing walls

With sufficient road width or the acceptability of a road closure and with minor services present, the simple solution is to excavate behind the wall and rebuilt it conventionally. To back the wall with mass concrete is a possibility, but to do so creates a deep, stiff beam edge to the arch, inconsistent in structural action with that of the arch.

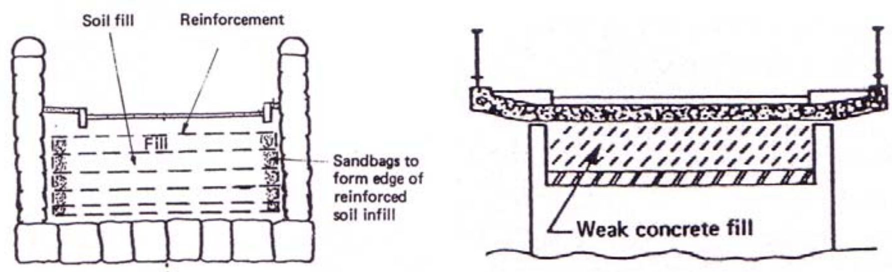


Figure 3. Strengthening of the fill material used for reducing the pressure on the spandrel walls

A more harmonious structural action results from incorporation of a reinforced earth system to support the fill, as presented in Figure 3. This prevents excessive pressure developing against the spandrel wall and the space between reinforced earth and back of wall is filled with single-size drainage material.

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3.4 Saddling

A particularly common repair technique which has been used in the case of a wide variety of arch bridges exhibiting almost any sign of distress is that of saddling (Figure 4). The technique is used in response to the observation of virtually any kind of cracks.

The merits are that with a rough existing extrados, composite structural thicknesses is increased, cracking is retained, historical widenings can be integrated, the saddle can carry a sprayed (ideally polyurethane) waterproofing membrane.

Drawbacks are that the arch is too narrow to allow single line traffic to pass while the arch is treated, due to the deep excavation necessary. Occasionally, historically widened arches may retain the old original spandrel at low level: this can be used again to facilitate ¨half and half˙ strengthening.

Saddles are typically 150-200mm thick, of relatively weak concrete and can, if judged necessary, be articulated to harmonise with the arch ring's structural action, either by bands of transverse brickwork or an inert transverse Debonding lamina.

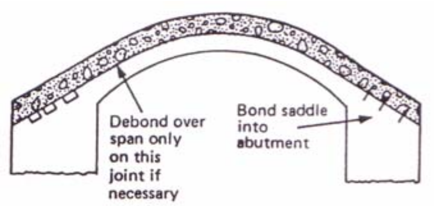

Figure 4. Saddling the extrados of the arch with a layer of concrete

Inclusion of fibers in the concrete has a merit: polypropylene fibers confer resistance to surface shrinkage cracking. Stainless steel fibers confer considerable strength and structural ability to unit arches and to bind cracks.

Saddling clearly changes the fundamental nature of the bridge and as such may often cause more problems than were originally present (e.g. the lack of stress in the original arch after saddling could give rise to the hazard of falling masonry blocks, additionally the ability of the arch to freely adjust to a changing environment is removed).

3.5 Invert slabs

An invert slab is a slab of concrete placed between the abutment walls or piers with its top surface at or below river bed level (older versions may be built of masonry). It helps to prevent scour. If incorrectly installed however, there is a risk of scour beneath the slab, particularly at its downstream end.

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3.6 Stitching longitudinal cracks

This system is applicable where more extensive dismantling or saddling is very disruptive to traffic or economically impossible.

Typically, alternate voussoir stones are cored laterally (30mm diameter) and the cores retained. A 30 mm hole is drilled normal to the spandrel and at mid-depth of the arch ring, to a length some 750mm beyond the crack to be tied. A practical maximum drilling length is about 12m. Installation of a CINTEC-type hollow stainless steel bar, with enclosing sock, takes place and the grout injected down the bar fills the sock, expanding it to key into all recesses. The CINTEC anchorage system is presented in Figure 5.

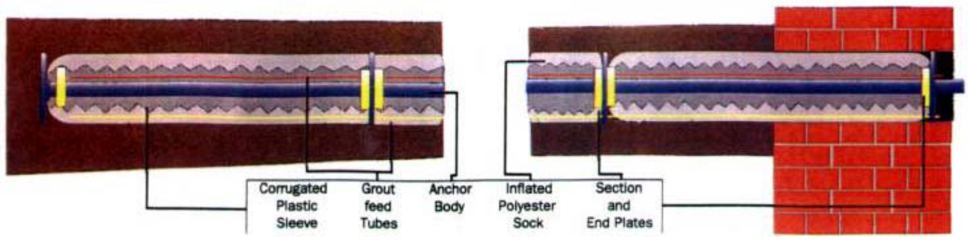

Figure 5. CINTEC anchorage system

The cracks are then pressured pointed and the ends of the stone cores reinserted to plug the holes at the face.

3.7 Guniting of Soffit

Guniting of soffit is a widely adopted technique, being non-disruptive to carried traffic and relatively economical. There are two principal drawbacks: firstly, the structure may be a cultural heritage construction, in which case the treatment would be visually unacceptable. Secondly, and of more significance for the future durability, is the failure of the method to address the most common cause of arch defects, water ingress from above. With time, this will detach the gunite skin from the arch barrel.

3.8 Overslabbing

At its simplest, overslabbing (Figure 6) consists merely of providing a load spreading slab to reduce local load intensity. It is of benefit to the barrel in that it allows the option of high-level waterproofing and it reduces lateral pressure on spandrel walls.

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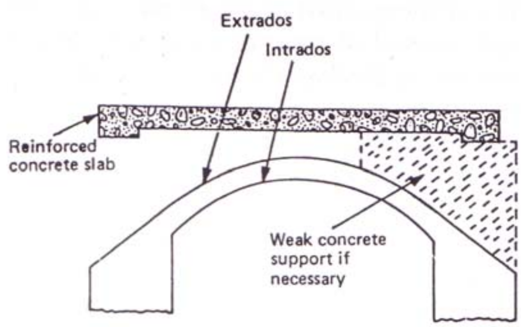

Figure 6. Overslabbing

3.9 Underpinning

Underpinning involves excavating material from beneath the foundations and replacing with mass concrete. A sequence of work is followed to ensure that the stability of the existing. Structure is not compromised. The work is labour intensive. The cases studied appeared to have been successful.

3.10 Replacement of edge voussoirs

Edge ring voussoirs are particularly prone to decomposition, due to their exposed position and the perpetual tendency for lateral load on spandrels to cause the face of the ring to detach.

To replace edge stones, it is usually necessary to provide a band of soffit shuttering to support the whole ring. While it is possible to remove stones individually without support, considerable awkward cutting is finally necessary to achieve a good soffit profile and displacement of the masonry above can occur.

3.11 Partial reconstruction

When arch ring damage is extensive, the only real resource is to rebuilt to a major extent. Construction is traditional in that it is necessary to build off centering, although several variations of constructional form have been adopted.

These are essentially mass concrete rings with articulating bands. Articulation can be achieved, at springing and quarter span points, by hard plastic formers, by bands of lime-mortar joined masonry or by open-laid bands of brickwork.

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4. MAINTENANCE

Routine maintenance consists of:

1) keeping the road surface in a good condition to maintain the waterproofing and to minimize dynamic loading from traffic due to potholes etc.
2) removing vegetation growing on the structure
3) repairing small areas of deteriorated mortar.

These three areas of maintenance involve modest expense compared with that which may result from neglect.

5. CONCLUSIONS

The problems arisen by bridge strengthening are very complex because existing bridges differ in structural materials, in construction periods, type and condition rating. The most frequent bridge building materials have been stone, wood, reinforced concrete and steel.

The causes of defects are material aging, environment pollution, poor maintenance, wrong repair works, and changes of live loads because design loads did not include the current ones due to the different type of traffic.

Any repair has to take into account not only defects and damage identified, but also the main features of the bridge, the intervention costs and operation difficulties.

Also, there are many stone bridges that are centuries-old and many of them are historical buildings, representing an important cultural inheritance. Therefore, their preservation is important, and the techniques used for their strengthening must be carefully chosen, to respond to both functional and structural demands and preserve their original characteristics.

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