STRENGTHENING AND PRESERVATION OF MASONRY STRUCTURES FOR CONTINUED USE IN TODAY´S INFRASTRUCTURE

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Abstract

An increasing number of historic masonry arch bridges need to be strengthened to current live loading requirements. The system utilises precisely placed, grouted stainless steel reinforcement and the benefits of the system are discussed. Both the accuracy of the assessment technique and the efficacy of the strengthening system have been verified against full-scale tests. The strengthening system can be applied to other classes of structure. It is concluded that the use of an innovative product is allowing historic structures to be preserved and retained as part of today´s infrastructure.

Keywords: Preservation; Strengthening; Masonry Arch Bridges; Retrofitted Reinforcement

1 Introduction

For example in the Czech Republic there are some 10,000 masonry arch bridges in daily use mostly on the roads of the third category, railways and canals. Most are over 100 years old, some are over 500 years old. Many of these pre-engineered structures are inadequate for modern live loading requirements.

Fig. 1 Baroque Masonry Bridge over The River Bilina, Czech Republic,
Railway Bridge between Chlumec nad Cidlinou - Turnov, Czech Republic.

This called into question the ability of many existing bridges to carry the increased load requirement. The cost of replacing in-service bridges is often prohibitively expensive and the cost of a temporary bridge and disruption to traffic also needs to be taken into account. Many

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masonry arch bridges are listed historical monuments, valued tourist attractions or local landmarks. Strengthening the bridge is often the only viable solution.

2 Existing methods of strengthening

A variety of strengthening methods are available. These vary in effectiveness and each has advantages and disadvantages.

2.1 Saddling

One of the simplest and most popular of the traditional methods is saddling. This involves removal of the fill to expose the extrados of the barrel. A reinforced or mass concrete flat or curved slab is subsequently cast in place over the original barrel.

Fig. 2 Woolbeding Bridge, Englan

Fig. 3 A Lined Bridge, England

Fig. 2 shows Woolbeding Bridge with the fill excavated prior to installation of a reinforced concrete saddle. Whilst saddling will undoubtedly increase the capacity of the bridge, with minimal change to the external appearance of the bridge, it is expensive and will cause considerable disruption to traffic and buried services which may be located within the fill crossing the bridge. The bridge is also in a temporarily vulnerable state once the fill has been removed, unless the barrel is supported from underneath which can be a costly process.

2.2 Sprayed Concrete

Another traditional method is the use of sprayed concrete applied to the intrados of the arch. This may be used in conjunction with a reinforcing mesh. Whilst this negates the need for drilling, the intrados is the part of the barrel exposed to weathering, resulting in friability. Applying sprayed concrete can cause moisture to be locked into the barrel. Other problems include poor composite behaviour and incompatible materials. **Fig. 3** shows a photograph of a lined bridge in North Lincolnshire, England. Sprayed concrete has been applied in conjunction with a corrugated metal lining.

2.3 Surface Reinforcement

There are proprietary systems available using a network of steel bars located in slots cut into the intrados and bonded using special adhesives. Such systems have been shown to increase the strength of the bridge. [1] However, access to the arch intrados is not always easy or possible. More importantly, the application of sprayed concrete and/or externally bonded or slotted reinforcement will have a detrimental effect on the appearance of the intrados. This is un-desirable in many situations and unacceptable for many structures of historic importance.

3 The Strengthening System

The Archtec strengthening system involves drilling through the road surface to install internal reinforcement into the arch, without causing any change to the existing appearance of the bridge and with minimal environmental disruption.

3.1 Retrofitted Reinforcement

A proprietary system known is used to enable reinforcement to be accurately retrofitted. The reinforcement anchor consists of three main components, a stainless steel bar, a fabric sock and a cementitiuos grout. The stainless steel bar provides increased tensile and compressive capacity. The woven polyester sock permits sufficient leakage of grout during inflation to develop a chemical and mechanical bond with the surrounding masonry whilst protecting the masonry from being displaced or otherwise damaged by the pressurised grouting and limits the volume of grout escaping into the surrounding masonry. The grout used is similar to Portland cement based products. It is easily pumpable with good strength characteristics and no shrinkage. The use of stainless steel and a high performance grout give enhanced durability and as the anchors are installed internally in the arch barrel, no maintenance is required. **Fig. 4** shows typical anchor positions for a single span masonry arch bridge and a view of the typical method of installation.

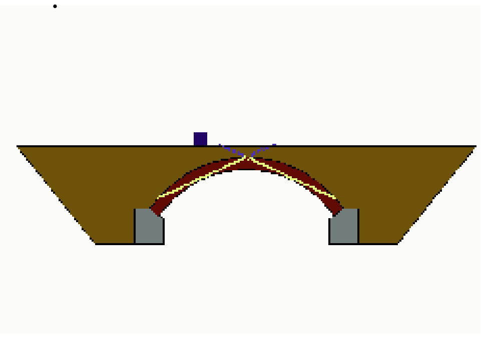

Fig. 4 Typical anchor positions and installation of reinforcement from the road surface.

Fig. 5 Convenient object for installation of reinforcement from the road surface, Czech Republic.

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3.2 Structural Analysis

The performance of the existing structure and the strength enhancement provided by reinforcement is predicted by numerical simulation using the DE method. This calculates the strength deficiency and targets the internal reinforcement where required.

3.3 Design Process

It is widely recognised that most masonry arch bridges fail in a manner that shows distinct hinge points. Targeting the reinforcement to where the hinges are predicted to form reduces the material used and thus the material cost of the system. Reinforcement is placed in a longitudinal direction in the arch barrel, approximately tangential to the curvature of the arch, generally around the quarter point, although the exact positioning to make optimal use of the strengthening is determined using the DE analysis method described. Depending on other specific defects observed during the visual inspection, reinforcement may also be installed in a transverse direction through the elevation of the arch barrel. In bridges where ring separation is a problem, radial anchors may also be appropriate.

3.4 Installation

The main longitudinal anchors are most often installed from the road surface, although installation from below or from adjacent arches in a multi-span structure can also be used.

3.5 Visual, Environmental and Heritage Benefits

The system has many visual, environmental and heritage benefits. The system involves minimal structural intervention. Strengthening is targeted only where it is required, utilising the existing structure to its maximum potential, thus reducing the amount of material resources required. The system needs no maintenance once installed. Disruption to traffic is minimised and no heavy construction traffic is required. The use of the fabric sock prevents grout leakage, especially important in installation over water courses. The system leaves no external visual trace.

3.6 Generic Applications

The engineering principles applied to the masonry arch bridge in the preceding part of this paper can be equally applied to other classes of structure subject to other loading effects. Numerical analysis using the DE technique is a generic tool and the system can be used in a wide range of masonry repair and strengthening applications.

4 Conclusions

The system is a suitable method of strengthening masonry arch bridges that has been proved to be cost effective and environmentally sympathetic. To date, many bridges have been successfully strengthened using this technique. The innovative anchor design and DE method can also be applied to other classes of structure including seismic and blast assessments and research is ongoing.

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References

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