Large-scale Testing of Retro-reinforced Brick Arches

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Summary

Vertical static load tests on sixteen 2,95m span multi-ring clay brick arches were carried out to investigate the effectiveness of retro-fitted steel reinforcement as a strengthening measure. The principal parameters investigated were the arch geometry; arch ring thickness; area and distribution of reinforcement; type of inter-ring shear reinforcement and mortar strength. In each case a full width line load was applied incrementally to the upper surface of the arch at quarter span until collapse occurred. In all cases, longitudinal reinforcement was found to delay the onset of cracking and to increase the load carrying capacity. Radial dowels were found to be the most effective means of preventing ring separation and the simplest and quickest to install. Longitudinal reinforcement was found to be the most effective when used with measures to prevent ring separation.

Keywords: Arch bridges; masonry; reinforcement; repair; strengthening; testing.

1. Introduction

It is estimated that has indicated that there may be in the order of 40000 masonry arch highway bridges and 30000 masonry arches carrying railways in the UK alone. It has also been reported that there are approximately 123000 railway bridges in Europe of masonry construction. Most of these bridges were constructed between the second half of the eighteenth century and the beginning of the twentieth century and many are now in need of repair or strengthening to meet modern operational demands. Various repair and strengthening measures have been developed for masonry arch bridges and other masonry structures. One such technique is near-surface reinforcement or "retro-reinforcement" [1]. This involves the installation of stainless steel reinforcing bars, usually between 6mm and 16mm in diameter, into grooves or holes that have been previously cut or drilled into the readily accessible surfaces of the bridge where tensile stresses are likely to occur. Typically bars may be installed in the intrados (or soffit) of the arch barrel and the exposed faces of the piers, abutments, spandrels, parapets and wingwalls. The principal aims of adding such reinforcement are to improve flexural crack control, increase flexural and shear strength and to increase robustness and ductility without causing a marked change in the structural behaviour.

To date, experimental studies of retro-reinforced brickwork arches have been limited to the small scale testing of single ring arches, very small-scale tests in a centrifuge or to tests on full-scale multi-ring arches in which very few parameters were varied. Multi-ring brick arches with fibre reinforced polymer sheet reinforcement have also been tested under static and long-term cyclic load conditions. This latter research also investigated the behaviour of radial pin inter-ring shear reinforcement. As far as the author is aware, the research summarised in this paper is the first in which the mortar type, the amount and distribution of longitudinal and inter-ring shear reinforcement and the arch geometry have been varied within a large-scale test programme.

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2. Summary

The main findings from the tests briefly described in this paper are:

a). All the retro-reinforced arches behaved as reinforced brickwork structures; the retro-fitted reinforcement behaved compositely with the brickwork in all cases. There was no evidence of any premature de-bonding failures at either the grout/brickwork or grout/reinforcement interfaces.

b). There were no discernible differences in the structural behaviour of the reinforced 2-ring and 3-ring arches or of the arches with different span : rise ratios (4,0 or 2,5).

c). There were no discernible differences in the structural behaviour of the arches reinforced with different arrangements of longitudinal reinforcement or with different distributions of inter-ring dowel reinforcement.

d). Longitudinal reinforcement installed in the arch intrados close to the surface was found to delay the onset of first cracking and to increase the load carrying capacity. This confirms the findings from the small-scale model qualitative arch tests previously carried out by the author [2]. All the reinforced arches behaved in an under-reinforced way with no signs of compression failure, even in the arches constructed from the lower strength brickwork.

e). Contrary to the research into the behaviour of multi-ring brick arches strengthened with external fibre reinforced polymer sheet reinforcement, none of the arches strengthened with steel bar reinforcement reported in this paper failed at a lower load than that of the un-strengthened control.

f). Longitudinal reinforcement was found to be effective as a strengthening measure whether installed in pre-cut grooves or pre-drilled holes. Reinforcement installed in grooves is more structurally efficient because of the larger effective depth, but bars installed in pre-drilled holes are less visually intrusive.

g). The mortar strength had a significant influence on the performance of the reinforced arches without inter-ring shear reinforcement. Those constructed using weaker mortar (compressive strength of the order of 2 - 3MPa) were found to be more likely to develop ring separation and to fail at lower loads than those built of stronger mortar (compressive strength of the order of 6MPa).

h). The arches that were reinforced longitudinally showed the greatest increases in load capacity when they were also fitted with reinforcement to prevent inter-ring shear failure.

i). Radial dowel reinforcement, installed through the full depth of the arch ring, was found to be more effective at preventing an inter-ring shear failure (ring separation) than U-bars and was easier to install. Given the variations and uncertainties in the mortar condition and bond strength that are likely to occur in practice, it is recommended that dowel reinforcement should be installed when refurbishing or strengthening multi-ring brick arches.

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References

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