THE USE OF MASONRY ARCH BARREL REINFORCING SYSTEMS

This note has been prepared by Gifford to assist The Bridge Owners Forum in preparing guidance on the use of arch reinforcing systems.

1. DETERMINING SUITABILITY AND MAKING THE BUSINESS CASE

Retro-reinforcement techniques can provide effective and economic methods of restoring and strengthening masonry arch bridges where the following issues are of importance;

- **Modest scope** of the required works; retrofitted system generally require a very modest scope of work and are relatively un-intrusive compared with other solutions such as saddling or reconstruction.

- **Ease of installation**; retrofitted system can generally be installed from above or below a bridge with relatively simple access arrangements.

- **Speed of installation;** retrofitted solutions can generally be installed in short time periods and if necessary the activities can be relatively easily undertaken in series of short road/lane closures or railway processions.

- **Ability to accommodate existing services;** it is usually possible to work around them thereby avoiding complex accommodation measures or expensive diversions.

- **Minimal disruption to users;** as a consequence of the aforementioned points.

- **Low Cost;** as a consequence of the aforementioned points.

- **Reduced Risk and Improved Safety;** as a consequence of aforementioned points.

- **Good whole life performance** provided that the technique has been properly tested and developed and makes use of long proven materials and components.

- **No or minimal effect on the appearance;** which can be of particular importance in relation to historic and listed bridges.

As with any technique, retrofitted strengthening solutions are not appropriate in every situation and in addition to the normal considerations the following particular points should be addressed when assessing the suitability in each case;

- Track record and experience

- Design basis and extent of verification undertaken

- Adequate life cycle performance

- Condition of the bridge

- Adequacy of substructures and foundations

- Installation

- Required maintenance and inspection regime.

Guidance on evaluating particular techniques for specific bridges is provided in the following sections.

2. TECHNICAL CRITERIA AND GUIDANCE

Standardised approaches to design, verification, specification and implementation of retro-reinforcement techniques do not yet exist and it is therefore important to establish the suitability and efficacy of a particular technique in relation to each specific project. The following notes provide guidance on carrying out this evaluation and identify the issues to be considered in undertaking a risk assessment to review the suitability of a retrofitted strengthening solution and to be addressed in the formal approval process.

2.1 Record and Experience of Propriety Contractor and Designer

- Currently available retro-reinforcement techniques are propriety systems provided on a design and build basis by specialist contractors.
- Whilst the benefits of encouraging innovation are recognised, strengthening systems should have some established track record on similar structures.
- The experience of the contractor and his designer of similar projects should be critically reviewed and, where appropriate, references sought.

2.2 Design Basis and Extent of Verification Undertaken

- The design approach and the method of structural analysis should be verified against appropriate tests of arch bridges at both ultimate and service load levels.
- The form and condition of the test bridges and the construction materials should be representative of the bridges to which the system is applied.
- The strengthening must retain or improve the natural ductility of masonry arch bridges and should not introduce potential failure mechanisms that could occur without obvious prior distress being readily identifiable.
- The design method should take account of the real condition of the specific arch and should not be based on simple extrapolation of test results that may not be representative.
- The verification process should be fully documented and reported.
- The verification of the design approach and method of structural analysis should be independently checked (Category III) and whilst this should include a review of the appropriateness and adequacy of the tests undertaken it is not expected that the tests themselves should be repeated.
- Load factors should be based on BD 21 for strength assessment and design as appropriate. Justification for load factors including consideration of lift-off, impact, dynamic augmentation, centrifugal, lurching and load frequency should be agreed on a project by project basis.
- BD 91 should not be used since this relates to the design of unreinforced masonry arch bridges. Implicit to its rules are new highway alignment standards so for example additional load factors due to lift-off and centrifugal effects are not considered.

2.3 Adequate life cycle performance

- The assessment of existing arch bridges and design of new arch bridges is conventionally carried out at the ultimate limit state. The ultimate load factors include an empirical allowance to cover serviceability and there are no specific serviceability criteria specified.
- It is recognised that retro-reinforcement strengthening of masonry arches partially modify the structural behaviour of an arch and it is considered prudent to give some additional consideration to the effects on serviceability.
- Serviceability limiting criteria for masonry arch bridges are yet to be established and rigorous assessment of serviceability is not possible. However, the Structural Responses (eg displacement, intrados strains and primary masonry stresses) that drive serviceability are known and therefore comparison of these responses in the unstrengthened and strengthened bridge can provide an indicator of the effects of the strengthening on serviceability.
- Maximum key Structural Responses in the masonry following strengthening should not exceed the maximum in the unstrengthened bridge under its maximum assessed load capacity, unless evidence to justify higher values can be provided.
- Adequate endurance of the retrofitted reinforcement system (ie of the reinforcement itself and the bond between reinforcement and the masonry) under cyclic loading for the

required service life should be established on the basis of representative laboratory cyclic load tests.
- The durability of the retrofitted reinforcement system should match or exceed the residual life of the existing bridge. The use of Stainless Steel (BS EN 1.4301) and cement based grout will normally comply with this condition.
- Adequate performance of the reinforcement and its bond with the masonry under environmental effects such as freeze-thaw, moisture content, chemical attack and temperature cycles should be demonstrated.

2.4 Condition of the Bridge and the Arch Barrel in Particular

- Adequate investigations, inspections and surveys must be undertaken of the existing bridge to provide a reliable basis for design of the strengthening. This should include confirmation of the general condition, degree of masonry weathering and structural dimensions and any other data required in relation to the proposed design approach.
- The degree of masonry weathering and the condition of the intrados surface is of particular significance where surface installed reinforcement is proposed.

2.5 Adequacy of substructures and foundations

- The horizontal thrusts developed at the abutments should be limited to those arising from the assessed load capacity acting on the unstrengthened bridge, unless evidence to justify higher values can be provided.
- Any increases in vertical loads on the substructure and foundations in the strengthened bridge should be assessed in relation to the overall foundation loads. Often, it is found that increases in live load are insignificant compared with the dead load of masonry arch bridges. This may not be the case for small bridges where more detailed foundation assessment may be required.

2.6 Installation

- The temporary stability and effects of concurrent loading during installation should be considered and adequate measures put in place such as a specified sequence of working, the erection of temporary works or props and control of concurrent bridge usage.
- Particular care is needed in this respect where chases or transverse holes are required to be cut or drilled into the intrados of the arch.
- The methods of installation (eg drilled holes, machined slots, scarification etc) should be selected to avoid damaging or irreparably weakening the bridge as a result of vibration etc.
- During installation, if the arch bridge remains open to traffic, it must be demonstrated that early age loading of reinforcement will not damage its bond with the masonry. This may require phased working and local exclusion of traffic or the installation of reinforcement in such a way that it is not loaded until the bond has achieved full strength.
- Appropriate quality control procedures should be agreed which may include collation of confirmatory data from installation activities, load tests to confirm reinforcement bond, cover meter surveys to confirm reinforcement locations and strain gauging of components to confirm they are functioning as expected.

2.7 Required maintenance and inspection regimes

- The strengthening should, ideally, have minimal impact on conventional arch bridge inspection and maintenance regimes.
- Guidance should be provided as to any additional aspects that should be included in the subsequent inspection and maintenance regimes of the strengthened bridge, including the likely signs of potential deterioration or failure of the strengthening components.