

1

Chris Austen, Bestech Systems Ltd, explains how computer software has been developed to assist the process

Masonry arch bridge assessment

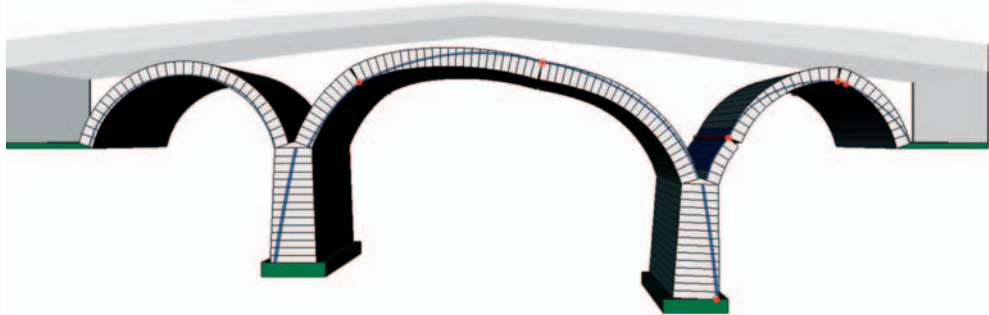
Although the masonry arch bridges which form the backbone of much of the UK's transport infrastructure are typically a century or more old, there is no reason why the assessment tools used to verify their safety need be of a comparable vintage. Indeed our understanding of how arch bridges behave has moved on significantly since the canal and railway building eras, and also since the day of notable engineer Alfred John Sutton Pippard, whose work in the 1940s led to the well known MEXE method of assess-

ment for masonry arch bridges.

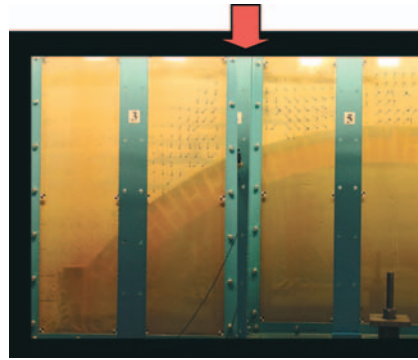
In contrast with MEXE, modern computer based analysis tools can help the engineer understand how a masonry arch carries load, how it might fail if overloaded, and, as will be demonstrated in this article, can also rapidly answer the kind of 'what if' questions engineers often face. And with in excess of 30 000 masonry arches on the UK rail network alone, it is also significant that computer-based methods can satisfy the requirement that an initial analysis model can be created and run

rapidly (and can also easily be refined as and when the need arises).

When the UIC (International Union of Railways) launched an ambitious masonry arch bridges research project in 2002 they were keen that one of the outcomes should be the availability of a new analysis software package, fit for 21st century engineers. As a way of fulfilling this objective they chose to sponsor the development of a new version of the well known RING masonry arch bridge analysis software (now developed by



2



3

Fig 1. Railway loading on multi-ring brickwork arch bridge (generated using LimitState:RING 2.0) / Fig 2. Load path (line of thrust) in a bridge following movement of a support (generated using LimitState:RING 2.0) / Fig 3. Large-scale test chamber incorporating clear sides housing a soil-arch interaction test (Courtesy Universities of Salford and Sheffield; tests sponsored by Essex County Council, Network Rail and EU)

LimitState Ltd and distributed by Bestech Systems Ltd). The resulting software, LimitState:RING 2.0, identifies the factor of safety on any specified vehicle loading at collapse, and allows the user to clearly visualise the associated failure mechanism, whether this involves one, two or more spans. The software can be applied to highway and railway bridges, and has a built-in library of loading vehicles (Fig 1).

Although traditionally, computer-based analysis tools applied to masonry arch bridges have either been very simple (e.g. 'mechanism analysis' programs incorporating *ad hoc* algorithms to search for the positions of four hinges), or have been very complex (e.g. based on non-linear finite element methods, which can experience convergence and other problems when non-tensile resistant materials are involved), LimitState:RING uses rigorous mathematical optimisation techniques to directly identify the critical load path and mode of response of the structure, idealised as an assemblage of rigid blocks. The general formulation means that there is no restriction on the number of hinging or sliding planes between blocks which can form.

Cracked masonry

It is often suggested that the cracked state is the natural state of masonry. Certainly it is rare to find a traditional loadbearing masonry structure of any size which is entirely devoid of cracks. Whether the cracks are of concern or not will generally depend on their root cause, which is sometimes not obvious. A new feature in LimitState:RING 2.0 is the ability to impose support movements so as to be able to view crack patterns and hence to help diagnose the underlying causes of observed cracks. Support movements can also be imposed simply as a means of identifying potential load paths (as demonstrated by William Barlow in 1846 there are an infinite number of possible load paths in an uncracked masonry arch, but once cracks form, load paths become clearer, as illustrated in Fig 2).

System behaviour

It is important to realise that even a single span masonry arch bridge acts as a system of interacting elements, rather than as a single element. Indeed in the case of a masonry arch bridge backfilled with soil it is not uncommon to find that 90% of the load carrying capacity can be directly attributed to the presence of the soil, which adds dead weight, disperses the applied load and provides horizontal restraint to movements of the arch barrel. Soil-arch interaction is complex, though modern digital imaging technology which allows individual soil particles to be tracked is ensuring that laboratory tests are now proving exceptionally useful in helping us to better understand behaviour (Fig 3). Perhaps most significantly, these tests are also being used to validate and, when necessary, improve the soil-arch interaction models



used by software such as LimitState:RING.

The role of internal spandrel masonry

Many bridges, especially those on the rail network, contain hidden internal masonry elements, such as backing, haunching, and/or spandrel walls, rather than soil backfill.

Unfortunately the geometry of these elements is diverse making them difficult to specify via simple user entry dialogs in a program. To address this, developers at LimitState Ltd have been working on a CAD import facility for the next major release of the LimitState:RING, allowing users to import any geometry from a CAD file.

Dr Matthew Gilbert, Senior Lecturer at the University of Sheffield and originator of the RING software had an early opportunity to test out the new functionality when he was

recently asked by the Bosnian Government to join a small international team charged with investigating the likely causes and potential significance of cracks which have appeared in the recently rebuilt Old Bridge in Mostar, Bosnia and Herzegovina (Fig 4).

This bridge, arguably the most iconic masonry arch bridge in the world, was carefully reconstructed and reopened in 2004 after being destroyed in the Bosnian war in 1993. Efforts were made to faithfully reproduce both the original distorted geometry of the arch and the materials used in the original structure.

Before visiting the bridge site Gilbert was able to import the bridge geometry from a CAD file which had been emailed to him. The bridge contains spandrel walls at the edges of the bridge and also internally. In the absence

of survey data it was then possible to impose a series of different types of relative support movement to establish the likely mode of response of the structure in each case – and in each case to obtain predicted crack patterns. This led to particular locations being identified as warranting close inspection in the subsequent site visit.

Although the crack patterns observed on site (and also the survey data which later became available) did not support the conjecture that support settlements were the cause of the observed cracks, the usefulness of the software as a forensic investigation tool is clear. se

- Further information: See website: (www.masonryarch.com), or email: (ring@bestech.co.uk).



Fig 4. Settlement analysis of the Old Bridge, Mostar, using geometry derived from CAD drawings prepared for its reconstruction (generated using LimitState:RING 3.0 beta)