



## Load-carrying capacity of masonry arch bridges estimated from multi-span model tests

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The authors report the small-scale experimental work they have undertaken on multi-span arch bridges. In addition, they have combined these results with earlier tests on small-scale single-span arch structures<sup>7</sup> and produced an equation that represents the summation of the work to date.

The authors are to be congratulated for undertaking a significant series of tests in an area where there are limited other results, with one notable exception.<sup>10</sup> The tests should provide the basis for further theoretical work on multi-span arches. My own experience has been on the analysis and assessment of multi-span bridges<sup>18</sup> and perhaps this allows me to comment on the usefulness of the data from that standpoint.

The experimental work covers a wide range of both soil/backing material properties and depth of fill. No attempt was made in the experiments to consider the effects of the arch geometry or, perhaps more importantly, the effect of the intermediate pier geometry which is of major concern to many engineers undertaking assessments on multi-span arches. The 60 tests reported are for effectively one geometry of arch but with six soil depths and ten load positions.

It may appear a gross generalisation but in my experience the depth of fill over multi-span arches generally has less variation than over single-span structures; in fact the soil depth is on average much less for multi-span structures. For those multi-span arches with significant piers it would be normal practice for the designers to raise the extrados at the crown level up to that of the formation of the road-over carriageway by simply extending the piers. For single spans, the arches tend to be founded at ground level and then with an appropriate span/rise ratio to allow traffic to pass under the structure. If the formation level of the road-over surface was greatly above this, then significant fill material was used. Therefore, in future work, perhaps some consideration could be given to the variations in arch geometry, for example span, rise, and ring thickness.

In undertaking the regression analysis the authors have added the 60 multi-span results to those of the 120 single-span results contained in the earlier paper<sup>7</sup> to produce 180 data points for statistical regression. The 120 results were for only

two geometries of arch, one with a span-to-rise ratio of 2 and the other with a span-to-rise ratio of 4. Again, six different soil depths and ten loading positions were tested. The results in total cover only three geometries and therefore the statement in the paper that 'The combined set of results covered the majority of the range of parameters likely to be experienced in arch bridge assessment' is perhaps an exaggeration.

The regression equation produced by the authors is repeated below for ease of discussion.

$$4 \quad W = 2.45h - 65.7(x_s)^{0.1}67.0n_a + 45.6s_r + 6.71s_r$$

There appears to be a mistake in that the second expression on the right-hand side should presumably be split.

Could the authors explain the origin of the equation they have developed. It is more usual to use a multilinear regression from which a product-based expression is developed rather than the additive form presented.

The authors appear to be promoting this equation not just as a representation of their small model results but as an equation potentially to be used in assessments of real structures. There are a number of problems with the use of this equation.

- The equation is dimensionally incorrect in that the left-hand side contains force units (N) while the right is a combination of length units (mm), sometimes raised to powers, and other non-dimensional parameters. This makes it difficult to transfer to real structures.
- The number of arches ( $n_r$ ) can only take the value 1 or 2, from the base data, which suggests that all multi-span arches have a constant strength enhancement of 67 N over identical single-span structures. This would seem very small for a full-scale structure. It also suggests that the more spans, the stronger the arch—which again does not appear logical.
- It is difficult to see how the span-to-rise ratio ( $s_r$ ) could properly deal with multi-span arches of different span-to-rise values when there are no test results on which the regression expression can have been based.
- Similarly, all the tests for the single-span and all the tests

for the multi-span arches were with the same ring thickness: 35 mm for the single- and 15 mm for the multi-span. It is therefore difficult to see how the regressed expression can properly deal with variations in ring thickness.

- (e) Finally, the authors present the results, in Table 2, of applying this equation to the geometries of the full-scale tests. It is difficult to see how the equation in the above form can be applied to real structures. Also it does not contain any of the parameters considered in all assessment methods, for example ring thickness or arch span.

In responding to this discussion perhaps the authors, for

clarity, should expand on the actual calculations undertaken to produce the results presented in Table 2, possibly with an example.

**Author's reply**

The authors declined to reply to this discussion.

**REFERENCE**

18. HUGHES T. G. The analysis and assessment of multispan masonry arch bridges. *Proceedings of the Institution of Civil Engineers Structures and Buildings*, 1995, 110, 373–382.