A simple, first filter assessment for arch bridges

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ABSTRACT: The number of arch bridges in continuing use is such that full scale quantitative assessment cannot be undertaken at a rate commensurate with deterioration. Visual inspection by trained artisans is a more frequent process.
The MEXE method of assessment is well established throughout the world. Recent studies, and examples, have sown that it may over estimate capacity of some smaller bridges. There are also some difficulties in application where required dimensions are not easy to measure and do not deliver useful discriminatory evidence. Arch builders produced remarkably consistent capacities across the range of structures.
A new approach is presented which begins with 19thC rules of thumb. The user is required to estimate the true shape of the arch, the relationship between span, rise and ring thickness and the amount of fill. This leads directly to an indication of capacity for a sound bridge

1 INTRODUCTION

The railway companies of the world, through the Union International Chemin der Fer have decided to develop a new tool for first level assessment of arch bridges. This paper describes the reasons for that decision, the processes of development and the current state of the model. The aim of presenting this paper, with the development incomplete, is to open discussion on the process in the hope of improving the robustness of the final model.

2 BACKGROUND

2.1 The problem

There are very many arch bridges around the world. The largest number were built during the railway era from perhaps 1825 to 1900. Railways demanded relatively level tracks but could not achieve that as canals did by following the contours. Speed of travel was the whole purpose of the railway and the supreme exponent was perhaps Brunel who alone foresaw the need for a wider gauge and level straight tracks. Stephenson's east coast route achieved a remarkably good alignment through difficult country but we haven't yet approached the limiting speed for Brunel's track.

Straight level tracks require cuttings and embankments which disrupt intersecting roads, tracks and field access. Railways needed huge numbers of accommodation bridges and the acknowledged current bridge stock, 180,000 in Italy, 100,000 in France, 70,000 in UK reflect that.

Since the railways were built the owners have assumed that arch bridges have no limit to capacity. This assumption has been reinforced by the crude assessment tools that have been available. It has also been sustained as a result of divisions of responsibility so that repair, maintenance and even replacement of bridges is in different hands from assessment. Assessing engineers do not learn that some bridges fail at loads much less than their assessments.

So, we need an assessment tool that delivers real distinction between sound bridges and those which may break up over time. The sheer number of bridges, though, means that we also need a tool that will allow artisan inspectors to provide a first line view of arch assessment.

2.2 Concepts

The established first level assessment tool, MEXE, is actually remarkably complex. It is certainly too complex for artisan use. The version commonly used for railways is also wrong. Not only does the basic analysis underpinning MEXE fail to represent the real behaviour of arches, there are a number of errors introduced during the development of the railway version (Harvey 2006). The most significant of those is the distribution of bogie loads over a length of 2.5m+2h which can only occur when the fill depth is greater than 1m.

The primary concept of the new approach is to shift the question from what load will this ring carry to what ring is required to carry this load.

A new distribution model has been developed which matches real arch behaviour more closely than the existing so called effective strip.. Using this model, it became clear that the old rules of thumb were remarkably good at delivering bridges with consistent strength. It is therefore possible to create simple charts from which an assessment can quickly made.

2.3 Development

Development of the method required a fresh analysis, without which the results would continue to over-estimate the capacity of some bridges. That analysis will be set out in detail elsewhere and in summary below, but the results are relatively simple. Once it became clear that there was a straightforward relationship between strength and geometry, it was possible to create very simple charts for use in the field.

3 ANALYSIS

3.1 Load distribution in arch barrels

In the great majority of assessment tools, the arch barrel subjected to patch loads is first reduced to a strip subjected to a load spread across the full width. That this is a poor representation of real behaviour has long been understood, but only recently has an approach to distribution within the barrel been brought forward ref. Through a combination of reviewing test results, exploring behaviour through simple FE analysis and comparison with long established results, it became clear that the arch barrel behaves very much like a wall (Harvey 2002), distributing the thrust in a pattern that relates closely to the Boussinesq result for an elastic field. It is necessary to superimpose on this a modification to take account of the finite width of the bridge. The model, however, remains simple to implement. The results used for the development of this method were delivered through a spreadsheet.

3.2 Load distribution in fill

The established model of distribution through fill in railway under line bridges has two independent elements. Transverse distribution is assumed to take place entirely in the fill, producing a rectangular pressure at the extrados of the arch. This, in itself, is clearly wrong. The distribution will certainly have a gentle edge and such an edge is actually easier to deal with computationally. Longitudinally, it is assumed that much distribution takes place within the track system, but it seems likely that the stiff base of the arch reduces the distribution from the track. In any case, a simple Boussinesq model from a single line load delivers very similar distribution to the complex two stage model defined for railways.

3.3 Load paths ignored

Throughout arch assessment it is always assumed that the spandrel walls contribute nothing to the capacity. What is more, a first level assessment tool is expected to deliver satisfactory results for bridges which may have many hidden strengthening elements. Of these, perhaps the hardest to detect is a ring which is slightly thicker at the springings than at the crown. Such thickening is rarely expressed in the exposed elevation. Other elements include masonry or concrete backing (flat topped) or haunching above the arch and, indeed, internal spandrel walls with either hollow or filled construction.

3.4 Loads not considered

There is some evidence, though not yet in the public domain, that moving loads develop a horizontal pressure wave in the soil which impacts on some arch bridges more than others. No quantitative values are available fir the effect of such a wave so it is impossible to include it in the process. On the other hand, it seems likely to have a more substantial effect on exactly those bridges of modest span and shallow fill which are known to fail at loads lower than the assessed capacity.

3.5 Conservatism

Over most of the range of bridges covered, the capacities indicated are believed to be conservative. That is chiefly because bridges are known to have alternative load paths which can be mobilised if necessary. It remains certain that this model, like most others, shows rapidly increasing capacity for very small spans and there is some reason to think that is not the reality.

4 OUTCOMES

The study produced strong evidence for substantial distribution of thrust in the arch. The live load thrust effectively spreads across the width of the arch as it flows towards the abutments. The evidence came from FE analysis, from older tests and from analysed elastic behaviour. A spreadsheet model was built, based on Boussinesq pressure patterns and a range of bridges was analysed using this tool. For simple square bridges, the required ring for 25 tonne axles with various levels of fill depth are presented in figure 1.

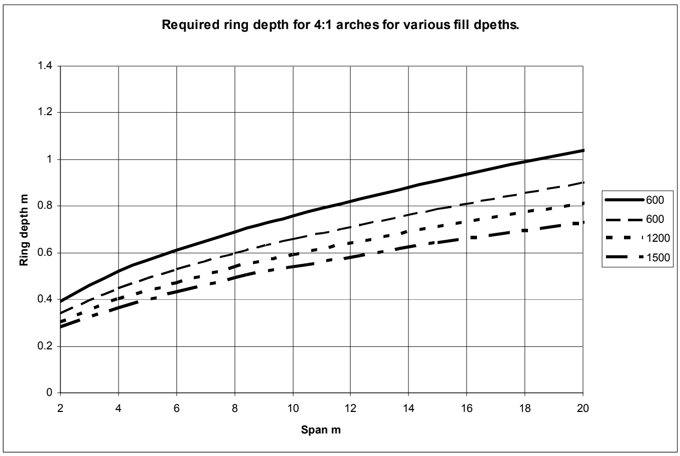

Figure 1 Ring thickness required for various fill depths, 25tonne axle, Span/rise 4

In each case, the fill depth is measured from the top of rail level.

5 APPLICATION

5.1 Observation

The first requirement of effective assessment is sound observation and measurement. The inspector should begin by considering the basic form of the structure, in particular, the shape of the arch and whether it has changed with time. A note should be made of whether the arch is skewed, and whether there is any observable damage.

5.2 Measurement

The traditional approach of measuring span, rise and quarter point rise is largely ineffective. The quarter point rise is very rarely measured with sufficient accuracy to allow a distinction to be made between likely arch shapes, or even to distinguish whether the arch has distorted. For first level assessment, measurements should be made using a pocket distomat and a small piece of angle to attach to the bridge as a reflector where necessary.

Using these tools it is possible to measure the width of the abutments or piers, the span at each edge of the abutment or pier and the two diagonals. With a little care, it is also possible to measure the rise and ring thickness from a moderate distance using references to the abutment edge to provide plan dimensions. Putting these measurements into a simple spreadsheet will allow a rapid check for rationality. It should be anticipated that all leading dimensions, including radius will be in round numbers of whatever units are used. Thus the smallest measure in metric units might be decimetres for major dimensions and centimetres for minor ones such as the ring thickness. In the British system, the modules would be feet, thirds and quarters, with round numbers of inches used for the ring thickness.

5.3 Processing

Once it is clear what the span and rise of the structure are, and an estimate has been made of the fill depth, it is a simple matter to look up the required ring depth for a particular load and compare that again set the observed depth. Approaching the assessment in this way gives a clear indication of the sensitivity of the process to the ring depth and allows he inspector to use judgement sensibly in acquiring data.

5.4 Alternative forms

As an alternative to a complex system of graphs, the original MEXE method used a nomogram, the basis of which is worth considering. The basis of a nomogram is the use of logarithmic scales. The linear scales shown in figure 2.

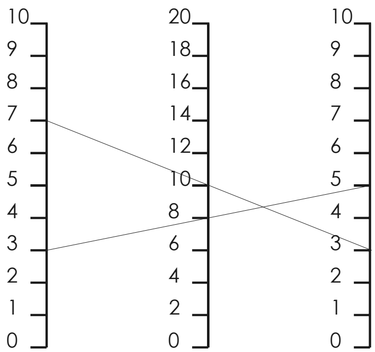

Figure 2

A nomogram can thus be constructed to represent the rule of thumb for arch ring thickness offered by Trautwine.

5.5 Recording

The leading dimensions should be recorded in a standard layout so that it is easy for anyone reviewing the work to check the numerical conformity. Wherever possible, the recorded data should include a photograph of the elevation of the bridge from which detailed dimensions might be recovered if necessary. To this end, it is probably sensible to try to orient the camera image plane vertical and parallel to the edge of the arch.

6 CONCLUSIONS

A new simplified approach to assessment is proposed to allow first level assessment by artisans. The method is robust and much simpler to apply than MEXE and does not require the use of calculators or computers. It is intended that the method should be used as a first sieve in order that the efforts of overstretched engineers can be concentrated on bridges which may present problems.

REFERENCES

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