Bridge of the Month No19 July 2012
Bridgemill

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Bridgemill no longer exists. It stood on the A77 near Girvan at http://goo.gl/maps/wxioU (you can see the old road between the cottage and the new bridge. It was tested, notionally to destruction, in 1984. The test has been used as part of the justification for a number of non-sensical statements about arch bridge behaviour. The test is therefore worthy of serious review here. Other publishers are reluctant to present reviews of such old data, not least because they carry the stamp of the Highways Agency (HA) and the Transportation Research Laboratory (TRL).

The real problem here is that we all understood masonry bridges much less well in those days. As a result, there were issues with the test and with the interpretation of the outcome. Having spent a few days reviewing this for a BoM, I must now write it up in more detail as a paper.

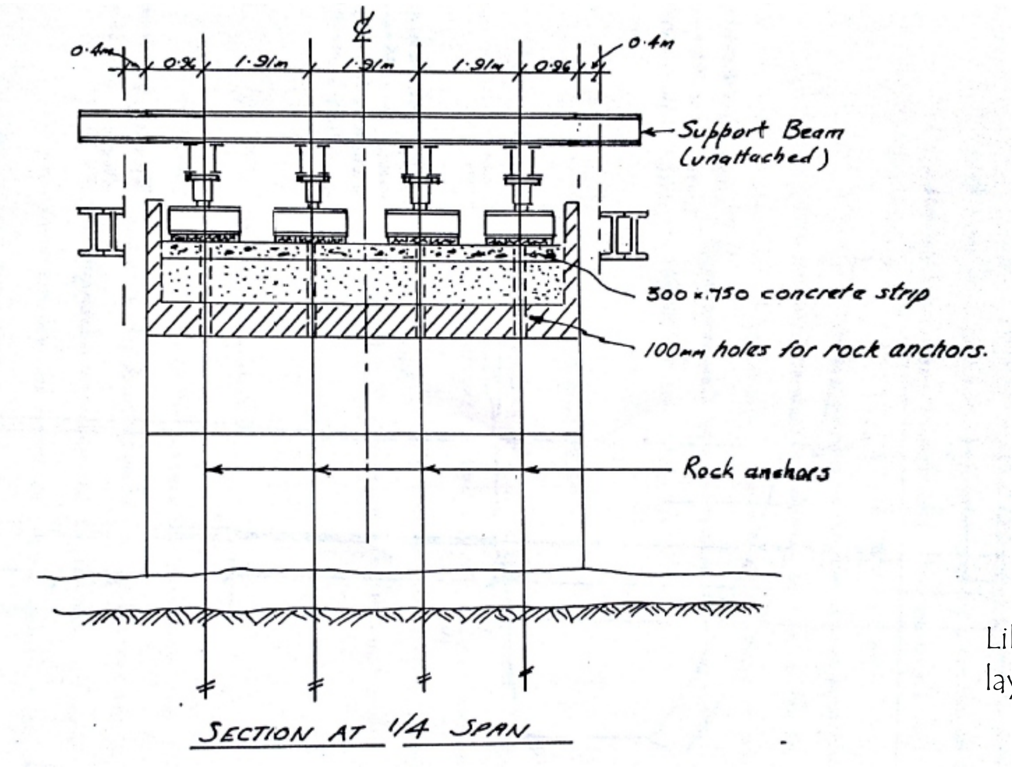
The bridge is typical of its period. Built at the height of the railway era in 1846, though not associated with a railway, we can be reasonably sure we understand the construction.

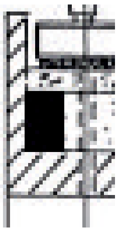
The bridge is recorded as having a span of 18.299m, rise of 2.845m and a ring of 0.711m Silly sounding numbers until they are re-interpretted as 60ft, 10ft and 28in. Of course, the arch sagged when the centring was struck so the rise measures 9ft 4in! The road surface was essentially flat and the cover a mere 200mm at the crown.

The 10ft rise gives a radius of 50ft which seems much more likely than the 52ft or so from the measured dimension. This photograph was taken before any load was applied. The slope of the beds in the spandrel, compared with the steel beam, is clearly visible at both ends of the span.

The test report declares the shape to approximate closely to a parabola but it is actually much close to a circular curve and there is no logical reason why the builder would produce a parabolic shape.

This photo has been pushed pretty hard but shows the loading system and the bridge width. The centres of the loads are 1.91m with a 0.96m edge distance so the overall width is 31.36ft which actually seems quite unlikely. Unless the width between parapets were a rounder number. Perhaps the most likely dimension is 31ft for the arch width and a spread of a little over 100mm at road surface level. Such a spread is normal in these frosty regions





Likely spandrel layout

This sketch comes from the TRL Contractors Report produced by Arnold Hendry's team from Edinburgh University. The sketch and photograph show a concrete distribution beam cast tight against the parapets, with the obvious assumption that the spandrel walls are the same thickness as the parapets. That seems most unlikely. The depth of fill at the load point is 900mm and such a thin wall (drawn here at about 250mm) would not work.

So, apart from anything else, the load is distributed on to a stiff wall at the edge of the bridge and we have no way of knowing what effect that had. In primary school science they ask "is it a fair test" and in this case (and even more so in others) the answer is emphatically no.

So, it seems certain that the end of the loading beam stood on a masonry wall and that this will have had some effect on the structural behaviour. Such effect would almost certainly enhance the apparent capacity.

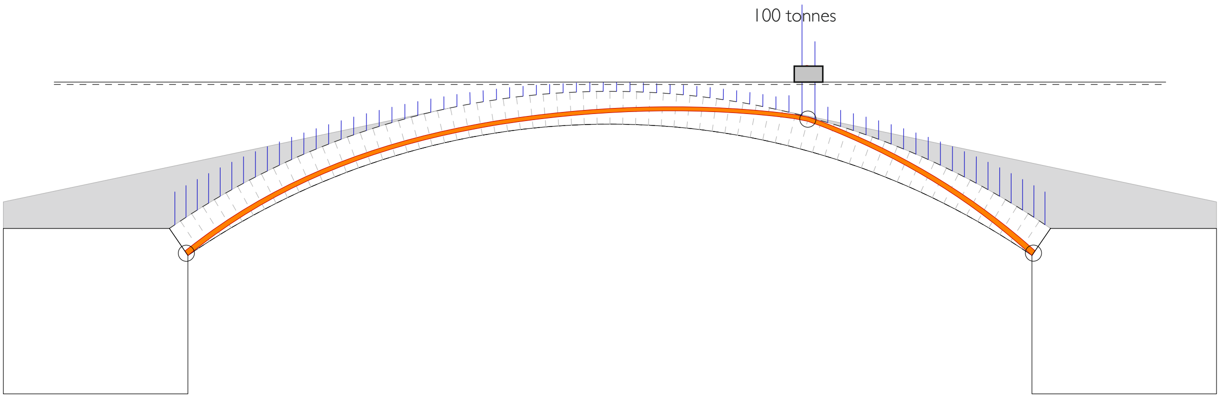
This is part of the first image, cropped to show detail. The overlayed white lines show the slope of the beds where the arch has sagged during construction of the spandrel walls.

The results of this test are quoted in many places. Perhaps the most significant is in Annex E to Ba16, the Highways Agency recommendations for bridge assessment. Very often, the only value used is the “ultimate load” which is always assumed to be relevant to a simple arch of constant thickness and with soil fill.

By 1846, when this bridge was built, simple fill was almost unheard of. Other bridges of the same vintage and in the same area have shard concrete haunching tangent to the arch extrados at about 1/3 span.

It is a simple rule of science that a mathematical model will return results for the model and not for the structure itself and this is especially true were the mathematical model is based on an erroneous concept of behaviour.

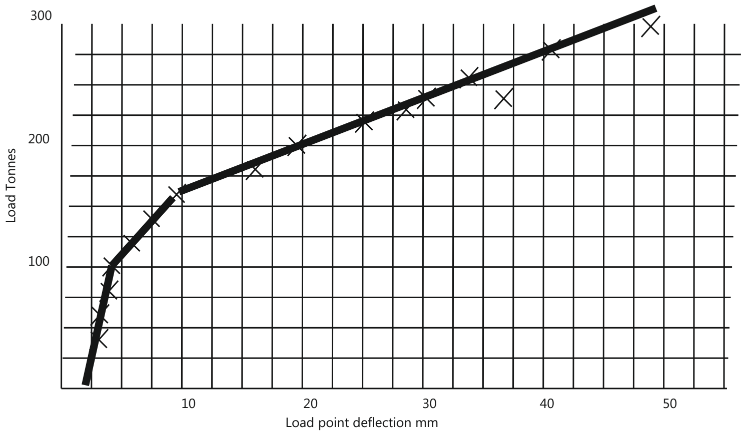
This enlarged image Shows an area of spandrel and arch directly under the load at an early stage in the test. Look carefully and you will see cracks between the two voussoirs to the left, which are nearest t the load point. In the top right there is a horizontal crack between two stones indicating a corbelling of the spandrel wall.



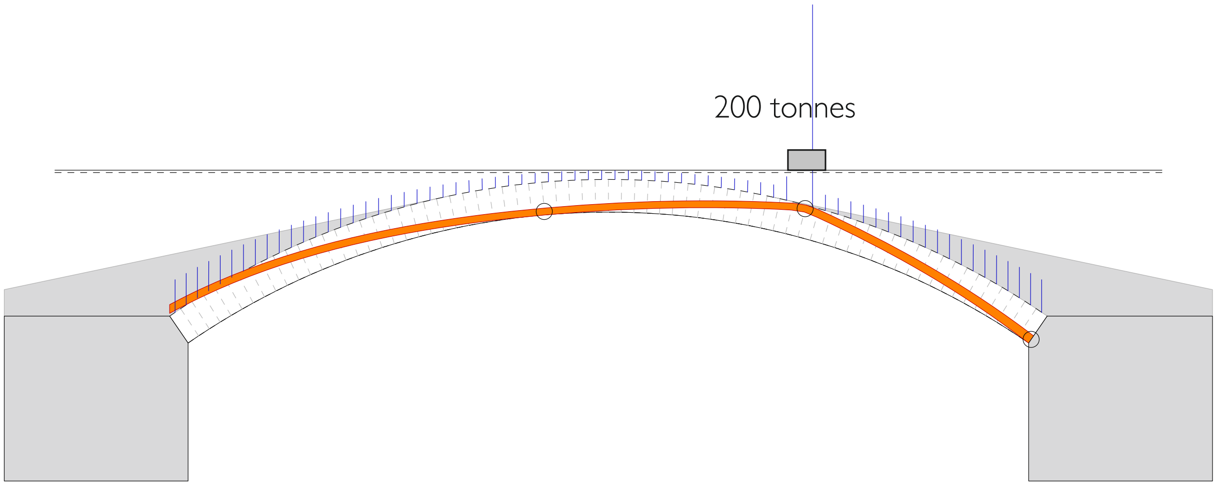
The basic Archie view of this load case is shown here. The bridge width is set at 3.3m so a load of 33 tonnes represents 100 tonnes on the full width. Here the distribution length is set very short to represent what I believe happens at low loads.

Here we see the same area rather later in the test. The joint between arch and spandrel is visibly damaged over a long length. The voussoirs are about 300mm thick so the picture shows 4m length of arch. The loaded 1/4 span point is behind the scaffold tube with the white tab attached.

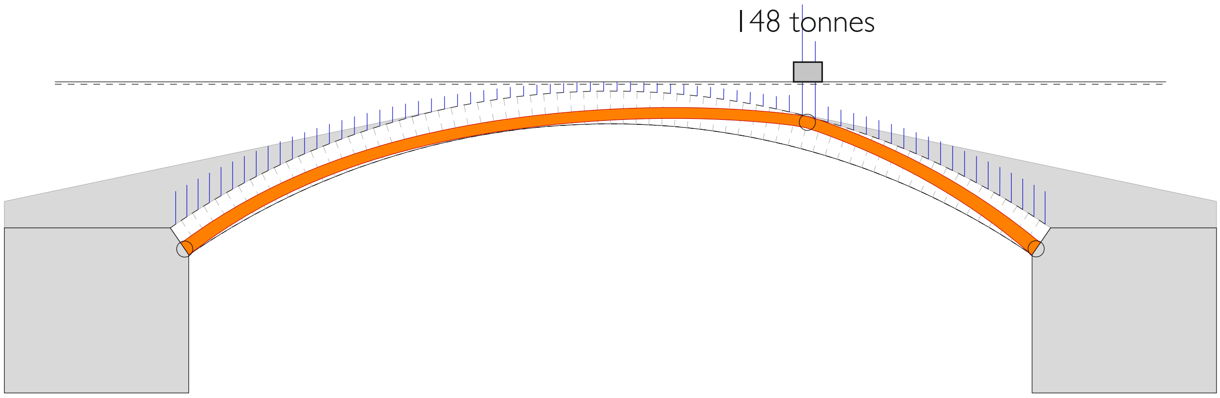
Mortar will creep preferentially on a joint with a greater eccentricity of load so the centre of thrust must cross consecutive joints at very close to the same depth if the joint is to open on both sides. This provides a clear indication of the spread of load in this case, since only with a widely spread load can the thrust follow the extrados closely.



The testing team drew the load deflection line as a curve but I believe the points recorded show a series of straight lines. this redrawn plot indicates a significant change in behaviour at 100 tonnes and 150 tonnes. The first of these changes is surely the point at which loading must stop and a sensible load factor should be applied too. Ba16 says that no bridge showed signs of damage at less then half ultimate, 300 tonnes in this case.



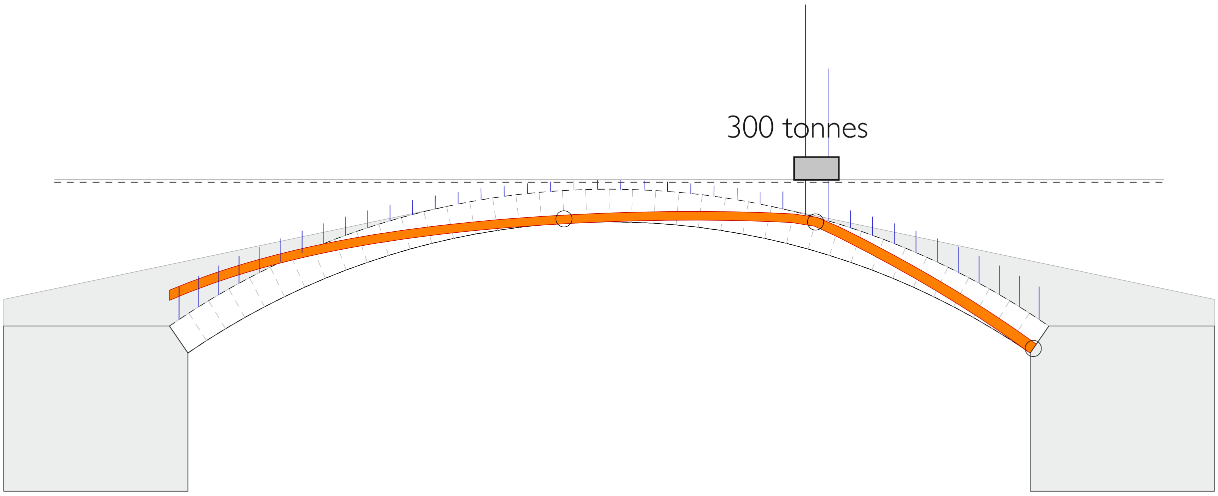
If the load is increased to 200 tonnes, this (rather simplistic) view shows a third hinge tending to form. A quick check shows the move from the end taking place just under 150 tonnes (below), though I have no desire to suggest this is an accurate or worthwhile prediction.



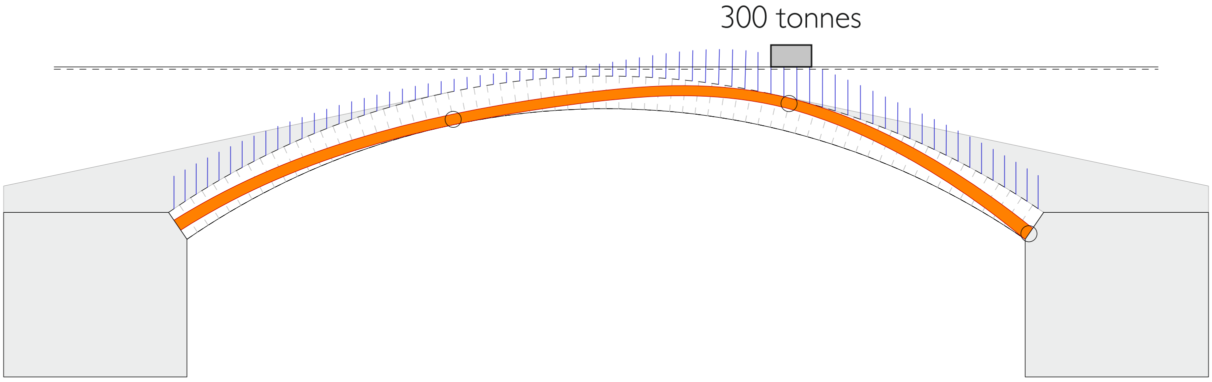
In this relatively low rise bridge, two things happen as the load increases. The first is that the bridge deflects, downwards at the load point and up at the opposite quarter point. This distortion, though small, has a detrimental effect on the load capacity.

On the other hand, the deflections help the soil to provide more distribution which increases the length over which the thrust is parallel to the extrados. This compensates for the downward deflection but possibly not for the upward.

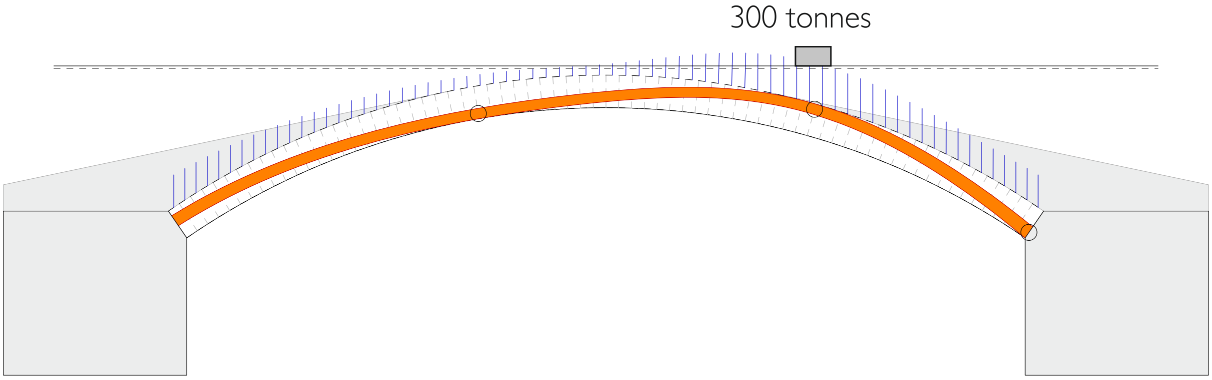
The pictures on the next page show how distribution affects the thrust zone and what then happens if you reduce (in Archie-M) the effective material strength.



If the load is concentrated on a narrow strip we get a thrust pattern like this with a sharp angle under the load which would deliver a single crack/hinge and a hinge near the crown. In terms of the arch alone, this would constitute failure, but the arch isn't working alone. This is a case with 300tonnes on the whole bridge.



We know from the photographs and from the site description, that there were multiple cracks under the load and this can only happen if the thrust offset is more or less constant through several voussoirs. That, in turn, is only possible if the load is broadly distributed as here. When you do that, though, with a "normal" view of thrust and strength, the crown hinge goes back towards the springing.



Using a material strength more appropriate for the mortar pushes the thrust back towards the extrados at the left but still doesn't indicate failure.

In any case, what we need to determine is the load to cause first damage and the load deflection curves and acoustic emission results agree that occurs at about 100 tonnes.

Consequences

The significance of all this is not immediately obvious.

I have been saying for many years that Annex E of BA16 is full of tendentious claptrap. Here is surely enough proof.

The load deflection graph shows that something untoward happens at 100tonnes total load. BA16 says that no bridge showed any sign of distress at loads less than half the ultimate and the ultimate load here is recorded as 310 tonnes. There is no doubt in my mind that the results say this bridge will deteriorate at increasing rates if the load greater than the equivalent of 100 tonnes were applied regularly. On road bridges that remains unlikely but on the railways, 50 tonne bogies are very common. This is not a railway bridge but it is very much of a railway scale. It was built in 1846, at the same time as John Millar (sometimes called the Scottish Brunel) was building the Glasgow and South West Railway which had a branch to Girvan and beyond. On a railway bridge, an optimistic (but in my view mistaken) view of load distribution is taken. This says that with 0.9m of fill the load will be distributed over 3.2m width at the arch. In fact, the local distribution is likely to be less because the arch itself contributes further distribution as the thrust flows towards the abutments.

Having regard to all of this, it seems to me that a train with 25 tonne axles in pairs on bogies would produce effects very nearly sufficient to cause damage, which would then accumulate. One would wish for an assessment to deliver a result safely below that, perhaps 20 tonnes or less for a safe axle load.

Now I must find time to write this up in more detail for full publication.

News and Events

Bill’s Sutherland History Lecture from 16th Feb is now available to watch on the web at http://www.istructe.org/resources-centre/webinars

After a long struggle with the new protection software we think that the Demo, available from http://www.obvis.com is now stable and can be properly activated when paid for. It will work in standalone or network mode. If you are ready for an update or thinking of buying please download this version and then contact us for activation.

We are now ready to embark on the next phase of proper development.

Moire TellTales now available from www.moiretelltales.com

Next known lecture engagement October 15th in Dublin. More details next month.