Bridge of the Month, November 2013
Bargower Test

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As will all previous Bridges of the Month, a pdf copy can be downloaded from the OBVIS web site.

News and Events
Bill will be in New Zealand from 29th Oct to 6th Dec. Accessible by email
Follow Bill on Twitter @BillHarvey2

Seminars and Lectures
Hertford County Council Offices 29th Jan 2014
MottMacdonald Altrincham office early 2014

Please contact Philip@obvis.com if you are interested in attending a day seminar on Arches and Archie. The program for this year includes:
Bill's recent work (some interesting bridges!)
Skew Arches
Ring separation
Causes of live load damage
We charge £100 for the day but if you wish to host a session at your office we then wave the charge.

Recent Publications
Bill's paper about the effect of stiff spandrel walls received the John Henry Garood King Medal. The medal is awarded annually for the best paper published by the Institution on tunnels, soil mechanics or bridges.
Stiffness and damage in masonry bridges. Proceedings of the Institution of Civil Engineers, Bridge Engineering 165 September 2012 Issue BE3 Paper 1100032 Pages 127–134 http://dx.doi.org/10.1680/bren.11.00032

A spatial view of the flow of force in masonry bridges, Proceedings of the Institution of Civil Engineers, Bridge Engineering 000 Month 2012 Issue BE000, Paper 1100026, Pages 1–8 http://dx.doi.org/10.1680/bren.11.00026
Sutherland History Lecture 2012 at http://bit.ly/J4gblz

Bargower test bridge

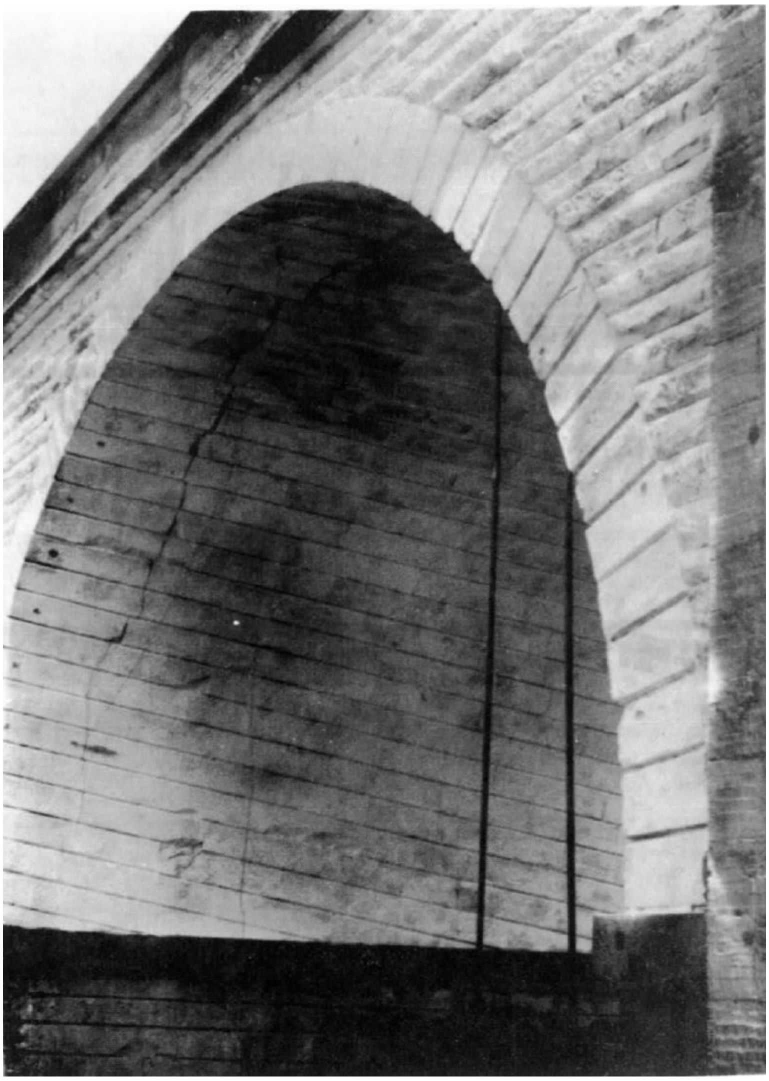
The bridge has actually gone, of course, and there is no record in the test report of where it was. However, there are some photographs, some graphs and some error strewn reporting in BA16 and nearly 30 years down the line it is time the record was straightened out while there is still someone able to do it.

The BA16 commentary

The commentary in BA16 is tendentious. It was set out with the deliberate aim of rubbishing certain treatments of "arch bridges" while promoting another. The results were declared to be "correct" but what does correct mean. The tests were carried out on bridges but they were analysed as arches with fill and tested in a way that was intended to force them to behave as such. That could not hope to work. The outcome was a series of tests for which the results were totally compromised by interaction between the structure and the loading frame. There will be more to say about this as the Tests are reviewed.

Bargower bridge

At Bargower, there were clues even before the test was set up. There were substantial cracks, parallel to the parapets and 1m or so in from the edge of the arch.



This photograph from the TRL Contractor's report shows the bridge whitewashed for testing but before any load was applied. Note the substantial crack about 1m in from the edge. Note also the tilt of the Voussoirs indicating a 16^o skew angle.

There were also some interesting issues with performance, such as the pushing out of the parapets.

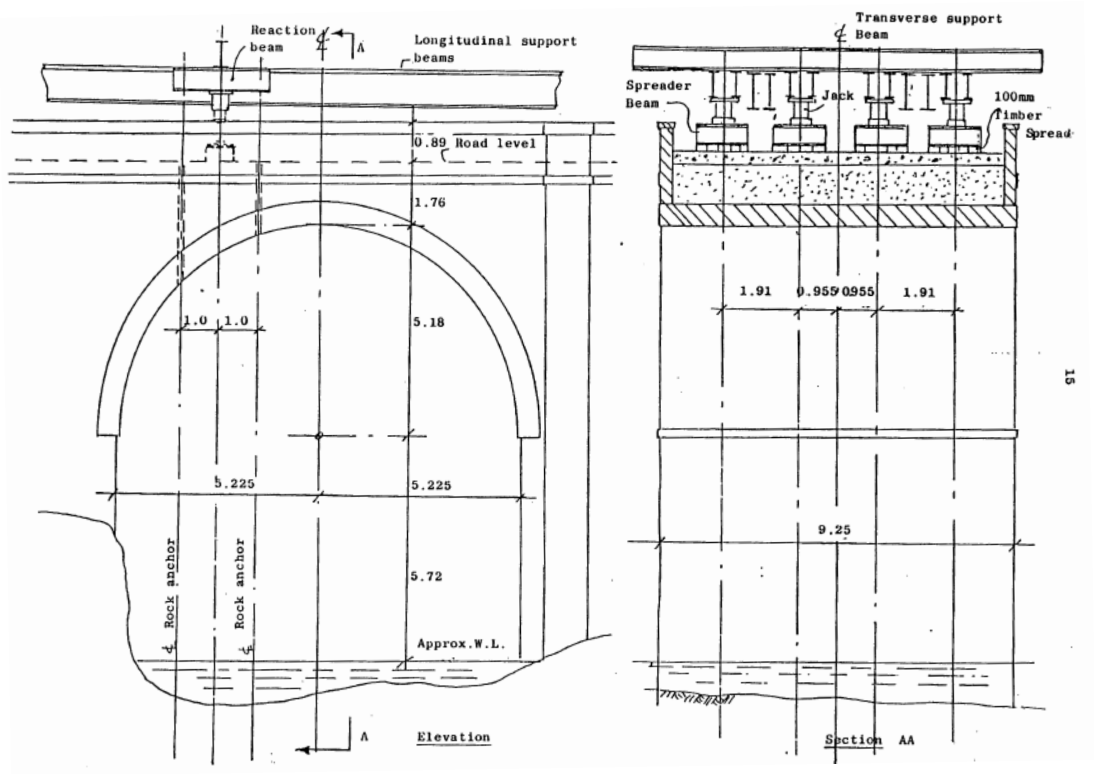
This is caused by freeze thaw action between the parapet walls and the road surface. Water gets in and freezes, expanding and pushing out the wall. When the ice melts, the wall stays where it is so there is a bigger gap for water and more ice to expand next time.

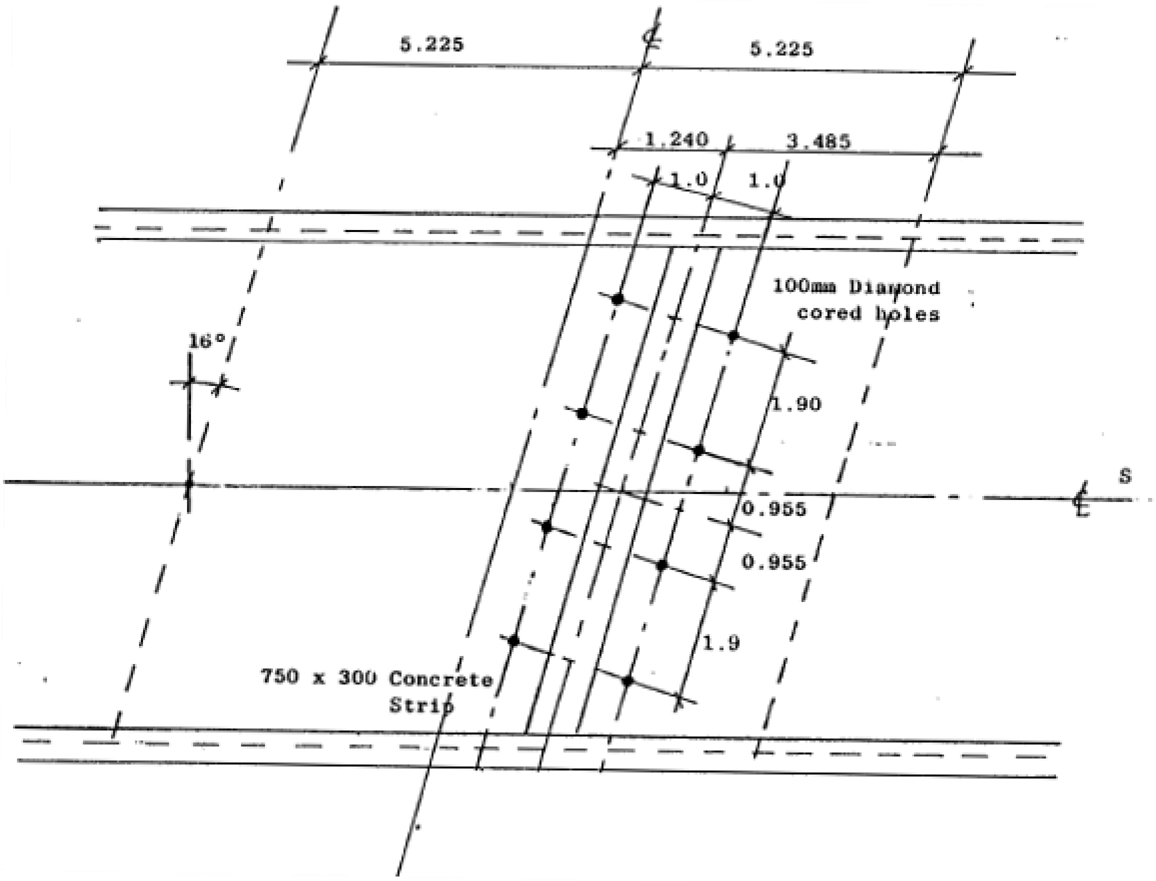
As with all the other tests, the bridge was loaded through a transfer beam across the width. At this early stage in testing, there was no thought about the internal complexity of masonry bridges. It was also established wisdom that the critical load point was at quarter span. In fact, for Bridgemill that would be nearer to 1/5 span and for Bargower here about 1/3. The difference is a result of span rise ratio but in any case only applies to a 2 dimensional arch.

The drawing below shows the perceived layout of the bridge and the load system. Unfortunately there are discrepancies. In the elevation, the load is shown at ¼ span but there is no dimension. In the plan the offset from the centre is shown as 1240mm and from the end as 3485mm giving a half span of 4725mm against the stated dimension of 5225mm. I f we assume that the 3485 figure is correct that would be very close to 1/3 span. On the other hand, the 1240mm dimension puts the load at around 3/8 span. If the tabs shown above are at the crown and load points, the seven voussoirs separation confirms that the load is at 1/3 span.

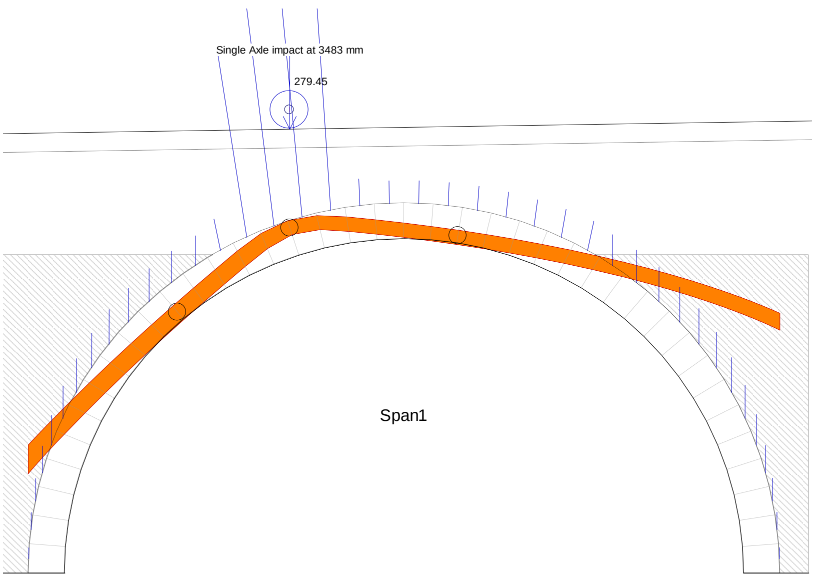
The span and rise are also interesting dimensions. The skew span is shown as 10450mm which is 34.28ft, giving a square span of 32.96ft. The radius is quoted as 5.18m or 17ft. Perhaps that is the best we can get to. If the centres were semi-circular and spanned on the skew that gives a skew span of 34ft (10.36m) and square span of 32ft8in (9.96m).

A further sketch shows 54 voussoirs round the ring, giving a width of almost exactly 1ft n the intrados, which seems sensible. The tabs in the photo above are survey targets for displacement measurement. The one to the right is near the crown, that to the left about 7 voussoirs away, which would mean roughly at the quarter point. Since the spandrel isn't painted, this is the East side, so the same view as shown below.





A very simple analysis says that the arch should be able to carry about 840 tonnes. Though that would depend on the material strength used. But the structure didn't fail as a mechanism anyway as we will see.



The picture below shows the bridge damaged beyond repair but before failure. At this distance, it remains uncertain what the load was at this point. However, it is clear that the arch proper is carrying a considerable amount of load. There is a visible crack stepping between the inclined voussoirs, somewhat towards the crown from the load. There is also some crushing to the left of the crown and near the right hand quarter point.

The report suggests that the crack under the inside edge of the spandrel at the far side was not present, or at least was not large, before the test. It is worth noting that the crack moves inwards to the inner rock anchor under the load.

Now is an appropriate time to jump straight to the so called “ultimate” load. The failed bridge is shown below and there are some interesting things to observe. First, note that the near end of the lad beam bends down severely and the rock anchor cables to the nearest jack are completely slack. Then, though, note that the remaining 6 ties are still essentially straight. The nearest two are apparently free of the arch so the load is being supported by the beam and any corbelling in the fill. The arch seems to have failed along the line of the crack that is visible in the photo above.

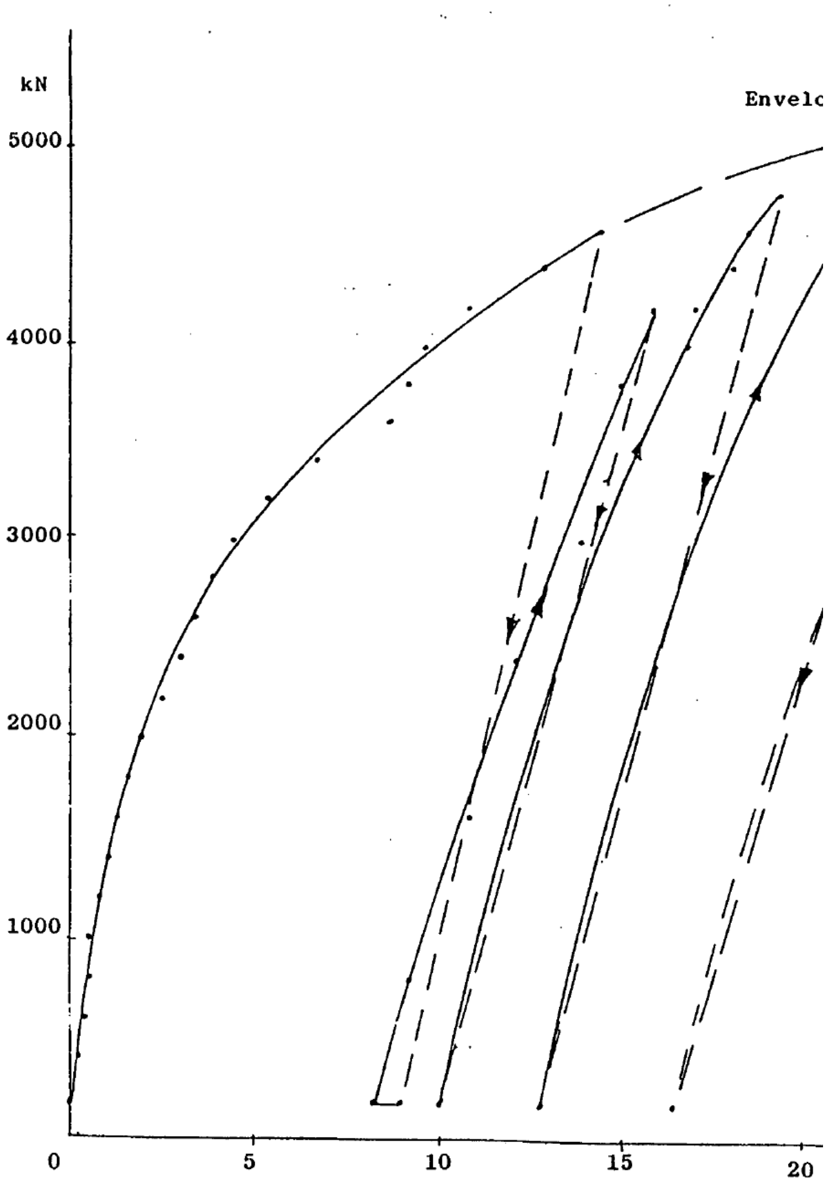
Then, examine the structure and note that the rubble masonry spandrel wall is more or less constant thickness right up to the under-side of the surfacing. The alignment of the duct against this wall and well under the loading beam, emphasises the fact that much of the load was carried direct on to the spandrel.

So there is some doubt about the value of the failure load so baldly and confidently stated in BA16.

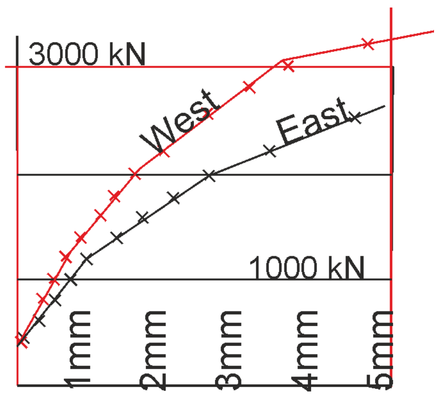
Now let’s look at the real record. The most basic is the load deflection curve.

This curve represents deflections in the spandrels. The report says that there was visibly greater deflection in the section of the arch between the spandrel walls. We can only guess at the distribution of load between spandrels and arch.

This load deflection curve is a mean between two values. The smooth curve plotted in the first phase does not flow well with the plotted points and there is no obvious way to see how the different components of the structure responded.

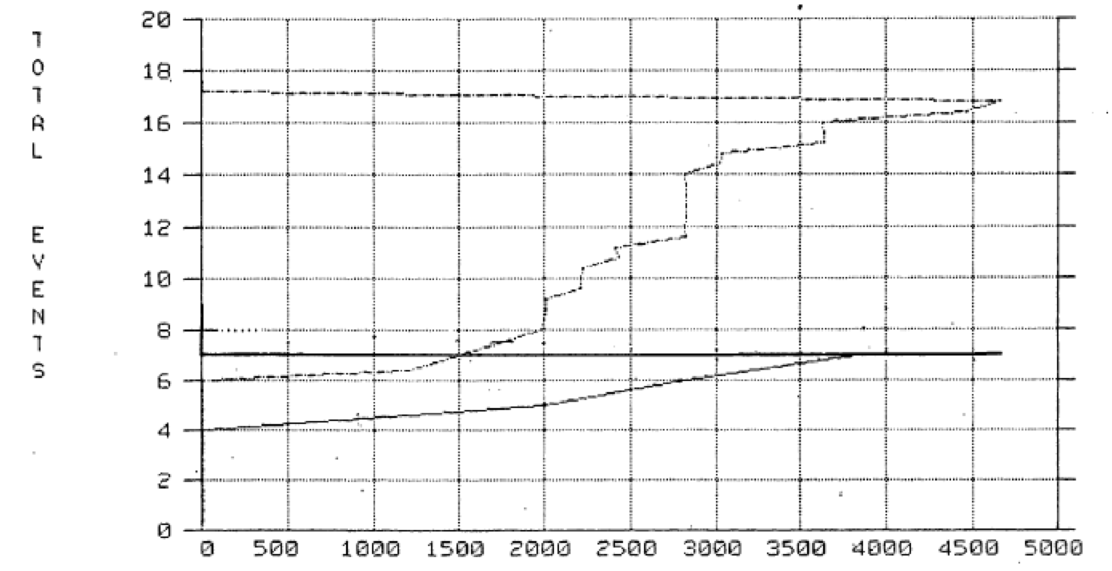


Replotting the first phase of this diagram and separating the East and West sides produces this.



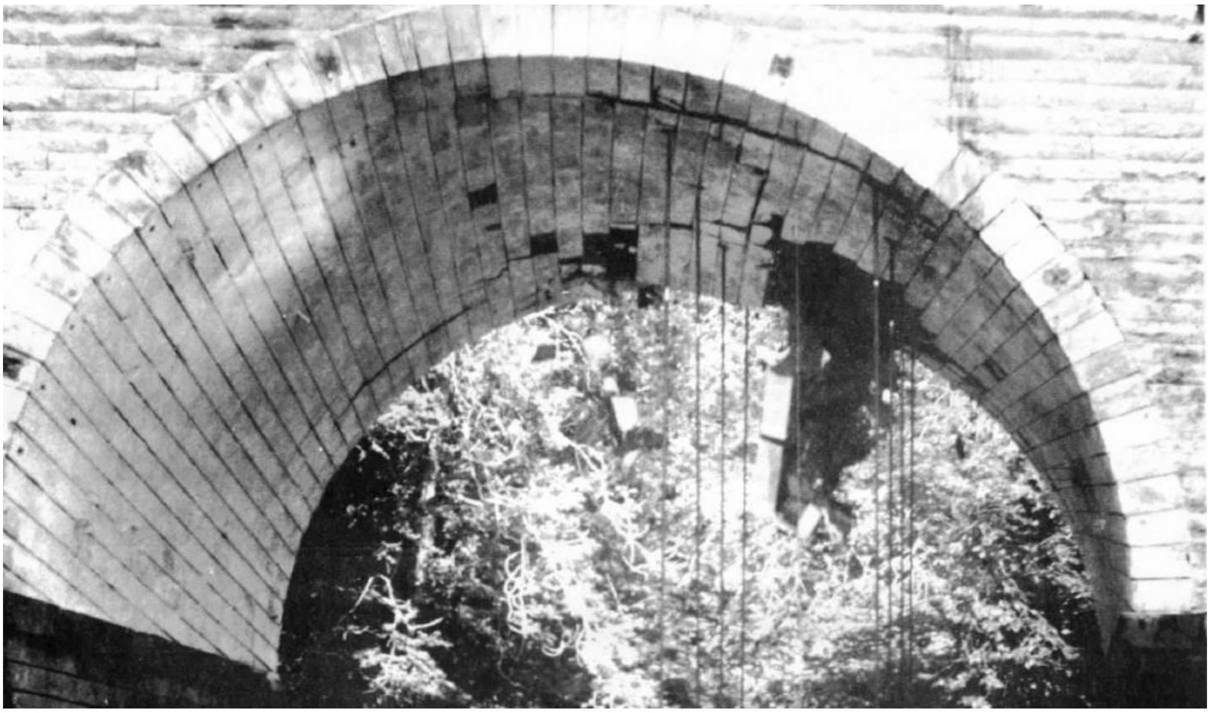
Initial load deflection curve

To me, the slope changes markedly at several points and the changes map from side to side. Given that the spandrel walls themselves are both stiff and strong, the first kink at around 1200kN may well be caused by the initial crack in the arch barrel itself, or possibly by the development of the second (Eastern) longitudinal crack.

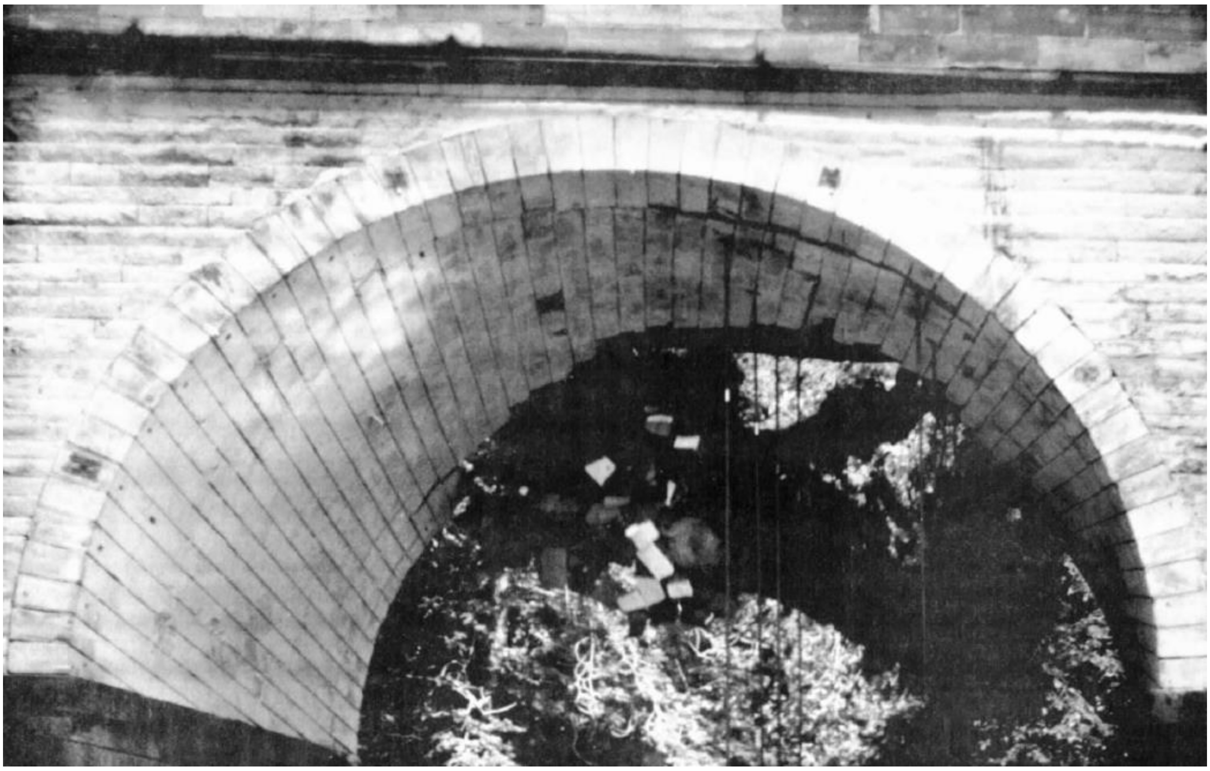


The dashed line above shows the acoustic emission response near the load point. Once again, there is a distinct change in the rate at which damage accumulates at around 1200kN. An acoustic emission "event" is basically a sound above a certain threshold.

And as to the actual failure, these two pics from the report say a lot.



Note here how the falling section is on the abutment side of the load hinge. I think that means the arch has split and crushed where the force is biggest. At this stage, the rock anchors are sill tight.

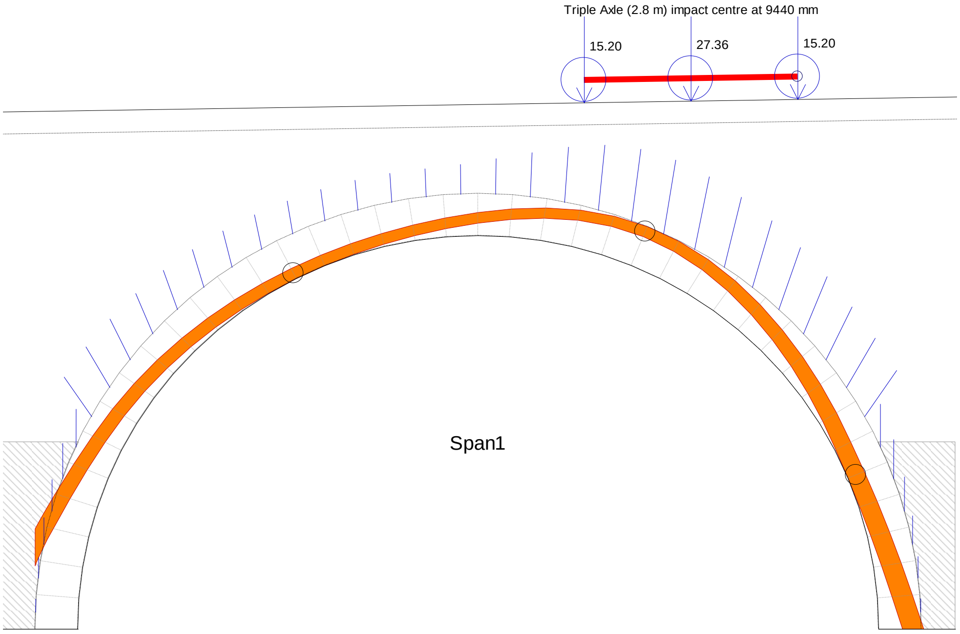


Here, the spandrel wall has gone and the parapet is following it down as a separate item.

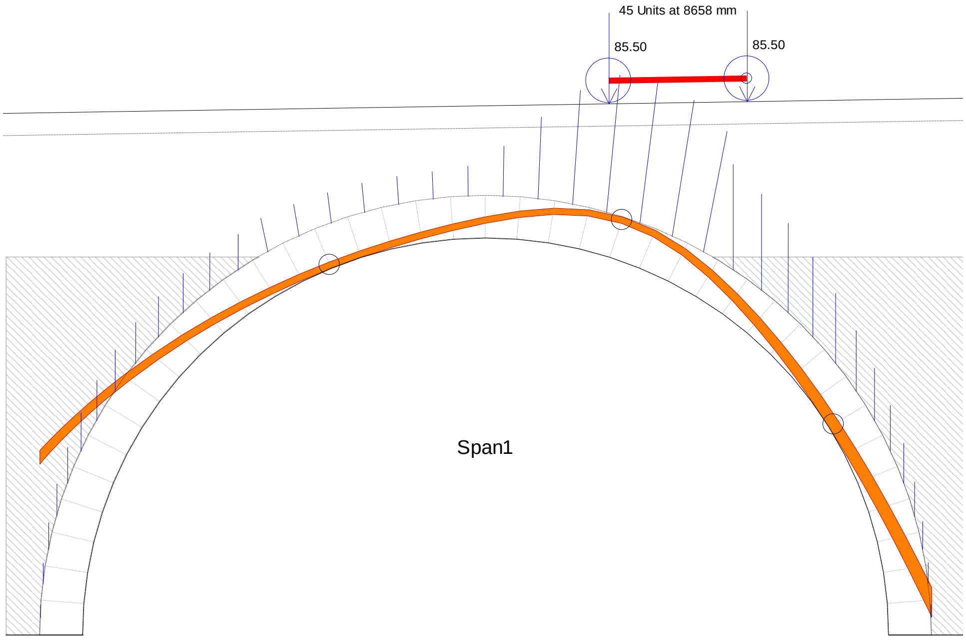
Conclusions

As I have said, drawing firm conclusions from this test is going to be very difficult. What can be said, though, is that some form of irreversible damage began at a load of about 1200kN. It is reasonable to assume that the damage occurred in the arch rather than the spandrels and that the arch was carrying no more than half the applied load. So, we might say 60 tonnes on the middle 6m.

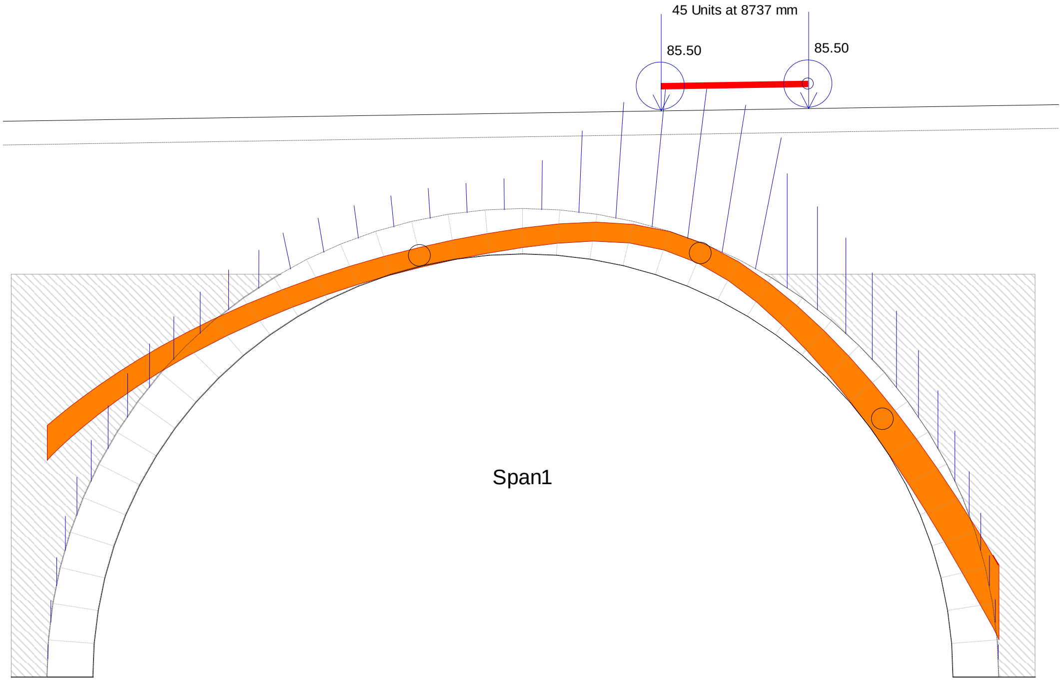
If the arch were modelled with backing to half the crown height (which roughly corresponds to the line where the face of the abutment projected upwards intersects the arch extrados) and the ring strength were reduced to 2MPa Archie would show the bridge to have a modest reserve of strength for all standard vehicles.



Putting the backing level with the crown and allowing a strength of 5MPa, which would be more normal for such a bridge, the structure would be amply able to carry 45unit HB vehicles.



Reducing the strength to 2MPa again consumes much of that capacity.



So where does that leave us.

1) The quoted capacity of the Bargower bridge is wildly optimistic.
2) Our aim in bridge assessment must be to ensure that actual live loads do not damage the bridge.
3) There is good evidence that Bargower suffered damage at around 120 tonnes, less than ¼ of the quoted ultimate.
4) Failure was due to crushing of the stone, which cannot be predicted by most analyses.
5) Masonry bridge assessment tools remain little more than a comfort blanket. WE may follow the rules but the structure has no idea what BD21, BA16 and NR……25 says on the subject.