OBVIS

Bridge of the Month No77, May 2017
Monitoring the Moco Bridge Lift

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This has been promised for some months. Uploading it to Mailchimp is too much right now so only the pdf available at the moment.

The full archive index with links is here.

Further news at the bottom.

Introduction

This note describes the monitoring implemented during the ElevArch trial at Moco Farm in 2016. The monitoring had three components.

1. Before and after load tests.
2. Continuous monitoring of span change throughout the construction sequence.
3. More intensive monitoring during jacking operations, with a "dashboard" style display.

Why monitor?

Monitoring at Moco Farm had two goals. First, to address the small residual risk in the construction process. The process was carefully engineered, and the open invitation to watch the lift indicates the confidence the team had in the process. But in a world first operation there are both real unknowns and perceived risks. Monitoring meant that had anything not gone according to design, we would have known about it early with time to consider and respond. Continuous monitoring span throughout the process and the additional monitoring of lift height and transverse movement at the vertical sliding bearings served this purpose.

Second, to back up the visual evidence that the trial was a resounding success. The before and after load tests were specifically for this purpose, while the data from the other monitoring contributes as well.

Equipment

Monitoring was conducted using the following equipment.

1. Moiré Tell-Tales to monitor crack movement.
2. Load test and span, transverse deflection measurement using BHA Ltd prototype system.
3. TS measurement of reflective targets on structure.
4. Water levels at each corner to check structure remained level.

Load tests

The purpose of these was to provide positive confirmation that the live load response of the bridge was not significantly worse after the lift than before. There was no intention to prove the capacity of the bridge either before or after, simply to show that the deflection under a given load was not materially increased by the changes made.

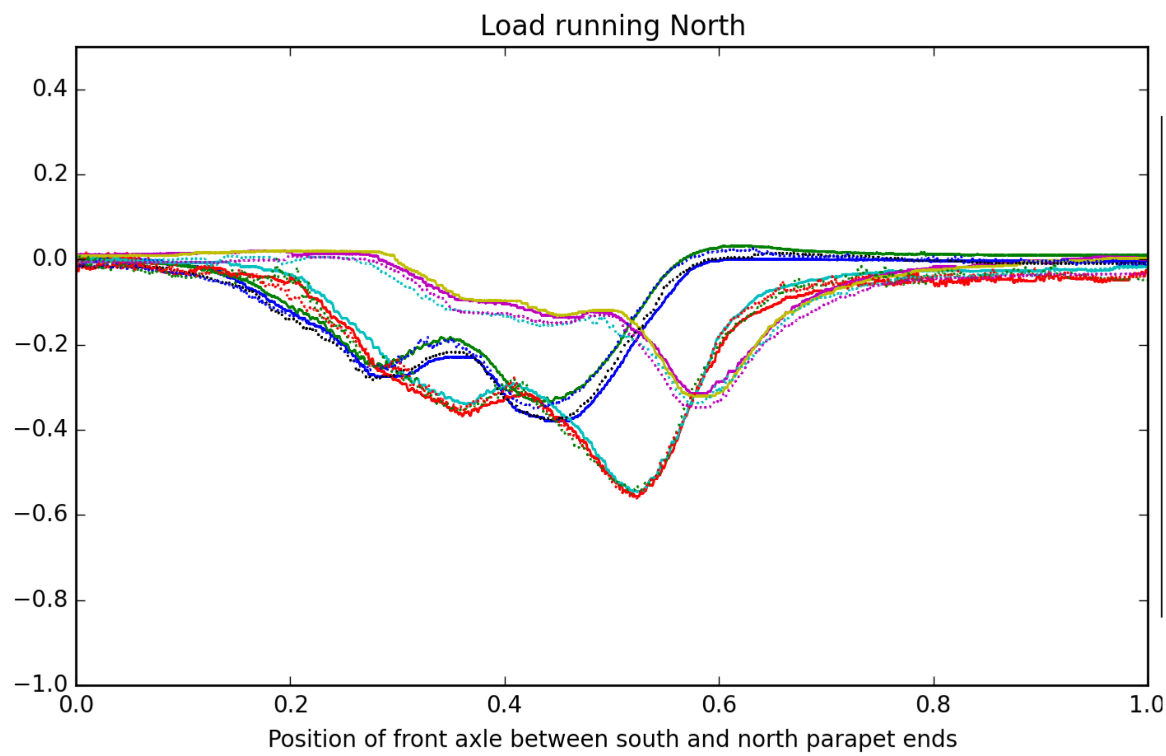
We needed a convenient load that could be applied twice, some weeks apart. Various options were considered, but in the end, the farmer offered a simple solution: a trailer load of manure.

He also suggested using the tractor's crawl mode. We could then post an observer at each end of the parapet to signal when the leading axle passed, and assume a constant speed between.

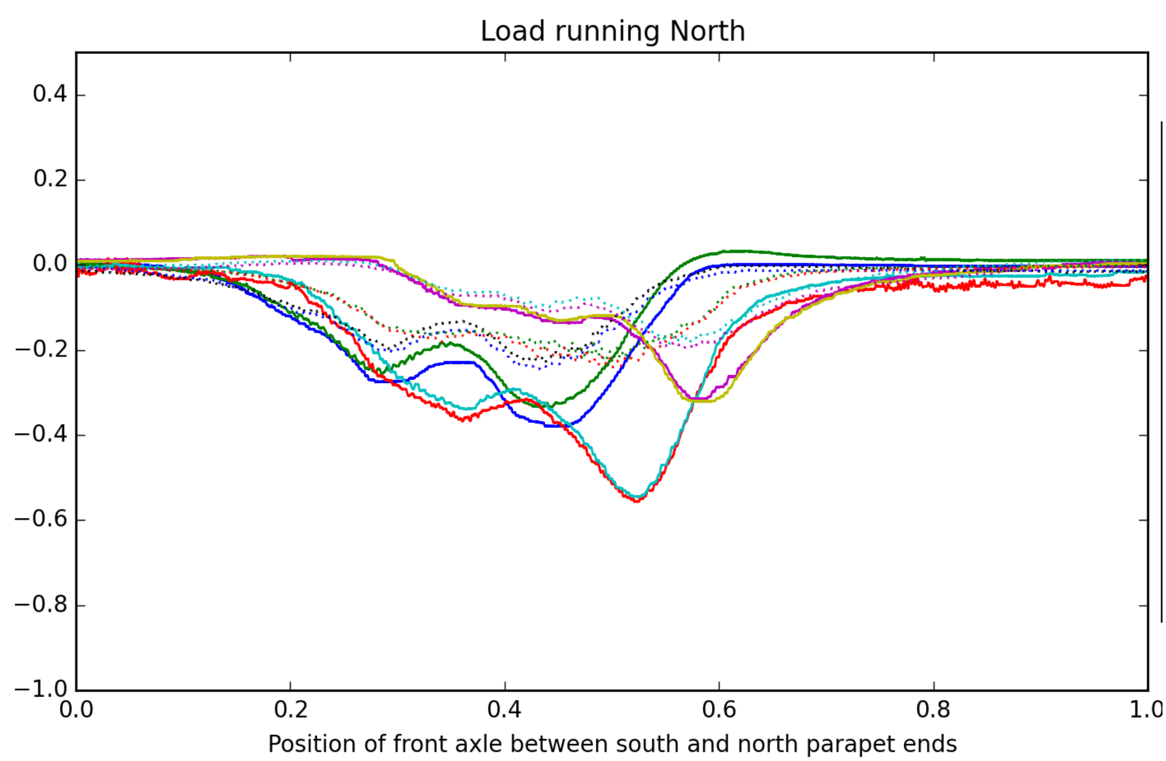
Vertical measurements were made using the BHA Ltd. light-weight deflection pole system. Gauges with 20mm range and a sprung rod are mounted on telescopic poles, and pushed against the soffit. The gauge spring holds the poles in position in the rough masonry surface. Six points were used, located in two rows, each one metre in from one edge, and at quarter span intervals.

The gauges are potentiometer type. The logger is portable, battery powered, and gives immediate feedback on an iPad, crucial when setting up in the field for a short test.

Plotting two runs from the before test together shows the repeatability of measurement, and a peak deflection of 0.6mm.



Plotting before and after results together, before solid, after dotted, shows the after test produces consistently lower deflections at all times in all locations.



Before the lift, with the bridge unmodified, the peak deflection under a trailer load of manure was about 0.6mm. After completing the lift, making good the masonry, and replacing the fill, the peak deflection was 0.25mm. While the axle load of the trailer will not have been exactly equal on the two occasions, the same tractor was used, and the deflection under the tractor also showed a reduction.

Medium-Term Monitoring (through full construction sequence)

To check for unexpected movements, and to confirm the magnitude of expected movements, as a result of the intrusive works, long term monitoring was installed and run from before those works started until after they were finished.

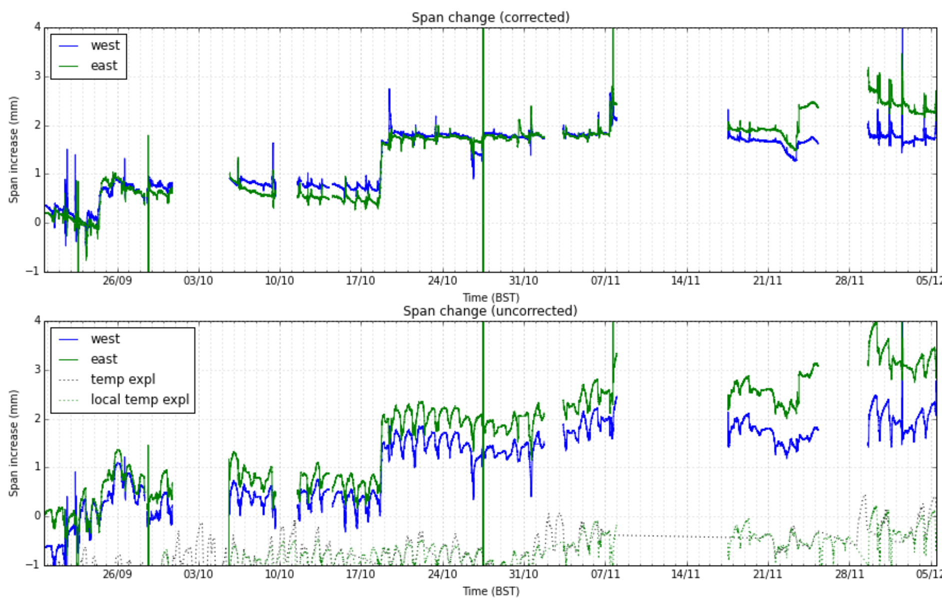
Moiré Tell-Tales were installed over all identified cracks well before the start of any other works. These two-part gauges are fixed one part each side of a crack. At installation, they show a set of three concentric rings. Should any movement occur, the pattern changes to indicate direction and magnitude of movement. The magnitude can be read to 0.1mm by comparing the pattern with a reference sheet. The Moiré Tell-Tales identified slight movement of the imperfectly attached brick “skin” of one abutment during grouting, and otherwise showed no movement, providing confidence in the integrity of the structure.

Span change was regarded as a key indicator of the behaviour of the structure during works. It is not a trivial thing to measure, however. This was achieved by mounting long deflection poles horizontally, suspended from frames attached to the soffit. The frames were fixed transversely (parallel with the abutment faces) and braced against in plane movement. The deflection poles themselves provided stiffness in the span direction. The foot ends of the poles were located on masonry screws to ensure positive location, and sprung back to the abutment with bungee cord to ensure all span change was carried to the other end. There, a simple cup mated with the deflection gauge mount and ensured that the gauge pin measured against the head of a masonry screw.

When measuring deflections under live load movements, it is usually possible to ignore temperature expansion of the deflection poles, because this happens relatively slowly, and the measured events (e.g. passage of a vehicle) take place quickly. In this case, temperature effects were critical, so temperature data were recorded on site as well. The system was installed with enough time that the system coefficient of thermal expansion could be calculated from data. This was then used to correct for thermal effects.

There were still short term erroneous signals, because the response time of the poles and the temperature sensors were different, and because direct sun hitting part of the system is not corrected for, but these are short lived and it is possible to quickly identify any actual movements in the corrected data.

Even then, real movements could be real movements of the structure, or real movements of the measurement system. Monitoring on construction sites has unique challenges. It is inevitable, even with the best of intentions and care, that monitoring systems will be disrupted on occasion by construction work. In this case, the span measurement poles were jogged once or twice by operatives working on scaffold towers at the abutments. These issues were anticipated, and addressed by measuring span at two locations. Real movement of an abutment would be highly unlikely to show in one and not, to some degree, in the other. On the few occasions where this happened, communication with site operatives confirmed the cause of the movement.



Span change throughout the construction sequence, top corrected for temperature, bottom uncorrected. Visible changes of span are at the time of the vertical saw cut 24 September, the first jacking cycle on 19 October, ?? on 7 November, and during back-filling of the abutments later in November. The total deflection throughout the process was less than 3mm, with the final span around 2mm greater than the initial.

Monitoring for jacking operations

Finally, continuous monitoring was undertaken during the jacking operations. The goals here were to show that the jacked part of the structure was fully controlled by the temporary works, and to provide the earliest indication of any unwanted movements.

The issues identified for monitoring during jacking were:

1. Crack movement.
2. Span change.
3. Transverse movement between the fixed and lifting sections of the abutments.
4. Tilt and twist of the lifting section of the structure.

Cracks were monitored using the Moiré Tell-Tales already installed for longer term use. These could be checked very quickly on each jacking cycle for indication of movement.

Span change was measured using the same system as for longer term monitoring. Transverse movement was measured using sprung deflection gauges mounted on the sliding plate of the vertical bearings, and measuring against the edge of the fixed plate (with a smooth aluminium angle fixed to provide a running surface). A draw wire potentiometer provided a direct measurement of the lift height to provide context to the other measurements.

Transverse movement gauge mounted on sliding bearing.

Vertical deflection gauge mounted in enclosure, with wire across gap.

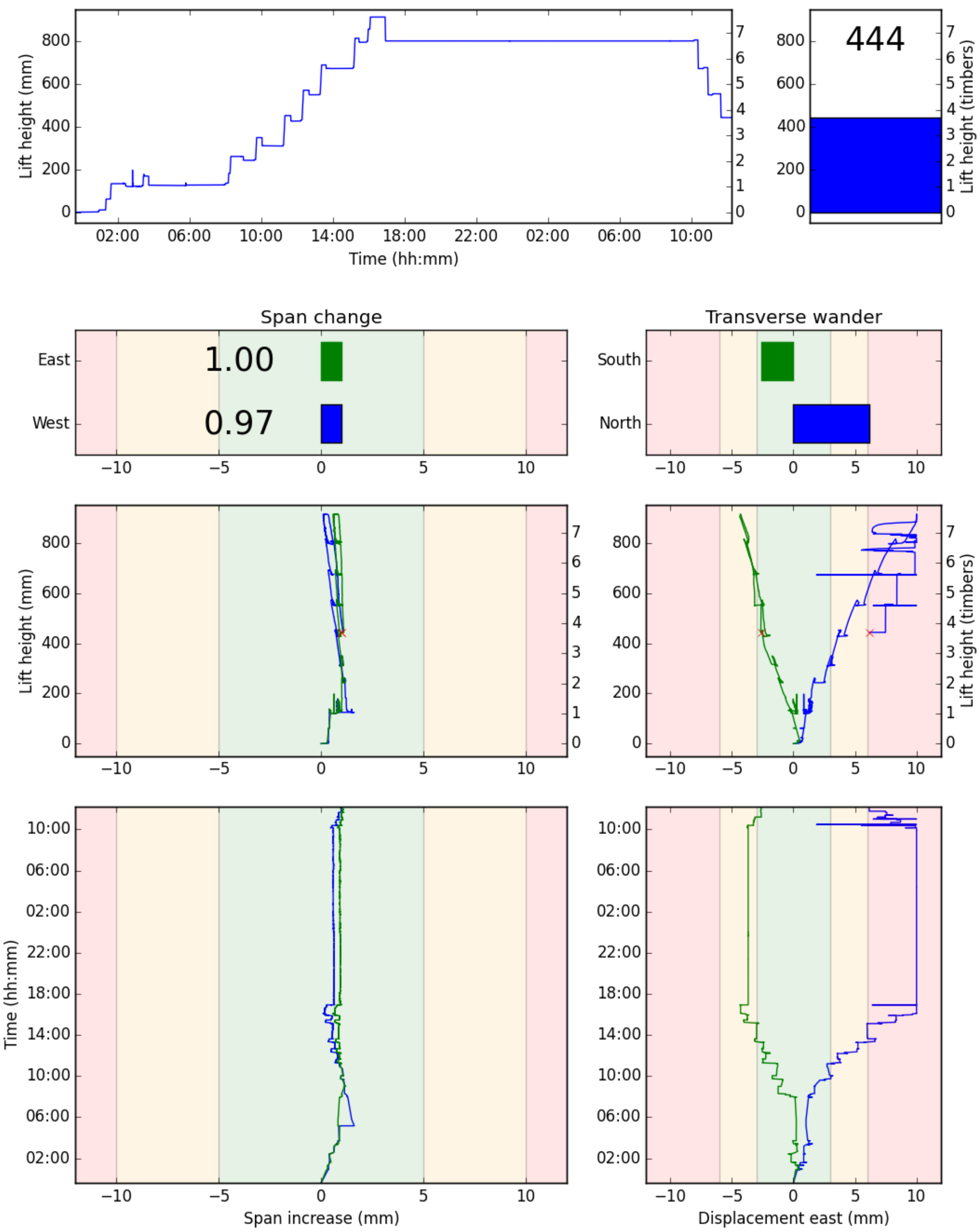
Tilt and twist were tracked both by the jacking system itself, which uses deflection controlled jacks, and using a water level system. Total Station measurements provided secondary measurement of tilt, twist, and transverse movement.

Monitoring small movements in the context of large movements in the orthogonal direction – as here with transverse movement against large vertical lift – is a particular challenge.

Whereas for the long-term monitoring, data were transmitted offsite for viewing, during jacking the requirement is for an on-site "dashboard" view for the jacking team. A clear understanding of the past and likely future behavior of the structure is needed at every moment. To provide this, all of the available *data* must be presented in a form that makes the relevant *information* contained within it immediately accessible.

A monitoring system that generates false alerts is almost as useless, though usually less dangerous, than one that fails to identify developing problems. To avoid false alerts, we presented the data in a form amenable to interpretation, and wherever possible conducted redundant measurement.

The output display of the main monitoring system at the end of the whole jacking process is shown in FIGURE. This display was updated in real time during the lift. The top row shows lift height, vs time to the left, and instantaneous to the right. The two columns below show to the left, span change, and to the right, transverse movement. There are two readings in each column, east and west measurement of span change, and south and north measurement of transverse movement.


Lift height (mm)
Time (hh:mm)
444
Lift height (timbers)
Span change
Transverse wander
East
West
1.00
0.97
South
North
Span increase (mm)
Displacement east (mm)

In each column, instantaneous measurements were shown, followed by displacement vs. lift height, then displacement vs time. The dashboard was designed to aid interpretation of any movements, showing clearly whether these were progressive in time, or related to light height. The jacking process involves jacking to leave space to place timbers and then de-jacking onto these, showing how measured quantities vary with de-jacking from early in the process.

The monitoring showed a slight transverse movement in opposite directions at each abutment. The plot vs. lift height showed clearly that this was linear in height, and reversed under de-jacking, with an apparent small non-reversible movement on each cycle at the north. Because the movement was rotational, the centre of mass of the structure, which was of primary concern, moved much less than either abutment.

The south abutment returned almost exactly along its outward trajectory. On de-jacking from 900mm, the north abutment transverse gauge mount was inclined to come free from the bearing plate. With re-mounting on each cycle, the fact that the north abutment was returning as well was confirmed. The degree of return is not known exactly, as it was impossible to replace the gauge in exactly the same position, but the final readings from total station measurement and the monitoring are consistent.

The span change during jacking was even smaller. After settling in on the first jacking cycle, the moving section of the structure showed a consistent, very slight shortening of span on each cycle, and an equal lengthening on dejacking from 900mm to the final position at 435mm.

Review and future monitoring needs

The monitoring processes implemented worked well. The before and after load tests have shown that the structure is stiffer in its new configuration than it was in the old. The long term monitoring likewise showed that the geometry of the structure was well controlled throughout the construction sequence. The monitoring during jacking allowed jacking operations to proceed with confidence.

In future, before and after load testing and long term monitoring would not be required, unless to address structure-specific concerns. Monitoring during jacking makes an important contribution to safety and robustness of the process.

For future implementation of the ElevArch system, the monitoring will be reviewed and a system designed that provides the measurement needed, with appropriate redundancy.

Measuring span change to high precision on live rail would be difficult. Mounting transverse deflection gauges on the bearing plates proved less straightforward than expected.

Instead of fixing plan movement transverse transducers to the bearing plates, these should be mounted securely to the masonry above the horizontal wire saw cut. A box section tube mounted to the masonry below can be set plumb for them to run on. The measurement system is then requires careful setting out, but is fully independent of the bridge guidance system.

Lift height could be measured electronically at all four corners, allowing tilt and twist monitoring to be integrated with the dashboard. In place of span measurement, longitudinal displacement can be measured at the same locations as transverse. This would eliminate the thermal expansion issue in span measurement, but relies on the setting out of the vertical box section, and indirect measurement of span by taking differences.

Measuring movements in all three axes at all four corners of the bridge provides inherent redundancy of the primary plan measurements (span change and transverse movement).

Measurement of vertical deflection by the displacement transducers in the jacks offers redundancy of tilt and twist measurement.

News

A paper from Bill on stability of railway viaducts available here, but behind a paywall.

The work discussed there has been presented at the IStructE History Group in London and will be again at IStructE Chester on 3rd August. Other invitations welcome, contact bill@obvis.com.

There will be **Archie Seminars** in Altrincham on 4th Aug and Charlestown in Fife at the Scottish Lime Centre on 24th August. Again for invitations to other venues please contact bill@obvis.com.

We have made substantial developments on modelling bridges (and other structures) in 3D from photographs. See this model of a span of Marsh Lane Viaduct in Leeds as an example. It was photographed in about 20 minutes. It is much reduced in quality to make display on the web viable but we can do much higher resolution in a downloadable file now. Contact Hamish@billharveyassociates.com for more details.