

Lessons learned from one of New Zealand's most challenging civil engineering projects: rebuilding the earthquake damaged pipes, roads, bridges and retaining walls in the city of Christchurch 2011 - 2016.

The Strengthening of Heritage Bridges - Construction Challenges

Story: Heritage Bridges

Theme: Construction

A conference paper prepared for the 4th Australasian Engineering Heritage Conference which outlines the challenges faced by SCIRT when repairing the Armagh Bridge, Colombo Bridge and Antigua Bridge.

This document has been provided as an example of a tool that might be useful for other organisations undertaking complex disaster recovery or infrastructure rebuild programmes.

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The Strengthening of Heritage Bridges – Construction Challenges

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Abstract

Many of the bridges in Christchurch were damaged by the Canterbury earthquakes in 2010 and 2011 and some of these were heritage structures. The task of repairing and strengthening heritage structures presents a number of interesting challenges for the Contractor. Downer NZ Ltd was the contractor for the repair of three single span heritage bridges spanning the Avon River in central Christchurch: Armagh Bridge, Colombo Bridge and Antigua Bridge. The authors describe some of the construction challenges encountered in the repair of these bridges.

1. Introduction

Armagh Bridge, Colombo Bridge and Antigua Bridge were all damaged in the Canterbury earthquakes by ground movement including lateral spreading. The repair of these City Council owned bridges has been the responsibility of SCIRT (Stronger Christchurch Infrastructure Rebuild Team), an alliance funded by the government (CERA), the Christchurch City Council and NZTA.

2. Armagh Bridge

Built in 1883 the Armagh Bridge is a Category 2 Historic Place (List No 1830). It is a road traffic bridge that also carries tram tracks for the inner city tram. The structure is a brick arch with a clear span of 12.2 m, a rise of approximately 2 m and a skew of 16°. The brick arch barrel is 685 mm thick and is supported on unreinforced concrete thrust blocks.



Figure 1. Armagh Bridge

The Feb 2011 seismic event caused a longitudinal crack in the arch soffit measuring up to 20 mm in width. The crack was visible in the soffit but did not present through the layers of basecourse and sealing to the road surface.

The repairs specified included investigation and reporting on the extent of the crack, repairs to the crack itself, refurbishment of the cast iron balustrading and repairs to the footpaths and road surface.

Some of the interesting challenges for the Contractor were:

- Creating a dry work area around the foundations, dealing with floods.

- Temporary support for the brick arch during partial removal and reinstatement of bricks in the arch soffit.
- Observing and documenting artefacts and liaising with heritage specialists during the course of the work.



Figure 2. Longitudinal crack in the soffit

Several methods have been used in the past to hold back the water and create a dry working space. These include sheetpiling and water filled inflatable rubber dams. Neither of these methods was suitable for Armagh Bridge – there was no headroom to drive sheetpiling and a rubber dam would have been too bulky.

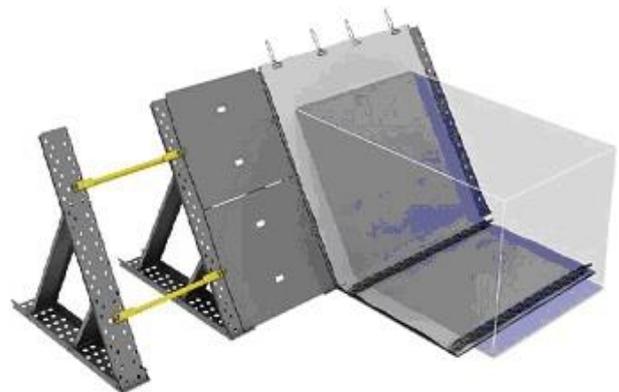


Figure 3. Proprietary A-Frames – courtesy Hydro Response Ltd.

The method used was to erect a set of proprietary steel A-frames supporting aluminium panels to

form a wall or dam around the work area. A continuous plastic sheet material was then laid over the panels by workers wearing waders and secured in place. The water isolated in the “working area” side was then pumped out and as this was done, the weight of the water on the “river” side pressed the plastic down, sealing it on to the river bed. It was still necessary to run a small pump in the work area to contend with leakage but this presented no difficulty.



Figure 4. The Hydro Response dam in place.

There was a flood event during the course of the repair work which overtopped the dam. Work was suspended for 2 days and the retaining structure reinstated within 4 hours of water returning to normal levels.

To enable work to progress safely under the bridge during brick removal, crack investigation and crack repair, a method of temporary support was required. The challenges for this part of the work included estimating the loads to be supported and configuring props to suit a curved soffit and a sloping riverbed.

Following initial inspections of the structure, it was decided that the temporary works would be designed to support ‘a tonne of bricks’ which may potentially come loose either as rubble or as a block. The work would be regularly monitored by engineers and the load re-assessed if necessary.

An ingenious bearer member, fabricated from a steel channel section and hinged to a plate bolted to the abutment was designed to rest on the river bed. The hinge allowed the bearer to rotate to the angle of the existing river bed and assured a reliable load path. A series of ‘chock plates’ were pre-welded into the channel so that readily available ‘Acrow Props’ could be placed with their bases fitting squarely in the channel and their tops set tangentially to the curved soffit.

Effectively, this provided a series of props to the soffit at spacings of 1.5m in each direction for the



Figure 5. The temporary works in place.

area to be repaired. Removable plywood panels were placed in the spaces between the props so that small areas could be sequentially opened up for repair whilst the remaining areas had temporary supports in place.

The other aspect unique to this project was that of discovery and documentation of archaeological artefacts. Excavations were necessary in the river bed to anchor the temporary works and this activity yielded items such as pre-1900’s bricks, timber formwork from the original construction, metalwork, a handmade shoe, a coin dated 1889, horseshoes and various pieces of china. Some excavations were also undertaken in the road surface on top of the bridge to inject cracks identified in the top course of brick and also fill the void beneath the tram tracks. For each discovery, the Christchurch City Council’s Archaeologist was notified and the item photographed and recorded noting the date and location of its origin. The records are currently being processed and artefacts studied by Underground Overground Archaeology.



Figure 6. Various artefacts found at the site

3. Colombo Bridge

Built in 1901, the Colombo Bridge is listed on the register of the New Zealand Historic Places Trust as a Category II Historic Place. The 1901 bridge replaced a 9 foot wide brick and timber structure built in 1858. In 1930, the bridge was widened to form the current structure which consists of 12 riveted steel girders supporting a reinforced concrete deck. The widening included the addition

of two non-structural steel outer arched girders that were erected to support the cast iron handrails and to improve the bridge aesthetics which reflect the Victorian era.

The unreinforced concrete abutments are founded just 1m below river bed level and both suffered cracking from rotational movement of up to 30 degrees. This was caused by liquefaction and lateral spreading during the February 2011 earthquake. Further repercussions of this saw the two outer-arch girders and the cast iron handrails on each side of the bridge buckle under the sudden axial load which occurred when the abutments rotated towards each other.

The Contractor was required to:

- Remediate the ground adjacent to each abutment and install inclined anchors from the abutments into the strengthened ground.
- Lift the bridge clear of its abutments, rebuild the top part of the abutments, install new bearings and set the bridge back down on the strengthened abutments
- Remove the cast iron handrails, repair off site and reinstate onto the bridge
- Grit blast and paint the outer-arch girders
- Repair cracks and spalls to the abutments and pilasters and re-point the stonework wall to match existing



Figure 7. Warped arch girder prior to grit blast and painting works

Deep Soil Mixing (DSM) was the method used to stabilise the liquefied ground surrounding the abutments. A grid of 800mm wide concrete columns was installed at varying depths ranging from 4 to 7 m to form a mass stabilised block. Initial efforts to install the columns were unsuccessful due to unforeseen ground conditions. The obstructions were removed by excavator and this led to some interesting discoveries.

Historical drawings indicated that the wingwalls of the 1901 structure had been removed during the widening of the bridge. This was not the case as can be seen in Figure 8 where the original

wingwalls remained in-situ. This effectively precluded the installation of DSM columns in that local area.



Figure 8. Original 1901 wingwalls found in-situ

In addition to the aforementioned discovery, a more significant archaeological find was the unearthing of the remains of the 1858 brickwork wingwalls. Since historical data for this structure was scarce, excavation proceeded with caution so that a qualified archaeologist could conduct an accurate as-built record of the structure.



Figure 9. Emma Clifford of Underground Overground Archaeology Ltd recording as-built dimensions of the 1858 brickwork wingwalls

Many of the bricks from the historical structure had collapsed inwards and had been used as structural fill behind the 1901 abutments. Consequently, a widespread area of obstructions had to be removed prior to continuing with the DSM works.

Remediation of the ground directly beneath the abutments, which could not be accessed by the DSM rig methods, was stabilized by "Jet Grouting". The procedure was to core a 150mm vertical hole through the abutment between each steel girder. The Jet Grouting equipment was inserted down through this hole until it reached a depth of 1m below the bottom of the abutment where a 1m

diameter grout column was formed. Difficulties arose when the buried brick remains were encountered just 1 to 1.5 m below river bed level – contrary to what was shown on the as-built drawings. This also led to concerns that the high pressure grouting would permeate under the abutment and into the watercourse, contaminating the river. It was therefore decided to create a dammed area between the abutment and the river, providing a controlled decontamination zone to cater for this possibility.



Figure 10. Hydro Response water dams were also used for Colombo Bridge.

An economical and innovative method was adopted to lift the bridge and support it so that strengthening work could take place on the abutments. This involved clamping a number of jacking pedestals to the lower part of the concrete abutments. A continuous beam was installed above the row of pedestals such that jacks could be placed in the space between the pedestals and the beam to jack the bridge up. The pedestals were fabricated with a widened top portion so that a pair of packers could be fitted, one each side of the hydraulic jacks. This allowed the jacks to be removed until the time came to lower the bridge back down on to the abutments.



Figure 11. Jacking the bridge

Jacking of the bridge was carried out with all 7 jacks operated from a panel which could instantly report jack loads and displacements. The jacking was carefully monitored by engineers to ensure that the bridge was raised evenly and that none of the temporary works pedestals were overloaded. Packing members consisting of short heavy walled steel RHS sections were cut to length on the day and welded in place.

An inspection regime was put in place whilst the bridge deck was propped up to monitor the pedestals and the continuous beam. No movement of the temporary works was observed during the course of the repairs despite the vibrations from heavy plant.



Figure 12. Hydraulic lines connecting the synchronised jacking control unit to the jacks shown in Figure 11

Grit blasting and painting of a historical structure poses many environmental, health and safety and quality threats. This is mainly due to the lead based paint which can become extremely harmful when it becomes airborne during grit blasting.



Figure 13 Shrink wrap encapsulation of bridge

In order to mitigate the risks associated with lead based paint, a bounded encapsulation of the outer girder was formed using shrink wrap hugged to the scaffolding. This stopped the contaminated garnet from entering the watercourse and allowed for an effective clean up after blasting. An exclusion zone was established around the confines of the encapsulation with only blasting and painting operatives with the appropriate PPE permitted entry.

One of challenges in the repair of historic structures is that of attempting to replicate existing materials that are no longer available. This

dilemma was pertinent to the repair of the pilasters and the repointing work required on the stone wall.



Figure 14 Repointing of the Stone Wall

Topcoat, a specialist coating contractor, were engaged to identify the existing materials and to propose suitable replacements acceptable to the Christchurch City Council and their Heritage Advisors. The existing material was found to be a lime based plaster and mortar. The evidence for this conclusion was the observation of hairline micro cracks that had self-healed over time, retaining the integrity of the plaster. The plaster used today is based on Ordinary Portland Cement (OPC) and is hard, non-breathable and does not self-heal. The stone wall, repointed as illustrated in Figure 14, benefits from a lime mortar which is more forgiving than OPC and allows the wall to “move” minutely and still retain its integrity. Due to the scarcity and substantial lead times for lime based plaster, the contractor formulated an alternative product made by mixing quicklime with water. The water was sat an inch or so above the quicklime to eradicate exposure to carbon dioxide and left to cure for a minimum of 6 weeks



Figure 15 Rendering of repaired pilaster corner spall

The final challenge was to colour match the repaired cracks and spalls to the existing fabric. Yellow oxide was used at a reduced dose of half a

teaspoon per kg of putty as today's oxides are five times more potent than those available in 1930.

Unfortunately, the immediate visual appearance of the new rendering is different to that of the existing. However, it is expected that the colour of the lime putty will fade over time and together with age and moss growth, the contrast will gradually become less apparent. In time, it is hoped that the repair work will blend seamlessly with the existing fabric and to aid with the aging process, a milk spray was applied at all rendered locations to encourage the growth of microorganisms.

Repair works were completed in 2014 with the tilted piers and buckled side girders left in their deformed shape as a reminder of the earthquakes.



Figure 16. The buckled side girders were retained.

4. Antigua Footbridge

Built in 1901 the Antigua Footbridge was damaged in the 2011 earthquake when lateral spreading caused the concrete abutments to rotate and move towards each other. The bridge is adjacent to the Category 1 Historic Antigua Boat Sheds.



Figure 17. . Antigua Footbridge

The structure consisted of a pair of trusses fabricated from rolled steel (or possibly wrought iron) angle and tee section members. The two trusses were braced together and anchored into the concrete abutments. The structure had a timber deck and timber handrails. Lateral spreading caused the trusses to hog in the centre by approximately 400mm. Furthermore, the structure had fallen into a state of disrepair prior to the earthquake and several of the riveted joints and members had rusted and failed either before or during the earthquake.

The specified repair works included:

- Removal and refurbishment of the steel structure
- Demolition of the existing abutments and construction of new abutments
- Re-installation of the steel structure with a new precast concrete deck.

Work is still underway (as at September 2014) with the steel structure removed and the new abutments under construction.

A major challenge for the Contractor was the safe removal and transportation of the earthquake damaged steel framework. The approach taken by Downer for this work was as follows:

- Remove all of the existing timber deck and any other superimposed loads such as services (pipes & cables)
- Undertake a detailed inspection of the damaged structure along with a review of the SCIRT designer's reports
- Investigate possible crane lifting positions and crane setup locations for the site
- Analyse the member forces under the proposed lifting arrangement
- Finalize the method and execute the lift.

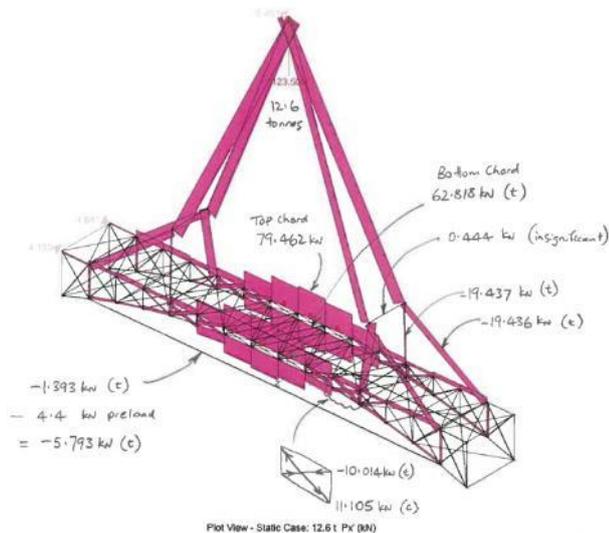


Figure 18. Analysis of the lift using "Multiframe"

A 200tonne crane was set up on the south bank of the Avon and rigging was set up for the lift. The design called for a pair of bowstring chords to be installed for each truss with a load cell connected to each bowstring.

Both top and bottom chords were encased in the concrete abutments and it was initially thought that they would both need to be cut to remove the bridge.



Figure 19 The crane was set up on the South bank

Prior to removal, however, it was found that the concrete could easily be broken away from the top chords allowing them to be removed intact.

Final gas cutting of the bottom chords commenced when the crane and rigging were set up for the lift. As cutting commenced, the bridge attempted to straighten from the pre-camber induced by the earthquake.



Figure 20. Cutting the bottom chord & diagonal braces

The removal of the bridge from its abutments was thus carried out incrementally with careful monitoring and gradual release of the tension in the bowstrings. Small bites of steel were cut from the bottom chords as the remainder of the structure straightened itself, gradually relieving the built-up compression forces.



Figure 21. Successful lifting out of the bridge. Note the bowstring wires with tior and load cell.

5. Conclusions

A number of bridges across the Avon River in Christchurch were damaged in the Canterbury earthquakes and they are currently being repaired by the SCIRT alliance.

Due to their heritage nature, they presented a number of interesting challenges for the Contractor. These included:

- Repairing a brick arch soffit on Armagh Bridge. Temporary support was provided by a series of radial props.
- Jacking up Colombo Bridge to retro-fit new bearings and abutment concrete. The entire bridge had to be supported on steel members that had to be small enough to carry in and install by hand.
- Lifting out Antigua Footbridge in one piece for repairs and refurbishment. A detailed analysis of the structure was carried out and care was needed to relieve the built-up compression forces.

All work was carried out with the involvement and advice of heritage specialists from the Christchurch City Council. Constant vigilance was needed, especially during excavations, so that discoveries of archaeological significance were identified, preserved and documented.

6. Acknowledgements

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