

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.

Armagh Street bridge – award application

Story: Heritage Bridges

Theme: Construction

An award application for the Civil Contractors NZ Hirepool Construction Excellence Awards 2015 which details Downer's approach to repairing the Armagh Street 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.

For more information about this document, visit www.scirtlearninglegacy.org.nz



This work is licensed under a [Creative Commons Attribution 3.0 New Zealand License](https://creativecommons.org/licenses/by/3.0/nz/).

The authors, and Stronger Christchurch Infrastructure Rebuild Team (SCIRT) have taken all reasonable care to ensure the accuracy of the information supplied in this legacy document. However, neither the authors nor SCIRT, warrant that the information contained in this legacy document will be complete or free of errors or inaccuracies. By using this legacy document you accept all liability arising from your use of it. Neither the authors nor SCIRT, will be liable for any loss or damage suffered by any person arising from the use of this legacy document, however caused.



Civil Contractors NZ Hirepool
Construction Excellence Awards 2015

Armagh Street Bridge Repairs

Armagh Street Bridge Repairs

Introduction

The Armagh Street Bridge is a key inner Christchurch city bridge, servicing the central business district as both a colonial tourist attraction and a functioning vehicular access point. A wooden bridge was first erected on this site in 1872. However, by 1878 the bridge was deemed to be in a dangerous condition due to decay and tenders were called to construct a new permanent bridge. The project was won at £1,390, and construction of the current, two-laned brick arch bridge was completed in December 1883.

The bridge carries Armagh Street traffic in an 8.2m wide carriageway with a single lane and cycle lane in each direction. There is a tram track within the east bound lane and 2m wide footpaths on either side.

The brick arch has a clear span of 12.2m, a rise of approximately 2m and a skew of 16°. The barrel is 685mm thick, supported on unreinforced concrete thrust blocks.

The February 2011 earthquakes caused significant damage to the brick barrel and the bridge was thereafter closed to vehicles (including the trams). The damage included a 20mm wide crack extending from the western abutment and spreading $\frac{3}{4}$ the length of the arch. It was believed that this crack may have split through all 6 layers of brick.



Historic map of Christchurch before the timber Armagh Street bridge was built in 1873



The main crack to the brick barrel



Armagh Street Bridge in 1914



Christchurch City Tour tram passing over the Armagh Street Bridge

Key Project Information

Client: Christchurch City Council (CCC)

Location: Armagh Street, Christchurch

Start Date: March 2014

Due End Date: January 2015

End Date: November 2014

Reasons for Difference: Work was completed ahead of schedule by strategic use of scaffolding systems, in conjunction with temporary coffer dams that enabled us to repair the entire main crack from the Western abutment. When the coffer dam was shifted to repair the eastern abutment, we were able to simultaneously complete repairs on the surface in conjunction with eastern abutment repairs.

Original Tendered Value: \$335,000.00

Final Delivered Value: \$495,355.00

Reasons for Difference: During the earthquake repairs, CCC requested additional works, including refurbishment of the balustrade handrails and internal fixing posts, as well as repairing of historical cracks to the wingwalls and general abutment repairs.



Iconic 130 year old balustrade handrails of the Armagh Street Bridge



Two iconic Christchurch City tourist attractions include the Armagh St Bridge in their routes: the Christchurch tram and Punting on the Avon

Scope

The earthquake damage included:

- Cracking of the brick barrel soffit. A 20mm wide crack extended from the western abutment for ¾ the length of the arch
- A block of brickwork around the area of the crack in the brick barrel soffit became dislodged and displaced vertically by approximately 50 mm
- Transverse cracks in the arch extrados
- Damaged bridge approaches and pavement
- Damage to the cast iron balustrade panels

Bridge refurbishment was carried out over nine months and included the following key activities:

- Installation of temporary coffer dams in the Avon River, providing access to fix the earthquake damage to the brick barrel and abutments
- Crack stitching and cross pinning across the longitudinal cracks in the brick barrel
- Grout injection of cracks
- Removal of the block of detached brickwork
- Replacement of cracked bricks with similar replacements
- Repairing cracks in the arch extrados to prevent water ingress
- Full removal and refurbishment of the cast iron balustrade handrails
- Fill void under tram tracks and surface reinstatement

Heritage & Community

The bridge forms part of the Christchurch tram route and locals and tourists enjoy Punting on the Avon, which passes beneath the bridge. Many of the buildings within the vicinity were badly damaged in the earthquakes and required demolition during our work period. Additionally, the bridge is listed as a protected structure on the Christchurch City Plan and is an archaeological site for the purposes of the Historic Places Act. Throughout the works extreme care was required to maintain the historical integrity of the bridge, and comply with various environmental, local body and stakeholder requirements. Stakeholder engagement was essential to the success of the project.

Planning & Control

Planning

Quality Assurance

The Armagh Street Bridge Repairs were delivered in line with Downer’s ISO accredited Quality system.

Downer’s Integrated Business Management System encapsulates AS/NZS 9001:2008, 14001:2004 and 4801:2001 standards, while our Quality Policy drives the delivery of consistently high quality outcomes for customers.

Preparation, implementation and progressive designer sign-off of an Inspection and Test Plan (ITP) ensured hold points were adhered to and the project specification was followed. Our Quality Assurance (QA) system is externally audited to ensure compliance to the relevant standards and requirements are maintained.

Significant QA inspection was required for the heritage elements of the works. In particular the dismantling and refurbishment of the original balustrades required additional auditing.

Skills & Training

Downer’s commitment to industry development and providing optimal service to our customers sees us investing heavily in the development of our people in terms of training and development.

This is actively managed through initiatives and programmes focusing on leadership development, career mapping, graduate and cadet rotational programmes, active mentoring and regular appraisals. Downer staff receive a variety of learning opportunities, ranging from literacy programmes through to formalised leadership skill development and postgraduate study. Diversity initiatives include a Māori Leadership Pilot Programme funded by Te Puna Kokiri and

extended to local iwi representatives. Downer was recognised for excellence in the development and implementation of industry best practice for training, recruitment and retention of employees, winning the Rooding Excellence Award 2012 and the Best Practice Award for People in the Rooding Excellent Awards 2013.

Tom Harding-Ilott, Site Engineer for the works, came to this project from the Heathcote Opawa Bridge Repairs. Downer is supporting Tom in completing his National Diploma in Civil Engineering part time while he gains practical experience on site. For Tom, working on challenging projects provides great practical skills and experience which can then be applied to the theory based diploma.

Environmental

Excellence in environmental management was achieved on the Armagh Street Bridge Repairs through the application of the robust Environmental Management System under the management of David Maucor, Zero Harm Adviser for Downer’s SCIRT division, and with full executive backing.

Downer is certified to the international ISO 14001 standard and has comprehensive Environmental and Sustainability policies. Downer was recently recognised for efforts to sustainability as our Green Vision Recycling operation achieved CEMARS (Certified Greenhouse Gas Emissions Measurement and Reduction Scheme), a world-leading greenhouse gas certification.

The works were environmentally challenging as the area of the Avon River that we dammed and dewatered is a trout spawning area. A trout survey was completed by Environment Canterbury (ECan) stating restrictions and key spawning dates. We dewatered the work site through a 6” pump, through a sediment tank and discharged back into the river downstream. We worked closely with ECan to ensure the operation was environmentally successful, and received positive feedback for our commitment to environmental excellence.



CCC asset managers, along with Heritage Consultants and subcontractors dismantling the 130 year old balustrade panels



Tom Harding-Ilott, Site Engineer, was completing his National Diploma in Civil Engineering while gaining practical experience from this site

“ The communication with consent compliance staff was excellent, proactive and professional. Minimal site visits were undertaken due to the confidence and trust in the site engineers and contractors. We look forward to working with this team on jobs in the future.”

-Fiona Nicol, Compliance Officer, ECan

Health & Safety

The team’s health and safety performance on this project demonstrates Downer’s commitment and the effectiveness of its industry leading systems in protecting its people.

In 2013/2014 Downer experienced zero fatalities and only 22 LTIs across 15,747,858 man hours, a remarkably low incident rate for a company of our size and scale. The Downer safety systems are accredited to AS/NZS 4801:2008 including tertiary level accreditation with the ACC Partnership Programme. Downer was awarded the Roothing New Zealand People award in 2010 for our Zero Harm Culture Change.

The Armagh Street Bridge repairs were completed with **zero** incidents and **zero** injuries.

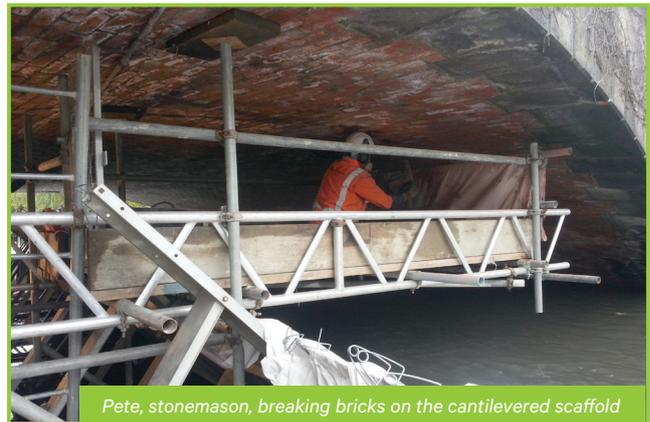
Project Management

A robust Project Management Methodology (PMM) provided the systematic framework required for the successful delivery of the Armagh Street Bridge Repairs.

Projects are at the core of Downer’s business. All of our projects follow a standard project management framework, driving a consistent, rigorous and group-wide approach to project management. Our PMM has been created to cover a project’s full lifecycle, from ‘handover’ to ‘closure’ with projects classified into one of five project categories. These are based on size, complexity, risk and design aspects of the project and depending on the category, dictate the level of contract management required.

Temporary Works

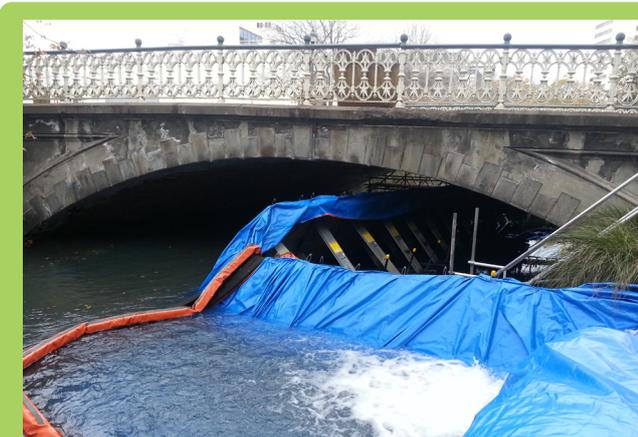
Downer identifies temporary works requirements in the early stages of the planning process.



Pete, stonemason, breaking bricks on the cantilevered scaffold

As the repairs were to be completed from underneath the bridge, a key health and safety risk was bricks and debris falling onto workers. To prevent this we developed a propping structure, designed to support ‘a tonne of bricks’. This structure involved anchoring three channel supports into the concrete abutments and using Acrow props on different angles to account for the shape of the brick barrel. Each channel held three props and a plywood sheeting system was placed on top of these props. As work progressed, sections of plywood were removed to enable us to move along the crack.

This innovative scaffolding design, combined with the coffer dams, enabled us to reach the full length of the main crack whilst only having the western abutment side of the Avon River dammed. We cantilevered a scaffold platform, using props and screw jacks to overhang the coffer dam. By completing all of the repairs to the crack barrel from one side of the river, we were able to complete both the surface and eastern abutment repairs simultaneously, accelerating the programme.



Dewatering exiting the coffer dam, most days the discharged water was cleaner than the river water



Our propping structure designed to protect workers from falling debris

Control

Engineering

The core structural repairs to the crack were completed by crack stitching and cross pinning. This work involved using 12mm stainless steel threaded rods drilled into the brick at a 45° angle.

We installed 6mm stainless steel Helifix bars in the mortar joints to tie the new brickwork into the old. The injection of the crack required a specific mix of cementitious grout. With our subcontractor BBR Contech, we tested and designed a low strength mix, to match the strength of surrounding brickwork, typically around 11MPa, to ensure the new brickwork does not attract higher loads which has potential to cause damage to the brickwork.

Construction Programme

The project programme was managed by Tom Harding-Ilott, Site Engineer, utilising Microsoft Project, and day-to-day updates on whiteboards on site. Involving all subcontractors in the programme helped all to see current and future stages of work and what was required before next steps could take place.

Financial

Budget management was key for the Armagh Bridge Repairs. Downer practises under the JD Edwards Financial Management system which covers project costing, payroll, plant management, sales and purchasing. This system also allowed Downer to provide up to date monthly cost reports and enabled the submission of regularly updated costs along with cash flow reports to SCIRT in conjunction with the standard monthly claim. We also captured plant and labour costs using daily job record sheets, ensuring we were able to keep a close eye on the project costs. At the client's request, we delivered a number of additional repairs and enhancements than originally planned, and accordingly the budget changed across the course of the project. We delivered the works to the client's satisfaction.

Relationships & Client Satisfaction

Relationships

Collaboration

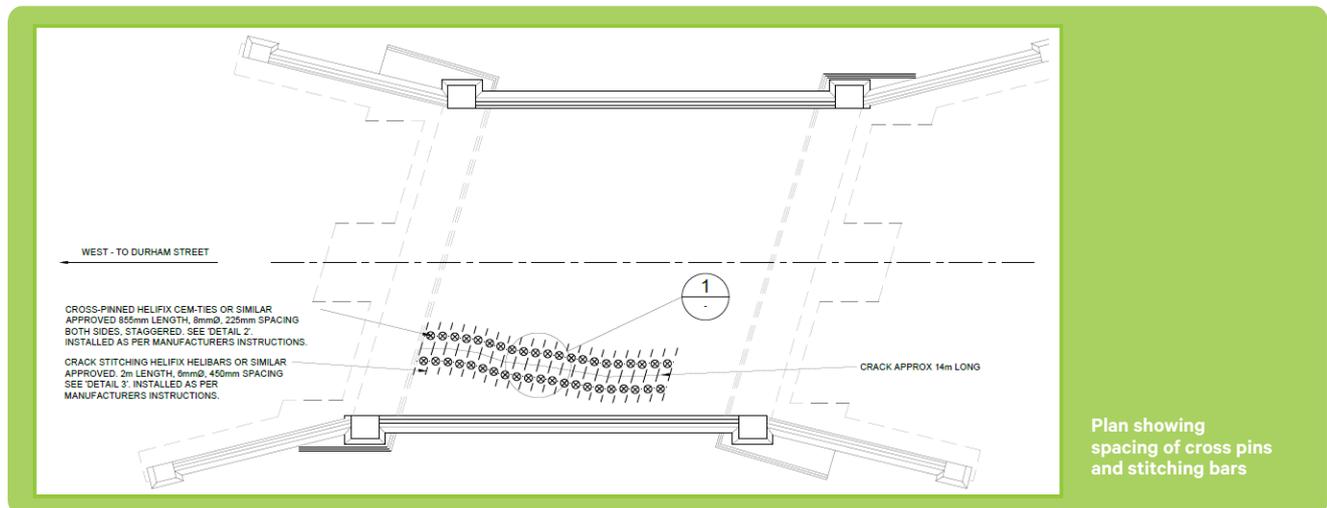
At Downer we believe we will secure our future success by building stronger and deeper relationship of trust with our customers, colleagues and communities, ergo our tag phrase "Relationships creating success". This project is a prime example of Downer working closely with our customers to help them succeed, using industry leading insights and solutions.

Downer carried out the works under an alliance type contract with the New Zealand Government as part of the Stronger Christchurch Infrastructure Team (SCIRT). There were many key parties to the delivery of these works, including CCC (client), ECan (environmental controls), Heritage New Zealand (heritage protection), in addition to subcontractors, stakeholders, SCIRT designers, and the SCIRT Engineer to Contract. We worked closely will all parties to ensure their contribution was meaningful and successful.

The unique arrangement of the SCIRT alliance includes open book accounting, regular internal reviews, and a great deal of Early Contractor Involvement (ECI) throughout the design process leading to best for project designs. The Design Team liaised with Downer throughout the design process, allowing us to give input and improvement suggestions from a construction risk and methodology perspective. Joint Consultant / Contractor risk workshops were held at Concept and Detailed Design stages.

Critical success factors were established at the very outset, in the form of key dates, key objectives and common goals for the project team. Continual monitoring of programme and finance by the Project Manager ensured targets were being met and exceeded.

Risk management was a critical aspect of project planning and development. Comprehensive risk schedules were developed,



Plan showing spacing of cross pins and stitching bars

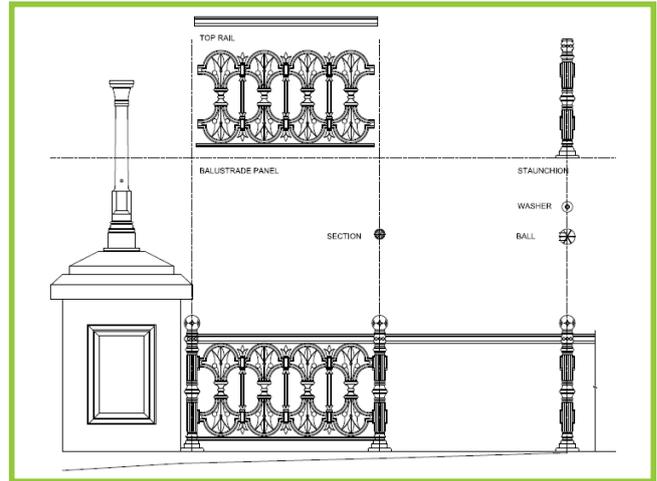
shared with our partners, and continually reviewed. Identification of new risks and adjustments to the status of existing risks were discussed at Project Review meetings. Safe Work Method Statements (SWMS) were developed by the Engineer in conjunction with the workforce for each activity to ensure the risks were fully identified, understood by all parties and controlled.

Client

We worked closely with CCC throughout the works to ensure their needs were exceeded. Their priorities included: re-opening the bridge as a functional vehicular route to the city, repairing this heritage bridge while protecting its historical integrity, and minimising disruption to the public, environment and other services during works. We were cognisant of these issues, and worked tirelessly to provide a faultless service, often going above and beyond to ensure all parties were catered for. For example, we worked with the Tram operations team to ensure the tram service was able to recommence operation as soon as practicable, and the damming of the Avon River did not disrupt the Punting on the Avon.

The Armagh Bridge was delivered ahead of schedule and met all client requirements. The bridge was kept open as much as possible to pedestrians and re-opened to trams and traffic in November.

Undertaking the balustrade panel refurbishment was a task with numerous unknowns for both the client and Downer. There were no drawings or as-built information of the panels and they hadn't been altered since their installation in 1883. To ensure each piece went back into its exact position a numbering system was generated and boxes made to keep track. We provided the client with updated drawings for the panels and details of how we reinstalled the pieces which was above and beyond their expectations. Our work around the balustrades exceeded client expectations and helped to build a good relationship between us.



Balustrade drawings generated by Client and Downer.

Supplier(s)

Downer makes every effort to support and promote the wider construction industry. Helifix supplied all cross pinning and stitching bars, Fletcher Reinforcing supplied the galvanised bars for abutment stitching and Hilti products were used to anchor these. Local welder Hewitts Welding fabricated the steel sections for the temporary works. We pride ourselves in having a good relationship with local suppliers, which ensures a quick response and no delays to programme when we manage projects.

Subcontractor(s)

Downer's subcontractors on the project were Goldfield Stone, BBR Contech, Hydro Response and Southern Cross Engineering (SCE).

Goldfield Stone completed all brickwork repairs, including removing damaged bricks, cross pinning, crack stitching, new brick installation and mortar work. It was their first time working with a large infrastructure company such as Downer. We formed a close working relationship to ensure the project ran smoothly throughout some rather challenging conditions.



Brick diorama showing cross pinning and stitching



A built for purpose storage box for the dismantling of balustrade. Each compartment was labelled to ensure it was returned to the correct place

“ At all times, from a heritage perspective, Tom provided a high and competent level of heritage project management and quickly understood, the at times not easy, heritage expectations and outcomes of the project and worked carefully within the parameters of the conservation conditions. Most importantly Tom sought advice about heritage conservation where it was required and acted on that advice rather than simply making a quick onsite uninformed decision. Tom kept us fully informed at all stages of the project, provided regular site diaries and photographic records and ran well organised and efficient site monitoring visits and meetings. The overall heritage outcome of this project was, in my opinion, excellent. I consider this was one of the best and most efficiently managed of the vast number of heritage earthquake repair and conservation programmes I have worked on.”

- Jenny May, Heritage Management Services Ltd

“ During the process of the Armagh Street Bridge reconstruction in 2014, Punting on the Avon Ltd was operating guided boat tours under the stretch of river where Downer were working. This work would obviously cause an impact to the operation yet Tom Harding-Ilott and his team were very communicative as to the whole process, thus reducing any potential issues. In fact, they went out of their way to ensure that we could still operate safely through the site. This involved restricting the flow and volume of water to allow us to punt safely; and also going to the extent to lay sand bags to allow for more purchase on the river bed, allowing for a smoother ride for the customers.

Tom even filled us in on interesting finds under the bridge, which allowed for a more informative and interesting spiel from our guides.”

- Jamie Storey, Punting Operations Manager

BBR Contech completed all crack injections, abutment repairs and grout injections in the brick arch and under the tram tracks. Working on a heritage site was a challenge for BBR, but one in which they excelled. Together with Downer they ensured all products used would not stain or mark the heritage fabric of the bridge. The low strength grout mix for the brick injection worked well and the strength rating and methodology was approved by the designer, client and heritage consultant.

Hydro Response was a key subcontractor, supplying the Hydro Barriers which provided access to work on the

abutments and brick barrel. Each abutment was completed individually to allow sufficient water flow and access for punters. The barriers were designed to flood in the event of heavy rain so as to not create any issues upstream.

SCE completed the challenging task of the balustrade refurbishment and repairs. SCE performed well here providing the right attitude and knowledge to achieve this task. We worked well together, supplying information to the client and heritage consultants and running inspections through-out the repair process.



The Goldfield Stone team, placing mortar around newly installed bricks



Installation of grout tubes ready for injection

“ The great thing about the Armagh Bridge project was that Downer was looking beyond their own fence line right from the start, and took into account the impact the project would have on central city businesses.

Tom was aware of the Council and Tramway’s desires to get the tram loop reinstated and of the positive outcome this would have on local business operators: particularly the small business owners and retailers in New Regent Street, Cathedral Junction and Cathedral Square.

From then on we had weekly appraisals on the progress each project was making, which was important in the scheduling of priorities. Without the Armagh Bridge completed on schedule we were in danger of missing the shoulder period of the new tourist season. The Bridge was not only partially opened ahead of schedule, but Downer also insured we could operate (before it was open to full traffic).

We couldn’t fault the input of the Downer team in the project: they not only did their job but went beyond the job brief. Downers Armagh team also took into account the needs of the inner city and what the project meant to local businesses”

- John Smith, Tram Operations Manager

“ You and your company impressed me so much, especially since the bridge opened ahead of time. That in itself is amazing for something like that to happen in post-quake Christchurch”

- Linda Purves, Department of Justice (from the neighbouring Courthouse complex)

Consultant(s)

The SCIRT Integrated Services Team (overarching tactical co-ordination) design division provided design support, led by the Engineer to Contract Jonathan Creelman of Opus. Downer formed a good working relationship with this team, helped by the collaborative nature of the alliance contract and early contractor involvement in design.

As Armagh Bridge is classed as an historic structure, the CCC heritage consultants were thoroughly involved in the project. Before work commenced a Temporary Protection Plan (TPP) was generated. The TPP outlined the project requirements and methodology for each stage of work. In addition to this, we held a pre-construction site meeting, and supplied a fortnightly Heritage diary, which was emailed to both council and consultant heritage advisors. The diary outlined future

works and the effects they would have on heritage fabric of the bridge. It also gave the heritage consultants a chance to query anything before that task actually took place. We nurtured an excellent working relationship with the heritage consultants on this project.

Stakeholder(s)

Stakeholder interface is vital to the success of any contract, and great care was taken to ensure affected parties were satisfied with Downer’s approach.

Punting on the Avon took tourists under Armagh Bridge and along Victoria Square and back. Regular updates to punters advising them of scaffold installations and the installation of coffer dams ensured they were aware of the river condition ahead of time. Punters were delighted to relay this information



Grout tubes placed around tram tracks



SCE dismantling the balustrade puzzle

to their clients, enhancing the punting experience. When the coffer dam was installed we held some training for the punters under the bridge as flow was temporarily increased. We worked together on this and assisted each other through-out the works.

The inner city tram loop was one of the many casualties of the Christchurch earthquakes. The tram tracks run over the Armagh Street Bridge, and could not reconnect until we had strengthened the bridge and levelled the track area. We were able to get the tram up and running while we were still working onsite.

Public

Community engagement, stakeholder satisfaction and a commitment to each other formed part of the delivery ethos. With the assistance of the SCIRT Communications Team, we had consistent, informative and timely briefs available to the public. We had informative pictorial posters pinned around the worksite, so that members of the public could read about the works, as well as regular online updates, including photos and interesting facts.

The project attracted a great deal of attention due to its historical significance and challenging work around waterways. Christchurch Polytechnic visited site with an Engineering class, and the New Zealand Institute of Highway Technology came to site with a projects class to discuss works on site. Both visits went well and great feedback received from students. The bridge featured in the Beca Heritage Week, with a walking tour of the site while under construction. Our team was only too happy to describe the works, heritage finds and challenges.

Reopening the city tram loop was a key post-earthquake milestone for the public as it signified a return to revitalisation of our city. This letter to the editor of The Press describing the first tram rolling over the Armagh Street Bridge on reopening day epitomises public opinion:

“ I had “a moment” today - a lovely one actually.

I looked out of my office window near Victoria Square and to my delight I saw the tram trundling past.

I had to terminate my phone conversation and go outside and watch it roll towards New Regent St.

On occasion, I weigh up what I feel our community has lost and what it has gained because of the earthquakes. In sombre moments, I wonder whether, in my lifetime, I will ever see us regaining even a fraction of what we have lost. It takes a lovely moment like seeing our trams returning to old territory to restore the faith that, while we have lost so much, we haven't lost everything. I gave the tram driver the most enthusiastic thumbs-up I could muster and he gave me the biggest smile.”

- Kylie Ehrich, Middleton (in a letter to the editor of the Press)



Loader towing the Tramway Restaurant onto bridge to test for clearance



Precious millimetres: the Tramway Restaurant clearing the bridge



The tram running over the completed Armagh Repairs



The completed bridge



The completed brick work

Client Satisfaction

Delivery of Client Requirements

We delivered all of CCC’s requirements: re-opening the bridge as a functional vehicular route to the city quicker than anticipated, repairing this heritage bridge while protecting its historical integrity, and minimising disruption to the public, environment and other services during works. Repairs to the Armagh Bridge were completed ahead of programme. More importantly, we took our stewardship role very seriously: it is very hard to tell that we have been there. We went above and beyond to ensure that the details were correct, for example, finding suitable replacement bricks was key in ensuring the bridge looked original for punters and tourists travelling beneath the bridge, as well as taking good care of the balustrades so that this iconic feature of the bridge was retained.

Level of Client Satisfaction

We delivered all of CCC’s requirements: re-opening the bridge as a functional vehicular route to the city quicker than anticipated, repairing this heritage bridge while protecting its historical integrity, and minimising disruption to the public, environment and other services during works. Repairs to the Armagh Bridge were completed ahead of programme. More importantly, we took our stewardship role very seriously:

it is very hard to tell that we have been there. We went above and beyond to ensure that the details were correct, for example, finding suitable replacement bricks was key in ensuring the bridge looked original for punters and tourists travelling beneath the bridge, as well as taking good care of the balustrades so that this iconic feature of the bridge was retained. The final product looks great and the client was extremely happy with this. This was an excellent project for both Downer and the client.

“Great job in completing the bridge early. Please thank all involved, the Client is very happy with the result. Well done.”

- Richard Topham, Central City Programme Manager, SCIRT

“Many thanks for the work you have done with the bridge. It looks great. We will be commencing punting as of this weekend, so soon everyone will be able to admire the bridge.”

- Jamie Storey, Punting Operations Manager.

Risk & Construction

Risk

Site Factors

This heritage project required innovative problem solving and committed teamwork due to the many challenges faced on site. Its location, next to Victoria Square and the Heritage Provincial Chambers, meant numerous pedestrians and tourists were in the area. Ensuring their safety was just as important as the safety of workers on site.

Throughout most of the project we were able to keep a pedestrian walkway open, but during closures, clear direction via pedestrian signs and maps directed them to the nearest bridges up and downstream.

The site itself, being a protected heritage site was a major challenge. Ensuring the full scope of repairs were completed whilst protecting the heritage fabric of the bridge often proved difficult. However, regular site visits with the client and consultants and good communication overcame this challenge.

SWMS were developed by the Site Engineer in conjunction with the workforce for each activity to ensure the risks were fully identified, understood by all parties and controlled.

Physical

The main physical hazard on this project was the two 66kv cables that crossed the bridge. The location of these cables proved difficult as they were directly on the path of the cross pinning works.

This risk was identified early, and we started by positively identifying the cables. It turned out that the asset owner as-builts were incorrect for the detail of the bridge crossing. The Downer Site Engineer then transposed the cable location to the underside of the bridge and began to map out the proposed coring.

The cross pinning work involved coring 48 880mm long holes on a 45° angle crossing the crack. The brick barrel is only 750mm thick (confirmed by two core samples taking during the design stage). Mapping out the direction of the core holes put the core direction straight into the outer 66kV. This meant an increased and significant risk of electrocution to operatives whilst performing repairs which, at that voltage, would almost certainly mean fatalities. It would also mean significant outages for consumers and issues for asset owner Orion. Switching off the power and removing the cables simply wasn't an option. The network could not sustain these cables being out of service due to loading issues.

Details of how this risk was overcome are detailed below under the innovation section.

Environment

Environmental challenges and issues were a specific focus throughout the contract and numerous risks were identified.

The repair methodology included measures to avoid sediment discharge, concrete and chemicals into the Avon River and protect the surrounding ecosystem. Once the coffer dams were installed, they were dewatered into sediment tanks and discharged into an area protected by a silt curtain. Two hourly monitoring of the discharge checked turbidity levels and PH to ensure water quality.

Flooding was also a risk and was planned for throughout the project. The coffer dams had low side heights to allow the dam to flood in heavy rain. We kept a careful eye on the forecast and if any significant rain was on the horizon, the dam was emptied of tools and debris at the end of each day just to be safe. Early in the project Christchurch was hit with two 100-year rain events which flooded the dam. Once river levels dropped, all it took was to check the plastic dam sheeting and re-start the pumps.



The two 66kv cables and pilots



The coffer dam under water during a flood event.



Location

The location of the bridge is right in the central business district of Christchurch on Armagh Street. It is key for the city tram loop and has the Christchurch Courthouse located on its western bank.

Following the earthquakes many of the nearby buildings had to be demolished, including the 12-storey Victoria Apartment block. Our sites were adjacent, so regular catch ups and planning ensured our works did not conflict and both sites were kept safe.

Climatic Conditions

Flooding was the only significant risk during the project, which we dealt with on a day-to-day basis. If it was raining heavily and the river was rising then once levels got to around 200mm to the top of the coffer dam walls, we would pack up and clear the area.

It was also cold, difficult work completing the brick repairs, but frequent breaks and a chance to warm up kept everyone focused and refreshed.

Ground Conditions

Only minor hand digging in the river bed and bridge deck excavation was required, so there few risks involved. One risk which was relatively unknown was the condition of the abutment concrete. To stitch the crack here we cored 30mm diameter holes 2.7m into the concrete. We found all sorts of construction waste and a lot of timber buried in the concrete, most probably sections of the old timber bridge. Hitting timber delayed our coring activities, as it blocked the core barrels and took time to remove.

Complexity

Repairs to the heritage fabric of the bridge was a high risk activity that required thorough planning and communication.

There was a risk in finding suitable replacement bricks for the bridge barrel. The original bricks were in imperial measure, and are no longer in production. We phoned around demolition companies and identified an old brick building marked for demolition on nearby Colombo St. Goldfield Stone went to inspect the bricks and found they were the same dimensions, colour and a very good match for strength. The heritage consultants approved this match.

Another complex risk was around the repairs to the cast iron balustrade. As this would always be in the public eye we wanted to complete repairs so they were imperceptible. A common technique generally used was brazing and was favoured by the consultant initially. However, with the number of repairs required this would have been extremely costly for the client. SCE submitted another product for review which was a Eutectic system (metal powder spray), which was faster and more cost effective. SCE repaired a section using each method for heritage review and it was decided to use the Eutectic system. This innovation saved time and money for the client.



The adjacent Victoria Apartments during demolition



Sample of an Eutectic repaired balustrade panel.

Contract Period

The original timeframe for this project was from March 2014 to October 2014. As the works were carried out in a high risk site with the potential for disruptions from inclement weather and increased work scope, the actual time frame was a risk. As additional damage was found and the client requested additional works to be carried out and extended timeframe of January 2015 was given. However, all repairs were completed in November 2014.

Contract Conditions

The project was carried out under the Stronger Christchurch Infrastructure Rebuild Team (SCIRT) which is an alliance type contract between five contractors (including Downer), New Zealand Transport Agency, Christchurch City Council, and the Christchurch Earthquake Recovery Authority. Financial risk is shared between the non-owner and owner participants in accordance with the alliance agreement. Various risks are involved with this type of contract and include: work being de-scoped out of a project, projects being cancelled, re-programming the sequence of projects, transfer work scope from one project to another and projects being issued to parties outside of the alliance.

Project Statistics	
Number of bricks replaced:	194
Number of fixing posts cored and replaced:	16
Pieces of balustrade removed:	200
Man hours worked:	3800
Lost time Injuries:	0
NCRs:	0

Complexity

The nature of the design and location of damage meant that repairs had to be completed in a specific sequence.

Stage 1 of works involved the establishment of site and installation of the coffer dam on the western abutment (most severely damaged).

Stage 2 included the design and installation of temporary works to protect workers and allow for the removal of the outer layer of bricks. It was not clear from the design and investigation stages the extent of the cracking and how bad internal cracking may be. Once we began removing the outer course of brick it was clear that the internal layers were still stable and nothing was sitting loose internally, even though the crack probably split through all 6 brick layers.

The coffer dam provided an opportunity for the client and heritage consultants to view and inspect parts of the bridge

that had never been exposed since its construction. Together we identified additional cracks in the brick barrel, historical cracks (unrelated to the earthquake) in the bridge wingwalls and sections of the abutment that had eroded.

One challenge to completing the repairs was completing everything from the bottom up, and fighting gravity all the way. It was investigated and suggested early on to complete the repairs from the top down, but due to uncertainty of the barrel cracking, if too much load was removed from the arch, it could have caused collapse.

Stage 3, grout filling the crack, occurred once the outer layer of brick had been removed. A specific grout mix was designed to match the strength of the brick. Once injected, we cored holes for the cross pinning and mortar joints cut for the stitching bars. In conjunction with this we took 2.8m deep cores to complete the abutment stitching repairs.

From here we started replacing bricks and filled mortar joints. In order for bricks to stay in place we drilled a threaded rod into the brick above and a tie placed between the two, timber wedges then secured them in place and allowed for remortaring to occur. This completed repairs of the main crack.

Stage 4 included shifting the coffer dam and all dewatering equipment to the eastern abutment to begin repairs to a smaller 5m crack there.

Another complex portion of works was the balustrade handrail repairs. These had not been removed since their installation in 1883, and with numerous paint layers applied over the years damage was difficult to see.

As a trial we removed one section of the handrails with the client and heritage consultants on site. This ensured everything was completed correctly and safely.

The handrails are not 'fixed' together, everything slots into place and so dismantling must start at one end and pieces twist and turn to come out. This trial run helped to set a final methodology to remove the entire system and complete the refurbishment. As pieces were removed and load was taken off the vertical stanchion posts, some disintegrated. It was also found that the internal fixing posts had also become heavily corroded and many required replacement.

To remove the fixing posts we had to core drill down over the top of them and into the stone. The client believed that they were only cast around 300mm into the stone. However, cores found that they were actually 750mm deep with a large washer placed at the bottom. Replacement posts were created which included having an old thread placed on top of the posts to allow for the reinstallation of the balustrade lock balls.

Working in a high risk archaeological area kept us all on our toes and Downer engaged the services of Underground Overground Archaeology. During construction the archaeologists were called to site many times to inspect findings and map out old features of the bridge.

Numerous finds were encountered under the bridge including the old wooden bridge piles, original abutment formwork still



The main crack and western abutment



1



Bricks placed along the crack



3



2



Above:
Samples of the heritage finds from site



4



6



5

in place, a handmade leather shoe, an old coin from 1889, numerous pieces of china and bottles. A bone was also found which stopped work immediately, thankfully it turned out to be a cow bone and no bodies were found.

Efficiency

The final project outcome is a credit to the whole Downer team, SCIRT and subcontractors. Collaboration between Downer and Goldfield Stone identified replacement bricks that would have otherwise been scrapped.

Efficient management of the programme and use of scaffolding enabled the project to be completed ahead of schedule. Scaffolding towers and a cantilevered platform enabled the entire main crack to be repaired whilst only having the western abutment dammed off. As this ensured sufficient strength was returned to the bridge, whilst the eastern abutment was being repaired work also began on the surface with the dig out of the bridge deck to expose the surface of the arch.

Completing the surface crack repairs and tram track repairs in conjunction with the eastern abutment repairs reduced the programme by weeks.

Innovation

During construction two main innovations were created to aid in the repair of the bridge.

Drill Guide

To assist with the cross pinning works we developed a drill guide. One row of cores for the cross pinning had us coring directly towards one of the 66kv cables. Calculations showed that we would be 130mm directly beneath the cable.

Through discussions with Goldfield Stone, an idea was

developed to utilise a wooden template to ensure coring was on a definite 45° angle and also to prevent coring any further than designed.

For this, a section of PVC pipe was attached to the wooden template, with the length of pipe cut to a size that ensured the core barrel could pass through, but the end physically couldn't. This ensured the core barrel could only core to 880mm and no further, in turn ensuring there was no possibility of coring into the cables. This eliminated the threat of electrocution during the repair.

The calculations and template were discussed with Orion who gave the approval to proceed with this work. Orion's Public Safety Advisor Trevor Hilton and colleague Darryl King from the Orion GIS mapping centre attended the site when the time came to use the template. They both concluded that the method worked very well, providing a practical, safe solution that did not impact the Orion network.

Balustrade Removal

The second innovation was related to the removal of the balustrade panels. Each individual panel weighed approximately 250kgs, so we adapted a car engine hoist to lift and manoeuvre the panels. This involved adding counter weights and fixed wheels to aid in controlling the panels.

The Armagh Bridge Repairs was the first brick barrel bridge to be repaired in the city. We held site visits from another contractor who was planning to start another bridge repair. The methodologies used on this project were also used and are currently being used on other heritage bridge repair projects across Christchurch.



Drill guide created to ensure angle of drilling was accurate, and prevent service strikes



Drill guide in action

Quality

A dedicated approach to quality control by Downer and our subcontractors resulted in all work being signed off as satisfactory by the design team and client.

A thorough ITP which was signed off throughout construction by both the Site Engineer and Designer ensured key steps were being made and records taken. Photographic records provided evidence of core holes being the correct depths and core samples showed that grouting works penetrated right through the brick barrel.

A numbering system ensured that each piece of the balustrade panels was returned to its exact location after it had been refurbished. Attention to detail such as this built considerable trust with the heritage consultants.

Environmental

At Downer, our 10 Environmental Principles help guide our Environmental Management practices, and our onsite environmental responses. Every Downer vehicle is equipped with a fire extinguisher and spill kit.

Due to the environmental sensitivity surrounding the works, Downer had to ensure adequate control measures were in place. Stringent environmental management and auditing ensured continual compliance. Methodologies were planned with the Project's Environmental Advisor, Jen Millar, and specific controls were discussed with ECAN compliance officers during pre-start visits.

Whilst completing grouting works, to ensure all possible areas were sealed, water was injected first. This allowed us to check for leaks around the brickwork and seal up areas before grout was used.

Downer completed the works with zero instances of non-conformities.



Downer takes Zero Harm seriously. The Downer 10 Cardinal Rules underpin all of our Zero Harm efforts.

Health & Safety

Downer is serious about **zero harm** and the management of safety was a key objective on this project. All members of the team undergo regular safety training, and whether they are subcontractors, temporary or permanent staff, all site staff are required to complete a Health and Safety induction prior to entering site. Downer's Health and Safety is underpinned by the 10 Cardinal Rules.

Staff adherence to these key safety rules ensured there were zero LTIs and zero MTIs across the project. The project achieved:

- Zero lost time injuries
- Zero WorkSafe prosecutions
- Zero service strikes
- Zero instances of non-conformance



Modified engine hoist lifting a balustrade panel.



A section of core sample showing grout filling the crack through two brick layers.