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Construction and Implementation of the Victoria Bridge Refurbishment

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Abstract

The 313m precast segmental box girder Victoria Bridge is a key Brisbane River crossing, which opened in 1969. The structure is a central link for public transport, pedestrians and cyclists within Brisbane and will be required to operate, carrying increased loading beyond its intended purpose.

As part of the Brisbane Metro Project, remediation of the bridge was required to reconfigure the deck to accommodate the future vehicle layout whilst undertaking local strengthening to several areas of the structure, to provide reliability for the future loading. Works included flexural strengthening using external post-tension tendons, shear strengthening using vertical prestressed bars, carbon fibre strengthening of half-joints, installation of near surface mounted reinforcement and post-installed reinforcement with chemical adhesives.

Construction of the works incorporated many challenges including several thousand drilling operations as well as multiple hundred coring operations into the existing structure with its dense fields of post-tensioned tendons. Work on these activities was carried out over the Brisbane River and Riverside Expressway with further construction required within confined box girder voids containing major services and utilities. Such challenges required close collaboration between the design and construction teams throughout both the design and construction phase.

This paper presents key learnings from the works including the non-destructive methods for identifying and avoiding tendons and reinforcement, in situ concrete pours in confined spaces within box girder voids, planning of works and use of offsite trials and access considerations over and adjacent to live traffic.

With a growing focus on sustainable management of infrastructure including the rehabilitation of bridges rather than replacement, such learnings associated are expected to be applicable to a wide range of future asset remediation projects.

Keywords: Bridge Construction, Refurbishment, Strengthening and repair, Access, Asset Management

1. Introduction

Victoria Bridge (313m) is a precast segmental box girder that is a key Brisbane River crossing, which opened in 1969. Since then, it has undergone reconfigurations with the addition of a rising sewer main in the mid-1990s and the incorporation of the Southeast Busway in the early 2000s.

As part of the Brisbane Metro project, Victoria Bridge was to be reconfigured and strengthened as part of the modifications to the bridge layout. The Brisbane Move Collaborative Partners were engaged to complete the works and included Brisbane City Council (BCC) as Owner Partner, Arup as Design Partner and Acciona as the Construction Partner as well as the Project Verifier (SMEC).

The extent of the modifications required included closure of the carriageway to general traffic, modification of the carriageway to include three bus lanes, the addition of bridge barriers for the entire length of the bridge, installation of new drainage scuppers and a stainless steel collection pipe over the live Riverside Expressway, the addition of three new rising sewer mains suspended below the bridge deck, the addition of a two-way bicycle path widening, flexural strengthening of the bridge using external post-tension tendons, shear strengthening using vertical prestressed bars, carbon fibre strengthening of half-joints, installation of near surface mounted reinforcement and post-installed reinforcement with chemical adhesives.

This paper presents key learnings from the works including the non-destructive methods for identifying and avoiding tendons and reinforcement, in situ concrete pours in confined spaces within box girder voids, planning of works and use of offsite trials and access considerations over and adjacent to live traffic.

2. Project Works

There are three main work scopes for the refurbishment of Victoria Bridge which include rising sewer main works, strengthening and above deck works. Much of the design and construction of the refurbishment works occurred from early 2021 through to early 2025. The below provides a brief overview of the scopes and will be explained further throughout the paper.

Rising Sewer Main Works

The new rising sewer mains beneath Victoria Bridge provide a greater wet and dry weather capacity for the Grey St pump station servicing South Brisbane. The new system constructed consist of externally mounting three new sewer lines to the external sides of the box girders and through structural diaphragms, with manifolds installed within each abutment. The rising main system consists of stainless-steel pipe sections joined with flange connections, and at various locations under the bridge, valves and expansion joints installed to compensate for bridge movements and control flow reticulation.

Strengthening Works

Strengthening works include the integration of a flexural and shear strengthening system to the bridge through the installation of an externally mounted tensioning systems. The system comprises of anchorages, precast and cast-in-situ, at either abutments that are stressed. Vertical and horizontal stressing along with near surface mounted reinforcement provided greater capacity at anchorage points and required zones. Carbon fibre strengthening of the suspended span adjacent to the half joints.

Surface / Above Deck Works

Reconfiguration of the bridge carriageway, within the existing extents, to accommodate a designated cycleway adjacent to the busway which was increased from two running lanes to three. Construction of a new Regular Performance Level post-and-rail type barriers to contain the reconfigured busway, median separator and downstream sides of the bridge. Modifications to the bridge deck stormwater drainage system as well as the removal and reinstatement of all bridge carriageway and footpath pavements and supporting structures for future shade structure installation.

3. Design Development

Design Management

The design was undertaken in four stages each requiring a review from the Construction Partner and external stakeholders. As the design developed there would be regular reviews with the Construction Partner. It provided the Construction Partner a greater understanding of the basis of design and provided opportunity for the Construction Partner to provide input into methods, availability of materials, lead times, sequence of works that could be understood and incorporated into the next stage of the design.

There was a consistent team or person from the Construction and Design Partner throughout the design stages and into the construction phases. This consistency mitigated the potential loss of information as the work progressed and it was found that it provided each partner a clear understanding of how and why items were designed/ constructed, mitigating potential problems allowing for quicker resolution of issues as they arose. It limited the need for people to ask questions on “why” and focused attention “how” challenges were going to be resolved.

Early in the design of the strengthening package of works it was recognised that industry engagement was required for the design and construction of the bespoke strengthening componentry elements. The Brisbane Move project went to the market using an Early Contractor Involvement (ECI) process in which four proponents provided concepts and pricing using the initial Concept Design. This is further discussed in the parallel paper “*Development of a Design Criteria for the Victoria Bridge Refurbishment*”[1]. Freyssinet Australia were engaged from this ECI phase to join the design and construction phase of the project.

Having this engagement from the industry coupled with regular reviews of the design and consistent personnel through the project lifecycle has been of great benefit in progressing the works.

Design Partner Role During Construction

During construction the Design Partner remained in frequent contact with the Construction Partner to assist with queries from site and responding to Request for Information (RFI). The consistency of personnel and working relationship developed during the design phase promoted collaborative relations between the Construction and Design Partner. As issues arose an initial meeting would occur between the partners to understand and gauge the possible remedy of the issue which could then be followed up more formally. On regular occasions construction progress was provided to the Design Partner through meetings and site visits. This circular engagement enabled the easy flow of information to ensure works continued at the desired rate and quality.

4. Pre-Construction Planning

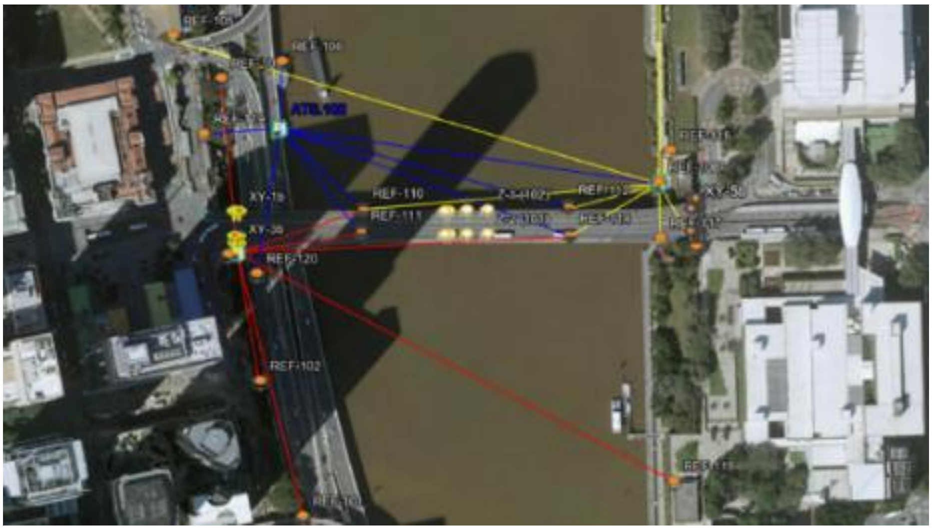
During the design phase and into the construction phase it was apparent that due to the age of the structure and the amount of works required to refurbish, that an extensive amount of information was needed of the bridge to assist with design and to enable execution of the works.

Together, the Design and Construction Partner developed an early site investigation plan. This plan provided a clear outline of what investigations were needed prior to the design being finalised and before construction could commence. This was then presented to the asset owner to gain acceptance to proceed. Consideration was given to the amount of destructive and non-destructive testing required and the financial impacts to undertake the works.

Instrumentation & Monitoring

An instrumentation and monitoring plan was established and installed on the bridge to monitor its performance during the design phase, construction phase, critical stressing activities and post completion. This provided metrics such as thermal and serviceability movements at key locations on the bridge such as the expansion joints, piers and abutments.

Figure 1 Reference prisms and survey stations



Establishing instrumentation and monitoring devices in a heavily urbanised area across the Brisbane River and in/on commercial properties provided some challenges that included

- Obtaining consent from land and or building owners to affix prisms and equipment
- Logistics of getting access to piers/underside of the bridge over the river or to the underside of abutments from the Riverside Expressway or along the Clem Jones Promenade at Southbank
- Ensuring position of equipment provided clear line of sight to all equipment
- Ensuring adequate power source was available

The set up and implementation of this monitoring required detailed planning and execution and because this was performed during the design phase it mitigated the delay in performing this work after AFC.

Non-Destructive Investigations

A Level 2 inspection of the bridge had already been completed on the structure by the asset owner which provided a good basis of understanding its condition. This was reviewed in detail and then confirmed if more detailed inspections were needed. For critical areas such as strengthening connection points, detailed crack mapping was undertaken before and post works. Mapping was subsequently scanned using high resolution Matterport scans.

Figure 2 Crack mapping inside a girder

Figure 3 Scanning trials and anchor testing

Semi-Destructive Investigations

The use of semi-destructive investigations which involve the precise and limited removal of existing concrete to determine further information of hidden details and/or of the existing tendon/reinforcement locations was required during the works. These investigations are known as pilot holes.

Anchor testing was also a semi-destructive investigation method undertaken on the existing deck to prove the design load on the future anchors and the adequacy of the existing concrete to take the anchors. Concrete cores were also taken to determine the existing bridge precast concrete quality and strength.

To ensure the method of semi-destructive testing was proven before implementation on the bridge a precast panel was sourced and used as trial to understand

- Scanning methods
- Drilling methods
- Bond strength for chemical anchors

This offsite trial informed the construction team on the methods to be used and feed into the construction work method statement needed to undertake the works.

Survey

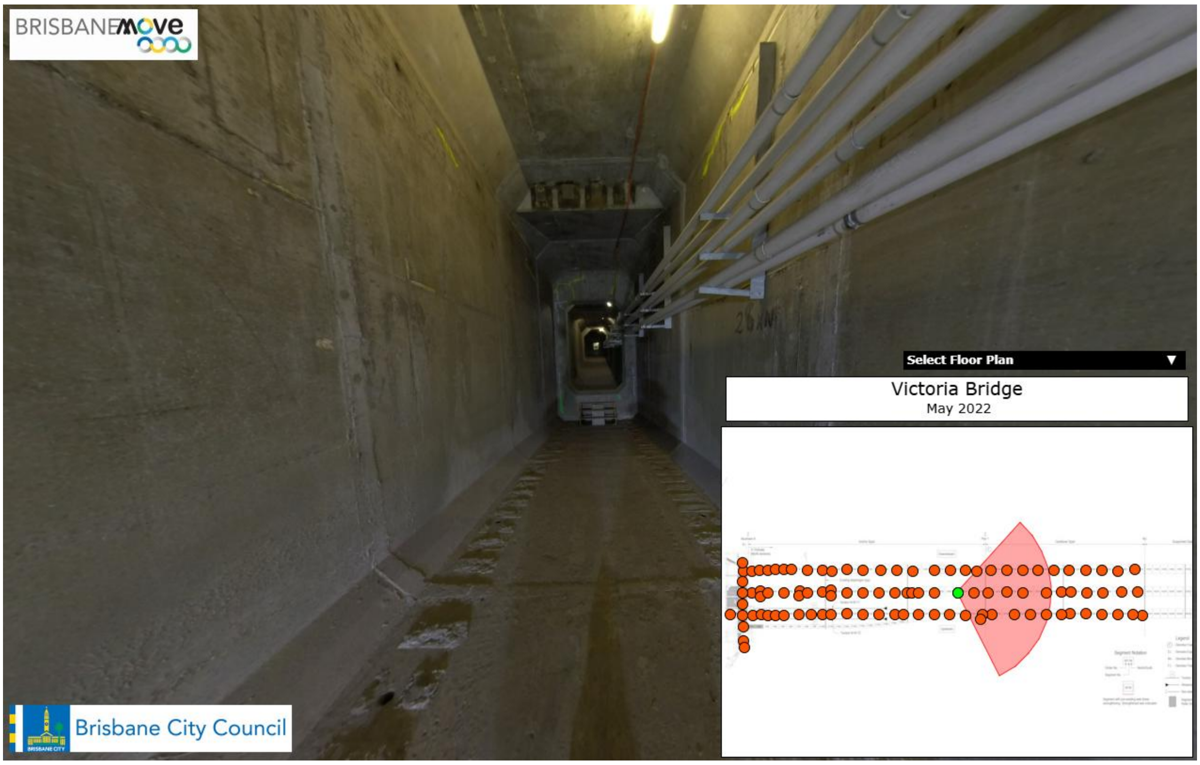
There were several types of surveys undertaken on the bridge such as external and internal LiDAR scanning. The LiDAR scanning provided accurate depiction of the position of the bridge to inform design and inform the construction team. The figure below shows the extent to which the LiDAR scanning reached when positioned on either abutment. The completed the scan brackets were installed on the piers, accessed by water vessel, to enable the centre span to be accurately scanned.

Figure 4 External LiDAR scanning

Another method of scanning used was 360° three-dimensional (3D) panoramic imagery inside the girders. This proved to be a reliable tool and reference point in understanding the existing condition through the design and construction phase. This was particularly useful when having online meetings and wanting to know what was inside the bridge at a particular location. Drones were also utilised for undertaking external inspections on the bridge.

Surveys indicated that the bridge frequently moves more than 120mm vertically and 30mm horizontally over a 24-hr period at the mid span due to the nature of its construction, a simply support mid span. Considering seasonal variation over the year, movements are of up to 240mm vertically and 70mm horizontally are observed. This meant that all survey and setting out needed to be relative to known bridge elements such as kerbs, joints and light poles on the bridge.

Figure 5 360° 3D Panoramic interactive sites



Stakeholders

Stakeholder management was essential. Identification up front of the main stakeholders and what their requirements were enabled the works to be executed. Key stakeholders that were considered included:

- Asset owner of the bridge
- Public Utility Providers within and around the bridge footprint
- Understanding the community used public spaces near the bridge and what constraints existed to performing the works
- Public transport routes and operating times
- Location of arterial and local roads and working conditions
- Landowner extents and requirements, Victoria Bridge had several different landowners each with varying and multiple requirements
- Marine operation requirements such as navigational channel width/ heights requirements/ frequency of water traffic

A stakeholder engagement and management plan was implemented, and the Construction Partner had full time communication personnel having direct contact with the stakeholders to ensure continuity and accurate flow of information.

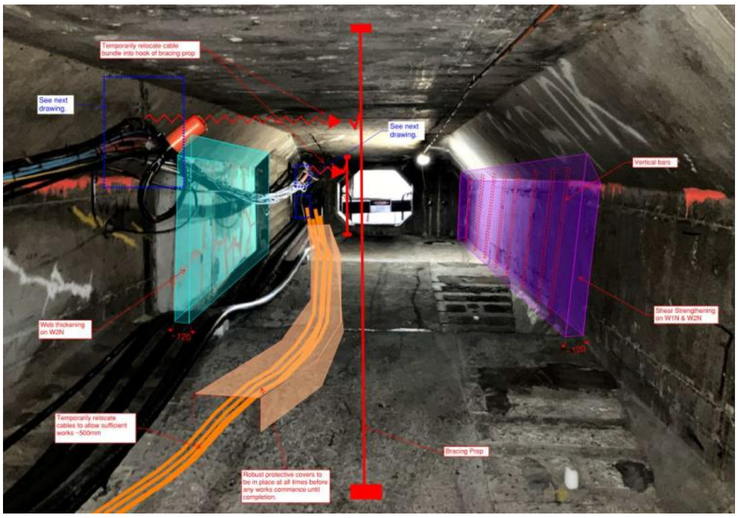
Public Utility Providers

Victoria Bridge is a main public utility corridor service creating a major link between South Brisbane and Brisbane City centre. Some Public Utility Providers, but not limited to, which utilised the bridge included:

- Several Energex 110kV power cables
- Several Energex 11kV power cables
- Optus main fibre optic communication cables
- TPG and Powertel communication cables
- Brisbane City Council communication fibre and traffic cables
- Aussie broadband backbone fibre communication and data cables
- Urban Utilities sewer

The refurbishment works included drilling, coring and accessing in very close proximity to these services all of which had varying protection control measures. The design where possible was modified to limit impact on the providers however on some occasions relocation was required.

Figure 6 Working area and protection of services inside a girder



To assist engagement with utility providers a Protection and Temporary Relocation of Services within Victoria Bridge method statement was developed. This enabled a clear and accurate document to communicate with the providers on:

- Assessment and identification of Energex and other services
- Protection of services

- Temporary relocation and protection of cables on the floor
- Temporary relocation and protection of hanging cables
- Reinstatement of cables to original position
- Temporary protection of existing Energex 110kV cables
- Permanent relocation of hanging cables

The document was continually updated as the design progressed or as construction methods were updated. This was widely distributed to the providers and meetings were held if required to convey methods of construction and protection.

5. Installation Challenges

Bridge Access

Victoria Bridge had some unique access challenges including the requirement of ensuring the bridge and the surrounding public areas and roads maintained their functionality. The refurbishment works required access to all parts of the bridge including:

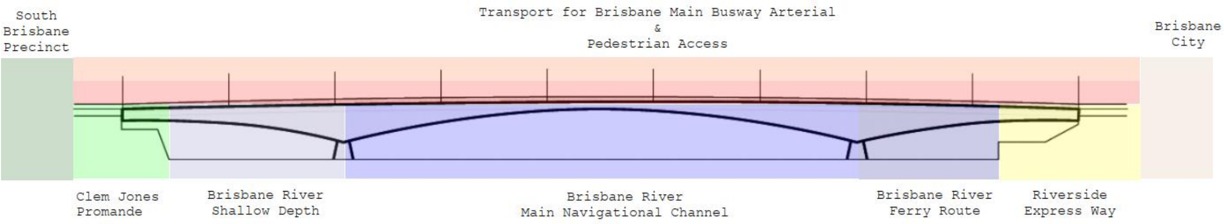
- The underside of the bridge deck and all external sides of the girders for sewer and strengthening installation including significant works at the mid span of the bridge
- The piers for survey equipment
- Inside the abutment and girders for strengthening works and connection of temporary works
- On top of the bridge to drill and affix, and at times core through the deck to the underside, for new cast in place kerbs, steel barriers and removal and replacement of asphalt wearing course

Each location of the bridge had different access requirements and was a key consideration into the design of some elements and how the works were to be undertaken. The below figure provides some context on the different types of access requirements depending on the location of the bridge.

Access restrictions and working times included:

- The South-East busway on top of the bridge could only be closed between midnight and 5 am and a minimum two lanes needed to be operational at all other times for buses.
- Pedestrian access across the bridge needed to be maintained at all times.
- Clem Jones Promenade needed pedestrian access to be maintained at all times.
- South Brisbane Precinct required clear access during events and for local traffic.
- Brisbane City required access for public and traffic to be to be maintained at all times.
- Riverside Expressway (with six lanes running beneath the bridge) is one of Brisbane's major Arterial roads and could not be shut and had weight restrictions for construction plant.
- The Brisbane River is required to always be open for public transport ferry crossings.

Figure 7 Access areas



As each of the pre planning and design of the packages of works progressed construction commenced. Each package of works was programmed, sequenced and detailed to confirm the refurbishment works could be undertaken while adhering to access requirements, design stage, method of construction.

Post-Installed Fixings and Coring

The refurbishment works included several connections, coring works and grooving into the existing bridge and box girders. This included:

- 6650 No. drilled holes
- 820 No. core hole of diameters ranging from 50mm to 105mm of varying lengths
- 600m length of vertical and horizontal grooves into the existing girders and decks to enable installation of Near Surface Mounted (NSM) reinforcement.

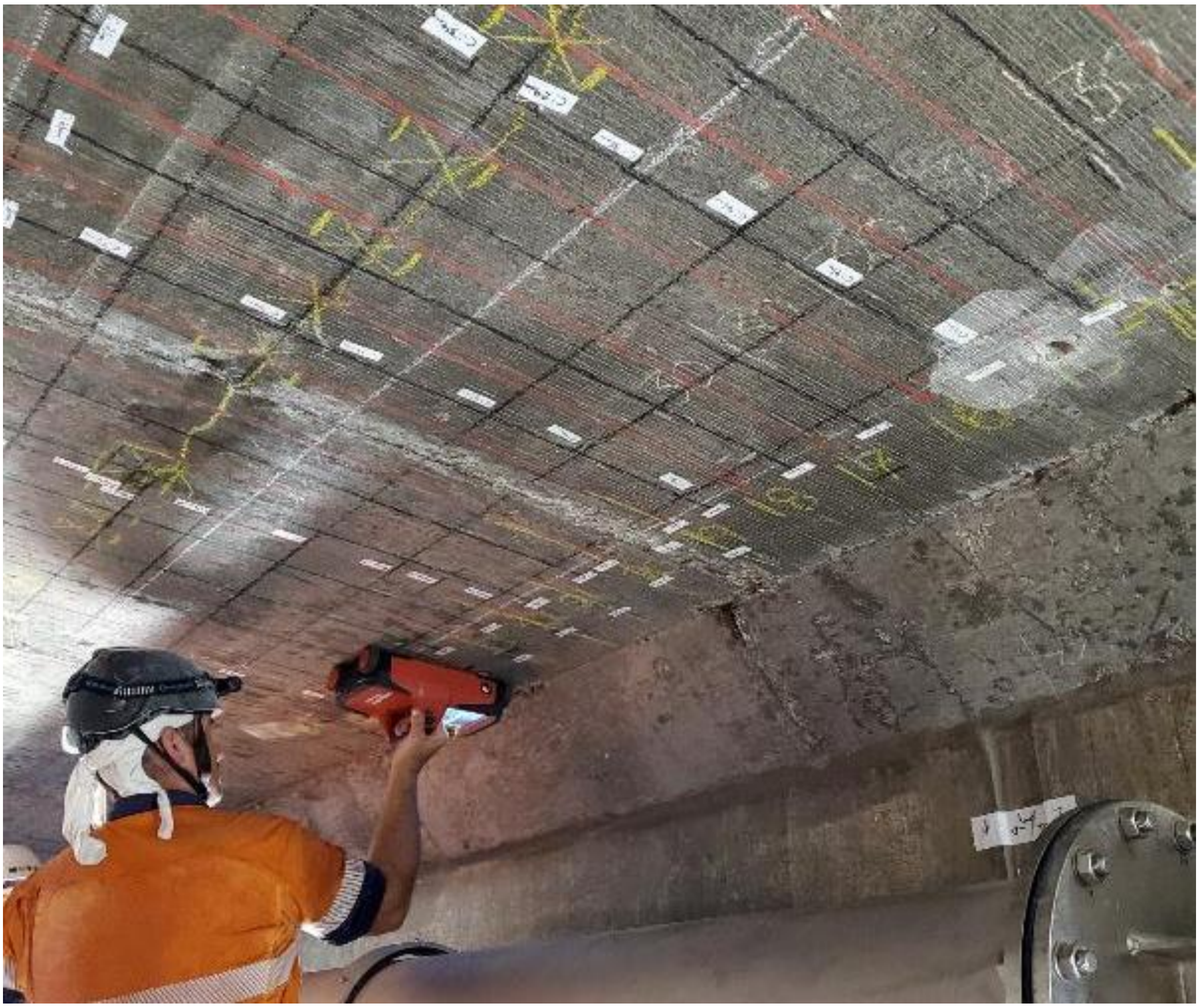
Understanding the location of reinforcement was an important step in undertaking these works. Following the pre-construction planning, detailed checklists were established to enable structured steps to be undertaken at each location of critical drilling, coring or grooving. The checklist covered:

- Undertaking a desktop study to compare the AFC drawings, 3D model and the 1969 drawings of the bridge to locate the reinforcement and/or tendons.
- Confirming onsite scanning had occurred to locate the reinforcement.
- Reviewing scanned information, comparing to the AFC drawings and check that the nominated clearances to reinforcement comply.
- Had a pilot hole been drilled to confirm no critical reinforcement or tendons.
- If there is any inclination of the drill/core had it been verified.
- Undertake the drilling/ coring/ groove.
- Record the inspection of the core for cut reinforcement and raise NCR if damage has occurred.

Reinforcement scanning was a critical step in identifying the location of reinforcement within the concrete. Output from the scanning can, at times, be difficult to interpret especially in areas of high reinforcement congestion. Proper trials, experience and familiarity with the scanning equipment being used is recommended.

In zones of congestion the Proceq GP8000 device was used as it provided high resolution and data that could be exported into software programs for greater interrogation. The Hilti PS300 and PS1000 were used on the project also.

Figure 8 Reinforcement scanning and marking on the bridge soffit



Given the criticality of the existing post-tensioned tendons and the primary transverse (shear) reinforcement, it was essential that these elements were maintained and protected from damage. Reinforcement marking onto the face of the concrete surfaces was carried out in the zones of strengthening intervention or where barrier/sewer connections were being made.

For coring works, pilot holes were used after the scanning and reinforcement marking onto the concrete in order to confirm the clear zone prior to undertaking the coring in order to ensure that the primary reinforcement was maintained. Pilot holes used 12mm masonry drill bits and with depth control measures used. Large core holes (100mm diameter) would often receive 3-4 pilot holes before confirming the position.

Figure 9 Rebar marking after scanning

Figure 10 Pilot holes after GPR scanning

Sewer Installation

953m of stainless-steel sewer pipe (OD324) required installation beneath and through the preformed diaphragms holes of the bridge. After engagement with the industry a flanged pipe connection method of construction was chosen to provide enough construction tolerances to affix the sewer to the underside of cambered bridge and through the preformed holes of existing structural diaphragms.

There were several specially designed temporary works made to install the sewer pipe which made use of existing penetrations identified during the pre-construction planning stages. An example lifting frame can be seen in the below figure with winches, connected to existing holes in the girder wall, was used to raise the pipes into position. The below figure is a trial that was undertaken on land to ensure it functioned as intended before commencing with the works over the river

Figure 11 Pipe pushing over the Riverside Expressway

Figure 12 Lifting frame with access from Clem Jones Promenade

Figure 13 shows the barge setup on the river and how the lifting frame was used to raise the sections of pipe into position.

Figure 13 Barge works with lifting frame

Installing lengths of pipe over the six lanes of the Riverside Expressway while maintaining access was a challenge due to traffic constraints. Works were undertaken at night under lane closures with permanent pipe brackets being installed first with temporary roller attachments. Once the brackets were installed, short three metre lengths of pipe were delivered into the abutment, welded together and incrementally pushed through the preformed holes from the inside the bridge abutment to the other team on the outside of the abutment on the Riverside Expressway under various lane closures with traffic control at night. Once enough pipe was pushed through, a new three metre length of pipe was welded on and tested for compliance. Secondary safety measures such as verification of welds and installation of over clamps were used to mitigate uncontrolled movement of the pipes while pushing to ensure the safe installation of the pipes.

Figure 14 Sewer lines pushed through and over the Riverside Expressway

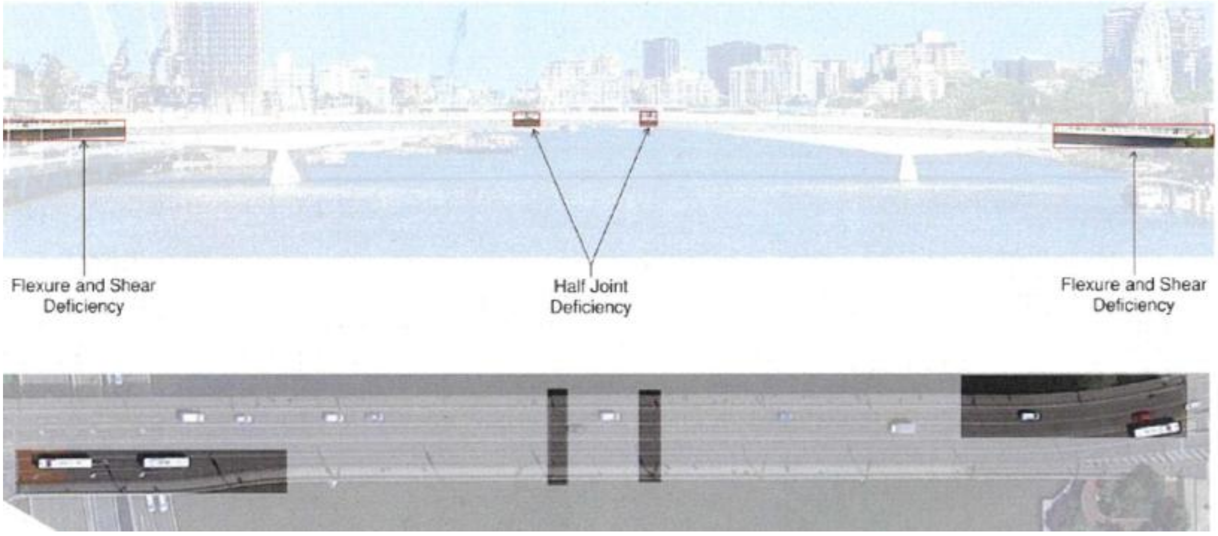
Strengthening System

The strengthening scope required 6 No. precast blisters and 1 major cast in-situ anchor to be affixed to the side of the girders as connection anchor points. Details of the strengthening system employed across the Victoria Bridge can be reviewed in the parallel paper "*Refurbishment and Strengthening of the Victoria Bridge*"[2] submitted for these proceedings.

To enable the blisters to be fixed to the bridge, additional reinforcement and web-thickenings were required to be installed around the blister zones to strengthen the local areas of the box-girders. Once the blisters were installed, stressing strands would connect them together. These were then stressed to a pre-determined load to provided additional strength to the bridge. There were three main areas of strengthening on the bridge with much of the work occurring beneath and on the side the bridge.

- Southbank Precinct side over the Clem Jones Promenade
- The mid span over the Brisbane River
- The Brisbane City side over the Riverside Expressway

Figure 15 Elevation and plan view of the zones requiring strengthening



A hanging scaffold system QuickDeck was chosen for both the Southbank Precinct and Brisbane City sides as they both had to meet the requirements in maintaining access for pedestrians, vehicle traffic and river traffic. The QuickDeck system used enable connection to the bridge through pre-formed holes in the soffit of the girders and allowed it to be built incrementally from one side. All had to be constructed at night with Brisbane City side being pre-fabricated into sections and lifted into position from a barge on the river.

Figure 16 Hanging Scaffold beneath the bridge at the Southbank Precinct side

Figure 17 Looking up at handing scaffold beneath the bridge at the Southbank Precinct side

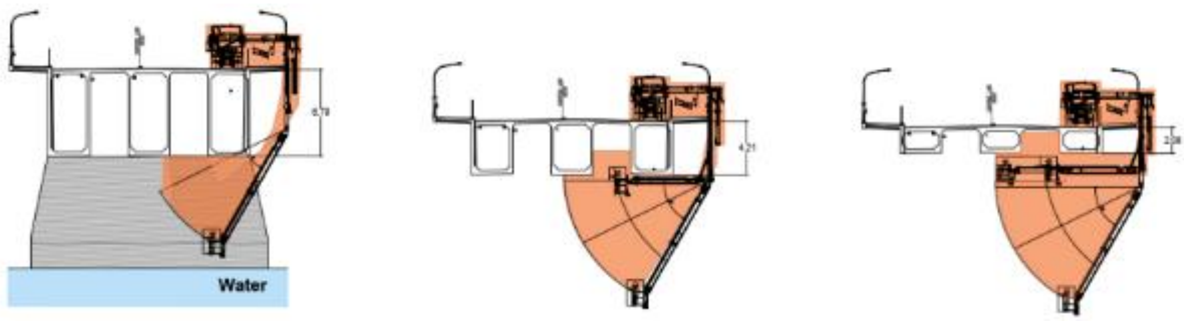
A key consideration to the type of access was to ensure that safe access and egress could be maintained for construction use and interface with the public. Width of stairs and clear access points for lifting were designed. Emergency response plans were developed, and mock trials undertaken to ensure personnel working on the temporary works understood the rescue procedures.

Figure 18 Hanging scaffold at the Brisbane City side with access from above

Other forms of access were used to perform strengthening works at the mid span. This location had height restrictions for vessel navigations, load restrictions and available working times due to this location being the main navigational channel and thoroughfare for river vessels. Conventional scaffolding was not possible, and the works required the use of carbon fibre wrapping on the external face. A number of Under Bridge Inspection trucks were used including:

- HiReach MOOG1200 Under Bridge Inspection Unit
- Lincon ABC180 Under Bridge Unit

Figure 19 Working room desktop studies for Under Bridge Inspection Trucks



When working on the Riverside Expressway at night floating in and out conventional elevated working platforms slowed down production. The use of vehicle mounted elevated work platforms enabled quicker setup and pack up times maximising the limited working times available. Vehicles used included:

- Lincon P130 (13m) access platform
- Lincon P260B (26m) access platform

Figure 20 Use of UBIU under lane closure

Figure 21 Vehicle mounted EWPs

There were also several areas where confined space works were required. This required the implementation of confined space measures such as rescue plans, air monitoring, adequate lighting. Figure 22 shows the level of scanning (blue/yellow/green marks) undertaken within confined spaces and protections measures used on drilling into concrete.

There were several concrete works inside the girders that needed to be constructed. This required thought into how formwork and the equipment could be brought into the girders and ensuring protection of services in the area. Concrete delivery was also a key consideration. Where possible delivery of concrete was made by line pump through the existing openings however in some instances, surface located core hole through the deck girder proved useful in delivering the concrete.

Figure 22 Confined space working

Figure 23 Restricted space working

The concrete mixes used were carefully considered and selected with Boral to identify mixes that provided high strength and high stiffness. Low drying shrinkage and low heat effects were also desired, while workability was essential to allow the concrete to be placed by tremie / funnelling into the box-girders from above. A triple blend 65MPa mix was selected for the internal web thickenings.

Ultra-High Performance Concrete (UHPC)

During the design phase it was recognised that limiting the weight added to the bridge, the impact of the strengthening system on the bridge's aesthetic and finding a suitable material to withstand the loads applied by the post-tensioned tendons would be key considerations. As part of the strengthening works four additional external post-tensioned tendons were proposed, each requiring connection to the bridge at each end and at a central deviation point. Due to the significant longitudinal force introduced by the tendons and limited access available to make the connection, it was not practical to rely on steel or other fixings in shear as the resulting element would become very large and difficult to construct on site.

Following the early stages of design, six of the eight tendon anchorages were selected to be constructed using precast UHPC. The seventh and eight locations required a diaphragm to be constructed between adjacent girders and traditional reinforced concrete was therefore chosen in these locations. UHPC exhibits exceptional material properties (strength to weight ratio) and durability performance which meant that the resulting anchorages were much smaller than those constructed using traditional construction materials such as steel or concrete.

At the time of design, there were no provisions for the design if structural elements comprised of UHPC in AS5100.5:2017[3] and, as such, the decision was made to design by prototype testing. Several prototypes were developed offsite during the design phase to better understand the structural performance of the UHPC anchorage blisters and the friction connection fixing them to the existing bridge. Several prototypes were developed and ultimately two underwent full scale load testing. The casting of the prototypes was also used to refine the UHPC mixing, pouring, and pre-casting processes. A summary of the prototypes cast is as follows:

- Prototype 1 – Testing mix properties, finishes, and mixing, pouring, and casting processes
- Prototypes 2 & 3 – Confirming most appropriate forms and cast-in items and curing method
- Prototypes 4 & 5 – Use of hot water curing baths to increase strength to 160MPa + and load testing of final prototypes.

Figure 24 Use of hot water curing baths

Prototype testing was undertaken on a post-tensioned concrete test bed using two UHPC anchorages tested against each other with a post-tensioned tendon threaded between the two and stressed to SLS and ULS test loads, respectively. The friction connection fixing the blisters to the test bed was installed in the same manner proposed for installation on the bridge. Stress bars were used to create a clamping force that provided the necessary friction to resist the longitudinal tendon force. The testing was completed successfully with no failure of the UHPC[4] observed.

Figure 25 Prototype testing arrangement

The UHPC anchorages were installed onto the bridge using lifting equipment installed between the girders to hoist them from a barge. Once in place, the interface between the blister and the girder was grouted and all transverse stress bars were stressed. The stress bars ensured adequate friction between the girder and the anchorage for transfer of the longitudinal tendon load.

Figure 26 Blister installed from the river

Figure 27 Example of installed blister

Carbon Fibre Reinforced Polymer (CFRP)

Externally bonded CFRP sheets were used for strengthening at the half joints, located at the suspended span in the centre of the bridge. Access to the joints could be achieved through two means including UBIU during night-works, or via a barge mounted elevated work platform.

The installation of the CFRP required surface preparation of the concrete in an environmentally safe manner. Primers and adhesive resins were needed to create the necessary bond for the CFRP laminate. Two continuous sheets of CFRP laminate, 2mm thick, were applied and wrapped around each web and the bottom slab of the first segment past the half-joint to strengthen the lower slab. Composite spike ('horse-tail') anchors were used for additional anchorage in the webs.

Test panels were also installed to confirm the bond strength was adequate. Sacrificial test panels were also left behind for future pull-off testing if required by the Asset Owner. The CFRP was painted with a coating to blend the panels to match the existing colour of the bridge.

Figure 28 CFRP test panel

Figure 29 Installation of CFRP at Mid-Span Half Joints

Near Surface Mounted Reinforcement (NSM)

Near Surface Mounted (NSM) reinforcement was needed to strengthen the localised areas at each of the strengthening connection points. The NSM works comprised of making a groove into the concrete cover zone or at times past the cover zone using a wall chaser, breaker with joint chisel and extraction equipment. This allowed additional reinforcement to be placed, sometimes epoxied, into the groove and then surrounded with a cementitious grout (Renderoc HB70).

The below figure indicates some of the extent that NSM reinforcement was completed at the strengthening connection points. These needed to be co-ordinated with other works and shared the same access as the strengthening works. The bridge always remained operational which necessitated the need to install the NSM and strengthening in a very sequential way to ensure the structural capacity of the bridge was not compromised.

Quite often after areas where scanned when NSM was to be installed there would be existing reinforcement in location not as expected in both position, depth and scanning. Constant communication and adjustment with the design partner was a regular occurrence. Without the collaborative approach established during the design phase the works could have had the potential to be delayed and progressed at a slower rate. The below is an example of some of the overhead NSM works that was required.

NSM was also required on the road surface and needed careful consideration of when the works could be completed and how to access it specially on the busway. Access was only allowed during the midnight to 5 am on the surface, so the use of steel plates and custom precast planks was needed to allow greater working times and allow operation of the busway. The below figure shows the scanning of the existing reinforcement and location of NSM on the operational busway, steel plates were installed at the end of each shift to ensure it could be trafficked.

Figure 30 Vertical NSM grooves in web

Figure 31 Overhead NSM grooves in soffit

Surface Works

The surface works included drilling and affixing new concrete kerbs to the bridge deck, installation of new drainage scuppers, new galvanised and painted guardrail and handrails, removal and replacement of the asphalt wearing course on the bridge, removal and placement of new footpath resin bound pavement.

All works had to ensure the busway and pedestrian movements were maintained. The works were sequenced on the busway to enable one lane was to be utilised for construction and the remaining for busway traffic, maximising daytime working hours as much as possible.

Some connections to the bridge required angled connections, templates and jigs to be fabricated to enable accuracy of the drilling as shown in Figure 33. The drainage scuppers required coring from the top surface of the bridge through the girder and out the underside of the bridge along the entire length of the bridge on both sides. These works were planned early and conducted at night with the use of the UBIU's for access to the girder soffits. This allowed the cores to be captured on the underside and provided a quicker more cost-effective alternative to accessing the works.

Figure 32 Drilling post-installed anchors for new barrier

Figure 33 Fabricated templates for bolt groups

In thinner sections of the deck, particularly on the downstream side, some connections of the barrier required connections with base plates mounted against the deck soffit rather than post installed fixing used elsewhere. When these works occurred, there was multiple works occurring on the surface and the UBIU was not suitable to space requirements. A barge was used with two elevated work platforms to be underneath the bridge while workers on the top scanned and drilled the connection points.

Busway resurfacing involved sequential removal of the existing asphalt wearing course lane by lane, ensuring there was always two lanes (one in each direction) for busway operations. Prior to any removal, an extensive investigation into the existing asphalt surface was done through GPR scanning and asphalt coring with survey pickups to determine the thickness across the entire bridge length. This helped inform design changes to the pavement type, and thicknesses which could be achieved.

The asphalt was removed by saw-cutting along permanent lane lines and then pulled up using suitably sized rubber tracker excavators with flat blade buckets to ensure the bridge deck was not damaged. The existing waterproofing fabric membrane was then removed with a poly planer attachment to a bobcat and the surface texturized with a shot blaster, prior to the deck surface receiving prime, spray seal and then asphalt. Image below shows the existing asphalt removed with the waterproofing fabric membrane exposed.

Figure 34 Example of lane configuration when removing asphalt wearing course

6. Construction Challenges

Unknown Conditions

On several occasions there were unknown conditions that were identified during the works. These included:

- Reduced cover to reinforcement
- Exposed, damaged and rusting reinforcement
- Varying concrete thickness
- Location of reinforcement in locations not as expected
- Tendon locations different from design
- Existing levels lower or higher than expected
- Subjective/unclear of reinforcement scanning
- Levels of existing deck beneath the wearing course

All effort were made during the design stage to identify these conditions however it could not be fully understood until works commenced onsite.

When these conditions occurred, having open and circular communication with the design team was important. The team quickly scoped up the unknown condition and the arranged reviews of method of repairs. In most instances, having predeveloped methods of repair in place such as the below provided beneficial in carrying out the works efficiently:

- Concrete patch repairs
- Flexibility in location of reinforcement
- Redundancy in design to allow modification or deletion of items to mitigate impact on the bridge

When the team were constructing the new barrier kerb, existing reinforcement with no cover (i.e. exposed) was identified. The exposed reinforcement showed signs of deterioration and was the main structural reinforcement for the cantilever footpath in this area. Once discovered, load limits were applied to the bridge and a repair method was established and undertaken. The figure below shows a blue containment screen implemented to enable high pressure water blasting (hydro demolition) of the affected areas to enable repairs to be undertaken. Due to the critical nature of the reinforcement, the works were carried out and repairs done in small sections in a certain sequence to ensure the structure was not weakened.

Figure 36 shows an example of a small section of the reinforcement exposed by high pressure water blasting, coated and then reinstated.

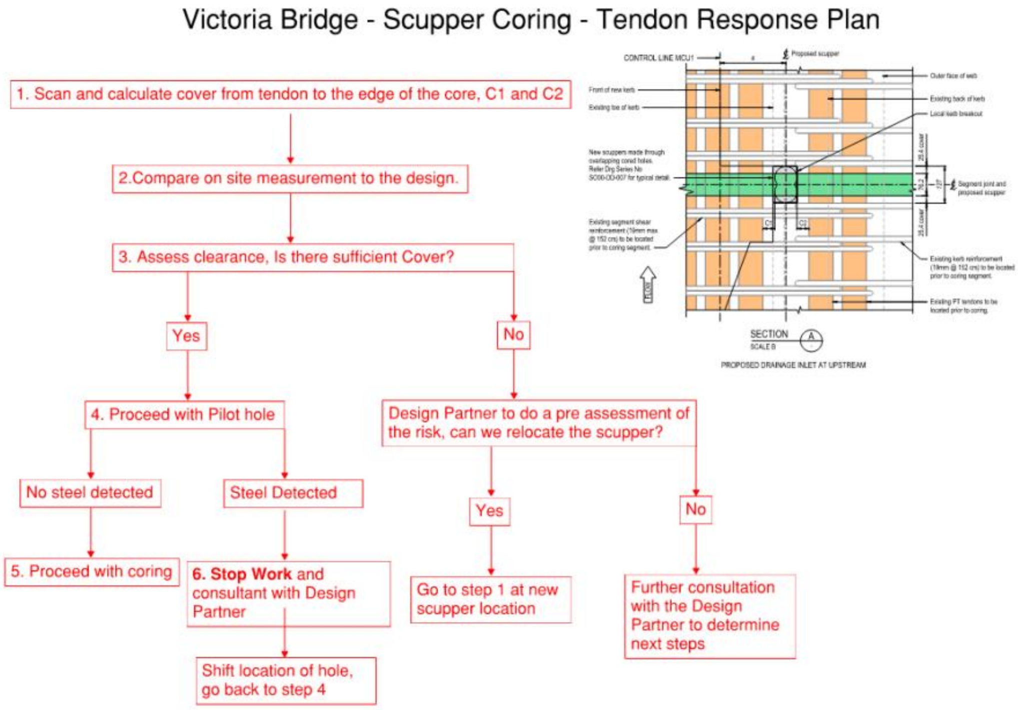
Figure 35 Containment hoarding

Figure 36 Exposure of rebar and repair

Response Plans

No matter how much planning or design is carried out there will always be occasions where unforeseen damage or issues occur. The refurbishment of Victoria Bridge certainly experienced occasions in which works did not go to plan. However, the construction partner and design partner developed response plans for such occasions. An example is the below response plan which provides a response flow chart for each stage of the works and what to do in the event of damage occurring and provides clear direction on when works are to stop or proceed. Also having a clear understanding of who the main contact persons are in case of emergency is important.

Figure 37 Coring Response Plan



7. Conclusion

The refurbishment of Victoria Bridge required a detailed period of site investigation which greatly informed the design and construction stages of the project. With this information and adopting a collaborative approach between the Brisbane Move Partners (Designer, Asset Owner and Construction Partners) the project was able to produce a design that both met the project design requirements and construction method used to complete the works.

Accessing the site was a key challenge across all areas of refurbishment and required well thought-out methods of access and engagement with stakeholders. Furthermore, understanding access constraints and stakeholder requirements upfront and during the design process can assist in reaching a design that meets these requirements as was the case with the use of UHPC precast elements for anchorage points and flanged connections for rising sewer main installations.

A key challenge was the unknown conditions of a bridge completed in 1969, without “As Constructed” drawings coupled with the need to perform numerous drill holes and connections. The development of response plans for the “what if” scenarios is vitally important to ensure that when something goes differently to the plan that there is a clear path forward to finding a solution within an appropriate time frame.

8. References

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