Extending the life of a coastal bridge affected by chlorides and ASR

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Munna Point Bridge was built in Noosa Heads, Queensland in the late 1970s. Over 1.8 million trips in each direction are made across the 106 metre bridge every year, by tourists and locals. The bridge is one of only two routes to reach the primary tourism attractions of Hastings Street, Main Beach, and Noosa National Park. Accordingly, it is a critical piece of infrastructure to facilitate Noosa's economy as a lifestyle and tourism destination.

In the 1990's, large cracks appeared in the precast concrete piles and cast-insitu pile caps. The cause was identified as chloride attack and alkali silica reaction (ASR). Later consultants concluded that the service life of the bridge would end in 2013, and drafted a $6 to 8 million plan to replace the full substructure.

In 2014, Noosa Shire Council and TOD Consulting's engineers investigated the condition of the prestressed strands and steel reinforcement. They determined that remediation was viable. They jointly prepared a performance specification for a design and construct contract with the aim of extending the service life of the bridge by fifty years. The successful Contractor, Marine & Civil Maintenance, with its structural and durability consultants, achieved the project brief in 2015 for less than $3 million.

This paper describes the investigation and procurement process, including the assessment of the options available to the bridge owner and the subsequent design and construction of the works. The works included structural strengthening of the piles and pile caps and durability enhancement of the superstructure with specialist coatings and an impressed-current cathodic protection system. Impact on local users of the road and waterway was minimised.

EVALUATION OF PROJECT OPTIONS

Background and Investigation

In the 1990s, Noosa Council (hereafter NSC) discovered numerous unexpected cracks, in the piles and pilecaps of the then 20-year-old Munna Point bridge. NSC engaged Queensland's Department of Transport and Main Roads (TMR) to investigate the problem. TMR identified the cause as alkali silica reaction (ASR) and chloride attack.

Many aggregates in Australia and throughout the world contain silica. When used in concrete, these react with alkalis in the cement. The resulting expansive gel causes concrete to expand and crack. Importantly, ASR only occurs in the presence of water. The piles of Munna Point bridge are in saltwater, with the pile caps in the tidal and splash zone. The ASR cracks allowed chlorides to reach and corrode prestressed steel strands in the piles and reinforced steel in the pile caps (chloride attack). The resulting corroding steel expanded in volume and cracked the concrete, providing an easier path for rapid chloride attack.

There is no "silver bullet" to solve ASR problems in existing concrete. The Federal Highway Administration (FHWA) in the United States says, 'the term "mitigation" is used in lieu of "repair" because the methods described [in their ASR Handbook] '*are generally not able to, nor are they intended to, repair or restore the original properties or integrity to the ASR-affected structure. Rather, the intention is to reduce future expansion of the structure or to lessen the detrimental impact of future expansion*'.

Consultants were commissioned to monitor the bridge between 2001 and 2013. The monitoring reports combined visual / diver inspection of cracks, with lab testing of concrete samples:

- The test labs included chemical and mechanical tests of the concrete, such as compression strength, chloride content, carbonation, sulphate, and ASR potential.
- The steel reinforcement condition was inferred from the crack width inspections and the lab tests, and not inspected.
- The prognosis worsened with time. Later, consultants concluded the 106-metre-long bridge's economic life would end in 2013, and planned for replacement of the full substructure for $6 to 8 million.

In 2014, NSC approached TOD Consulting (hereafter TOD) to develop a lower cost alternative. The available information was reviewed. The earlier materials testing gave valuable data, indicating the chloride levels in the pilecaps and piles had exceeded corrosion threshold values (0.2-0.4% by mass of cement). Alone, this information could not reliably indicate the bridge's structural safety level, nor its remaining life. It was decided that the physical condition of the prestressing strands and reinforcement needed to be investigated.

TOD conducted a joint investigation with NSC, by breaking out small volumes of concrete in the piles and pile caps to visually identify the embedded steel condition:

- Pilecap top bars were better condition than expected. TOD's structural analysis confirmed that these bars carried the dead loads and traffic loads from the superstructure.
- Pilecap bottom reinforcement bars were in poor condition as expected. Fortunately, TOD's structural analysis showed that there were more bars than necessary for the design loads.
- Pile prestressed strands were in very good condition, despite the numerous ASR cracks in most piles.

This information was a 'gamechanger', and for the first time since the 1990s, remediation became seen as a real possibility:

- As mentioned earlier, chlorides had exceeded the corrosion threshold. But this could be controlled with cathodic protection, which had become more affordable since the problem first appeared.
- The ASR-induced cracking needed to be addressed. Research by TOD and NSC indicated that ASR had been previously contained with concrete encasements incorporating anti-bursting reinforcement. The fresh concrete needed to be carefully designed to avoid introducing more alkalis to the old ASR-prone concrete. This could be done by replacing some portland cement with a pozzolanic cement such as flyash. Even if some ASR crackIng still occurred, cathodic protection could protect the reinforcement.

A preliminary whole-of-life cost estimate was prepared for remediation, and compared to two other options:

a) Remediation: $3 million capital [$2750/m2], $2.3 million maintenance, 50 year life. Estimated total $96.81/m2/year. Remediation concept design included concrete encasement of piles, breakout and replacement of pilecap drummy concrete, repair/replacement of corroded pilecap reinforcement, addition of anti-bursting reinforcement to contain ASR cracking, impressed current cathodic protection, and protective coatings;

b) Replace the substructure as recommended by earlier consultants: $6.4 million capital [$5844/m2], $1.7 million maintenance, 50-year life. Estimated total $147.95/m2/year; and

c) Replace full bridge: $13 million capital [$11872/m2], $1 million maintenance, 100 year life. Estimated total $127.86 /m2/year.

Even with higher maintenance costs, remediation appeared likely to achieve significant overall cost savings. The construction methodology required smaller, less noisy equipment. The majority of work could be done underneath the bridge, while it was open to traffic. Accordingly, remediation would mean less disruption to the community and Noosa's $600 million per annum tourism industry.

Procurement and Scope: Traditional, D&C, Collaborative

NSC's project manager, Adam Britton had previously been involved in Port Wharf remediation projects, and he educated Council to expect unanticipated issues.

A Performance specification was designed to allow Tenderers the flexibility to adopt many solutions, so long as these could achieve the required outcomes. In brief, the specification included:

- Primary aims (must haves): target design life, T44 load capacity per original design, protecting the waterway, balanced whole of life costs, and achieving a safe two-lane bridge across the canal at the completion of work.
- Secondary aims (nice to haves): keeping the bridge open to traffic at all times during the works, maintaining aesthetic appearance, minimising construction noise, and the like
- A Reference design, to indicate one possible way of achieving the required outcomes

Traditional lump sum contracting has been NSC's business-as-usual model; and it has worked well when the project scope could be well defined at the start of the project. Remediation projects aren't like that. The Bill of Quantities (schedule) supplied to tenderers is, importantly, a common basis for tenderers to prepare their tender sums, but it should be expected that quantities will change as the work proceeds. Methodology is likely to change as well. Accordingly, provisional quantities formed an

important part of the Munna Point remediation tender quantities, which allowed Tenderers to supply a cost rate with the expectation that the quantity could be adjusted.

NSC decided that a Design and Construct (D&C) contract was the best way to obtain specialist expertise and innovation; and accordingly manage project risk. TOD recommended incorporating a collaborative approach to achieve the best-possible project outcomes.

The experience of Australian State Governments and Governments overseas, has shown that complex projects or projects with undefined scopes, can be delivered under budget and under time, through a collaborative contract model known as Alliancing. Immense value can be added to a project, by harnessing the knowledge and expertise of client, designer and contractor, fostering a creative environment, and treating “all ideas as valid”. Risk is structured to be allocated to the party who can best manage it.

Queensland’s Local Authorities cannot use the Alliancing model under that state’s Local Government Act. Having said that, many of the Alliance benefits can be brought to a Design and Construct contract by:

- Developing a collaborative work-together culture to solve problems. This isn’t always easy. We would say that the crucial thing is to have people that are good collaborators in charge of their teams. These people must also be technically strong in their discipline, so they can contribute to the problems at hand.
- To develop and maintain a collaborative environment, NSC engaged Doug Reynolds of TOD as Superintendent. He adopted a friendly, practical and consultative approach and fostered involvement from all parties. Doug had significant construction engineer experience, with the Hong Kong airport, Sydney airport upgrades, Hume highway and Bruce highway upgrades, so he understood construction methodology and constraints well. Doug’s experience as a former Works engineer for NSC was also very beneficial.
- Assign risks appropriate to the party who can best manage it:
    1. For Munna Point, our Bill of Quantities contained provisional quantities for all work items that were difficult to define accurately (concrete breakout m3, repair of reinforcement kg / tonnes etc). As the client, NSC therefore assumed the cost risk on these items.
    2. Risk for the quality/appropriateness of the design and construction was placed with MCM, who were responsible for certification of the solution.
    3. TOD was also engaged to review the technical suitability of the design and construction. TOD’s bridge engineer for the project, and co-author of this paper, had worked in three previous remediation projects. He had also worked in a collaborative alliance project, which was helpful.

NSC accordingly went to the market in April 2015 and invited Design & Construct tenders from suitably qualified contractors. The tender documentation was downloaded over one hundred times and, upon close of tenders in June 2015, thirteen submissions were received. Four of these included alternative designs.

After a detailed review, NSC identified that the tender from Marine & Civil Maintenance Pty Ltd (MCM) was best able to meet the stated non-price requirements. MCM’s alternative tender was also the lowest price submitted. After further discussions and clarifications over the following few weeks. NSC formally awarded the contract for MCM’s alternative design on 10 July 2015.

PROJECT DELIVERY

Design

The Performance Specification for the bridge refurbishment contract included the following main requirements:

- A serviceable life to 2065
- Continued capacity for T44, L44, HLP320 and W70 loads
- Optimised whole of life cycle costs including construction, operational and maintenance

When tendering for the project, the contractor (MCM) made various assumptions in offering an alternative tender as well as one conforming to the reference design. It was considered that the prior testing might indicate only minor ASR damage in the pile caps and, if this was so, a carbon-fibre laminate strengthening system applied to the tops and sides of each pile cap would suffice to improve its structural capacity and dispense with the need for a central column. If the ASR was more severe, it would be necessary to fully encapsulate each pile cap in reinforced concrete and, if warranted by further structural analysis, add the central column.

More investigation of the structure was necessary to confirm the severity of the ASR in the piles and pile caps, as well as to ascertain the scope and design details of the cathodic protection that would be needed to achieve the structure's design life. The contractor's first priority on contract award was therefore to investigate the structure's present condition and verify the tender assumptions.

MCM appointed AECOM Pty Ltd as its structural strengthening and concrete durability designer, and in August 2015 the structure was inspected, both above and below water. Testing included covermeter surveys, concrete resistivity, potential mapping, Schmidt Hammer, chloride profiles and petrographic examination. All sixty piles were surveyed by divers.

The investigations concluded that ASR has affected the concrete piles underwater, with many cracks but no corrosion damage evident in the reinforcing steel when exposed. It was also considered that ASR would significantly affect the pile caps through the design life.

Corrosion activity was found to be predominantly in the pile caps, the surfaces of which were delaminated significantly in the sides and ends. The columns, headstocks and precast deck units were found to be in adequate condition generally, although some isolated delaminations were noted and the transverse stress-bar tie rod anchor plates were severely corroded.

The proposed conceptual structural repair options were therefore to

- Install a reinforced concrete encasement around all pile caps, in order to resist the effects of ASR and repair any spalling and delamination that was present
- Install a reinforced concrete jacket around all piles from pile cap down to below bed level, in order to contain the effects of ASR

Impressed-current cathodic protection (ICCP), consisting of ribbon anodes cast into the new concrete encasement, was proposed for the tops and sides of all pile caps, with the potential for extension into the columns if required.

These concept designs are shown in Figures 1 and 2.

The concept structural and ICCP designs were agreed with NSC and were then detailed, with full design drawings and specifications for the works. Other elements in the refurbishment included:

- Patch repairs to all concrete spalls and delamination
- Protective and decorative coatings to concrete columns, headstocks and abutments
- Protective silane impregnation to deck slab soffits
- Repair of corrosion-damaged handrails and painting of handrails
- Treatment of corroded tie rod anchors
- Replacement of longitudinal expansion joints
- Extension of drainage scuppers in the deck slab

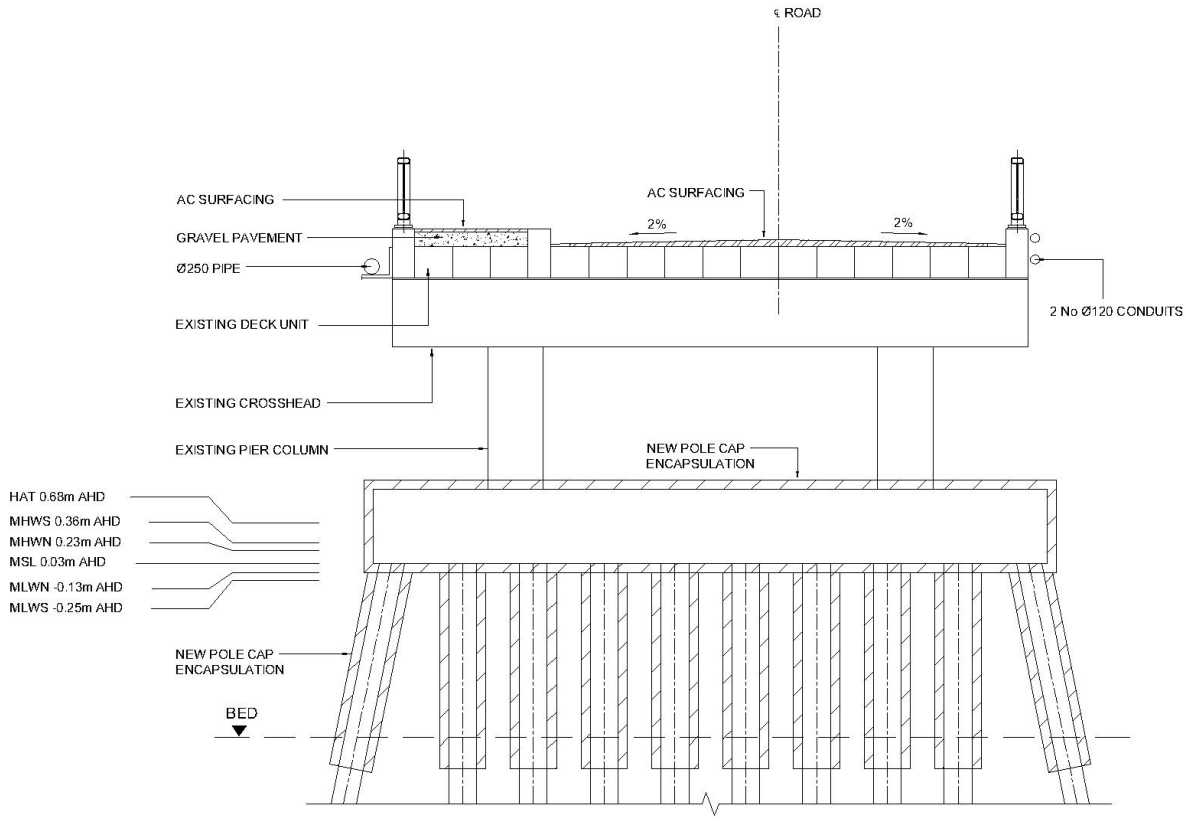

FIGURE 1 - TYPICAL PIER CROSS SECTION

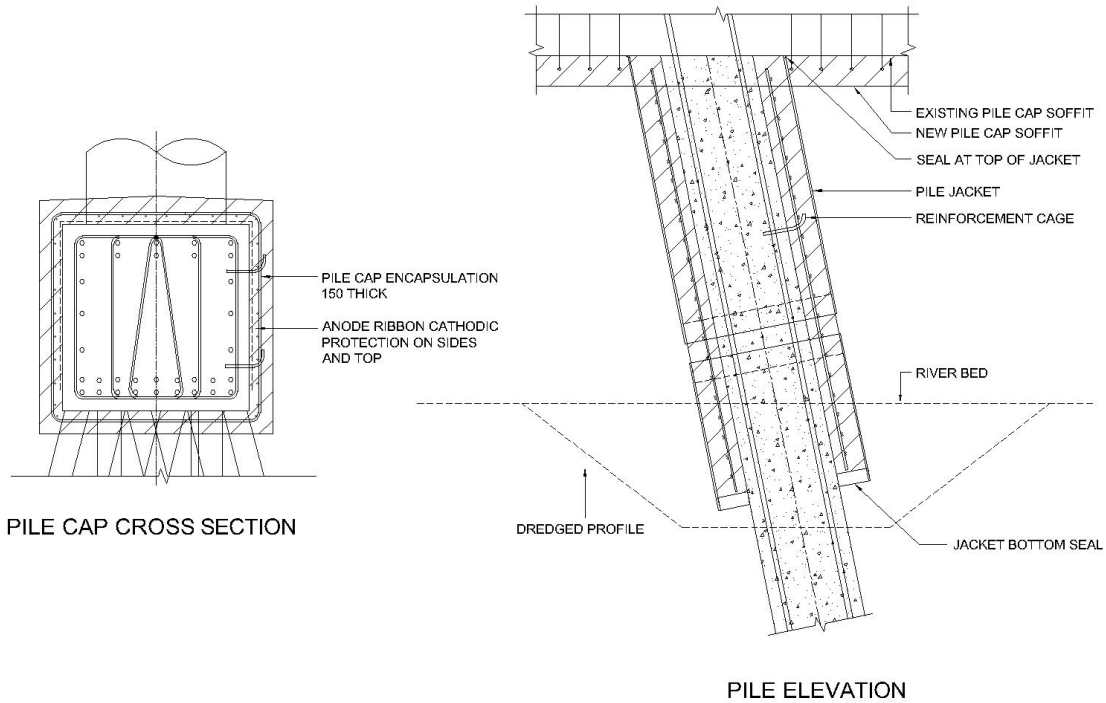

FIGURE 2 - PILE CAP AND PILE ENCAPSULATIONS

CONSTRUCTION

Access

Every part of the bridge required some treatment, from the riverbed to the road surface. The constraints from public activities included vehicular traffic on the road; tourist boats, dinghies and paddleboards on the river; and pedestrians on the footpath. It was important to minimise disruption to these groups and it was essential to ensure that at least one road lane was always available for vehicles and at least two river spans for watercraft. The logistics, particularly in the water where major works were carried out on multiple fronts, were complex.

As most of the work was accessible from beneath the bridge, access was water-based. Underwater work was carried out by divers working from a dive support vessel. Repairs and cathodic protection on the pile caps were undertaken from steel platforms suspended by chains from the deck soffit. Being always below the water surface, these were decked with steel mesh to allow the tide and currents to pass freely through them.

Access to the span soffits for repairs and coating was provided by a floating platform which could be raised and lowered via webbing slings attached to the bridge crash barriers. This gave access to the full width of the bridge over half a span, and included an upstand section to provide access to the sides of the bridge. Moving the platform in the water from one end of a span to the other was done with the aid of a punt.

To repair the crash barrier posts and rails, a one-man, aluminium cage was designed and built. This was clipped over the top rail and was sufficiently light to be moved by hand as required.

Photograph 1: Floating Access to Deck Soffits

PILE ENCAPSULATION

The design for the encapsulation of the octagonal prestressed piles consisted of a circular annulus of Grade 40 concrete, reinforced with pre-assembled steel bar cages. A permanent outer form of fibreglass was proposed; its hoop strength was included in the structural design.

The concrete was to be pumped to the base of the jacket after flushing its entire contents out with potable water. The pour was then to continue to the underside of the pile cap from the one pumping port, with the water displaced from the top of the form as the concrete level rose.

A ready-mix concrete was required that would provide the specified strength and could be pumped into the formwork and fill it without segregation at any point. The maximum length of the underwater jackets was 4.4m and they were congested with reinforcement, so prevention of blockages was an essential consideration. Initial trials of three mixes were carried out in the batch plant and the

preferred mix was then trialled on site, first with a full-scale pile jacket assembled on the ground and then with one assembled underwater.

Occasional blockages occurred at the inlets, however, which tended to increase the pumping pressure and cause damage to the seams of the fibreglass formwork. After completing some 20 jackets, it was decided to substitute temporary steel forms for the permanent fibreglass ones. This meant that the hoop strength of the forms would be lost, and additional reinforcing bars were required as compensation. At the same time, further trials were conducted to improve the pumpability and cohesion of the concrete mix, and after incorporation of an anti-washout agent the remaining pours were completed with little difficulty.

PILE CAPS ENCAPSULATION

The pile caps were fully encapsulated in a 150mm thick reinforced concrete of 40MPa minimum strength. Because the bottom of the forms was always submerged, the same concrete mix used for the pile jackets was also used for the pile caps.

Detailed investigation showed that the pile caps were quite significantly damaged by corrosion of the reinforcement, though few bars required replacement. In all, some 88m^2 of concrete was found to be delaminated. The piers nearest the banks were the least damaged, while the middle two piers were delaminated over 49% and 58% of their top, side and end surfaces.

After removal of the damaged concrete by hydrodemolition, all bars with corrosion losses greater than the minimum acceptable were augmented with new reinforcement. As this generally applied only to the stirrups, new bars were either welded to the existing steel or were epoxied into holes drilled into the substrate.

New reinforcing steel was required in both directions and all around each pile cap. As the pile caps were rarely out of the water completely, the soffit bars had to be fixed underwater, which was further complicated by the ten raking piles on each soffit. The new steel was fixed after the ICCP anodes were fixed as described below, and immediately before the formwork.

For maximum efficiency, each pile cap was concreted in one pour, including backfilling of all defective concrete removed earlier. The forms were built from ply and timber, including the soffits. The side and soffit forms were supported by steel bars from transverse steel beams propped off the top surface of the existing concrete. The props were encased in pvc sleeves which were removed and grouted after completion of the pour.

On completion of concreting, the forms were left in place for 7 days before stripping.

Photograph 2: Pile Cap Encapsulation under Construction

CATHODIC PROTECTION (ICCP)

Taking advantage of the encapsulation requirement, the anodes and associated reference electrodes, connections and cabling were placed inside the new reinforcing cage before it was fixed. Where the original concrete surface was undamaged, the mesh ribbons were attached directly to the concrete. Where delaminated concrete had been removed and the existing reinforcing steel was exposed, the ribbons were fixed to plastic spacers tied to the bars.

This provided 150mm of high-quality concrete cover to the hardware and ensured its durability during the design life of the installation. It also provided additional verification that there would be no short circuits between the existing steel and the anodes.

There were three horizontal zones – tidal, splash and atmospheric - provided for each pile cap. The lower 400mm was in the tidal zone and the top 250mm and above were deemed to be in the atmospheric zone.

The existing reinforcing steel was tested in all exposed locations for electrical continuity, and where discontinuity was found (in one pile cap only), a 6mm bar was welded across all the existing bars. All anodes and connections were tested as the work progressed to make sure that there were no short circuits between the reinforcing steel and the anodes, or between any two zones.

The junction boxes were positioned high on each pier on the upstream end of the headstock and all cabling from the positive, negative and reference connections to the junction boxes was grouted into slots cut in the concrete columns. This provided optimum durability to the system and ensured the visual appearance of the columns would not be compromised by conduits.

The cabling from the junction boxes was nestled in conduits alongside the existing power cables on the upstream side of the bridge. A transformer/rectifier unit with remote monitoring capability was mounted on a bracket on the north abutment wing wall. This location allowed it to be readily connected to the mains power while putting it out of reach from below. A lockable gate was cut in the fence to add security to the cabinet, which was also lockable.

The ICCP system was energised on 31 May 2016. It has since been monitored both remotely (via in-built telemetry to a website) and directly, by carrying out 24-hour decay tests on site.

Photograph 3: Pile Cap Encapsulation & Headstock Repair

SPALL REPAIRS

Isolated delaminations were found on some columns, headstocks and kerb units. These were repaired by breaking out the concrete to behind the corroding rebars, removing corrosion products from the bars and coating them with a zinc-rich primer. Sacrificial zinc anodes were fixed to the rebars around the perimeter of each repair and the patch was then backfilled with a polymer-modified repair mortar by hand rendering.

On completion, cores were cut through some repairs and, after gluing dolleys to either end, pulled apart in a laboratory to confirm that the strength of the bond between the repair mortar and the substrate concrete was acceptable.

CONCRETE COATINGS

The columns, abutments, headstocks and bridge sides were water-blasted and then painted with two coats of an aliphatic acrylic coating over a primer of silane/siloxane. This proprietary product is designed to resist chloride ingress and water, and was tinted to the client's requirements.

The prestressed deck soffit planks were water-blasted and coated with an octyltriethoxysilane impregnation. A crème formulation was chosen rather than a liquid, to minimise the potential for runoff into the waterway. This colourless proprietary product is designed to resist the ingress of chloride ions and water, while remaining permeable to vapour. It was applied in two coats to ensure sufficient penetration; this was tested on each span by cutting samples from the concrete surface; after oven-drying them in a laboratory for 24 hours, they were split and a vegetable dye applied to the split surfaces to determine the depth to which the concrete had been sealed.

HANDRAILS

The galvanised steel handrailing was designed as a vehicle crash barrier. Two light poles in the line of the footpath rail had previously been removed by cutting them off at handrail level; the bottom sections needed to be replaced with new posts to the same impact capacity as the rest of the railing. Some of the handrailing, particularly one section (next to the light poles) that children used for jumping into the river, was severely corroded and required grit blasting and painting. In addition, it was found that many of the internal RHS posts were severely corroded at the top or bottom and needed to be cut out and replaced with hot-dip galvanised steel.

After repairing the structural elements, all surfaces of the two external handrails were prepared and coated with 80 microns of surface-tolerant epoxy primer and 65 microns of polysiloxane topcoat.

TRANSVERSE TIE RODS

To ensure the extensively corroded tie rods retained their structural capacity, six ultrasonic thickness tests were made to identify any cracking or loss of section near the end of the bar. None was found. In addition, the presence of grout in the ducts was checked at every anchor plate by drilling through the grout injection hole. The drill holes were backfilled with mortar.

All accessible tie rod end plates were grit blasted and then protected with three coats of solvent-free epoxy to a minimum 450 microns' dry film thickness. Those on the east side of the bridge were generally obstructed by existing electrical conduits; it was clear, however, that the plates and rods had been painted when the conduits were installed, and there was little evidence of corrosion.

EXPANSION JOINTS

The existing joints in both the road and the footpath were to be replaced in this contract. The new road joints in the asphalt wearing surface were to consist of an elastomeric polymer nosing on either side, with a silicone rubber sealant between the nosings. The footpath surface comprised asphalt over gravel fill on the precast concrete planks, and the joints were to consist of fibre-reinforced concrete nosings, with the gap sealed with silicone rubber and capped with a stainless steel cover.

A traffic management plan was drawn up for the road works and the joints were repaired one lane at a time with full traffic control. The asphalt either side of the road joints was cut back to the line of existing cracking in the asphalt, making them up to 425mm wide. The depth of asphalt was found to be up to 150mm deep and the movement gap between the concrete elements was found to be approximately 70mm – both larger than expected. The latter aspect led to some increase in wheel noise.

During the contract, it was proposed to replace the footpath thickness, which consisted of asphalt on fill, with fibre-reinforced concrete for the full thickness down to deck plank level. It was discovered on digging trial holes that the footpath fill contained a number of uncharted service ducts, including electrical, that increased the cost of this work as well as the cost of replacing the footpath joints. It was then decided to defer this work, including the specified joint replacement.

DRAINAGE SCUPPERS

The 98 scuppers draining the roadway to the bridge soffit were relined and extended below the deck to reduce salt water and dirt contamination of the precast planks.

PROGRAMME

The refurbishment contract was awarded in July 2015. The investigation and concept design were completed by early September and final design by the end of October.

Site establishment commenced on 23 October 2015 and site disestablishment was completed on 8 June 2016. The ICCP system was energised on 31 May 2016.

Photograph 4: Completed Project

ACKNOWLEDGEMENTS

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