INVESTIGATION AND REMEDIATION OF THE COLD TEA CREEK BRIDGE

- A CASE STUDY ON THE REMEDIATION OF A CONCRETE BRIDGE STRUCTURE USING A HYBRID CP SYSTEM

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ABSTRACT:

The Roads & Maritime Services (RMS) Cold Tea Creek Bridge is located on the Pacific Highway, New South Wales, approximately 20Km south of Newcastle and passes traffic over the Cold Tea Creek. The structure was investigated and found to be suffering from chloride induced reinforcement corrosion. Various elements were showing visible signs of concrete deterioration in the form of cracking, delamination and spalling. RMS selected a Hybrid CP system to control the active corrosion within these elements and to provide ongoing corrosion protection to the reinforcement for 30 years. The system was installed entirely by the RMS maintenance crew with the design and construction phase technical support provided by Infracorr. Infracorr commissioned the Hybrid CP system in July, 2017, with the assistance of RMS personnel.

1 PROJECT BACKGROUND

1.1 Structure Background

Cold Tea Creek is located 21 km south from Newcastle, New South Wales, and flows tidal seawater from the ocean to Lake Macquarie. The creek passes under the Pacific Highway B01366 Bridge (Cold Tea Creek Bridge). The three span bridge, constructed in 1968, is a four-lane reinforced concrete structure with an overall length of 18.3 m and a width of 18.5 m. The bridge is supported by two headstocks and two abutments, each consisting of a headstock beam supported by 10 reinforced concrete piles.

Figure 1. The 3 span Cold Tea Creek Bridge

Figure 2: Each headstock was supported by 10 precast piles

1.2 Condition Assessment

The condition of the bridge was investigated by Roads and Maritime Services (RMS) in September, 2013, during which the headstocks and piles were assessed. The investigation included both destructive and non-destructive surveying and testing methods.

Visual inspection and delamination testing identified defective concrete, in the form of cracking, delamination and spalling, on approximately 10% of the piles and 5% of the headstock. The defective areas were in general found to be located above mid-tide level.

Figure 3: Spalling to the piles.

Figure 4: Cracking and spalling to the lower headstocks

A Half-cell potential survey was undertaken in representative areas to determine the risk of reinforcement corrosion. The survey indicated that active corrosion was likely to be occurring in approximately 80% of the lower 250mm of the headstocks and in 100% of the piles. These results were confirmed by chloride content testing results, which found that critical chloride levels had been exceeded at the depth of the reinforcement in the piles and lower section of the headstocks.

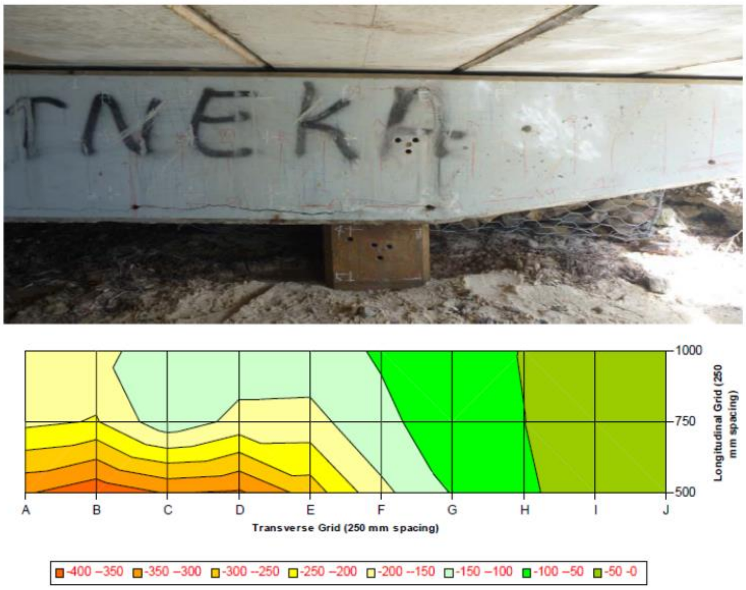

Figure 5: Half-cell potential survey, is a relatively rapid field test that maps the corrosion potential (voltage) of the reinforcement, with the magnitude and the gradient of the potentials indicating the likelihood of active corrosion.

Based on the investigation results it was concluded that the vast majority of reinforcement in the piles and the lower 250mm of the headstocks was suffering from chloride induced corrosion. The upper headstocks and the precast bridge deck units were not found to be corroding, with the chloride below critical levels at the depth of the reinforcement.

RMS considered the options of repeated patch repairs, Impressed Current CP and Hybrid CP for the corrosion control in the piles and lower headstocks and selected Hybrid for this project. The upper areas of headstocks and precast deck beams with lower chloride levels were to be protected by silane impregnations to reduce the ingress of chloride.

2 BACKGROUND TO CATHODIC PROTECTION

2.1 Impressed Current Cathodic Protection (ICCP) and Galvanic Cathodic Protection (GCP)

Impressed current cathodic protection (ICCP) provides protection to the reinforcement utilising a permanent DC power supply and non-reactive anodes, commonly titanium MMO anodes installed in the concrete elements. The anode spacing is commonly at spacings of 250mm to 400mm, subject to the type and output of anodes, reinforcement density, chloride content, concrete resistivity and several other factors to be considered by the CP designer. The anodes are connected in "zones" to positive cables that are routed to the transformer rectifier location(s) to provide the required permanent DC voltage usually between 2 -5 volts.

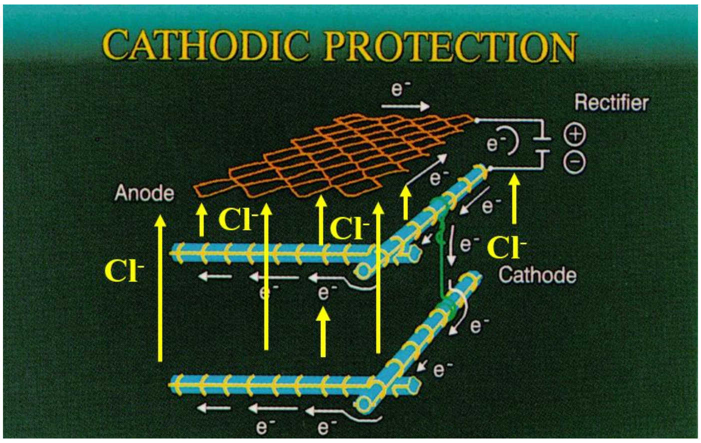

Figure 6: Impressed Current CP provides permanent corrosion protection by forcing a DC current to the reinforcement by connecting the titanium anodes to the positive and reinforcement to the negative of a power supply (Transformer Rectifier)

Galvanic or sacrificial CP (GCP) utilised a protective current, which results due to a potential difference between the steel reinforcement and a more anodic metal (usually zinc) to provide protection. Where chloride is present in high concentrations and corrosion has initiated, the current provided by GCP may be insufficient to arrest the corrosion process.

2.2 Hybrid Corrosion Protection (CP)

Hybrid CP is a system that utilised a combination of ICCP and GCP principles to provide long term corrosion protection to structures with actively corroding reinforcement. The patented Hybrid [1] system was developed by Concrete Preservation Technologies of the UK. The initial phase of Hybrid CP is the impressed current phase and aims to arrest corrosion and restore the passive, alkaline environment around the reinforcement. This phase requires a temporary constant DC power supply of around 9 Volts and typically last for approximately two weeks or until sufficient charge has passed to the reinforcement to meet the required criteria.

Once the required criteria has been reached the temporary power supply and associated cabling is removed and the system is connected in its permanent galvanic phase, during which the reinforcement will be protected by the ongoing galvanic current from the anodes. As this process results in consumption of the anodes, the system's design life is determined by the period of time over which the anodes are exhausted. The design life of the system can be varied by altering the number, size, and the spacing of the anodes.

Figure 7: Typical installation of a Hybrid CP system featuring 30mm diameter drilled holes, with hybrid anodes connected by a titanium wire.

Figure 8: Typical temporary power supply and temporary cabling to provide commonly ~9 Volt DC for the Hybrid impressed current phase.

3 DESIGN PHASE

3.1 Remediation Objectives

The remediation design objective for Cold Tea Creek Bridge was for the reinforced concrete piles and headstocks to attain a minimum of 30 years corrosion protection. Additionally, due to the relatively accessible positioning of the bridge it was preferred by RMS that the remediation system not utilise a permanent power supply to avoid any potential damage that could be inflected by vandals. Based on these requirements and the results from RMS's investigation it was concluded that a Hybrid CP system was to be utilised for the remediation of the bridge.

3.2 System Description

The Hybrid CP system was designed such that all locations on the piles and headstocks with active, or potentially active, reinforcement corrosion were remediated. The system was installed to all piles above mid-tide level and the headstocks to protect the lower 300 mm. The anode arrangement was designed based on the structural configuration of the elements and the reinforcement layout and density. The most suitable anode layout for the system was determined to be Hybrid D750 anodes (~154mm long) spaced at 250 mm centres in the piles and Duoguard D1000 anodes (~220mm long) spaced at 350 mm centres in the headstocks, shown in Figure 9 and Figure 10, respectively.

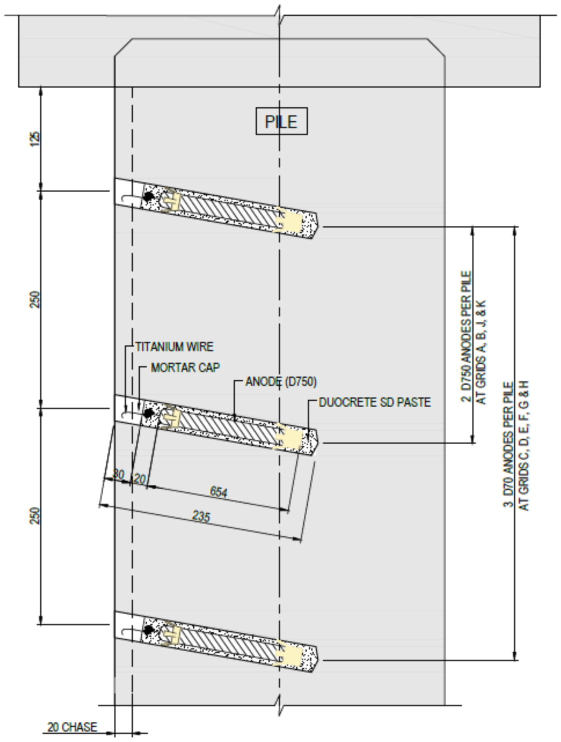

Figure 9: Hybrid CP anode arrangement design for the 380mm square piles.

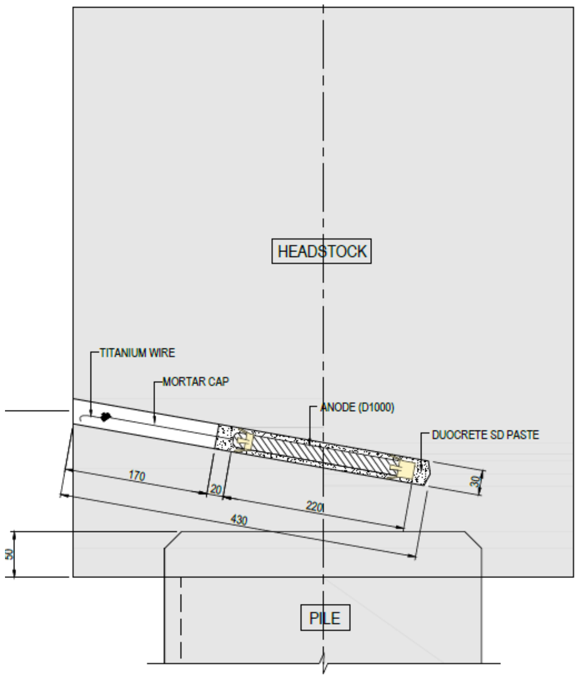

Figure 10: Hybrid CP anode arrangement design for the headstocks.

3.3 Construction Phase

The RMS work crew carried out all remediation works under the technical support provided by Infracorr. The works commenced in February, 2017. The first part of the works included the removal of all loose or delaminated concrete on the piles and headstocks and repair via partial depth patch repairs.

Once the concrete in all piles and headstocks was in sound condition, the electrical continuity of the reinforcement within the piles and headstock of each pier was tested and confirmed. Some isolated areas that were found to be discontinuous were corrected to ensure the correct operation of the designed system.

Preparation works for the system installation commenced in April 2017. These works included drilling of the anode holes, preparation of cable chases, installation of negative connections (connection to the reinforcement), positive connections (connection to the anodes) and reference electrodes (required to monitor the performance of the system). Infracorr assisted RMS by undertaking a ground penetrating radar (GPR) survey to determine the location of the reinforcement, so that the anode holes could avoid the reinforcement and increase work efficiency. Once this preparation had been completed, the anodes were pre-wired using titanium wire and prepared to be installed.

Figure 11: Hybrid CP anodes pre-wired and ready for installation in the lower headstock.

Figure 12: Hybrid CP anodes installed in the headstock and piles prior to backfilling the cable slot.

The anodes were installed by the end of April 2017 and the Hybrid CP system was energised using a temporary power supply operating at 9 Volts DC to operate in the impressed current phase. It was a concern for RMS that vandals would disrupt this phase by damaging the power supply. To avoid this, it was arranged for the power supply to be housed in a concealed protective enclosure of the duration of this phase. Each zone required two to three weeks in the impressed current phase to meet the minimum charge passed of 50 kC/m^2 steel requirement of the Hybrid system.

Once the impressed current criteria was met, the power supply and cables were removed in preparation for the conversion to the “galvanic” phase of the system. The reinforcement was allowed to depolarise (minimum 24 hours) prior to conversion to galvanic operation where the negative (steel) and positive (zinc anodes) where connected in the junction boxes. During the galvanic, long term phase of the system, the zinc anodes continue to corrode in preference to the steel, providing a small protective current to the reinforcement.

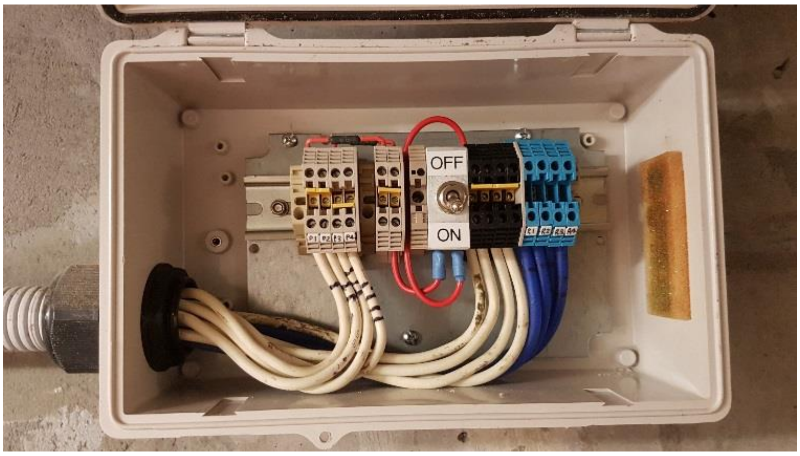

Figure 13: Example of a junction box layout

3.4 Commissioning Phase

After 5 weeks in galvanic operation the system’s performance was evaluated by Infracorr with assistance from RMS. This included undertaking typical cathodic protection monitoring of galvanic current level and “instant off” and depolarisation testing at the installed reference electrodes. The commissioning and future monitoring of Hybrid CP systems is completed in accord with ISO12696-2016 Cathodic Protection of Steel in Concrete. [2] This standard refers to traditional CP criteria, such as 100mV depolarization and also allows the assessment that the corrosion rate of the steel is maintained at a low, passive level of <2mA/m^2 as determined by applying the Butler Volmer Equation to the measured values. An excerpt of the current density calculation completed for Pier C are shown in Table 1.

Table 1: Current density calculations for Pier C, including piles and headstocks

Current Density (Corr. Rate) - PIER C					
Panel/Zone	C1	C1	C2	C2	C2
Reference ID	R1	R2	R3	R4	R5
Reference Location	Headstock	Pile	Headstock	Headstock	Pile
Natural (Base) Potential (mV)	-80	-164	-70	-82	-263
Instant Off Potential (mV) Recorded 17th July 2017, 12:10pm	-154	-293	-103	-131	-311
Depolarization Potential (mV) - Recorded 18th July 2017, 12:05pm (24hrs)**	-76	-216	-53	-68	-266
Depolarization [ΔV] (mV)	78	77	50	63	45
Galvanic Current (mA)	11.67	11.67	13.42	13.42	13.42
Steel (reinforcement) Area (m^2)	12.46	12.46	12.46	12.46	12.46
Corrosion Rate [icorr] (mA/m^2)	0.221	0.226	0.484	0.353	0.553

According to ISO 12696 a corrosion rate of less than 2 mA/m^2 indicated that the reinforcement is passive. As can be seen in Table 1 each of the zones at Pier C were calculated to have a corrosion rate of less than 2 mA/m^2, indicating that the Hybrid CP system installed has effectively halted the previously active reinforcement corrosion. Based the corrosion rate figures determined the system life was calculated based on the reinforcement density, the anode configuration and the expected consumption rate of the anodes and is shown in Table 2.

Table 2: Calculated design life for the Hybrid CP system at Cold Tea Creek Bridge.

Anode Life (Years) - PIER A		
Panel/Zone	A1	A2
Time (yrs)	>30	>30
Anode Life (Years) - PIER B		
Panel/Zone	B1	B2
Time (yrs)	>30	>30
Anode Life (Years) - PIER C		
Panel/Zone	B1	B2
Time (yrs)	>30	>30
Anode Life (Years) - PIER D		
Panel/Zone	B1	B2
Time (yrs)	>30	>30

4 CONCLUSIONS

The Cold Tea Creek Bridge, which was previously showing visible signs of distress in the form of concrete cracking and spalling, has been remediated via a joint effect of Infracorr and RMS. The Hybrid CP system design, has proven to halt the previously active reinforcement corrosion and is expected to extend the design life of the bridge by the required minimum of 30 years. The designed system requires no permanent Transformer Rectifier power supplies or major cable network, with simple junction boxes utilized to monitor the performance of the system.

Future monitoring of the system is to be conducted a 12 month intervals, including recording of galvanic current and depolarization testing, to confirm that the low corrosion rate of less than 2mA/m2 has been maintained. Should the corrosion rate in the future be found to increase over the passive level (2mA/m2) the zone or zones could be re-energized with a temporary current utilizing a portable power supply or even a battery for a short period (eg 3-5 days).

ACKNOWLEDGEMENT

Infracorr wish to acknowledge and thank the RMS Bridge division and the RMS Hunter region and work crews for their assistance in this project.

REFERENCES

[1] Glass GK, Roberts AC and Davison N, Hybrid corrosion protection of chloride-contaminated concrete, (Construction Materials) 161 (4) (2008)

[2] ISO 12696:2016 Cathodic Protection of Steel in Concrete