Cathodic Protection of a 1.2km long Harbour Tunnel

A 1.2km long 4.35m diameter cross-harbour tunnel was constructed in 1996 for an iron ore conveyor. This used 5,154 reinforced concrete lining segments bolted together with mild steel bolts located within bolt pockets. Since early in its construction the tunnel experienced seawater leakage through segment seals and grout ports. Due to the water pressure, leakage of tunnels under a harbour is not uncommon and regular wash down and maintenance would be required. However, with a conveyor that operates continuously, it is only possible to undertake minimal maintenance. Over time seawater ingress caused severe corrosion of the exposed mild steel bolt assemblies. This corrosion has led to surface cracking and spalling of the concrete (Figure 1). The salt encrustation from leaks had resulted in diffusion of chlorides into the concrete thereby initiating reinforcement corrosion. Concrete remediation and installation of an impressed current cathodic protection (ICCP) system was required in order to achieve the desired life of 50 years for this 15 year old asset.

Concrete Remediation Works

Aurecon developed a methodology to remediate the corroding steel bolts and mitigate corrosion on mild steel components and reinforcement. This would allow the tunnel to achieve its required life with minimal ongoing maintenance. This involved the repair of damaged concrete, encapsulation of mild steel bolts and application of cathodic protection (Figure 2, 3).

During a scheduled shutdown period, extensive repair works were undertaken utilising spray grouting. These works were performed by multiple crews moving along the tunnel under restricted access conditions due to the presence of the conveyor structure and the walkway. These repairs addressed damage visible at the time.

ICCP System Design Consideration

During the design consideration had to be given to:

- Resolving the lack of continuity between individual reinforced concrete segments
- Achieving even current distribution along the structure
- Monitoring of the performance of the ICCP system by measuring polarisation levels along the tunnel
- The presence of a vast network of buried and immersed metallic structures surrounding the tunnel such as pipelines and wharfs, many of which with their own high current output ICCP systems installed
- Requirements by tunnel operations such as short shut down periods, limited access and other works in the vicinity e.g. the construction of multiple new berths including piling straddling the tunnel.

Design Options for the Cathodic Protection System

Various design options to provide cathodic protection to the tunnel reinforcement were considered. The three main options were:

- a) Ribbon/discrete anodes in slots/drilled holes in the concrete.
- b) A distributed anode system along the full length of the tunnel.
- c) Installation of remote anode groundbeds at the two ends of the tunnel.

Option c) stood out due to simplicity of the approach, lower risks and comparably low cost and was consequently selected as preferred option. A trial was performed to assess the suitability of this approach.

Based on positive results from the trial this option was selected for a feasibility study and subsequently for detailed design and implementation.

Detailed Design

The ICCP system was designed with remote anode groundbeds located onshore at the two ends of the tunnel in order to inject current into the steel reinforcement via the soil/sea water/concrete medium. (Refer Figure 4 for Schematic). The locations were chosen to minimise the risk of stray current interference effects upon buried or immersed metallic structures in the vicinity of the tunnel. The ICCP power supply and monitoring control units (PSMCU) are integrated into an extensive monitoring system which feeds into the client’s SCADA system. The PSMCs are linked with a fibre optic communication cable and have 3G modems which allow remote diagnostics and software upgrades. A continuity system was installed along the tunnel to interconnect the segments and provide a return path for the CP current.

Platinum coated, copper cored nickel anodes were selected for the groundbeds. These anodes offer a long service life, high current output density and high permissible driving voltages in a chloride environment. The total output capacity is 450 amps with a 50 year design life. The anodes are located in a calcined coke backfill.

The greatest challenge during construction was installation of the anode groundbeds with coke backfill within tidal areas (Figure 5 and 6). Challenges involved:

1. Grounded trenches would fill with water for a significant portion of the day, with high tides fully immersing the locations
2. Trench walls dug in sandy water saturated soil would easily collapse
3. Any damage to mangroves present at the locations would have to be environmentally approved, hence, had to be minimised.
4. Coke backfill could be washed out of trench during tide movement

To overcome these challenges canistered anodes were manufactured consisting of 5.0m long steel tubewells. The entire canister was wrapped in geotextile fabric to prevent washing out of the coke. One 2.0m long anode was placed centrally in the coke. These canisters were lifted into the trench and joined with the previous canister to obtain a continuous groundbed.

Construction

No coke was washed out during construction or can be washed out during the operation.

The risk for trench wall collapse was minimised

Trenching/installation could continue during the subsequent low tide without significant preparation.

Commissioning and Operation

Commissioning was performed in accordance with AS 2832.5 to achieve internationally accepted criteria for protection.

After 12 weeks depolarisation testing found that >98% of the reference electrodes had achieved satisfactory levels of protection. Additional polarisation would continue with time with a total output from the PSMCU of 265 amps. An example of the depolarisation trends is shown in Figure 7.

Interference testing was conducted as part of the commissioning process. Some adverse effects were noted on nearby buried pipes and wharves. To mitigate these effects bonding systems were designed. Cables were run from the interference mitigation terminals provided at each PSMCU to each affected asset where the adverse effect was most prominent and connected via blocking diodes.

This project demonstrated that a long reinforced concrete segmented tunnel structure can be protected by cathodic protection utilising remote external anode groundbeds. Construction and site issues provided challenges to the development and implementation of this ICCP system due to dense heavy infrastructure.
and ongoing infrastructure expansion activities. However these were mitigated by flexibility, communication and innovative design during all stages of the work. Stray current issues were encountered but have been readily mitigated as early consideration was given to this during the design. A project of this nature requires close coordination amongst the designers, the owner, manufacturers, and installers as well as stakeholders to achieve the desired outcome.

(Editors Note: For more information about this project refer to NWC Proceedings, Paper No. 357.)

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