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CORROSION CONTROL

Analysing 15 years of hybrid anode performance data

Long-term monitoring of innovative corrosion control system yields fascinating results

David Bewley and **Christian Stone** of **Concrete Preservation Technologies** (**CPT**) present 15 years of hybrid anode performance data from Whiteadder Bridge.

Corrosion is well understood to be a major cause of reinforced concrete deterioration. The first line of defence against corrosion is to provide barriers to the ingress of moisture and aggressive agents. Adequate concrete cover, the use of high-performance concrete and the application of coatings and sealants can all play a part in protecting the embedded steel reinforcement. The maintenance of coatings and sealants, which may only have a ten-year life, is critical for the protection of structures that may have a design life in excess of 100 years.

However, in the real world we are left with a legacy of structures suffering from the absence of effective barriers to ingress often exacerbated by a lack of maintenance. As a result, we have a stock of structures that are either exhibiting corrosion damage or are on the cusp of corrosion initiation. At this stage in the life cycle, it is critical that an appropriate corrosion control system is used to keep a structure safe, maintain functionality and extend life. Bridges, car parks, jetties and concrete-framed buildings are all vulnerable to corrosion and increasingly, preservation is considered preferable to replacement given the inherent fiscal and environmental costs.

A MONITORING CASE STUDY – WHITEADDER BRIDGE

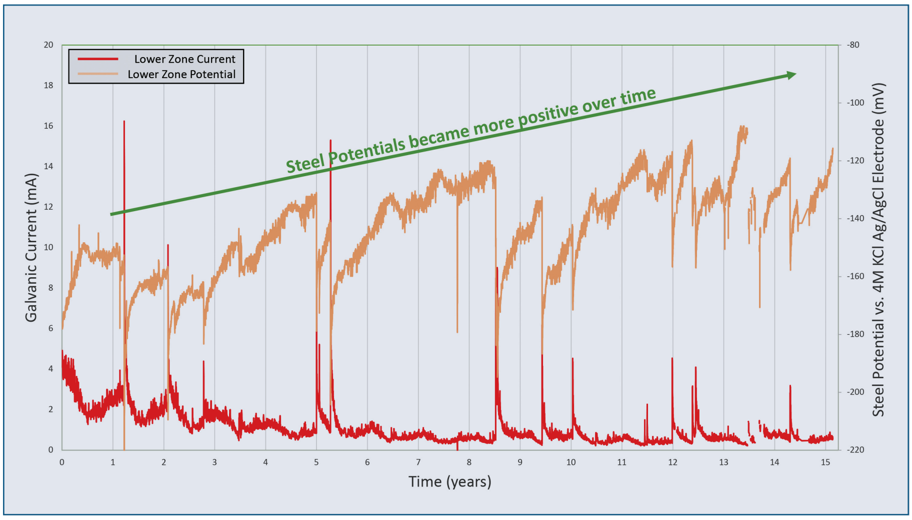
In February 2007, an innovative corrosion control system was installed on Whiteadder Bridge, near Berwick-upon-Tweed in Northumberland (Figure 1). The site was chosen for intensive monitoring for the following reasons: there was visible cracking and delamination of the concrete cover (Figure 2); chloride contamination was high at up to 1.68% by weight of cement; and the piers were subject to extreme wet–dry cycling due to periodic flood events.

Some 15 years on, the data gathered provides a fascinating insight into the workings of the world's first hybrid anode cathodic protection (CP) system.

HYBRID ANODES – CORROSION CONTROL

In simple terms, a hybrid CP system uses both impressed current and galvanic anode technology to induce, and then maintain, steel passivity (Figure 3). The impressed current phase typically only requires one week to halt ongoing corrosion, after which time the temporary

MAIN IMAGE:
Figure 1 – Whiteadder Bridge, April 2023, 16 years after installation of the hybrid corrosion protection system.



LEFT:
Figure 2 – cracking of bridge pier prior to repair in 2007.

MIDDLE:
Figure 3 – installation of hybrid anodes.

BOTTOM:
Figure 4 – steel potential and current readings from the lower anode zone.

power source is removed from site. A naturally self-regulating galvanic system is left in place, providing protection proportional to the local corrosion risk. Hybrid CP addresses some of the common complaints about permanently powered systems, ie, that they are vulnerable to neglect, breakdown and vandalism and that they are expensive to maintain with monitoring costs potentially in the tens of thousands of pounds over an equivalent 15-year period (see CPA Technical Note[1]), plus electricity costs and possible replacement of key components.

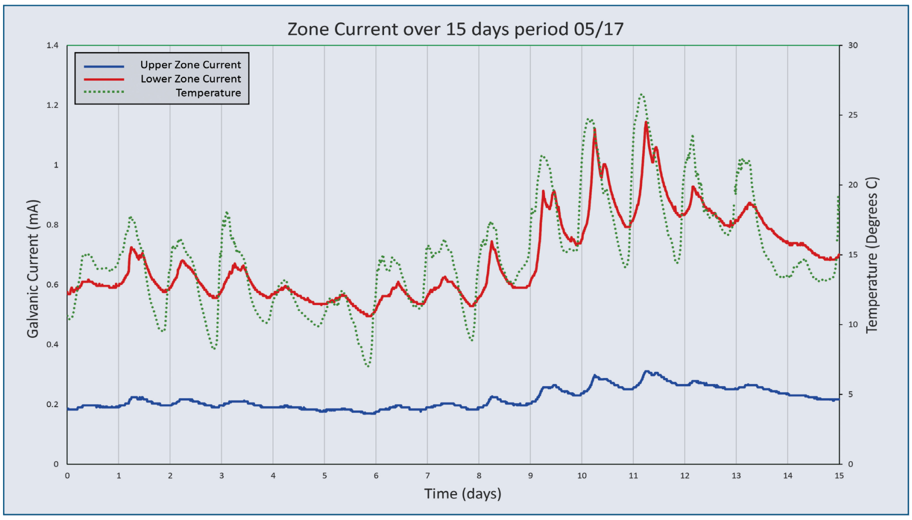
MONITORING METHODS

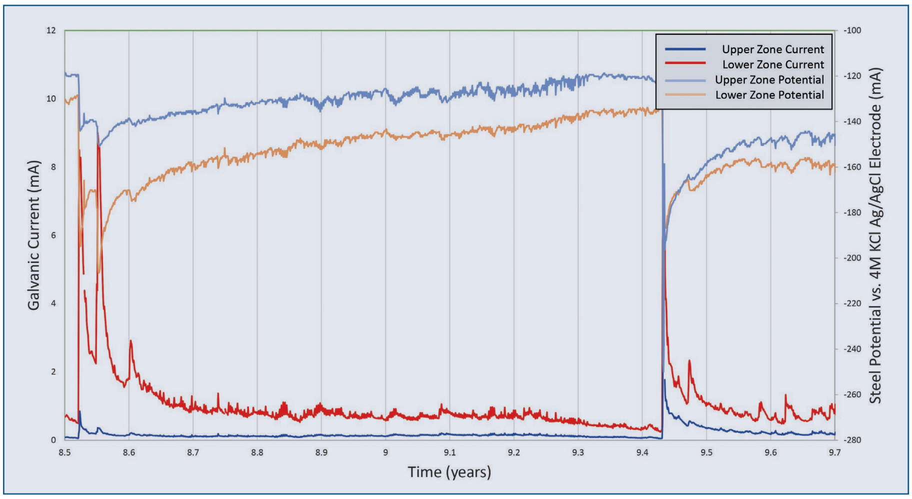
Over the 15-year study period, over ten million datapoints were collected, including anode currents in both high- and low-risk zones and the steel potential in 12 locations. Data loggers were used to continuously record anode current and steel potentials, revealing patterns that would otherwise be undetected by periodic spot readings. The data presented is of the system operating in galvanic mode, ie, it excludes the initial impressed current phase.

CURRENT BEHAVIOUR AND STEEL POLARISATION

It is notable from Figure 4 that the current initially tapers off with time after starting off at an increased level. This period of elevated current is a unique design feature of the technology and reflects the early low-resistivity environment around the anode. The data indicates that, over time, the current reaches an equilibrium. Recent measurements show an increase in current over the past five years, reflecting environmental conditions. Throughout the 15-year period, the steel potentials can be seen to be heading in a more positive direction, which is an indicator of increased steel passivity.

An interesting feature of the data is





RIGHT:
Figure 5 – fluctuations in galvanic current versus temperature, logged at ten-minute intervals over a 15-day period, May 2017.

MIDDLE:
Figure 6 – effect of river flood on anode current and steel potentials.

BOTTOM:
Figure 7 – April 2023, the piers remain free of cracks and spalls.

the peaks and troughs. Every year, the current slowly undulates up and down, reflecting the system reacting to the changing corrosion risk as temperature rises and falls. Similarly, there are many sudden peaks in the current and corresponding protective polarisation of the steel, both modest and substantial, which relate to rainfall and flooding respectively.

It is interesting to note that the same patterns seen over a 15-year period can also be seen when focusing in on a 15-day timescale, as illustrated by Figure 5. The gentle rise and fall in daytime temperature can be seen to generate a similar response to seasonal shifts in temperature.

In contrast, rainfall produces sudden spikes in protective current, which directly affect the steel potential. During more extreme weather events, the galvanic anodes in the higher-corrosion-risk lower zone deliver current at a similar level to a fully impressed current system, peaking at over 6mA/m^2 current density. Data taken during the last severe weather event 14.5 years after installation show all six corrosion rates for the wet lower zone to be less than 2mA/m^2, where 2mA/m^2 equates to negligible steel section loss of ~1mm over 500 years. The dramatic impact of a flood event on anode current and steel potentials can be seen in Figure 6.

VISUAL INSPECTION

A recent (April 2023) visual assessment of the Whiteadder Bridge piers confirmed the absence of spalling or cracking of the concrete cover (Figure 7).

CONCLUDING REMARKS

After 15 years of hybrid anode protection, the bridge piers show no signs of corrosion-related deterioration and steel potentials continue to trend towards more positive values, indicating steel passivity. Continuous monitoring has provided a valuable insight into the extremely responsive nature of the hybrid corrosion control system. By only providing current proportional to corrosion risk, the anodes have plenty of residual capacity. Currently, the more active anode zones are on track for an effective lifetime well in excess of the original design life with only approximately 6% of anode mass consumed. Most importantly, for the owner of Whiteadder Bridge, the system has proven to be highly effective and maintenance-free. C

Further information:

Whiteadder Bridge was the subject of a study by Aecom published by the ICE in 2022[2]. Monitoring results were referenced in the October 2016 edition of *Concrete*[3]. The purpose of this update is to enhance industry knowledge in a sector where there are few long-term studies into the performance of corrosion control systems. All data presented is specific to the DuoGuard hybrid cathodic protection system.

References:

1. BROOMFIELD, J. *Budget cost and anode performance information for impressed current cathodic protection of reinforced concrete highway bridges*. Corrosion Prevention Association, Technical Note 12 Bordon, 2019.
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3. BEWLEY, D. High power, low maintenance hybrid corrosion protection. *Concrete*, Vol.50, No.8, October 2016, pp.25–27.