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Protecting the UK's critical infrastructure – Impressed Current Cathodic Protection on the Midland Links Motorways Network

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ABSTRACT

The Midland Links Motorway Viaducts (MLMV) are located around the UK's second largest city - Birmingham - and comprise 21 kilometres of elevated bridge motorway structures. Impressed Current Cathodic Protection (ICCP) has been used to prolong the life of more than 700 concrete structures in the MLMV, in a significantly sustainable manner, by reducing the need to remove chloride contaminated (but otherwise structurally sound) concrete.

The present study was initiated after identifying that some of the ICCP systems were reaching the end of their design life, whilst others had deteriorated or been vandalised, therefore requiring a significant level of maintenance, and cost. The objective of this work was to collate evidence from field structures to support preliminary laboratory results that the application of ICCP to a reinforced concrete structure over a period of time can transform the protective environment around the reinforcement.

The results can indicate when repairs to ICCP systems are likely to be critical; provide new evidence for determining the design life; reduce the requirement to replace systems at the end of their functional life; and the interval between planned maintenance of existing systems may be extended with corresponding reduction in monitoring frequency and costs. The work is unique and novel as it is the only ICCP field trial across Europe on full-scale motorway structures. It also contributes to sustainability as the results form a basis for an improved maintenance strategy.

INTRODUCTION

Impressed Current Cathodic Protection (ICCP) is a well-established repair method for corroding reinforced concrete elements with a track record of more than 30 years worldwide. The single largest application of ICCP in Europe is in the United Kingdom on the Midland Links Motorway Viaducts where over 700 concrete structures are currently protected.

Long-term monitoring of field structures suggests that after steel passivity has been induced then the protection current may be interrupted. The technical reason for this is that the application of ICCP has resulted in an increase in the reservoir of inhibitive hydroxide ions at the metal surface which will stifle the corrosion process.

However, a recent report by the Transportation Research Board, U.S.A. (2009) surveyed National Transportation Agencies in the USA to identify where ICCP is used, the reasons for its selection and

explanations why it is not used by other States. They concluded that the technique is not used because of disappointing past experience, being more expensive than other options, and monitoring and maintenance was a significant burden.



In addition, recent experience in the UK has demonstrated that several ICCP systems were now reaching the end of their design life while others were suffering from material deterioration (Figure 1) or vandalism. This has resulted in several structures being in need of refurbishment.

Figure 1: Typical material deterioration

This work sought to identify the existence of long-term effects from the use of ICCP in a number of field structures. The objective was to systematically collect data from in-service structures that can be compared to published laboratory testing and hence establish if field evidence exists for the effect of long-term ICCP application (Christodoulou et al. 2010).

METHODOLOGY

Figure 2 illustrates a typical arrangement of the sub-structure for the Midland Links Motorway Viaducts. Approximately 700 reinforced concrete crossbeams have so far been protected with ICCP to extend their service life due to chloride contamination. Ten crossbeams were selected for testing based on the age, condition and environmental exposure of the ICCP system and chloride contamination of the crossbeams.

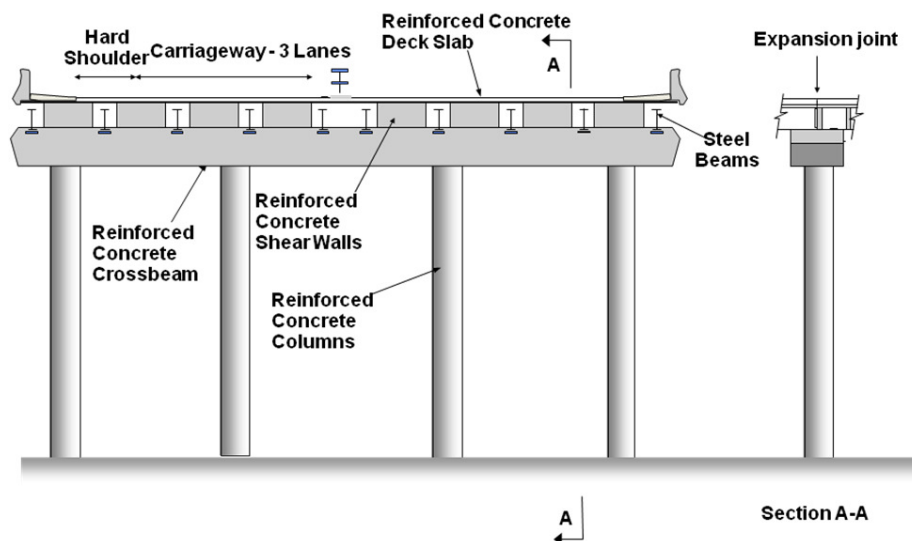


Figure 2: Typical structural arrangement of the Midland Links Motorway Viaducts

The protection offered by the ICCP system was switched off for a period of 52 months and the crossbeams were monitored for signs of corrosion onset. Corrosion activity was assessed based on: a) corrosion potential measurements, b) polarisation resistance and c) impedance testing for

corrosion rates. All of the techniques are well established techniques in the field of corrosion assessment and in particular employing impedance analysis on site structures was another unique and novel feature of the current work.

RESULTS

From the monitoring data over a period of 52 months, there were no evidence of corrosion activity of the reinforcement. Steel potentials remained stable in general without any great fluctuations indicating passive condition of the reinforcement. Corrosion rates calculated both from polarization resistance and impedance analysis returned extremely low values indicating the absence of corrosion (Figure 3). This is despite the fact that the tested crossbeams did not receive any protection for the past 52 months and they retained high residual levels of chlorides which posed a significant corrosion risk to the structures.

Furthermore, it was demonstrated that impedance analysis can be successfully employed on site to assess the corrosion condition of reinforced concrete structures. The technique requires a very large data set for analysis which significantly improves accuracy and eliminates errors. In addition, measurements are taken when there is no electrical current passing through the structure, which eliminates errors in the calculation of the corrosion rate due to interference of the concrete resistivity.

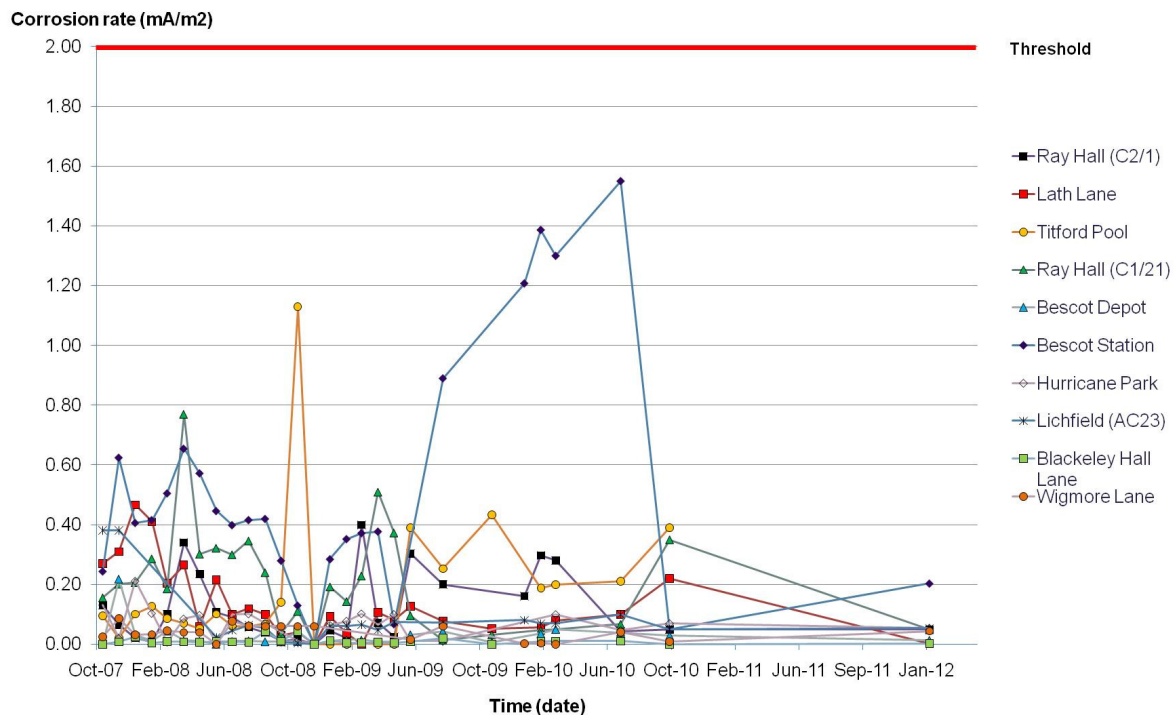


Figure 3: Corrosion rate monitoring over a period of 52 months

DISCUSSION

At the start of the study all the structures were assessed for their corrosion risk. It was found that the structures located at Lath Lane and Ray Hall Lane (C1/21, see Figure 3) were the two at most risk due to high residual chloride contamination. Chloride sampling results showed that these two structures had more than 40% of their test locations with chlorides greater than 1% by weight of

cement and about 60% 66% of their test locations with more than 0.4% chlorides by weight of cement at the depth of the steel.

With reference to the steel potentials and the corrosion rates from polarisation resistance testing over a period of 52 months, the data suggests that there is no significant corrosion activity on the structures. More specifically it can be observed that a poorly performing system, as illustrated by **Error! Reference source not found.**, it had been capable of inducing and maintaining steel passivity even after protection has been lost.

The results of this field study can help improve the asset management strategy of Maintenance Agencies. When considering the repair of old ICCP systems the passivation of the reinforcement from the previous system should be taken under consideration. Therefore, new ICCP systems need only to be designed for corrosion *prevention* rather than corrosion *protection*. In addition, other forms of corrosion management should be considered, such as monitoring only, concrete repairs, galvanic anodes etc (Christodoulou et al. 2009). Alternatively, the failed ICCP systems can just be periodically monitored until corrosion activity becomes significant and the ICCP system can then be renewed. Overall, this approach should result in reduced refurbishment and maintenance costs of ICCP systems.

CONCLUSIONS

The site data presented here is consistent with the laboratory and other results, indicating a persistent protective effect after the interruption of the ICCP systems. More specifically we conclude:

- 1) After 52 months with no ICCP current, all the structures investigated have remained passive, including cases where 60% of the test locations exceeded 1% chloride concentration at the depth of steel reinforcement. This supports previous laboratory evidence suggesting that ICCP does not only arrest ongoing corrosion but it also prevents future corrosion.
- 2) The polarisation resistance, steel potential and impedance data show that ICCP protects reinforced concrete structures not only by shifting potentials to negative values (i.e. pitting potential model) but also by transforming the steel-concrete interface.
- 3) The absence of corrosion should be taken into account when repairing old CP systems. Replacement anode systems need only to be designed for corrosion prevention rather than corrosion protection. Other forms of risk management include just having corrosion rate monitoring on its own as opposed to a repair of the ICCP system.

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