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Assessing the long term benefits of Impressed Current Cathodic Protection

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Abstract

This experimental field study interrupted the protection current offered by Impressed Current Cathodic Protection (ICCP) to ten in-service reinforced concrete structures. The study aimed to identify the long term effects of ICCP after it was recognised that some of the systems are now reaching the end of their design life and require a significant level of maintenance. It was found that after five or more years of ICCP, the steel remained passive for at least 24 months after interrupting the protection current despite chloride contamination that would represent a corrosion risk.

Keywords: Steel Reinforced Concrete (A) ; Polarization (B) ; Cathodic Protection (C) ; Passivity (C) ; Pitting Corrosion (C) ; Repassivation (C)

1. Introduction

ICCP of atmospherically exposed steel reinforced concrete structures has been used since 1970s and it is a proven technique which is able to arrest ongoing corrosion and induce and sustain steel passivity [1]. The main principle of cathodic protection is applying an impressed current such as to induce negative steel polarisation [2], in other words to drive the steel potentials more cathodically than -850 mV (SCE), where corrosion process is thermodynamically impossible to occur [3]. Under these conditions the steel will be immune to corrosion.

However, for atmospherically exposed reinforced concrete, changing the environment from actively corroding (i.e. pitting) to passive, where pitting is unstable will be sufficient. Steel protection has been attributed to the negative potential shift achieved from the impressed current [4] but it has also been reported that it also contributes to the production of hydroxyl ions, an increase of the pH and driving the chloride ions away from the steel – concrete interface [5].

It is widely accepted that the application of cathodic protection to a reinforced concrete structure transforms the environment around the reinforcement over a period of time [5]. The metal surface is now polarised negatively, thus repelling the chlorides (Cl^-); oxygen (O_2) and water (H_2O) are consumed and hydroxyl (OH^-) is generated at the metal surface. The hydroxyl alkalinity will then be responsible for restoring the pH to the metal surface and inducing passivity of the metal.

Evidence suggests that after steel passivity has been restored then the protection current may be interrupted, as illustrated by Broomfield and Tinnea [6]. This study looked at steel potentials prior to the application of an ICCP system and compared them with the potentials after the structure was protected for approximately one year and the cathodic protection system turned off for three months. It was observed that the application of ICCP shifted the steel potentials towards more positive values.

A recent study was undertaken in the U.S.A. by Presuel-Moreno et. al [7] on the effect of long-term cathodic polarisation in reinforced concrete columns in a marine environment. The structures tested were partially submerged with the splash zone exposed to very high chloride contamination levels, in some cases up to 4.7 % by weight of cement and they had been protected by ICCP for an approximate period of 9 years. The study concentrated the testing on the splash zone and illustrated that corrosion did not initiate immediately after the current was interrupted. Some of the reinforcement was reported to start corroding

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again after approximately 35 days but even after the study was stopped at 220 days, not all the reinforcement was actively corroding at the time. It is also very interesting that steel passivation was achieved with current densities of 0.5 µA/cm^2 (5 mA/m^2). With reference to BS EN 12696 [2] such current density is considered to be on the lower spectrum of the suggested design current to achieve cathodic protection on actively corroding structures.

Although the above study concluded that given enough time the corrosion could initiate on all the reinforcement again, there is evidence from a very aggressive environment that ICCP has long-term persistent protective effects [7]. It is also supporting the experimental data presented in this paper, which was collected on a far less aggressive environment with chloride levels not exceeding 2 % by weight of cement as opposed to the 4.7 % by weight of cement recorded in the U.S. field study.

In addition, there is a substantial amount of laboratory data obtained under more rigorous circumstances to support this observation of an increase in the tolerance to chloride contamination and the persistent protective effects. Figure 1 shows the results of a study in which a brief period of electrochemical treatment that would have generated hydroxide ions at the steel caused a substantial increase in the tolerance to chloride contamination [8]. The observation that electrochemically treated structures are more tolerant to chloride contamination is countered by an observation that in very heavily chloride contaminated concrete; corrosion may start again.

The study aims to identify the existence of persistent protective effects afforded by the application of ICCP in a number of field structures. Midland Links Motorway Viaducts represents the largest application of ICCP in the U.K., with over 700 reinforced concrete structures being protected by cathodic protection. Data was collected from in service structures that can be compared in context of published laboratory data.

2. Field Study & Methodology

The following sections describe the field study by stating the location of the works, briefly describing the structures and their history and by analysing the selection methods used in order to obtain a representative sample of structures. Furthermore, the methodology used to assess corrosion risk is described and examples of technical calculations are also given.

2.1 Structures Selection

Figure 2, illustrates a typical arrangement of the sub-structure for the Midland Links Motorway Viaducts. Each span of the viaduct is simply supported on a reinforced concrete crossbeam. In total there are approximately 1200 crossbeams in the network and about 700 of them have been protected by means of ICCP over the last 20 years.

The beams tested were selected in such an order to represent reinforced concrete with a high risk of chloride induced corrosion that had been subject to cathodic protection for a range of protection periods. A total of 10 beams were selected based on the age of the installed CP system, accessibility and chloride levels indicating a residual corrosion risk. On every beam two locations were selected for monitoring based on the chloride analysis to install anode segments, with the total number of monitored locations therefore being 20. Figure 3, illustrates one of the beams that were tested to assess the long-term benefits of ICCP. It is showing severe anode deterioration but no active corrosion.

The 10 beams that were selected are given in Table 1. All the structures were constructed in the period of 1966 to 1970. Samples for chloride analysis were collected to identify areas of residual risk. The locations of testing were in original un-repaired concrete and the chloride contents are expressed as weight percent of cement and for a 25 to 50 mm cover depth. No chloride contents above 2% by weight of cement were detected at this depth. All the structures were treated for a period of time with ICCP as illustrated by Table 1 and the anode system comprised a conductive coating. The structures selected have anode systems provided by different suppliers in order to also compare their performance.

2.2 Methods of Assessment

In order to assess corrosion activity in the structures, a number of tests were undertaken, including:

1. Corrosion potential measurements, undertaken monthly and in some cases continuously

2. Polarisation resistance determination of corrosion rates, undertaken monthly to calculate corrosion rates

3. Impedance measurement of corrosion rates initiated after 6 months

Measuring steel potentials against the potentials of a standard reference electrode is a long established technique [9,10]. Typical ranges of steel potentials for various conditions against different types of reference electrodes are widely available in the public domain [10,11]. In accordance with BA 35/90 values more positive than -200 mV $Cu/CuSO_4$ (saturated) indicate a low probability of corrosion. Steel potentials

can give a good approximation of the corrosion risk of steel but they are affected by various other factors [11].

Corrosion rates are usually expressed as a current density, a rate of weight loss or a rate of section loss. A corrosion rate of 1 mA/m^2 when expressed as a current density is approximately equal to a steel weight loss of 10 g/m^2/year or a steel section loss of 1 μm/year. In general corrosion rates higher than 1 – 2 mA/m^2 are considered to be significant and in cases where there is easy access of oxygen (i.e. non-saturated with water) then average corrosion rates can reach values up to 100 mA/m^2 [12]. The calculation of corrosion rates through the polarisation resistance method is a well established technique and its feasibility has been demonstrated in numerous occasions [13,14,15,16].

Rates below 2 mA/m^2 (500 years to lose one mm of steel section) are considered negligible and corrosion development is highly unlikely. At a rate higher than the 2 mA/m^2 localised corrosion activity becomes increasingly likely. This results from the loss of protection provided by the passive oxide film and the concrete cover [17].

Figure 4, illustrates how corrosion rates are calculated based upon the applied current and the achieved potential shift. A small current density is applied to the steel for a period of 10 minutes. This produces a steel potential shift and a voltage drop (IR drop) through the concrete. The potential shift and applied current density are inserted into the Butler-Volmer equation, which provides the basis for polarisation resistance theory, to calculate the corrosion rate. There are several variations on this method, but this variation is more suited to the determination of corrosion rates in site conditions as it uses a larger potential shift and less complex equipment than is commonly applied in the laboratory and makes use of the existing CP anode system as a guard electrode [18].

Impedance is an alternative technique to calculate corrosion rates and was added to the testing regime during this project to provide additional data. A short current pulse is applied to the structure and the potential shifts over a short period of time are recorded. The potential shift achieved and the time of the potential decay can then be associated with the corrosion rate of the structure [19].

Impedance testing differs from polarisation resistance testing in the form of the perturbation applied and the subsequent data analysis. A current pulse delivers a charge to the steel that affects the steel potential and the potential response is recorded and analysed.

2.3 Testing Arrangement

The arrangement used to assess steel passivity is illustrated in Figure 5. Briefly the main elements were the existing power supply enclosure located at ground-level, the existing CP enclosure at high-level, the anode segment and a new enclosure at high-level to facilitate the new connections to the system.

A segment of the anode (patch) approximately 0.35 m^2 was isolated from the rest of the anode system by removing the old anode. This isolated area was cleaned up and a new anode was installed locally and coloured black as shown in Figure 6. The existing anode segment acts as a counter electrode and the rest of the anode system acts as a guard ring to confine a current perturbation of the anode segment to the steel below the anode segment during the corrosion rate measurement process. A reference electrode located in the middle of the anode segment is used to assess the steel potential shift.

The new electrodes were installed in order to monitor high chloride concentration areas that were not previously monitored from the original electrodes installed during the installation of the ICCP system. All the new reference electrodes installed in the 10 beams were Ag/AgCl/0.5 M KCl, the same as the originally installed reference electrodes. The data was recorded using data loggers or recorded manually. The system was designed with the existing power supply providing the current perturbation. However, some of the existing supplies were unstable and a battery power supply was used for all measurements from the second month.

3. Results

This section describes the findings obtained from the monthly monitoring of the structures over a period of 24 months and discusses in detail the findings.

3.1 Chloride Content

Samples for chloride analysis were collected at the start of the project. 5 locations were tested for every structure. The values referred to Table 1 correspond to chloride levels found at the depth of steel (i.e. 25 mm to 50 mm). The values express total chloride content by weight of cement. The test locations were all

in the parent concrete not previously repaired, in order to identify residual corrosion risk. From Table 1 it can be observed that higher chloride contents were present in the older beams whereas in the recently repaired beams chloride levels did not exceed 1 % by weight of cement.

3.2 Steel Potentials

Figure 7, illustrates the most negative steel potentials for all 10 structures monitored for a period of 24 months with respect to the newly installed reference electrodes. In accordance with BA 35/90, values more positive than -200 mV $Cu/CuSO_4$ (saturated) which is equivalent to -120 mV (Ag/AgCl/0.5 M KCl), indicate a low probability corrosion risk. Values more negative than -270 mV (Ag/AgCl/0.5 M KCl indicate a high corrosion risk. The values recorded during this study were in most cases more positive than -120 mV (Ag/AgCl/0.5 M KCl) and therefore the corrosion potential data suggests that corrosion risk is currently negligible on these structures.

Looking at the steel potentials of structure C2 from Figure 8, it can be observed that in most cases the original 11 (Ag/AgCl/0.5 M KCl) reference electrodes (installed on the crossbeam at the time the ICCP was installed) were more positive than -120 mV. The highs and lows observed are usually dependant on the weather conditions. Although the ambient conditions were not recorded as part of this study, the site notes indicate that in the majority of the occurances parts of the crossbeam were very wet whereas other competely dry. The absence of a trend to more negative values indicates that the passive condition is stable.

Figure 9, illustrates steel potentials with regards to the Ag/AgCl/0.5 M KCl reference electrode for one of the segments obtained from the continuous monitoring of structure A1 over a period of seven days. The fluctuation of the readings is associated with changes in the environmental conditions (i.e. temperature, moisture, etc.) and indicate that there is no residual corrosion risk as the values are fairly positive.

3.3 Polarisation Resistance Testing

Manual polarisation resistance testing was undertaken monthly for every structure. Figure 10, illustrates potential data obtained from structure A3 during November 2007. Structure A3 was one of the two structures where a data logger was installed. The location of these loggers was based on the condition of the anode systems, accessibility and safety issues. The two structures selected were part of the early installations with one of them performing very well whereas the other one showed signs of severe anode

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deterioration. The data collected was very important as it offered a direct comparison between a failing and a very good performing system and both where installed with a small difference in time.

The installed data logger controlled the current output and the system was switched on for 20 minutes twice a day. During this period a current pulse was applied and the steel potentials were recorded. The readings obtained were used to evaluate the potential shift for corrosion rate measurements.

It was observed that a current of 2 mA/m^2 applied for 20 minutes induced a steel potential shift of 20 mV and affected the off potentials for more than 12 hours. This again shows that the steel is passive as such a large and slow response would not result if the corrosion rate (corrosion current) was large. The measurement of corrosion rates by means of polarisation resistance testing was actually producing a polarisation effect as indicated by the steel potential decay. Close interval automatic corrosion rate measurements were discontinued.

Figure 11, provides a summary of corrosion rates calculated from the manual polarisation resistance testing undertaken monthly on each structure. It can be observed that in all cases the corrosion rates were well below the threshold level of 2 mA/m^2, reinforcing the view that cathodic protection will have persistent long-term effects. Occasional peaks can be observed from the readings but these are primarily associated with the influence of galvanic currents as discussed before.

3.4 Impedance Testing

As discussed previously, for impedance testing a short pulse is applied and the potential decay is recorded. The current - time (current pulse) and potential - time (Figure 12) data are combined and transformed into impedance data (Figure 13). Impedance is a frequency dependent resistance that includes phase angle information. It is commonly plotted on an x-y graph. Each point on the graph is obtained at a different frequency and the data represents the magnitude of the resistance and phase angle at that frequency.

The units on the axes in Figure 13 arise when potential is divided by current density and are also the units of polarisation resistance. The point at a phase angle of zero (the x-axis intercept) is the polarisation resistance (Icorr). The corrosion rate may be derived from this in the usual manner. The frequency at the peak of the curve is termed the characteristic frequency (f). It is affected by the condition of the steel and lower frequencies indicate a more intact passive film.

The data obtained for structure C3 (Figure 13) is compared with published laboratory data for active and passive specimens in Figure 14. It is evident that the shape of the impedance data from site corresponds closely to the data obtained from the passive steel specimen. This is indicated by both the x-axis range and the characteristic frequency.

4. Discussion

At the start of the study all the structures were evaluated for corrosion risk. Structures A2 and B1 were at most risk because the impressed current conductive coating anode had suffered significant deterioration. Chloride sampling results showed that these two structures had 40 % to 50 % of their test locations with chlorides greater than 1 % by weight of cement and 60 % to 66 % of their test locations with chlorides more than 0.4 % by weight of cement at the depth of steel. Thus, both of these beams had a substantial residual corrosion risk.

In the study presented here, the protective current has been interrupted for 24 months and the off steel potentials have shifted towards more positive values and have remained passive. Furthermore, the corrosion potential and corrosion rate data suggest that there is no significant corrosion activity on these structures. These results confirm the published hypothesis that long term-application of ICCP renders the steel passive and has a persistent protective effect in the absence of a negative potential shift. Of the two effects, chloride extraction and hydroxide production, the latter is considered to be the most important [20].

Most importantly, the cathodic protection treatment applied with a poorly performing anode system (as that shown on Figure 3) has been sufficient to induce and maintain steel passivity for a period of 24 months. These anodes were never capable of sustaining more than 20 mA/m^2 of current at the concrete surface, with steel surface area ranging between 1.4 to 2.2 times the concrete surface area. In several occasions the power supplies of the anode systems were voltage limited at current densities less than 2 mA/m^2 of concrete surface area. Whilst this is a low cathodic protection current density, it was capable of inducing a substantial protective effect as indicated by the negative steel potential shift (refer to Figure 10).

Moreover the condition of the impressed current conductive coating anode systems at the start of this project indicated that in some locations on these structures the current had been interrupted for a substantially longer period. Based on the results of this study it has been shown these anode systems have

been capable of arresting ongoing corrosion and sustaining steel passivity despite providing low current densities. This is also supported by Polder et al. [21] who illustrated that only a small current will be sufficient to induce and sustain passivity.

Furthermore, it was observed that the zone layout of the ICCP systems was different, with older systems, such as those on structures A2 and B1, having a single zone for the whole of the structure whereas newer systems had multiple zones. However, no apparent difference was observed and the steel was rendered passive in all cases. Another observation was that newer installations of ICCP systems involved substantial concrete repairs which removed excessive chloride contamination (refer to Table 1).

The polarisation achieved by a short current pulse as shown for structure A3, indicates that long-term application of ICCP transforms the environment around the steel reinforcement. The steel has now been polarised to such a degree that only a brief current pulse (densities usually used for corrosion prevention) is required to achieve polarisation.

Repairs to old CP systems are clearly not critical for at least 24 months after the protection current has been interrupted. When considering refurbishment of existing ICCP systems which have deteriorated, the absence of corrosion signs and the polarisation of the reinforcement should be taken under consideration. The replacement system will need to be designed for cathodic prevention rather than cathodic protection as the steel has already been sufficiently polarised.

5. Conclusions

The site data presented here is consistent with laboratory data and results reported in previous works by others, indicating a persistent protective effect after the interruption of ICCP systems. More specifically we conclude the following:

1) After 24 months with no cathodic protection current, all the structures investigated have remained passive and with no corrosion signs. This includes structures where 60 % of the test locations had chloride contents exceeding 1 % by weight of cement at the depth of steel and would normally present a corrosion risk. This supports the published hypothesis that ICCP arrests ongoing corrosion and has persistent protective effect in the absence of a negative potential shift.

2) Low design current densities from low grade conductive coating anodes have been capable of inducing steel passivity in chloride contaminated structures. These anodes were never capable of sustaining more than 20 mA/m^2 of concrete surface, with steel surface area ranging between 1.4 to 2.2 times the concrete surface area. This suggests that design current densities can be kept to the lower spectrum of the suggested values of the design standards.

3) Dividing the ICCP system in smaller zones it did not appear to give any benefit with regards to protection or durability. At all cases of single and multi-zone systems, the reinforcement was found to be passive and the concrete repairs undertaken prior to the installation of the ICCP system would tend to remove excessive chloride contamination.

4) The absence of corrosion should be taken into account when repairing old CP systems. The replacement anode systems need only to deliver a low current density to achieve polarisation and prevent corrosion initiation.

References

[1] D. A. Koleva, Z. Guo, K. van Breugel, J. H. W. de Wit, Conventional and pulse cathodic protection of reinforced concrete: Electrochemical behaviour of the steel reinforcement after corrosion and protection, Mater. Corros. 60, (2009), 344-354.

[2] BS EN 12696:2000, Cathodic Protection of Steel in Concrete, British Standards Institution, London, 2000.

[3] M. Pourbaix , Atlas of Electrochemical Equilibrium in Aqueous Solutions, NACE International, Houston, TX, USA, 1996.

[4] B. S Wyatt, Developments in Cathodic Protection of Steel in Concrete: Concrete Bridge Development Group, Annual Conference: Eurocodes and Innovation, Oxford 2009.

[5] G. K. Glass, J. R. Chadwick, An investigation into the mechanisms of protection afforded by a cathodic current and the implications for advances in the field of cathodic protection, Corros. Sci. 36, (1994), 2193-2209.

[6] J. P. Broomfield, J.S. Tinnea, Cathodic protection of reinforced concrete bridge components, final report. ID no: SHRPCUWP92618, 1992.

[7] F.J. Presuel- Moreno, A. A. Sagüés, S. C. Kranc, Steel activation in concrete following interruption of long-term cathodic polarisation, Corrosion 2002, Paper no. 02259.

[8] G. K. Glass, B. Ready, L. Clark 2007, Making reinforced concrete immune from chloride corrosion, Proc. Inst. Civ. Eng. Constr. Mater 160, 155-164.

[9] R. E. Stratful, The corrosion of steel in a reinforced concrete bridge, Corrosion 13, (1957), 43- 48.

[10] B. Elsener, Half cell potential measurements – Potential mapping on reinforced concrete structures, RILEM TC 154-EMC: Electrochemical techniques for measuring metallic corrosion, Mater. Struct. 36, (2003), 461-471.

[11] BA 35/90, Inspection and repair of concrete highway structures, British Standards Institution, London, 1990.

[12] J.P. Broomfiled, Corrosion of steel in concrete, understanding, investigation and repair, E & F. N. Spon, London, 1997.

[13] M. Stern, AL.L. Geary, Electrochemical polarisation I: A theoretical analysis of the shape of polarisation curves, J. Electrochem. Soc.104, (1957), 56-63.

[14] D. D. McDonald, M. C. H. McKubre, Electrochemical impedance techniques in corrosion science, Electrochemical Corrosion Testing ASTM STP 727 – F. Mansfeld and U. Bertocci Eds., 1981, 110-149.

[15] R. Polder, A. Tondi, R. Cigna, Concrete resistivity and corrosion rate of reinforcement, TNO report 93-BT-r0170, TNO Delft, 1993.

[16] C. Andrade, C. Alonso, Test methods for on-site corrosion rate measurement of steel reinforcement in concrete by means of the polarisation resistance method, RILEM TC 154-EMC: Electrochemical techniques for measuring metallic corrosion, Mater.Struct. 37, (2004), 623-643.

[17] Concrete Society, Technical Report 60, Electrochemical tests for reinforcement corrosion, Surrey, U.K. 2004.

[18] C. Andrade, C. Alonso, On-site measurements of corrosion rate of reinforcements, Constr. Build. Mater. 15, (2001), 141-145.

[19] G. K. Glass, A.M. Hassaein, N. R. Buenfeld, Obtaining Impedance Information on the Steel – Concrete Interface, Corrosion 54, (1997), 887-897.

[20] G.K. Glass, A.C. Roberts, N. Davison, Hybrid corrosion protection of chloride-contaminated concrete, Proc. Inst. Civ. Eng. Constr. Mater. 161, (2008), 163-172.

[21] R. Polder, W.H.A. Peelen, B.T.J. Stoop, E.A.C. Neeft, Early stage beneficial effects of Cathodic Protection in Concrete Structures, Eurocorr 2009, Nice, France.

Figure Captions

Figure 1: Effect of cathodic protection treatment on corrosion risk at high chloride contents [8]

Figure 2: Typical sub-structure arrangement

Figure 3: Beam tested for long term effects of ICCP, showing evidence of severe anode deterioration but not signs of corrosion

Figure 4: Example of a corrosion rate calculation

Figure 5: Testing arrangement

Figure 6: Isolated anode segment and reference electrode location

Figure 7: Steel potentials of the 10 structures monitored over a period of 24 months

Figure 8: Steel potentials with respect to original reference electrodes for structure C2

Figure 9: Steel potentials for structure A1 over a 7 day period

Figure 10: Potential data for structure reference A3, illustrating the long term effects of polarisation induced by a brief and low current density pulse

Figure 11: Corrosion rates summary from polarisation resistance testing over a period of 24 months.

Figure 12: Raw data for impedance analysis for structure C3

Figure 13: Analysis of raw data to obtain corrosion rate for structure C3

Figure 14: Published impedance data illustrating passive and corroding steel [19]

Tables

Structure Reference	Year of Installation	Locations with Cl- greater than 1% by weight of cement	No of test locations	Locations with Cl- greater than 0.4% by weight of cement	Comments	Age of system (as of 2007)
A1	1991	2	4	4	24/7 data logger	12-16 yrs
A2	1995	2	5	3	-	
A3	1995	2	5	5	24/7 data logger	
B1	1996	3	6	4	-	9-11 yrs
B2	1998	1	5	4	-	
B3	1998	2	5	3	-	
B4	1998	2	5	3	-	
C1	1999	0	5	2	-	5-8 yrs
C2	2002	0	5	1	-	

C3	2000	0	5	1	-	

Note: Cl⁻ sampling at 25 mm to 50 mm

Table 1: Details of the 10 selected structures.