Design Manual for Roads and Bridges

Highway Structures & Bridges
Design

CD 370
Cathodic protection for use in reinforced concrete highway structures

(formerly BA 83/02)

Revision 2

Summary
This document provides requirements and advice for the design of cathodic protection to stop/halt corrosion of reinforcement in highway structures.

Application by Overseeing Organisations
Any specific requirements for Overseeing Organisations alternative or supplementary to those given in this document are given in National Application Annexes to this document.

Feedback and Enquiries
Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated Highways England team. The email address for all enquiries and feedback is: Standards_Enquiries@highwaysengland.co.uk

This is a controlled document.

Contents

Release notes

Version	Date	Details of amendments
2	Apr 2020	Revision 2 (April 2020) Correcting references from CD 359 to CS 462 in clauses 2.1, 2.2, 2.3, 3.3, 3.3.1 NOTE 2, 3.5, 3.6, 3.8, 3.8.2, 3.8.3, 3.8.4, and 3.18. Revision 1 (March 2020) Revision to update references and detail related to costs in clauses 3.1, 3.2 NOTE 1, 4.10.1 NOTE 1, 4.16.1 NOTE, Appendix B1 3).Revision 0 (September 2019) CD 370 replaced BA 83/02, which is withdrawn. This full document has been re-written to make it compliant with the new Highways England drafting rules. This document has been aligned with the latest standards and current practice.

Foreword

Publishing information

This document is published by Highways England.

This document supersedes BA 83/02, which is withdrawn.

This document has been prepared with the assistance of the Technical Committee of the Structural Concrete Alliance, which includes the Corrosion Prevention Association. Members of the association are a source of expertise in cathodic protection of reinforced concrete and include CP installation companies, specialist design organisation and material suppliers.

Contractual and legal considerations

This document forms part of the works specification. It does not purport to include all the necessary provisions of a contract. Users are responsible for applying all appropriate documents applicable to their contract.

Introduction

Background

The content of this document is based on that of BA 83/02, re-written to make it compliant with the new drafting rules. The technical content has been updated and improved to reflect the current practice for the cathodic protection of reinforced concrete highway structures. This document is compliant with relevant parts of BS EN ISO 12696 [Ref 2.N], BS EN ISO 15257 [Ref 3.N] and BS EN 1504-9 [Ref 7.N].

Assumptions made in the preparation of this document

The assumptions made in GG 101 [Ref 6.N] apply to this document.

Mutual Recognition

Where there is a requirement in this document for compliance with any part of a British Standard or other technical specification, that requirement may be met by compliance with the Mutual Recognition clause in GG 101 [Ref 6.N].

Abbreviations

Abbreviations

Abbreviation	Definition
AAR	Alkali aggregate reaction
a.c.	Alternating current- is to be converted into direct current (d.c.) for use in corrosion prevention.
d.c.	Direct current - Typically corrosion is concerned with d.c. It is generated by corrosion, and can be used to stop corrosion via cathodic protection.
Ag/AgCl/0.5MKCl	Silver/Silver Chloride/0.5M Potassium Chloride gel electrode
AIP	Approval in principle document
ASR	Alkali silica reaction
CFRP	Carbon fibre reinforced polymer
CP	Cathodic protection
HISC	Hydrogen induced stress cracking
ICCP	Impressed current cathodic protection
Mn/MnO_2/0.5MKCl	Manganese/Manganese Dioxide/0.5M Potassium Chloride electrode
RH	Relative humidity
TAA	Technical approval authority
TEG	Thermal electrical generator
UTS	Ultimate tensile strength

Terms and definitions

Terms and definitions

Term	Definition
Anode	The part of a corrosion cell at which metal is lost into solution and electrons are released into the metal. In a cathodic protection system, an anode is an electrode deliberately introduced into the structure to prevent the original metal corroding.
Cathode	In a corrosion cell, the cathode is the metal surface that accepts electrons from the anode and at which the electrons are consumed in a reaction with oxygen and water to produce hydroxyl ions. In a cathodic protection system, the cathode is the steel being protected.

1. Scope

Aspects covered

1.1 This document sets out requirements, advice and considerations in addition to BS EN ISO 12696 [Ref 2.N] which shall be used for the design of cathodic protection (CP) to stop/halt corrosion of reinforcement in reinforced concrete highway structures.

NOTE 1 CP is an electrochemical process involving the use of low voltage direct current (d.c.) electricity which flows through the concrete and discharge on the reinforcement resulting in control of corrosion to insignificantly low rates. The d.c. can be provided via an electrical power supply (termed impressed current cathodic protection (ICCP)) or as a result of the reinforcement being connected to a metal which corrodes in preference (termed galvanic anode cathodic protection).

NOTE 2 This document relates principally to reinforced concrete highway structures at risk of reinforcement corrosion damage due to chloride contamination.

1.1.1 This document may also be used where the corrosion is due to other factors like carbonation.

1.1.2 This document provides guidance on particular cases where CP may not be appropriate.

1.2 This document sets out requirements, advice and considerations in addition to BS EN ISO 12696 [Ref 2.N] which shall be used for the design of CP for new structures exposed to chlorides (also known as "cathodic prevention").

Implementation

1.3 This document shall be implemented forthwith on all schemes involving design of CP for stopping/halting corrosion of reinforcement in reinforced concrete highway structures on the Overseeing Organisations' motorway and all-purpose trunk roads according to the implementation requirements of GG 101 [Ref 6.N].

Use of GG 101

1.4 The requirements contained in GG 101 [Ref 6.N] shall be followed in respect of activities covered by this document.

2. Introduction to cathodic protection

2.1 This document shall be used in conjunction with CS 462 [Ref 8.N] to ensure that CP is only applied to structures that have been assessed and where the causes of their deterioration have been determined.

2.2 This document shall be used in conjunction with CS 462 [Ref 8.N] so that CP along with associated repair and/or strengthening works is the most appropriate technique to extend the life of the structure.

2.3 This document shall be used in conjunction with CS 462 [Ref 8.N] to ensure that the repaired/protected structures are fit for purpose following the remediation works.

NOTE 1 This document covers only Principle 10 of BS EN 1504-9 [Ref 7.N].

NOTE 2 CP can be used where chloride contamination is threatening or causing corrosion of reinforcement but little or no physical damage has occurred, or where physical damage has occurred, but where it is not economic or practical to remove physically sound chloride-contaminated concrete. Where CP is used, sound concrete can be left undisturbed wherever possible.

NOTE 3 Further information on CP on steel in concrete is provided in Concrete Society CS TR73 [Ref 3.I].

2.4 All CP design and check as listed and detailed within this document shall meet the requirements of BS EN ISO 12696 [Ref 2.N].

NOTE BS EN ISO 12696 [Ref 2.N] is the main international design and performance standard for CP of steel in concrete, which is to be used for all CP design, installation, operation and assessment of CP on highway structure.

2.5 The design and certification of an a.c. electrical supply, to power an ICCP system or any permanent monitoring provision associated with a galvanic anode system, shall be in accordance with BS 7671 [Ref 9.N].

2.6 All CP personnel as listed and detailed within this document shall meet the requirements of BS EN ISO 15257 [Ref 3.N].

NOTE BS EN ISO 15257 [Ref 3.N] is the main international standard for evaluating and certificating CP personnel which is to be used for all personnel responsible for designing, installing and operating CP on highway structures.

System selection and life

2.7 Satisfactory performance in accordance with BS EN ISO 12696 [Ref 2.N] before maintenance for a CP system shall be between 10 and 50 years.

2.7.1 Some impressed current anode systems, such as mixed metal oxide titanium (MMMO/Ti) mesh or ribbon, may have a theoretical design life of up to 120 years.

2.7.2 Electrical power supply and monitoring systems may require replacement between 12 and 25 years.

2.7.3 Electrical power supply and monitoring systems should be designed so that replacement is straightforward.

System monitoring and long term costs

2.8 A continuous and uninterrupted flow of d.c. electricity shall be supplied for the operation of any CP system.

2.8.1 Such electricity should be provided by mains a.c. power which is converted to d.c. for ICCP, or via the consumption of galvanic anodes for galvanic cathodic protection system.

2.9 The effects of CP on the steel/concrete potential resulting from electrochemical changes shall be monitored and recorded.

NOTE There is an ongoing cost associated with electrical power (for ICCP) and a cost of specialist monitoring, communication (if remotely monitored), control and assessment (for all types of CP system). These costs are to be incorporated into any life cycle cost analysis.

3. Assessment prior to cathodic protection

Life cycle cost, sustainability, environmental and other whole life benefits

3.1 CP shall be selected when it is the most effective solution in terms of whole life costs.

3.2 Assessment of the structure and its condition shall determine whether or not to apply CP, and the extent to which CP is applied across the structure.

NOTE 1 By applying CP compared with the alternate long term repair option of removal and replacement of all chloride contaminated concrete, the whole life cost can be lower. CP can also have whole life cost benefits when there are difficult or disruptive access issues.

NOTE 2 CP can be an effective method of stopping corrosion for those structures that require a long residual life after repair. Further cycles of repair patching are typically avoided as only maintenance of the anode system, cabling and electronics are required.

3.2.1 CP can allow chloride contaminated but otherwise sound concrete to remain which should reduce the cost of repairs and provide significant and lasting environmental and sustainability benefit.

NOTE 1 ICCP of reinforced concrete highway structures has been rigorously assessed and demonstrated to be reliable and effective in stopping corrosion of reinforcing steel in chloride-contaminated concrete (for further information including history of cathodic protection of reinforced concrete see CS TR73 [Ref 3.I] and Technical Note 3 [Ref 2.I]).

NOTE 2 An ICCP system is capable of preventing reinforcement corrosion at any level of chloride contamination (please refer to CS TR73 [Ref 3.I] and Technical Note 3 [Ref 2.I] for further information).

3.2.2 There should be significant cost savings for prestressed structures where it can not be possible to remove all chloride contaminated concrete.

Comparison of cathodic protection with other techniques

3.3 Selection of repair methodology for corrosion damaged reinforced concrete shall be in accordance with CS 462 [Ref 8.N].

3.3.1 Irrespective of the selected treatment to stop or repair corrosion related damage, it may be advantageous to minimise future chloride contamination, where possible, by preventing ingress of chloride laden water through deck waterproof liners or waterproof plug joint.

NOTE 1 Improvement to the provision or maintenance of drainage, replacement of expansion joints and waterproofing can reduce future water ingress.

NOTE 2 For further details about advantages and limitation of the different treatment method to stop or repair corrosion related damage, refer to CS 462 [Ref 8.N].

Evaluation

3.4 All available drawings and records shall be reviewed to assess the location, quantities, nature (e.g. smooth, galvanised, epoxy coated, prestressed) and electrical continuity of the reinforcement.

3.5 The information on the available drawings and records shall be confirmed and supplemented as necessary by site and laboratory tests as described in CS 462 [Ref 8.N].

3.6 In order to determine the most technically suitable and cost effective repair solution, the structural, physical and electrochemical condition shall be determined in accordance with the guidelines provided in CS 462 [Ref 8.N].

3.7 A structural integrity check shall be assessed in accordance with CS 454 [Ref 1.N] and CS 455 [Ref 11.N] to determine the current state of the structure in the deteriorated state, the impact of proposed repair and remediation activities and the final state of the structure following remediation activities.

Site survey

3.8 All areas of the structure requiring CP shall be checked for delamination of the concrete cover or other defects as detailed within CS 462 [Ref 8.N].

3.8.1 Cracks, honeycombing, or poor construction joints that permit significant water penetration should be recorded.

3.8.2 Chloride content, in increments of depth through the cover zone and past the reinforcement should be measured as described in CS 462 [Ref 8.N].

3.8.3 Carbonation depth measurements should also be conducted as described in CS 462 [Ref 8.N].

3.8.4 Concrete cover and reinforcement dimensions should be measured as described in CS 462 [Ref 8.N] for correlation with chloride and carbonation measurements and to confirm quantities and locations of reinforcement.

3.9 Existing repairs shall be checked to ensure they are in good condition and are compatible with CP, i.e., capable of passing current to the reinforcement.

3.9.1 Concrete resistivity testing may be conducted, where there is any doubt as to the compatibility of the concrete or any repair in the concrete areas requiring cathodic protection.

3.10 The risk of electrical short circuits between anodes and reinforcement and with other steel for example, tie wires shall be assessed.

3.11 The risk of possible stray-current interference shall be assessed and includes the risks to discontinuous reinforcement, other metalwork, buried services or other structural elements.

3.12 Methods to alleviate stray-current interference, by for example continuity bonding or isolation of items assessed at risk shall then be included in the cathodic protection design.

3.13 Loss of reinforcement section within the repair area, due to corrosion, shall be assessed in accordance with CS 455 [Ref 11.N].

3.14 Following the assessment in accordance with CS 455 [Ref 11.N], necessary repairs and strengthening works to the reinforcement shall be carried out prior to the installation of any cathodic protection system.

3.15 The availability of power supply and communication for the CP system shall be investigated by conducting a services/utility search.

3.16 The extent of electrical continuity shall be determined in accordance with Clause 5.7 of BS EN ISO 12696 [Ref 2.N].

3.17 The method of electrical continuity verification shall be in accordance with the guidelines provided in CS TR60 [Ref 4.I].

3.18 Potential (half-cell) surveys of representative areas, both damaged and undamaged, shall be carried out in accordance with the guidelines provided in CS 462 [Ref 8.N] and CS TR60 [Ref 4.I].

3.19 For all structures which are to be protected with CP, a potential (half-cell) survey shall be completed for the entire structure following electrical continuity testing/bonding and concrete repairs but prior to anode installation activities.

3.20 All potential (half-cell) survey data shall be recorded and presented graphically for interpretation.

3.21 The information obtained after the potential survey shall be used to identify suitable locations for permanent reference electrodes and identify the as-found natural potential prior to anode installation.

NOTE This potential (half-cell) survey data can be used to evaluate the long term benefits of applied CP at the end of system life or following a period of system interruption.

Cathodic protection of critical elements

3.22 Caution and attention to detail shall be required when the application of CP to critical or vulnerable structural details such as prestressed, post-tensioned concrete hinges or half joints is considered to meet the requirements of BS EN ISO 12696 [Ref 2.N].

3.23 The existing condition and structural performance of critical or sensitive elements shall be assessed in order to determine that stopping corrosion by the application of CP can result in continued safe operation.

3.24 Critical or sensitive elements tend to have complex reinforcement details and as such, the design shall include the assessment and distribution of current and the provision of performance monitoring devices.

3.25 All CP design for critical elements shall be subject to assessment and checking in accordance with CG 300 [Ref 10.N].

Additional requirements for cathodic protection

3.26 Any CP system shall require electrical continuity of the reinforcement.

NOTE 1 Fusion bonded epoxy coated reinforcement is difficult to protect by CP unless the reinforcement cage has been made electrically continuous prior to coating. Any other coatings could have similar problems. Metallic coatings on the reinforcement (e.g. galvanising) can change the requirements for cathodic protection and require evaluation. In all cases, the level of protection by CP is limited due to normally high resistance of coating.

NOTE 2 CP applied in accordance with the procedures described in BS EN ISO 12696 [Ref 2.N] to reinforced concrete has been demonstrated to have no adverse effects on the bond between the steel reinforcement and the concrete.

3.27 Where alkali silica reaction/alkali aggregate reaction (ASR/AAR) is a principal cause of deterioration and not reinforcement corrosion, CP shall not be used.

3.27.1 There is a theoretical risk that the alkali generated at the reinforcement by the cathodic reaction may exacerbate any tendency for alkali silica reaction in the aggregates.

NOTE CP designed and installed in accordance with BS EN ISO 12696 [Ref 2.N] has been demonstrated to have no influence on alkali silica reaction/alkali aggregate reaction. This has further been verified by laboratory testing and site installations over the recent years.

3.28 The steel/concrete potential limits listed within BS EN ISO 12696 [Ref 2.N] shall be adhered to.

NOTE 1 The application of CP changes the steel/concrete potential which is measured between an embedded reference electrode and the steel.

NOTE 2 Where the potential becomes too negative, the cathodic reaction generates excessive hydrogen.

3.28.1 Steel with ultimate tensile strength (UTS) of >550MPa may be sensitive to hydrogen embrittlement resulting in hydrogen induced stress cracking (HISC) and, due to the high tensile loading of prestressing members, failure can be catastrophic.

3.28.2 The risk of HISC is even more acute if there is any chloride contamination or corrosion of the prestressed steel as corrosion pits or notches form initiation sites for failure due to increased stresses and are more susceptible to hydrogen evolution as corrosion pits may contain low pH solutions.

3.29 Where carbon fibre reinforced polymer (CFRP) strengthening materials are installed or planned to be installed within a repair and strengthening scheme in conjunction with CP, there shall be no electrical connection between the CP system and the CFRP elements (that can detrimentally affect the bond between CFRP and the parent concrete or impact the CP system performance).

3.30 CP design for elements containing coated reinforcement, prestressing or CFRP shall be subject to assessment and checking in accordance with CG 300 [Ref 10.N].

4. Description of cathodic protection systems

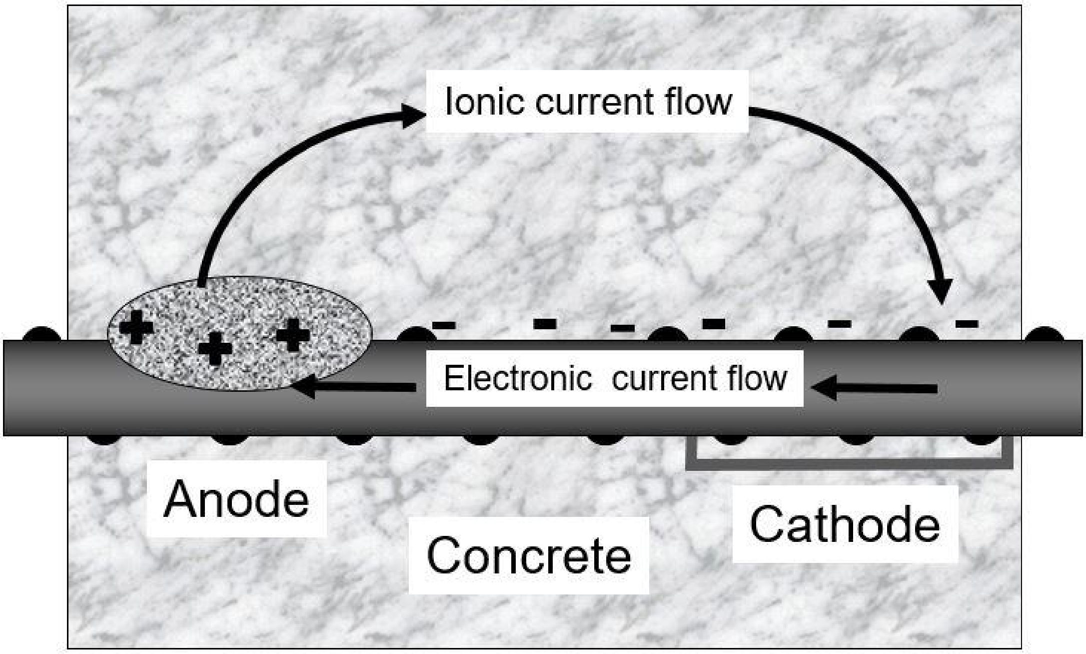
General

4.1 Where it has been determined that CP is required this shall be by the use of ICCP unless it can be assured at design stage that the use of galvanic anodes meets the performance criteria for cathodic protection in Clause 8.6 a, b or c of BS EN ISO 12696 [Ref 2.N] for full design life of the system.

NOTE 1 Both impressed current and galvanic anode systems are discussed in this section although galvanic anode systems have limited performance data available in UK applications to demonstrate the required cathodic protection criteria in atmospherically exposed reinforced concrete structures.

NOTE 2 Corrosion occurs by the formation of anodes and cathodes on the reinforcement surface, as shown in Figure 4.1N2 below. Corrosion occurs at the anode; a generally harmless reduction reaction occurs at the cathode. By introducing an external anode and an electric current, the reinforcement is forced to become cathodic and reduces corrosion to insignificant levels.

Figure 4.1N2 Anode and cathode formation on corroding reinforcing bar in concrete



Galvanic anode cathodic protection

4.2 Galvanic anode cathodic protection shall operate in the same principles as an ICCP, except that the anode is a less noble (i.e. more active) metal than the steel to be protected and is consumed preferentially, generating the cathodic protection current.

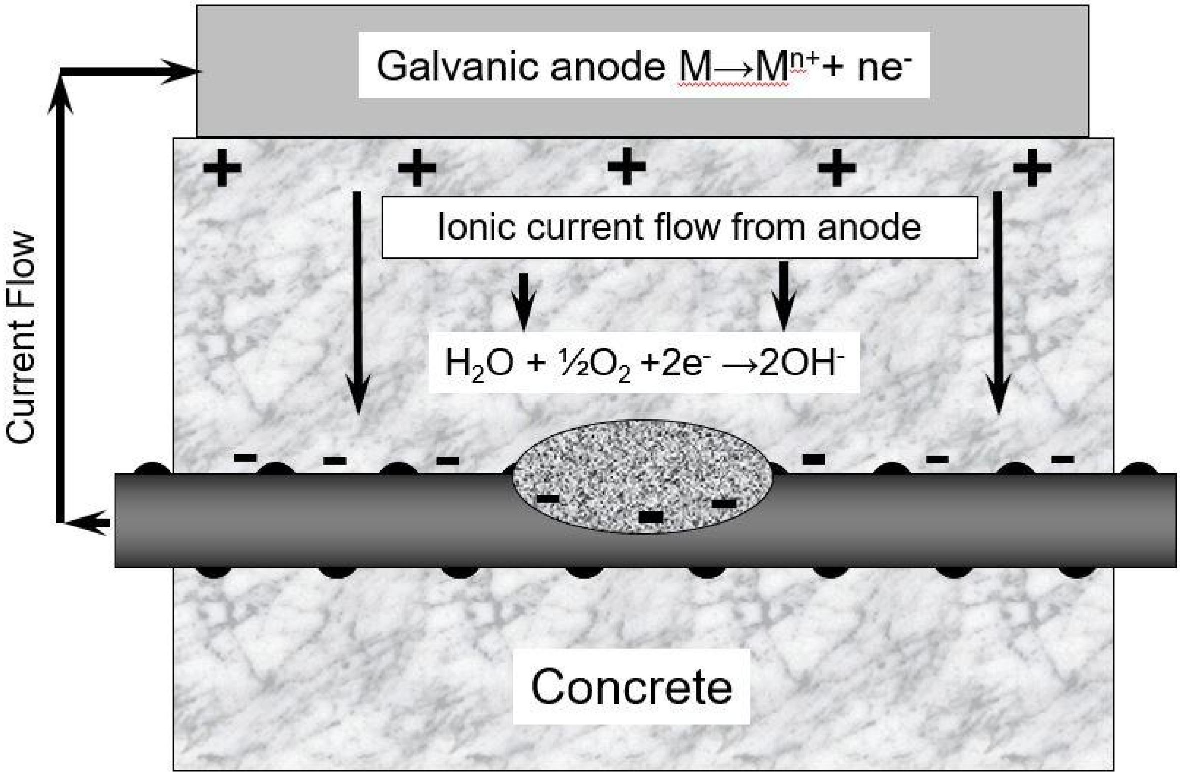
NOTE 1 Galvanic cathodic protection of buried or submerged reinforced concrete structures from anodes installed into soil or water surrounding the concrete structures are well proven and have been demonstrated to be reliable and effective. For example, galvanic anodes of magnesium (normally for soil applications), zinc or aluminium alloys (normally for sea water applications), have a long and proven record.

NOTE 2 Galvanic cathodic protection of atmospherically exposed structures from anodes installed onto or within the parent concrete have greater applicability as part of a corrosion management system rather than for provision of full cathodic protection as defined by the criteria of protection in Clause 8.6 of BS EN ISO

12696 [Ref 2.N]. There is not adequate data to demonstrate galvanic anodes are suitable to provide full cathodic protection for atmospherically exposed concrete.

NOTE 3 The potential difference between anode and cathode is a function of the environment and the relative electrode potentials of the anode and cathode materials. The current is a function of the potential difference and the electrical resistance. Figure 4.2N3 below illustrates a galvanic system.

Figure 4.2N3 Schematic of a galvanic anode system



NOTE 4 As the voltage and current cannot generally be controlled, the level of protection cannot be guaranteed and a low resistance environment is required.

NOTE 5 Some systems that operate long term as galvanic anode systems include an initial impressed current charge period, typically using an external d.c. power supply. This is sometimes termed hybrid cathodic protection.

NOTE 6 Where new anode systems are proposed, evidence is to be provided to demonstrate good performance and a high probability of achieving the desired design life. This evidence includes adequately researched and monitored accelerated laboratory testing and field trials. Field trials incorporate a minimum of two UK winters and are to be applied to a civil engineering structure exposed to conditions that are representative of the environment of the highway structure being considered as a recipient of the new anode system.

Impressed current cathodic protection

4.3 ICCP system shall consist of an anode system, a d.c. power supply (typically a power supply connected to an a.c. supply which is converted to d.c.) and monitoring probes, with associated wiring and control circuitry.

4.4 ICCP system shall be designed to operate at a current density to the steel surface in the range of 2-20mA/m^2.

4.5 The suitable current density to be used shall be defined in the design based upon the exposure conditions and extent of chloride contamination of the structure.

NOTE An anode zone is an area that can be independently adjusted and monitored to provide cathodic protection for the specified element. Typically each anode zone has a dedicated d.c. power source and monitoring facilities which enable localised adjustment of current and voltage without affecting isolated and adjacent anode zones.

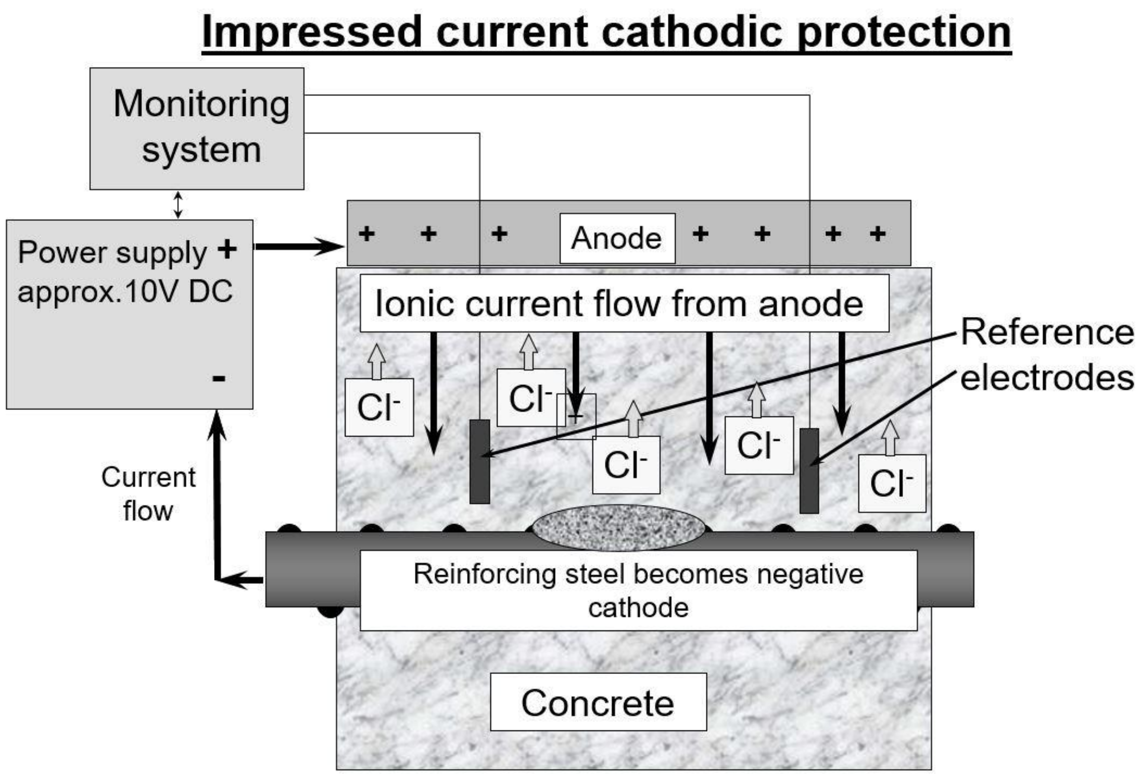
Impressed current anode systems

4.6 Each structure shall be divided into anode zones to account for different levels of reinforcement, different environments or different elements of the structure.

NOTE 1 The ICCP anode is a material that is consumed at a negligible or controlled rate by the anodic oxidation reaction.

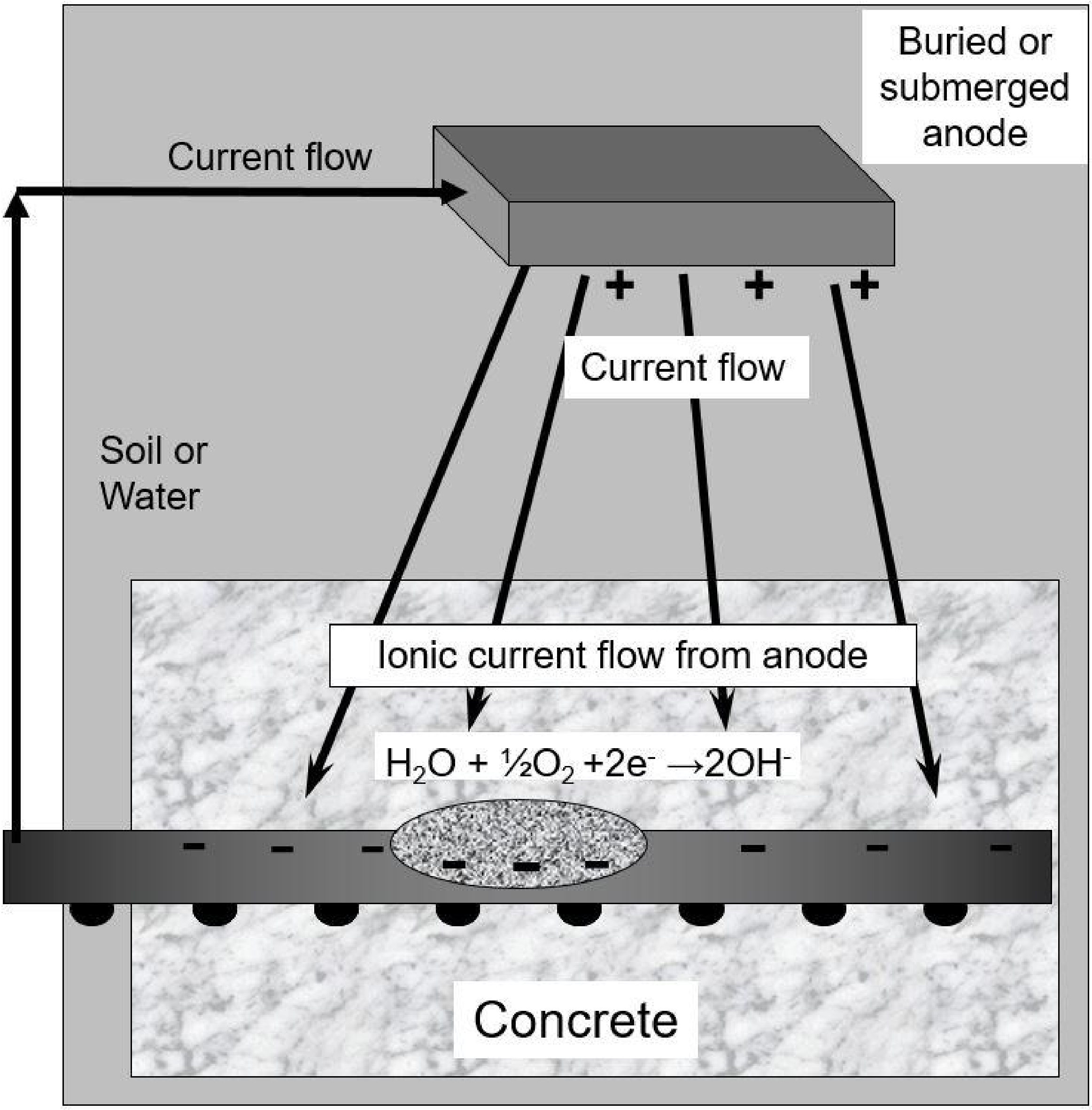
NOTE 2 One of the key decisions is the choice of anode. The alternatives are conductive coatings applied to the concrete surface, mixed metal oxide coated titanium mesh or grid encapsulated within a concrete overlay, conductive mortar and overlays, mixed metal oxide coated titanium ribbon in slots, or various discrete anode materials embedded in holes drilled in the concrete. A schematic of an impressed current system is shown in Figure 4.6N2 below.

Figure 4.6N2 Schematic of an ICCP on an atmospherically exposed reinforced concrete structure



NOTE 3 Figure 4.6N2 above illustrates an atmospherically exposed concrete structure where anodes are distributed across the concrete surface to pass current evenly to the reinforcing steel. For buried or submerged concrete remote anodes can pass current through low-resistance soil or water. In this application conventional anodes similar to those used for pipelines or submerged structures can be employed, as shown in Figure 4.6N3 below, provided that consideration is given to the extra resistance of the concrete.

Figure 4.6N3 Buried or submerged anode protects large areas of steel



4.7 Conductive coating anodes shall be applied to the surface of the concrete.

NOTE Conductive coating anodes include a variety of formulations of carbon pigmented solvent or water dispersed coatings, and, with a much smaller UK track record, thermal sprayed zinc.

4.8 Mixed metal oxide coated titanium mesh or ribbon anode systems shall be fixed to the surface of the concrete and overlaid with a cementitious overlay which can be poured or pumped into shutters or sprayed.

4.8.1 Anode ribbon may also be installed in purpose cut slots in the concrete.

4.9 Discrete anodes shall be installed in purpose drilled holes in the concrete. They are either:

1) mixed metal oxide coated titanium tubes;
2) mixed metal oxide coated titanium ribbon formed into cylinders;
3) conductive ceramic tubes in cementitious grout.

4.10 For any application, the CP design shall meet the requirements of BS EN ISO 12696 [Ref 2.N].

NOTE Corrosion Prevention Association Technical Note 12 [Ref 1.I] provides information on anode performance and associated budget costs for different anode systems.

4.10.1 Where the foundations are either buried or immersed in sea or brackish water, cathodic protection using buried or immersed anodes remote from the foundations may be applied.

NOTE 1 Impressed current anodes (high silicon cast iron or mixed metal oxide coated titanium), have a long and proven record in the applications of cathodic protection to steel exposed to soils and waters.

NOTE 2 Typically these anode systems in soils or waters can be designed with an anticipated life in the range 20-40 years, but they are easier to replace than anodes installed in or on atmospherically exposed concrete.

Impressed current power supplies

4.11 A permanent power supply shall be provided for any ICCP system.

NOTE 1 The direct current is to be be provided by an a.c. powered transformer-rectifier or equivalent power unit, taking single phase a.c., transforming it to lower voltage and rectifying it to d.c. and outputting it at typically 1-5 ampere, 2-24 volts to each independently operated anode zone.

NOTE 2 The electrical consumption of an ICCP system is low but is accounted for within the operation and monitoring cost.

4.12 Where the power supply is locally not available, arrangements shall be made and allowed for in the assessed system costs.

NOTE 1 Where a.c power is not available, there are emerging alternatives such as solar panels, thermal electric generators (TEG) and wind generators.

NOTE 2 The solar and wind generators are used to charge batteries which in turn provide power to the CP system. It is noted that the batteries have a fixed operational life based on the charge and discharge cycle and can fail at end of life or due to lack of maintenance.

4.12.1 Street lighting may be a useful source of power to the ICCP system.

4.12.2 The power supply may be distributed across the structure and connected to a central control unit, or clustered at a single access point.

NOTE Distributed systems reduce the amount of cabling required, but future access to the outstations can be complicated, compared with a single central access point. If communications to the outstations fail it requires work to identify the cause and re-establish communication. The d.c. power supply can be controlled:

1) manually;
2) remotely via a modem;
3) a combination of both.

Monitoring system

4.13 All CP systems shall be designed with full system monitoring in accordance with the requirements of BS EN ISO 12696 [Ref 2.N].

NOTE Historically some galvanic systems have been installed without any monitoring facilities; this approach has prevented accurate performance assessment of these systems and negated any potential benefits associated with an evidence based management strategy.

4.14 The performance of CP systems (both galvanic and impressed current) shall be monitored by measuring the effects of the cathodic protection current flow on:

1) steel/concrete potential measured with respect to reference electrodes installed in the concrete adjacent to the steel;

2) steel/concrete potential measured with respect to reference electrodes or (less accurate) probes installed in the concrete and the magnitude of potential decay with time after the cathodic protection system is switched off.

4.15 Reference electrodes shall have a life expectancy of at least 20 years.

4.16 Reference electrodes or probes shall all be selected on the basis of documentary data from the manufacturers or system suppliers to demonstrate their accuracy, their functional ability and their longevity as required within the CP system.

NOTE 1 Suitable reference electrodes are:

1) silver/silver chloride/0.5M potassium chloride gel electrode (Ag/AgCl/0.5M KCl);

2) manganese/manganese dioxide/0.5M potassium hydroxide electrode (Mn/MnO_2/0.5M NaOH).

NOTE 2 Potential measuring probes (sometimes called pseudo electrodes) are less accurate but have a life expectancy in excess of 20 years.

NOTE 3 Steel/concrete/reference electrode potential measurements taken with the cathodic protection current switched "ON" will contain errors due to the voltage established by the current (I) flowing through the resistive (R) concrete and films on the reinforcement. These are termed IR drop errors. To avoid these errors the steel/concrete potential is measured "instant off" typically between 0.1 seconds and 0.5 seconds after switching "OFF" the cathodic protection current. The absolute value of the steel/concrete potential is one of the criteria in BS EN ISO 12696 [Ref 2.N], as well as the decay from that value over a period of 24 hours or longer with the cathodic protection current switched "OFF".

4.16.1 The voltage signals from the performance monitoring reference electrodes or potential decay probes and their associated connections to the steel reinforcement may be data logged either locally or via a modem interface for remote interrogation and data collection.

NOTE The decision on the requirement for inclusion of remote monitoring and control is to be structure specific. Considerations include the need to reduce exposure of personnel to hazards by reducing the requirement for manual monitoring, the requirement to site equipment at high level to prevent vandalism and other site specific issues.

4.17 Remotely controlled distributed d.c. power supplies shall incorporate remote monitoring and control as an integrated part of their package.

NOTE The larger multi-channelled systems in centralised enclosures can typically be provided with or without remote monitoring.

4.18 Remotely controlled and/or remotely monitored cathodic protection equipment shall transmit their data and be commanded with control instructions via communication networks.

NOTE 1 Communication networks can be hardwired telephone, wireless (mobile) telephone, e-mail or radio.

NOTE 2 Possible extensions of the CP system and associated communication network can be considered in design and the relative merits of simple stand-alone systems or extensive networked systems can be considered.

4.19 Additional reference electrodes shall be placed in the concrete at locations of particular structural sensitivity, at representative locations of high reinforcement complexity or at locations of sensitivity to excessive protection.

Other life determining factors

4.20 The d.c. cables for any CP system shall be suitable for embedding in concrete.

NOTE 1 Many cathodic protection systems, particularly those using mixed metal oxide coated titanium mesh or grid anodes encased in cementitious overlays, encase all cabling within the concrete. Encasing the cables within the concrete protects them from environmental damage and, in particular, vandalism.

NOTE 2 The anodic reaction products generate acidic conditions adjacent to the anodes, requiring careful selection of sheath materials, particularly if the cable is in close proximity to the anode.

NOTE 3 *Cabling systems installed on the external surfaces of highway structures in cable trays or similar cable management systems have been vulnerable to vandalism and present maintenance problems.*

4.21 Where it is required cables shall be buried in chases within the concrete for protection.

4.22 The connection between the copper wire and a titanium element of an anode shall be sealed to prevent water ingress.

4.23 Power supplies, monitoring systems and their enclosures, located in external environment, shall not be vulnerable to damage and to atmospheric corrosion.

4.23.1 The specification and location for these enclosures should aim to minimise the risks of vandalism and mechanical damage.

4.23.2 The enclosure should provide environmental protection and impact against the worst case environment and impact risk in accordance with BS EN 60529 [Ref 4.N] and BS EN 62262 [Ref 5.N].

4.23.3 The enclosure materials and/or corrosion protection treatment should provide a minimum of 20 years to first maintenance in respect of atmospheric corrosion.

NOTE *It is reasonable to anticipate a minimum 20 year life before replacement of the electrical and electronic systems that comprise the transformer-rectifiers and monitoring systems.*

4.24 The location of the power and control equipment shall be selected to facilitate future access without the need for elevated access or road closures if possible.

Cathodic protection of new or undamaged structures

4.25 A CP system applied to reinforcing steel in concrete that is not presently corroding shall be capable of reducing future corrosion (this is sometimes referred to as 'cathodic prevention').

NOTE *The application of cathodic prevention at construction is beneficial for any structure where the exposure conditions to chlorides mean that significant corrosion can occur during the design life of the structure. This includes the tidal zones of marine highway support structures or tunnels where the external ground water or estuarine conditions are saline.*

4.25.1 A CP system may also be applied where new reinforced concrete elements are included into/onto old chloride contaminated structures which have an increased risk of concentration of cell corrosion.

NOTE 1 *Cathodic prevention has not been extensively used in the UK but it is increasingly used in regions with severe durability problems. Examples include CP to structures near coastal areas, marine structures or inaccessible elements of structures subjected to severe exposure conditions.*

NOTE 2 *Cathodic prevention, particularly if installed at the time of construction, can be significantly lower in cost than cathodic protection installed during the service life of a structure.*

4.25.2 Where chloride contamination due to exposure is sufficient to result in corrosion damage during the design life of the structure, but does not presently justify the installation of a cathodic prevention system at construction, a corrosion/durability monitoring system may be installed. This can give early warning of the ingress of chlorides, and the ability to plan a cathodic prevention system installation or other preventative maintenance.

4.26 The reinforcement shall be made electrically continuous to assist with installation of future corrosion monitoring or cathodic protection.

4.26.1 A dedicated electrical connection point to the reinforcement may facilitate future electrochemical testing.

5. Personnel

Cathodic protection design persons

5.1 Persons responsible for the activities associated with the design of the CP systems shall be competent and certificated to Level 4 or higher for reinforced concrete structures as per BS EN ISO 15257 [Ref 3.N].

5.1.1 Where an organisation cannot provide cathodic protection persons from their own permanent staff, it may be acceptable for an appropriate external specialist or company to be brought in as a specialist consultant or contractor.

Structural persons

5.2 Persons who are responsible for structural assessment of the concrete repairs required prior to incorporation of the cathodic protection system shall be competent in assessing the structures and be chartered members of the Institution of Civil or Structural Engineers, or suitable equivalent.

Electrical persons

5.3 Persons who are responsible for design of a.c. electrical supply for any CP system shall be chartered member of the Institution of Electrical Engineers, or suitable equivalent.

6. Technical approval

6.1 Where the installation of a CP system has structural implications, it shall be subject to assessment and checking in accordance with CG 300 [Ref 10.N].

6.1.1 Non-exhaustive examples where structural assessment should be required for CP include:

1) the addition of dead weight by the application of particular anode types, or where the system requires the drilling/coring of holes;
2) the installation of discrete anodes (either galvanic or impressed current type) into drilled holes in elements such as down-stand beams, half joints and bearing plinths or any location where multiple closely spaced holes are required;
3) continuous cut chases exposing the reinforcement for cables chases, continuity bonding or reinforcement identification purposes; and
4) prestressed or post-tensioned structures.

6.2 All CP systems shall be subject to the technical approval particular requirements of the Overseeing Organisation as set out in CG 300 [Ref 10.N].

6.3 Submissions for AIP to the technical approval authority (TAA) shall be in accordance with the Overseeing Organisation's particular requirements.

6.4 The following information shall be provided:

1) project name, structure name and structure reference number;
2) site details, including location plan and general arrangement drawings;
3) existing structural form/arrangement/materials;
4) proposed extent of the CP system(s);
5) location/source of electrical power;
6) list of primary system components and expected working life of each;
7) proximity of proposed CP systems to high risk areas (including prestressing, half-joint/hinges, ASR affected/susceptible concrete);
8) details of any additional loading or reduction in structural capacity because of the works;
9) proximity of CP components to carriageway/railway, etc. and effect of works on clearance/headroom;
10) requirements for and proposed arrangements for future maintenance and inspection/operation;
11) CP system design and performance criteria;
12) proposed category of check and proposed name and qualifications of person undertaking the check;
13) name and qualifications of the person responsible for the CP design.

6.5 In case of the following, a Category 3 design and check shall be provided:

1) any system installed on or immediately adjacent to prestressed tendons or post-tensioned elements;
2) any system installed on or immediately adjacent to half-joints/hinges;
3) any system installed on or immediately adjacent to elements with ASR/AAR that is resulting in active structural deterioration of the concrete, or known to contain highly reactive aggregates;
4) any system installed onto structures containing coated reinforcement;
5) any system installed onto structures containing carbon fibre reinforced polymer (CFRP) or electrically conductive or isolating strengthening materials; and
6) any system using primary system components (incl. anode systems) with a successful track-record of less than 5 years.

7. Normative references

The following documents, in whole or in part, are normative references for this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Ref 1.N	Highways England. CS 454, 'Assessment of highway bridges and structures'
Ref 2.N	BSI. BS EN ISO 12696, 'Cathodic Protection of Steel in Concrete'
Ref 3.N	BS EN ISO 15257, 'Cathodic protection – Competence levels of cathodic protection persons – Basis for certification scheme'
Ref 4.N	BSI. BS EN 60529, 'Degree of protection by enclosures (IP code)'
Ref 5.N	BSI. BS EN 62262, 'Degree of protection provided by enclosures for electrical equipment against external mechanical Impacts (IK code)'
Ref 6.N	Highways England. GG 101, 'Introduction to the Design Manual for Roads and Bridges'
Ref 7.N	BSI. BS EN 1504-9, 'Products and systems for the protection and repair of concrete structures - Definitions, requirements, quality control and evaluation of conformity. Part 9: General principles for use of products and systems'
Ref 8.N	Highways England. CS 462, 'Repair and management of deteriorated concrete highway structures'
Ref 9.N	BSI. BS 7671, 'Requirements for Electrical Installations, IET Regulations'
Ref 10.N	Highways England. CG 300, 'Technical approval of highway structures'
Ref 11.N	Highways England. CS 455, 'The assessment of concrete highway bridges and structures'

8. Informative references

The following documents are informative references for this document and provide supporting information.

Ref 1.I	Corrosion Prevention Association. Technical Note 12, 'Budget Cost and Anode Performance Information for Impressed Current Cathodic Protection of Reinforced Concrete Highway Bridges'
Ref 2.I	Corrosion Prevention Association. Technical Note 3, 'Cathodic protection of steel concrete: The International Perspective'
Ref 3.I	Concrete Society. CS TR73, 'Cathodic protection of steel in concrete'
Ref 4.I	Concrete Society. CS TR60, 'Electrochemical Tests for Reinforcement Corrosion'

Appendix A. Impressed current systems versus galvanic anode systems

A1 A brief comparison of the two systems

The majority of cathodic protection systems applied to reinforced concrete internationally and, particularly in the UK, are impressed current cathodic protection (ICCP) systems where the electrical d.c. power supply is a mains powered transformer-rectifier or similar power supply.

ICCP systems can be controlled to accommodate variations in exposure conditions and future chloride contamination. The systems require an external power source, are more controllable and can often be remote monitored and controlled. This can minimise the requirement to attend site for monitoring providing health and safety benefits. The ICCP system has demonstrated that the reinforcement corrosion can be arrested through its application.

Galvanic anode systems do not require an external power source, and so cannot be adjusted. They typically do not come with remote monitoring systems. The life of the system is limited by resistivity of the parent concrete, extent of contamination, which are factors that affect the consumption of the anode, and other factors such as anode corrosion product formation.

Galvanic anode systems for atmospherically exposed reinforced concrete have had more limited use in the UK and a number of trials are ongoing on the strategic highways network. Their use has generally been to areas with low levels of chloride contamination and less critical structural areas. There is some evidence of a positive impact of their use in these environments. However, it is considered that more extensive performance data will be required for galvanic anode systems applied to atmospherically exposed reinforced concrete in UK conditions before their use can be recommended for highway structures in the UK beyond use as part of a corrosion management system.

Appendix B. Merits of cathodic protection

B1 The main advantages of cathodic protection are:

1) undamaged chloride contaminated or carbonated concrete does not require replacement meaning concrete repair costs are consequently minimised;
2) concrete breakout is minimised meaning temporary works such as structural propping during repair will also be minimised;
3) concrete repair work and structural propping frequently requires lane closures and traffic control. The CP minimises the need for these activities;
4) minimising concrete breakout reduces uncertainties over structural behaviour due to redistribution of stress;
5) there is no need to cut behind the reinforcement to remove chlorides. In practice this can be required, in part or whole, to ensure adequate bonding of the patch repair material;
6) the ability to not remove, dispose and replace chloride contaminated concrete negates the associated environmental impact resulting from CO_2 production generated during concrete removal, concrete replacement and transportation of the waste;
7) cathodic protection controls corrosion for all the steel regardless of present or future chloride level or extent of carbonation;
8) cathodic protection can be applied to specific elements, e.g., cross heads, or to entire structures;
9) the cathodic protection current controls corrosion in areas adjacent to concrete repairs that are susceptible to incipient anode formation if only patch repairing were carried out;
10) regular monitoring of a cathodic protection system ensures that a continuous assessment of the corrosion condition is available;
11) the integration of continuous corrosion condition monitoring can be an important benefit for critical structures and for structures in severe exposure conditions.