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British Standard

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BRITISH STANDARD

BS EN 12696:2000

Cathodic protection of steel in concrete

The European Standard EN 12696:2000 has the status of a British Standard

ICS 77.060; 91.080.40

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National foreword

This British Standard is the official English language version of EN 12696:2000.

Reference should also be made to BS 7361, Code of Practice for land and marine applications, which will eventually be withdrawn when all the CEN Standards relating to Cathodic Protection currently being prepared, are published.

The UK participation in its preparation was entrusted to Technical Committee GEL/603, Cathodic Protection, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled “International Standards Correspondence Index”, or by using the “Find” facility of the BSI Standards Electronic Catalogue.

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Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 40, an inside back cover and a back cover.

The BSI copyright notice displayed in this document indicates when the document was last issued.

This British Standard, having been prepared under the direction of the Electrotechnical Sector Committee for , was published under the authority of the Standards Committee and comes into effect on 15 June 2000

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EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 12696

March 2000

ICS 77.060; 91.080.40

English version

Cathodic protection of steel in concrete

Protection cathodique de l'acier dans béton

Kathodischer Korrosionsschutz von Stahl in Beton

This European Standard was approved by CEN on 12 December 1999.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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Foreword

This European Standard has been prepared by Technical Committee CEN/TC 219, Cathodic protection, the Secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2000, and conflicting national standards shall be withdrawn at the latest by September 2000.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

This European Standard is limited to cathodic protection of steel in atmospherically exposed concrete. Many atmospherically exposed reinforced and prestressed concrete structures incorporate foundations or lower elevations which are buried or submerged. Because the technology for the application of cathodic protection to steel in buried or submerged concrete and the criteria of protection for steel in buried or submerged concrete are both significantly different to those applicable to cathodic protection of steel in atmospherically exposed concrete, these foundations or lower elevations are not addressed in this European Standard.

There are other electrochemical treatments intended to provide corrosion control for steel in concrete. These techniques include re-alkalization and chloride extraction and are not incorporated into this European Standard. At the time of preparation of this European Standard CEN/TC 219/WG2 were in the process of collecting data on electrochemical re-alkalization and chloride extraction to prepare European Standards on these techniques at an appropriate time.

Cathodic protection of steel in concrete is a technique that has been demonstrated to be successful in appropriate applications in providing cost effective long term corrosion control for steel in concrete. It is a technique that requires specific design calculations and definition of installation procedures in order to be successfully implemented. This European Standard does not represent a design code for cathodic protection of steel in concrete but represents a performance standard for which it is anticipated, in order to comply with the standard, a detailed design and specification for materials, installation, commissioning and operation will be prepared.

1 Scope

This European Standard specifies performance requirements for cathodic protection of steel in atmospherically exposed concrete, in both new and existing structures. It covers the atmospherically exposed parts of building and civil engineering structures, including normal reinforcement and prestressed reinforcement embedded in the concrete. It is applicable to uncoated steel reinforcement and to organic coated steel reinforcement.

This European Standard does not apply to buried or submerged elements of the buildings or structures.

NOTE: Annex A gives guidance on the principles of cathodic protection and its application to steel in concrete.

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2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

ENV 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 the use of products and systems
EN 60742:	Isolating transformers and safety isolating transformers - Requirements
ISO 8044:	Corrosion of metals and alloys - Vocabulary
IEC 60502:	Extruded solid dielectric insulated power cables for rated voltages from 1 kV up to 30 kV
IEC 60529:	Degrees of protection provided by enclosures (IP Code)

3 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in ISO 8044 and ENV 1504-9 and the following apply.

3.1

zone

a defined part of a cathodic protection system

NOTE: Anode systems may be divided into zones to supply current to a fully continuous reinforcement matrix. Alternatively a single anode zone may supply current to separate, electrically isolated, zones within the reinforcement system. Finally zones may comprise an individual anode zone for each reinforcement zone.

As the current provision to each of the zones in each of these alternatives can be separately controlled and measured all are generically called ‘cathodic protection zones’ and specifically as ‘anode zones’ or ‘cathode zones’.

4 General

4.1 Quality management systems

The design, the installation, the energizing, the commissioning, the long-term operation and the documentation of all of the elements of cathodic protection systems for steel in atmospherically exposed concrete shall be fully documented.

NOTE: EN ISO 9001 constitutes a suitable Quality Management Systems Standard which may be utilized.

Each element of the work shall be undertaken in accordance with a fully documented quality plan.

Each stage of the design shall be checked and the checking shall be documented.

Each stage of the installation, energizing, commissioning and operation shall be the subject of appropriate visual, mechanical and/or electrical testing and all testing shall be documented.

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All test instrumentation shall have valid calibration certificates traceable to national or European Standards of calibration.

The documentation shall constitute part of the permanent records for the works.

4.2 Personnel

Each aspect of the cathodic protection system design, installation, testing of the installation, energizing, commissioning and long-term operational control shall be under the supervision of personnel with appropriate qualification, training, expertise and experience in the particular element of the work for which he is responsible.

NOTE: Cathodic protection of steel in concrete is a specialist multidiscipline activity. Expertise is required in the fields of electrochemistry, concrete technology, civil and/or structural engineering and cathodic protection engineering.

4.3 Design

This standard does not represent a design code but is a performance standard.

Cathodic protection systems for steel in atmospherically exposed concrete shall be the subject of detailed design.
The design shall, as a minimum, include the following:

a) detailed calculations;
b) detailed installation drawings;
c) detailed material and equipment specifications;
d) detailed method statements or specification for installation, testing, energizing, commissioning and operation.

NOTE: Annex B lists items that should be considered in the detailed design.

5 Structure assessment and repair

5.1 General

The assessment of a structure, including its material condition, its structural integrity, and whether and how to repair it, shall be performed in accordance with ENV 1504-9.

NOTE: This assessment will normally be undertaken prior to a decision to use cathodic protection and will not normally be undertaken by personnel, trained in cathodic protection procedures.

When cathodic protection is proposed as the repair/protection method, or part of it, for a structure, additional investigation shall be undertaken in order to:

a) confirm the suitability of cathodic protection;
b) provide system design input information, see Annex B.

These investigations shall include but shall not be limited to those in 5.2 to 5.10 below:

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5.2 Records

All available drawings, specifications, records and notes shall be reviewed to assess the location, quantity, nature (e.g. normal, Zn-galvanized, epoxy-coated, prestressed) and continuity of the reinforcement, and the constituents and quality of the concrete.

The available information shall be confirmed and supplemented by site survey and laboratory tests as specified in 5.3 to 5.8.

5.3 Visual Inspection and Delamination Survey

Visual survey data shall be collected to ascertain the type, causes and extent of defects, and any features of the structure or its surrounding environment, which could influence the application and effectiveness of cathodic protection. Areas which have been previously repaired and the repair methods and materials shall be identified.

All areas of the structure which require to be cathodically protected shall be checked for delamination of the concrete cover.

Defects such as cracks, honeycombing, or poor construction joints which could permit significant water penetration and which could in turn impair the effectiveness of the cathodic protection, shall be recorded.

5.4 Chloride analysis

The chloride content of the concrete shall be determined, in accordance with ENV 1504-9.

5.5 Carbonation depth measurement

Distribution of carbonation depths shall be measured in accordance with ENV 1504-9.

5.6 Concrete cover and reinforcement location

Concrete cover and reinforcement size and position measurements shall be carried out in order to assess whether the anode/cathode spacing will be adequate for the particular anode system envisaged and to identify dense regions of reinforcement which may require high current density. Shielding of the reinforcement to be protected, caused by embedded metal meshes, metal fibres or plates, plastic sheets or non-conductive repair materials, which could impair the efficiency of cathodic protection shall be assessed. Possible short circuits between reinforcing steel and anode shall be assessed.

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5.7 Reinforcement electrical continuity

Drawings of reinforcement and other steel elements shall be checked for continuity which shall then be proven on site by measuring the electrical resistance and/or potential difference between bars in locations remote from each other across the structure as specified in 7.1 for the purpose of confirming cathodic protection feasibility and providing design information. This shall include at least an assessment of the following on a representative basis:

a) electrical continuity between elements of the structure within each zone of the cathodic protection system.
b) electrical continuity of reinforcement within elements of the structure.
c) electrical continuity of metallic items, other than reinforcement, to the reinforcement itself.

At the subsequent repair and installation stage, reinforcement electrical continuity shall be further checked in accordance with the methods, and to the extent, specified in 7.1.

5.8 Steel/concrete potential

Representative areas, both damaged and apparently undamaged, shall be surveyed for reinforcement corrosion activity, using portable reference electrodes conforming to 6.3.2. Measurements shall be taken, preferably on an orthogonal grid, at a maximum spacing of 500 mm.

NOTE 1: It is not necessary to carry out a steel/concrete potential survey of the entire structure. It is appropriate to survey in more detail those areas where reference electrodes are planned to be permanently installed in order to place them in most anodic and other suitable locations.

Continuity of the reinforcement within any steel/concrete potential survey area is essential and shall be checked, using the method in 7.1 before the steel/concrete potential survey.

NOTE 2: It is essential that measurements in any areas identified as delaminated, in the survey specified in 5.2, should be treated with caution, because delamination can produce readings inconsistent with the level of corrosion of the reinforcement.

5.9 Concrete electrical resistivity

The impact of variations in concrete resistivity on the cathodic protection system shall be considered.

5.10 Repair

5.10.1 General

All operations comprising repair shall be performed in accordance with ENV 1504-9 except where stated otherwise in this clause.

NOTE: Installation of cathodic protection to an existing structure may be associated with other forms of repair work such as strengthening, patching or coating, as determined in accordance with ENV 1504-9. In this clause the term 'repair' signifies reinstatement of the damaged/deteriorated concrete substrate to provide an uninterrupted path for the flow of cathodic protection current prior to the installation of cathodic protection, as well as reinstatement at locations where concrete has been removed to provide access to reinforcement, install cable connections and monitoring sensors, and such like.

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5.10.2 Concrete removal

All repair materials from previous installations with an electrical resistivity outside the range 50 % to 200 % of the nominal parent concrete electrical resistivity shall be broken out to achieve a clean concrete surface.

Any tying wire, nails or other metal components visible on the concrete, that might contact the anode system or might be too close to the anode for optimum anode/cathode spacing shall be cut back and the concrete shall be repaired.

NOTE: Any metallic objects electrically isolated from the cathodic protection cathode circuit may corrode and may require to be electrically bonded to the reinforcement or removed

The removal of physically sound chloride contaminated or carbonated concrete prior to applying cathodic protection is not necessary.

5.10.3 Reinforcement preparation

Any loose corrosion product particles shall be removed from exposed reinforcement to ensure good contact between the steel and the repair material, but there is no need to clean reinforcement to bright metal.

Neither primers nor coatings on the steel nor insulating/resistive bonding agents shall be used.

5.10.4 Concrete reinstatement

Concrete reinstatement shall be in accordance with ENV 1504-9.

Subject to the need to provide adequate cover to avoid short circuits, concrete shall be reinstated using cementitious materials. Repair materials containing metal (either fibre or powder) shall not be used. The electrical resistivity characteristics and mechanical properties of the repair materials shall be similar to the original concrete. Proprietary curing membranes shall not be used prior to subsequent anode installation over the repair area.

The electrical resistivity of concrete repair materials shall be within the range 50 % to 200 % of the nominal parent concrete electrical resistivity.

5.11 Cementitious Overlay

Following repair as specified in 5.10, and anode installation in accordance with 7.5, 7.6 and 7.7 a cementitious overlay shall be applied over appropriate types of installed anode. All materials and application methods shall be in accordance with ENV 1504-9. The average bond strength between existing concrete and overlay shall be greater than 1,5 N/mm² and the minimum shall be greater than 1,0 N/mm², or the test failure shall be within the existing concrete.

Overlay application may be combined with concrete repair.

In such cases the electrical resistivity of concrete repair materials shall be within the range 50 % to 200 % of the nominal parent concrete electrical resistivity. Anode overlays may exceed 200 % of parent concrete electrical resistivity subject to a maximum of 100 kΩ cm at ambient conditions and subject to the anode within the overlay being able to pass its design current at the design voltage in an overlay of this resistivity.

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The selected material, thickness and placement method shall be compatible with each other and with the anode material.

Electrical resistance between anode and reinforcement (cathode) shall be monitored to detect short circuits.

Curing membranes shall be removed or shall have sufficiently degraded to avoid adversely influencing the performance of the cathodic protection system.

5.12 New structures

In the case of a new structure, if cathodic protection as a preventive system is to be included in the original construction, the following issues shall be assessed in the design, specification and construction procedures, in addition to the requirements of the remainder of this standard and of the standards governing the design and construction of the new structure:

a) Provision and checking of reinforcement electrical continuity, in accordance with 7.1.
b) Adequate securing and protection of monitoring sensors and all cables and their connections, to avoid damage or disturbance during concrete placement and vibration.
c) Connection, location or insulation of other metallic fixtures, fixings, or other items, so as to avoid undesirable influences from the cathodic protection system.
d) In the case of anodes cast into the concrete structure, provision of sufficient rigid insulating spacers and attachments to secure the anodes in position and prevent creation of short circuits during concrete placement and vibration. Electrical resistance monitoring between anode and reinforcement (cathode) shall be used to detect short circuits during concrete placement.

6 Cathodic Protection System Components

6.1 General

The cathodic protection system shall include an anode system intended to distribute the cathodic protection current to the relevant surfaces or parts of the concrete, to facilitate its conversion from electronic to ionic current at the anode/concrete interface and to allow its distribution to the surfaces of the embedded steel in the concrete. The cathodic protection system shall further incorporate positive and negative d.c. cables between the anode and steel respectively and the d.c. power supply, which for impressed current systems is the source of the cathodic prevention current. Reference electrodes, other electrodes and other sensors are key elements of cathodic protection systems and constitute the performance monitoring system within cathodic protection systems. The data from the electrodes and sensors may be interrogated and displayed by portable instrumentation, permanently installed instrumentation of either automatic or manual type. The entire cathodic protection system shall be designed, installed and tested to be suitable for its intended life in its intended environment.

6.2 Anode systems

The anode system shall be capable of supplying the performance required by the cathodic protection design (see 4.3). The anode system's calculated or anticipated life shall be sufficient for the design life incorporated in to the design, with, where necessary, planned maintenance or replacement of the anode system or parts of the system at periods designated in the design.

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The anode current density shall conform to the design and shall not exceed such values resulting in a performance reduction of either:

a) the concrete at the anode/concrete interface; or
b) the anode;

during the design life of the anode.

The design and/or the selection of the anode material shall consider likely variations in cathode current density requirements, steel distribution, concrete electrical resistivity and any other factors likely to result in uneven distribution of current demand or current discharge from the anode and the possibility of this resulting in early failure of isolated parts of the anode system.

NOTE 1: A variety of anode systems have been developed, tested and demonstrated in long-term field applications to be suitable for use in the cathodic protection of steel in atmospherically exposed concrete. The requirements for such anodes are unique for usage of cathodic protection in concrete as the anodes have to be installed or applied distributed across the concrete surface or within the concrete as required to meet the design distribution and magnitude of current. The anode is therefore in close contact with the highly alkaline concrete pore water. In operation the anodic electrochemical reactions at the anode/concrete interface are oxidizing, producing acidity.

NOTE 2: The anode systems described in this standard are in two categories. Anode systems which have been in use for a minimum of 5 years and which have extensive, generally successful, track records are covered by this standard in 6.2.1 and 6.2.2. It is not intended that the use of other, perhaps newer or less well proven, anode materials is to be precluded as this would restrict the necessary and advantageous development of new, possibly improved, anode materials. These are listed in C.1.4.

NOTE 3: It is likely that new and effective anode materials will be developed for cathodic protection of steel in atmospherically exposed concrete. It is not the purpose of this standard to preclude their use. It is recommended that the use of any anode should only be undertaken where performance can be demonstrated by laboratory testing, trials and/or past projects.

NOTE 4: It is suggested that new anode materials for cathodic protection of steel in atmospherically exposed concrete should be the subject of rigorous laboratory testing and, wherever possible, extended and/or accelerated field trials prior to commercial non-trial applications.

6.2.1 Conductive Coating Anode Systems

6.2.1.1 Organic Coatings

The anode system shall comprise an organic conductive coating (solvent based or water soluble, containing a carbon conductor) and a series of conductors (primary anodes) fixed to the concrete surface or integrated into the coating in order that the conductors can distribute current within the coating. The conductors shall be of material able to resist anodic reactions, e.g. platinum coated or platinum clad titanium or niobium which may be copper cored, or mixed metal oxide coated titanium.

The combination of conductive coating and primary anodes shall be demonstrated by trials or past projects to enable the design anode performance to be achieved. The spacing of primary anodes within the conductive coating shall be such that it can be calculated or demonstrated that the variation in anode current output attributable to the resistance, within the coating, between primary anodes, does not exceed ±10 % of the average current output measured as a ±10 % voltage drop.

The particular application technique selected shall be demonstrated by trials or past projects to enable the design anode performance to be achieved.

The adhesion of the coating to the concrete, subject to appropriate surface preparation and the above application technique, shall be suitable to achieve the full design life of the anode system.

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Data shall be provided determining the wet or dry film thickness requirements to achieve the required dry film conductivity.

See C.1.1 for further information.

6.2.1.2 Metallic Coatings

The anode system shall comprise a thermally sprayed metallic coating.

NOTE: Metallic coatings of zinc and zinc alloys and of subsequently activated titanium have been used as anodes. The last two do not have a 5 year track record and are categorized as in Annex C.1.2 and C.1.3.

The combination of metallic coating and connectors shall be demonstrated by trials or past projects to enable the design anode performance to be achieved. The spacing of connectors within the metallic coating shall be such that it can be calculated or demonstrated that the variation in anode current output attributable to the resistance, within the coating, between connectors, does not exceed ±10 % of the average current output measured as a ±10 % voltage drop.

The particular application technique selected shall be demonstrated by trials or past projects to enable the design anode performance to be achieved.

The adhesion of the coating to the concrete, subject to appropriate surface preparation and the above application technique, shall be suitable to achieve the full design life of the anode system.

Data shall be provided determining the application process requirements to achieve the required film thickness and conductivity.

Metallic connectors (of Cu, Cu-Zn-alloys or Ti) electrically insulated from but mechanically bonded to the concrete surface shall be installed prior to metallic coating application.

6.2.2 Activated Titanium Anode Systems

6.2.2.1 General

The anode system shall comprise a substrate of titanium [1] and an electrocatalytic coating containing oxides of platinum group metals, platinum, iridium or ruthenium along with oxides of titanium, zirconium and tantalum together with anode/cable connections and a cementitious overlay or surround.

The coating composition and thickness, or mass per unit area, shall be demonstrated by trials and/or laboratory testing to enable the design anode performance to be achieved.

6.2.2.2 Surface installed

The activated titanium shall take the form of a mesh or grid distributed, in accordance with the design, on the concrete surface. Titanium connectors shall be spot welded to the mesh or grid to distribute current to all component parts of the anode and to facilitate electrical connections to the anode. Where anode/cable connections are to be incorporated into the cementitious overlay, they shall be of a type and installed in a manner that can be demonstrated by trials or past projects to enable the design anode and anode/cable connection performance to be achieved.

Non-metallic fixings shall be utilized to facilitate the fixing of the anode material to the surface of the concrete or to reinforcement prior to pouring concrete and shall ensure that there are no short circuits between anode and reinforcement.

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6.2.2.3 Installation into recesses in covering concrete

The anode shall take the form of solid or mesh titanium strips or grids complete with the electrocatalytic coating, suitable for recessing into grooves cut into the cover concrete, or be activated titanium strips and grids with non-metallic fixings to facilitate installation on to exposed reinforcement prior to concrete placement.

The size and distribution of the strips or grids shall conform to the anode design and the maximum anode current density.

6.2.2.4 Embedded within the structure

Activated titanium shall be embedded within the structure in one of the following ways:

a) Electrocatalytically coated titanium in the form of strip, mesh, grid or tubes shall be embedded into a cementitious repair mortar in holes drilled into the concrete.
b) Anodes of a similar form or platinum coated titanium rods shall be used in conjunction with a conductive graphite based backfill.
c) Anodes of a similar form shall be cast into new construction for cathodic prevention or into concrete repairs for cathodic protection.

Where a backfill (e.g. graphite) is part of the anode system, its operating current density based upon the dimensions of the hole drilled in the concrete, and the anode current density within the backfill shall conform to the design (see 4.3) and shall be limited to values which can be demonstrated by trials or past projects to enable the requisite anode, backfill and anode/cable connection performance to be achieved. Where graphite backfill is utilized, the graphite shall be considered as the anode in calculating the minimum anode/reinforcement spacing.

6.2.3 Other Anode Systems

See Annex C.1.4.

6.3 Monitoring sensors

6.3.1 General

In order to determine the performance of the cathodic protection, a monitoring system shall be incorporated. The monitoring system shall incorporate sensors at representative points over the entire structure/anode zone to be protected.

Usually performance shall be determined by measuring the steel/concrete potential, using reference electrodes.

NOTE 1: Suitable reference electrodes for permanent embedding in concrete include double junction Ag/AgCl/0,5 M KCl-gel- and Mn/MnO_2/0,5 M NaOH-electrodes.

NOTE 2: Other sensors such as potential decay electrodes, current density coupons, macrocell probes, etc, may also be used in conjunction with reference electrodes.

All sensors shall be sufficiently robust for installation and permanent exposure in highly alkaline conditions. The cables and cable connections to sensors shall be similarly robust and alkaline resistant and also be acid resistant if in contact with, or close to the anode system.

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6.3.2 Portable reference electrodes

Portable reference electrodes shall be reference electrodes designed to be used either directly on the concrete surface or in conjunction with Luggin-probes.

Portable reference electrodes to be used directly on the concrete surface shall have an integral, but replaceable, sponge for contact with the concrete.

Portable reference electrodes shall be supplied with a calibration certificate and shall be stored, maintained and handled in full accordance with the manufacturer's instructions. Portable reference electrodes shall be checked against a known laboratory standard reference electrode, or similar, at the beginning and end of each site application.

NOTE: Suitable portable reference electrodes include gel filled, double junction Ag/AgCl/0,5 M KCl- and standard calomel electrodes (in a non-glass housing) (SCE). Cu/saturated $CuSO_4$-electrodes (CSE) are not recommended for use on concrete surfaces due to the high risk of significant errors if copper sulphate leaks onto the concrete surface.

6.3.3 Other Sensors

6.3.3.1 Potential Decay Probes

Potential decay probes shall not be used to measure absolute steel/concrete potential (as specified in 8.6 a)) or long term potential decay beyond 24 hours.

NOTE 1: Potential decay probes are sensors enabling the measurement of steel/concrete potential but do not have the reversible stability of their own half cell potential to be classified as a reference electrode. They may be used to determine the potential change, (during ‘on and off switching’) over a limited time period, typically a maximum of 24 hours.

NOTE 2: Suitable potential decay probes for permanent embedding in concrete include graphite, activated titanium and zinc.

6.3.3.2 Coupons and macro-cell probes

Coupons and macro-cell probes shall be manufactured from steel of similar composition to the structure reinforcing steel and shall either be of rugged construction suitable for permanent embedding in concrete or be constructed by isolating and instrumenting existing reinforcement which is already in place.

Macro-cell probes shall be encased in chloride rich mortar cylinders. The chloride content of the cylinders (with respect to mass of cement) shall be at least five times the average chloride content of the structure concrete (with respect to mass of cement) at the depth of reinforcement.

NOTE 1: Current density coupons or macro-cell probes may be used to determine the current density collected on the reinforcing steel cathode.

NOTE 2: Macro-cell probes also can be used to confirm that local active corrosion sites (‘hot spots’) receive sufficient current from the cathodic protection system to control corrosion. This is indicated by a reversal of the net current flow between the macro-cells and the main reinforcement after the cathodic protection system has been energized.

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6.3.3.3 Luggin probes (electrolytic bridge)

Luggin probes shall comprise an ionic conductive medium within a rigid or semi-rigid insulation material. All materials shall be suitable for being permanently embedded in concrete and shall be prevented from completely drying out

NOTE 1: Luggin probes or similar devices can be used to enable the potential of embedded steel deep within a structure to be determined using a portable reference electrode.

NOTE 2: Suitable Luggin probe systems for concrete include small diameter polyvinyl chloride (PVC) or polypropylene pipe containing sand or mortar, water saturated wooden dowels sealed in heat shrink tubing, silicon rubber tubing containing gel and conductive polymeric membranes.

6.4 Monitoring instrumentation

6.4.1 General

Monitoring instrumentation shall be used to interrogate monitoring sensors installed to determine the performance of the cathodic protection system and the operating condition of the d.c. power supply.

NOTE: Monitoring instrumentation may comprise manual devices, portable data loggers or permanently installed data loggers. Instrumentation is principally required to measure d.c. voltages. If coupons or macro-cell probes are incorporated or other measurements are required then other specialist instrumentation is necessary.

All instrumentation shall be constructed in accordance with relevant national or European Standards relating to electronic and measurement equipment and shall be provided with a valid calibration certificate. All equipment shall be handled, installed, commissioned and operated in accordance with the manufacturer's recommendations.

6.4.2 Digital Meters

Voltmeters for measuring sensors and d.c. power supplies shall have a minimum resolution of 1 mV, an accuracy of ±1 mV or better and an input impedance of not less than 10 MΩ.

Analogue meters shall not be used.

Current flow between coupons or macro-cell probes and reinforcement shall be measured using an zero-resistance ammeter or other suitable device of such accuracy and resolution that the current is measured to an accuracy of better than ±1 % of the value measured.

NOTE: Depending on the coupon or macro cell probe size and their environment the currents can range from tens of microamperes to hundreds of milliamperes.

6.4.3 Data loggers

6.4.3.1 General

Data loggers shall have suitable multi-channel input or multiplexers to enable all channels selected for data logging to be measured and recorded.

Data loggers shall operate under a real date-time clock which shall be included in all measurement units. Data loggers shall have a minimum input impedance of 10 MΩ and a resolution of at least 1 mV in a range of at least 2 000 mV and an accuracy of ±5 mV or better.

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Data loggers shall have output(s) for control of and synchronization with d.c. power supplies for control of d.c. current interruption, to enable correct measurement of instantaneous off potentials (see 8.5) and with an on:off cycle as appropriate. Noise rejection, accuracy and measurement (count) period of the data logger shall be sufficient to allow collection of steel/concrete potential data within a time interval of 100 ms to 500 ms of switch off to an accuracy of ±5 mV or better.

Data loggers shall be supplied with software allowing test locations, sensors, d.c. power systems, anode zones, etc. to be identified.

NOTE: Data loggers can be used to collect data from both sensors and d.c. power supplies. Data loggers may be either portable or permanently installed.

6.4.3.2 Portable data loggers

Portable data loggers shall be suitable for rough handling and temporary exposure to the site environment. Connection of portable data loggers to test boxes, d.c. power supplies, etc. shall be by suitable multi-way connector(s) and cable as appropriate.

6.4.3.3 Permanently installed data loggers

Permanently installed data loggers shall be located in an enclosure suitable for the environment and climate conditions at the site, in accordance with 6.7 and 6.9.

Permanently installed data loggers shall be hardwired to relevant sensors, d.c. power supplies, etc. Instrumentation cable connections shall be in accordance with 6.6.

NOTE 1: Permanently installed data loggers can be operated independently, on a network or via a modem link. The power supply can either be a.c. mains or via the network cable as appropriate.

Interconnection into a network shall be in accordance with relevant national or European Standards and the network manufacturer's recommendations.

Each permanently installed data logger shall have an unique identification reference number.

NOTE 2: Permanently installed data loggers can operate as either passive or active systems. If passive they collect data only when instructed by a system controller. If active they can be programmed to collect data for selected intervals. Either they may transmit all data or transmit summary data (e.g. mean, maximum, minimum, standard deviation, over a selected period) on request or automatically.

Access to permanently installed data loggers either directly or via network shall be via a user defined password.

6.5 Data management system

A data management system shall be provided to collate, order, sort and present the performance data arising from the cathodic protection system.

NOTE 1: This may be either a manual (paper) system or a computerized data based management system or a combination of both.

The system shall contain the following data as a minimum:

a) anode zone layouts;
b) sensor type and location;
c) d.c. power unit rating;
d) initial (precommissioning) sensor readings;
e) commissioning data;
f) sensor data obtained since commissioning (at time intervals conforming to clause 10);
g) d. c. power supply output data since commissioning;
h) event record (i.e. inspection dates, changes in system operation, etc).

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Sensor data obtained and recorded shall be compatible with, and sufficient to enable conformity to the selected performance criterion given in 8.6 to be assessed.

Computer data base management systems shall be provided with full documentation. Facilities for automatic data back-up and archive shall be incorporated.

The system shall be capable of presenting data/information in both tabular and graphical form.

NOTE 2: Data superimposed on mimic diagrams (layout sketches) may also be used.

The system shall be capable of identifying data points outside pre-set (user definable) limits on request.

6.6 D.C. Cables

Single core cables shall be colour coded according to their function.

NOTE 1: The following colours are preferred:

a) red from positive d.c. power supply to anode/cable connection;
b) black from negative d.c. power supply to reinforcement steel/cable connection;
c) grey for monitoring test (reinforcement connection for monitoring) cable;

NOTE 2: Monitoring test cables may be black if of different size to the d.c. negative return cable.

d) blue for reference electrode cable [not Red or Black]
e) yellow for other monitoring sensors [not Red or Black]

Multi-core cables shall be colour or number coded.

Cables shall meet the following requirements:

1) carry the design current +25 % within permissible temperature increases allowed under IEC 60502 as appropriate to the maximum environmental temperatures;
2) limit the voltage drop at 125 % of the designed maximum current in the cathodic protection system circuit to a value compatible with the power supply voltage output and the anode/cathode voltage requirements and provide uniform zone current distribution.

Minimum core sizes of multi-core cables for mechanical purposes with all cables encapsulated in concrete, or in conduit or trunking shall be as follows:

- d.c. positive and negative supplies	1,0 mm²;
- monitoring cable	0,5 mm²;
- data networking	in accordance with network standards.

If single core cables are used the minimum core size for mechanical purposes shall be 2,5 mm².

All cables shall have a minimum of seven strands.

All cables shall have a minimum of a single layer of insulation and a single layer of sheathing which shall conform to IEC 60502. The selection of insulation and sheath shall take due account of the proposed installation and functional requirements. Cable to be installed in contact with anode material shall be suitable for long-term exposure to acidic conditions, typically pH = 2 and those to be installed in concrete for long-term exposure to alkaline conditions, typically pH = 13.

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6.7 Junction boxes

Junction boxes shall be rated in accordance with IEC 60529 to render appropriate protection against environment taking into account the type of connections made within the box and the worst case external environmental and mechanical exposure to which the box is to be subjected.

NOTE: It is recommended that all junction boxes should be non-metallic and conform to IEC 60529 classification IP 66 or better.

6.8 Power supplies

Where a.c. power distribution is available, the d.c. power supply shall be provided by a transformer-rectifier.

NOTE: Where a.c. power distribution is not available, other types of supply such as diesel, wind, or turbine generators may be used to generate a.c. as a supply to a transformer-rectifier. Controlled d.c. supplies can be generated directly by thermoelectric or solar generators and wind or turbine generators may be used with rectification to provide a supply to intermittently charged battery systems which supply current to d.c. controllers.

6.9 Transformer-rectifiers

The transformer-rectifier unit shall be continuously rated, self-contained and suitable for the environment in which it is to operate.

The unit shall be housed in a robust enclosure suitable for wall or floor mounting as applicable. The enclosure shall provide protection against the worst case environment in accordance with IEC 60529.

The incoming a.c. supply shall be terminated via an appropriately rated, double pole neutral linked switch fuse or circuit breaker and residual current device in accordance with the electricity supplier's requirements and national and/or European Standards.

The main transformer shall be an isolating transformer conforming to EN 60742 continuously rated and suitable for connection to the low voltage a.c. supply.

The transformer-rectifier output shall not exceed 50 V d.c. with a ripple content not exceeding 100 mV RMS with a minimum frequency of 100 Hz.

Equipment, which does not conform to EN 60742 because it is required by environment or service to operate above an ambient temperature of 30 °C or to utilize oil or forced air cooling, shall in all other aspects conform to EN 60742.

The rectifier shall conform to appropriate national or European Standards with suitable a.c. surge protection. Fast acting fuses shall be used to protect the rectifiers on the a.c. side and varistors to protect them on the d.c. side. Rectifiers shall be rated for continuous operation at the specified outputs with a peak inverse voltage of at least 600 V. Varistors shall be compatible with the rectifier peak inverse voltage levels.

The d.c. circuits shall be separated from those of any other system (e.g. the incoming a.c. supply).

For cathodic protection systems placed in locations accessible to persons or animals, and where preventative measures such as barriers, obstacles or electrical insulation are not provided, the output from the transformer-rectifier unit shall not exceed 24 V d.c. with a ripple content not exceeding 100 mV RMS. This shall specifically apply to cathodic protection of reinforced concrete structures and buildings where conductive coating anode systems are used.

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The output shall be controlled to provide stepless constant voltage, constant current or potentiostatic control from zero to full rated output.

A d.c. relay system interrupting the output shall be provided to facilitate ‘instantaneous off’ potential measurement [see 8.6 (a)].

NOTE 1: Facilities to link this system to the control signals from data-logging equipment may be provided.

Facilities shall be provided to enable portable instrumentation to be used for measurement of the following:

a) output voltages;
b) output currents (by voltage drop across a shunt resistor with an accuracy of ±0,5 % or better);
c) steel/concrete potential with respect to the reference electrodes.

NOTE 2: Facilities may be used for measurement of:
i) steel/concrete potential with respect to potential decay sensors;
ii) coupon or probe/reinforcement current.

The function and rating of all sockets and the multiplying factor of all shunts shall be clearly marked.

All fuses shall be labelled with circuit designation and fuse characteristics.

NOTE 3: Permanently installed digital panel meters may be used to measure the data required in items a) to c). Calibration checks on a regular basis are necessary.

A minimum of one positive and one negative terminal for cable connections shall be provided. All output terminals shall be fully insulated from any metal within the box.

The connectors shall be clearly marked ‘+ANODE’ and ‘-REINFORCEMENT’

NOTE 4: It is recommended that the positive and negative terminals should be of different sizes in order to avoid transposition of cables.

LEDs (light emitting diodes) or other means of indicting a.c. power supply ‘on’ and d.c. output ‘operating’ shall be provided.

For equipment with multiple transformer-rectifiers or multiple channels, each transformer-rectifier and channel shall be fully identified and shall conform to this clause.

Tests shall be conducted at the manufacturer's works to demonstrate full functional conformity and fitness for purpose. The tests shall be arranged to represent realistic on-site working conditions and the results shall be fully documented and shall constitute part of the permanent records for the works.

All electrical tests shall be carried out in a manner prescribed by the relevant national or European Standards.

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7 Installation procedures

7.1 Electrical continuity

Unless alternative testing procedures and criteria have been selected in the design the electrical continuity between reinforcing bars or elements of steel in concrete shall be tested by a d.c. reverse polarity resistance measurement technique, by measuring the resistance using a d.c. resistance instrument and then reversing the polarity of the test leads, or by a d.c. potential difference measurement technique. The acceptance criteria for such testing shall be stable values and a resistance less than 1 Ω or a potential difference less than 1 mV. All steel exposed during concrete repairs or other works shall be continuity tested and any bar or component tested failing the test, shall be continuity bonded to ensure long-term resistance of 1,0 Ω or less. At additional representative locations in each unit or discrete part of the structure sufficient reinforcement shall be exposed and tested at selected locations to determine the general level of electrical continuity of the reinforcement.

The continuity testing results, all available construction drawings, the nature of the structure and its construction shall be assessed in order to determine whether additional reinforcement should be exposed for testing and possible bonding.

All ancillary steel fixed to or part of the concrete structure (e.g. embedded steel beams, bearings, drainage pipes) either shall be continuity tested as above and bonded if required or shall be bonded in accordance with 7.3.

Electrical contact shall be prevented between reinforcement or ancillary steel and the anode system of any impressed current cathodic protection system.

NOTE: Attention should be given to the location, removal or insulation of steel in the surface of concrete particularly if conductive coatings (including conductive overlays or sprayed zinc impressed current) anodes are to be used. Contact between the anode and such steel will either result in short circuits between anode and reinforcement or in corrosion of isolated steel.

7.2 Performance monitoring system

Each zone of the cathodic protection system shall be provided with the means necessary to monitor its power supply output voltage and output current and its steel/concrete potential using reference electrodes (6.3.1) permanently embedded at representative locations.

NOTE 1: Each zone may also be provided with potential decay probes to monitor potential decay, with corrosion coupons to measure anodic or cathodic current density on parts of the reinforcement or with other methods to measure or assess corrosion rate or extent of cathodic protection. The data collection system may be manual, electronically data logged and/or electronically data transmitted.

The permanently installed performance monitoring system shall be located so that representative data can be assessed at typical intervals in accordance with clause 10.

NOTE 2: This assessment may involve manual data collection, recording data collection with portable equipment or locally, area networked/modem linked, permanently installed data logging systems.

The extent and locations of deployment of the permanently installed performance evaluation system shall be in accordance with the design. The areas addressed shall include the following:

a) high probability to corrosion or under-protection;
b) high probability to excessive protection;
c) high corrosion risk or activity.

NOTE 3: The data from or the performance of permanently installed reference electrodes, coupons or other sensors, are likely to be adversely affected or rendered non-representative by placement in or adjacent to concrete repairs incorporating reinforcement.

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Reference electrodes and other sensors shall not be placed in, or close to, concrete repairs unless there are no alternative locations. In the vicinity of the sensor, concrete surrounding the steel shall remain undisturbed.

Permanently installed reference electrodes, and other sensors that can be calibrated prior to installation, shall be calibrated.

7.3 Connections to steel in concrete

Each zone of the cathodic protection system shall be provided with multiple negative connections of cables to reinforcement for the cathodic protection current and a minimum of one test connection to the reinforcement for measurement of steel/concrete potentials with respect to permanent or portable electrodes.

The electrical continuity between all negative connections and test connections of each individual zone shall be tested and shall be 1,0 Ω or less. If this requirement is not initially achieved, additional reinforcement exposure for testing and bonding shall be undertaken in accordance with 7.1.

NOTE: Continuity between the negative connections of different zones of a cathodic protection system may be required in accordance with the particular design.

The cable connections to the reinforcement shall be made by methods providing a long-term cable/reinforcement resistance of less than 0,01 Ω.

7.4 Concrete repairs associated with the cathodic protection components

Any concrete repairs associated with the installation of performance monitoring system electrodes, other sensors and the connections to steel in concrete shall be undertaken using methods and materials conforming to clause 5 and ENV 1504-9.

7.5 Surface preparation for anode installation

The concrete surfaces intended to receive installation of anode material, e.g. conductive coatings or activated titanium mesh within a cementitious overlay, shall be prepared so as to present as a minimum a clean, non-friable, mud free surface. [See ENV 1504-9].

Cathodic protection conductive coatings generally require a minimum of preparation to leave a maximum of cement paste and minimal exposure of aggregate and should be as specified in the coating product specification.

7.6 Anode installation

The anode system shall be installed by methods and under controlled environmental conditions which can be demonstrated by trials or past projects to enable the requisite anode performance to be achieved.

The anode system shall be installed in accordance with the design method statements or specification for installation.

Particular attention shall be given to the avoidance of short circuits between the anode system and any reinforcement steel, ancillary metallic components or reinforcement tie wire or debris steel in the surface of the concrete.

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After conductive coating or cementitious overlay application the atmospheric conditions and concrete surfaces shall be maintained at temperatures and humidity or moisture levels necessary to ensure proper curing/solvent loss/water evaporation of the anode and/or overlay.

The design method statements or specification for installation shall be followed in these respects.

Prior to application of any overlay, surface sealant or decorative coating over the anode systems, the anode/cathode resistance and potential difference shall be measured in order to determine whether short circuits have been established and, if so, they shall be detected and corrected before further work.

7.7 Connections to the anode system

Each zone of the cathodic protection system shall be provided with multiple positive cable/anode connections such that the failure of any one anode/cable connection shall not reduce the performance of the cathodic protection system in that zone.

The anode/cable connection system shall be of a type and installed to such standards as can be demonstrated by trials or past projects to enable the requisite anode and anode/cable connection performance to be achieved.

In each individual zone the electrical resistance of all anode/cable connections shall be tested and compared with calculated values for the particular anode type and distribution. Data shall be assessed to determine whether additional testing or additional anode/cable connections are required.

A 100 % visual inspection shall be undertaken of the anode system prior to application of any coating.

7.8 Anode overlay, surface sealant or decorative coating application

Any requisite anode overlay, surface sealant or decorative coating shall be applied by methods and under controlled conditions which can be demonstrated by trials or part projects to enable the requisite anode and overlay, sealant or coating performance to be achieved and in accordance with the design method statements or specification for installation.

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7.9 Electrical installation

All electrical installation works shall be undertaken in accordance with European (or, if none exist, with national) electrical safety standards.

NOTE 1: The electrical power supply for the cathodic protection system may be provided by transformer-rectifier(s) powered by an electrical supply from a mains voltage distribution system.

In addition to the particular requirements of the cathodic protection system, the following electrical safety measures shall be applied to all installations:

a) Mains voltage cables shall be electrically isolated and separated from low voltage d.c. cables.

b) Cables shall be uniquely identified with marker tags at the d.c. power supply, at any junction box and at their point of connection.

c) Cables shall be adequately supported and protected from environmental, human and animal damage.

NOTE 2: In locations where there is high risk of damage, cables may be embedded into concrete or may be protected by steel wire armouring.

d) Except for the cable connections covered in item f), cable connections shall only be made at locations in enclosures or junction boxes.

e) Connections inside boxes, whose construction and/or installation renders their environmental protection rating below the worst case external environmental exposure, including boxes with non-sealed conduit entries, shall be made by methods suitable for long-term water immersion.

NOTE 3: Connections inside water resistant or sealed boxes constructed and installed with an environmental protection rating above the worst case external environmental exposure may utilize copper or brass threaded or proprietary connection assemblies.

f) It shall be permissible for anode/cable connections for anodes, e.g. activated titanium mesh, which are to be permanently embedded in an overlay material to be installed without junction boxes if the anode/cable connection and its method of electrical/mechanical/moisture sealing can be demonstrated by trials or past projects to enable the requisite performance to be achieved.

g) Anode systems for which there is no overlay or electrical barrier to prevent direct human or animal contact e.g. conductive coating, shall be limited to a supply voltage of 24 V d.c. with a maximum ripple content of 100 mV RMS.

h) Equipment shall be marked with all relevant electrical safety/testing/maintenance markings in accordance with European and national standards.

NOTE 4: The electrical characteristics required of the low voltage d.c. circuits of cathodic protection systems may render full conformity to European (or national) electrical safety standards inappropriate.

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7.10 Testing during installation

Testing in accordance with the quality plan (see clause 4) shall include the following for the cathodic protection system:

a) polarity checks for all circuits (the results shall be unambiguous);
b) continuity checks for all circuits, (the results of which shall demonstrate individual circuit resistance values within 10 % of those calculated from cable and component values);
c) insulation checks for all circuits, which may have to be undertaken prior to connections to either anode or reinforcement, and which shall demonstrate the electrical isolation of d.c. positive cables from d.c. negative cables.

NOTE: Reference electrodes and rectifier circuits may be damaged by insulation checks. Reference electrodes may be damaged by continuity checks. The intended low resistance between anode and reinforcement and between adjacent zones anode or cathode circuits renders conventional electrical circuit insulation and continuity testing inappropriate.

The mains voltage electrical power supply system and the transformer-rectifier(s) providing low voltage d.c. to the cathodic protection system shall be tested and documented for electrical safety in accordance with European (or, if none exist, with national) electrical safety standards.

8 Commissioning

8.1 Visual inspection

The cathodic protection system and all its component parts shall be subjected to a complete visual inspection confirming that all components and cables are installed properly, labelled where appropriate and protected from environmental, human or animal damage.

8.2 Pre-energizing measurements

Prior to energizing, measurements shall be made and recorded in accordance with the quality plan (see clause 4) and shall include the following for the cathodic protection system:

a) Potential of steel/concrete with respect to permanently installed reference electrodes and potential decay sensors. Measurements shall be taken at low (about 10 MΩ to 20 MΩ) and high (about 500 MΩ to 1 000 MΩ) input impedance to determine whether the contact resistance of all the reference electrodes or sensors to the concrete is above the designed value.

NOTE: The difference in potential between low impedance and high impedance measurements should generally be less than 10 mV but this value will vary with the ratio of input impedances used and other resistances in the circuit.

b) Potential of steel/concrete with respect to portable reference electrodes at any locations determined in the design method statements or specifications.
c) Potential of steel/concrete with respect to the anode system.
d) Any base line data from additional sensors installed as part of the performance monitoring system.
e) Proving of any electronic data logging and/or data transmitting facility installation as part of the performance monitoring system.

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8.3 Initial energizing

The system shall not be energized until any cementitious overlay has been adequately cured or any conductive coating has achieved adequate solvent release/cure.

NOTE: For cementitious overlays this period normally corresponds to 14 days after placement at a temperature of 20 °C. For conductive coatings this period will normally correspond to 48 hours with adequate ventilation.

The cathodic protection system shall be energized initially at low current (about 10 % to 20 % of current capacity). Measurements shall be made and recorded in accordance with the quality plan (see clause 4) and shall include the following:

a) the potential of the steel/concrete with respect to all permanently installed reference electrodes and with respect to portable reference electrodes at any locations determined in the design method statements or specification;
b) the output voltage and current values of all d.c. power supplies providing current to the cathodic protection systems;
c) confirmation that the polarity of all values conform to the quality design and that the steel/concrete potentials, measured with respect to all permanently installed reference electrodes, potential decay sensors and to any portable electrode locations measured, shift in a negative direction from the values measured in accordance with 8.2 a) and b). If any steel/concrete/electrode potential values shift in a positive direction, they shall be investigated to determine any requirements for additional testing and/or remedial works.

8.4 Initial adjustment

The system shall be energized to a level of current estimated to enable the cathodic protection system to meet its performance objectives. See notes 1 and 2.

NOTE 1: This may be a pre-calculated level of current (e.g. a particular cathode current density) or it may be based upon the response of the system when first energized (e.g. to achieve a negative potential shift of 200 mV or 300 mV measured with the current on).

NOTE 2: Slow polarization at relatively low current density may be beneficial.

The period of initial polarization for which these initial settings of current shall be maintained prior to initial performance assessment shall be sufficient, based upon previous experience, to achieve significant polarization.

NOTE 3: The period is typically between 7 days and 28 days after initial energization although, if a slow polarization energizing policy (low initial current) is adopted, full polarization may require longer than 28 days.

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8.5 Initial performance assessment

After the period of initial polarization (see 8.4), the initial performance assessment shall be undertaken in accordance with the quality plan. This assessment shall include the following:

a) Measurement of output voltage and current supply to each zone of the cathodic protection system and the calculation therefrom of circuit resistance.

b) Measurement of 'instantaneous off' (IR free) potentials at all permanently installed reference electrodes and any other locations indicated in the quality plan a short period after switching open circuit the d.c. power supply to the cathodic protection system.

NOTE 1: Typically, measurements of ' instantaneous off' are taken between 0,1 s and 0,5 s after switch 'off ' but appropriate values will vary from system to system and with the extent/period of polarization. The measurement period (for digital 'counting') should be sufficiently short to avoid significant depolarization during the measurement period but of sufficient length not to degrade the accuracy or noise rejection capability of the measurement system. Whilst the typical measurement periods are between 0,1 s and 0,5 s, calibration and other instrumentation calculation steps may dictate a longer period than this between subsequent measurements.

After switching 'off' for 'instantaneous off' (IR free) potential measurements, sufficient time shall be allowed before measurement to avoid any transient voltage arising from switching surges, capacitance or resistance effects that would affect the measured values but this waiting period shall be sufficiently short to avoid significant depolarization.

c) Measurement of potential decay after switching the cathodic protection d.c. supply to constant open circuit. The period of potential decay and the intervals for measurements of steel/concrete/electrode potentials shall be as indicated in the quality plan.

NOTE 2: Typical periods of decay are 4 to 25 h with measurements taken at some or all of 0,5 h, 1 h, 2 h, 3 h, 4 h, 23 h, 24 h and 25 h after switch off as appropriate to determine the extent of potential decay and the rate of any ongoing decay at the end of the selected period. Rates of potential decay will decrease with increasing periods of polarization.

d) Measurement of parameters from all other sensors installed as part of the performance monitoring system.

e) Measurement of 'on' steel/concrete potentials (including IR drop) if required in the quality plan.

NOTE 3: During measurement of instantaneous off potentials it may be necessary to switch the d.c. power circuit off and on to facilitate sequential measurements of a number of steel/concrete/electrodes.

The off:on ratio of any such switching regime used for 'instantaneous off' potential measurements shall be a minimum of 1:4

NOTE 4: Typical values for manual data collection are 3 s off, 12 s on. For electronic data collection it is advantageous to link the data logging system to the switching system in order that measurement waiting periods and measurement periods are accurately related to the instant of switch off. Longer switching periods would slow data collection and risk depolarization during the off period.

8.6 Criteria of protection : Interpretation of performance assessment data

The data collected in accordance with 8.5 shall be reviewed and interpreted in respect of the following or such criteria as modified by the particular requirements of the structure, its environment or developing expertise in respect of criteria of protection for steel in concrete.

No instant off steel/concrete potential more negative than –1 100 mV with respect to Ag/AgCl/0,5 M KCl shall be permitted for plain reinforcing steel or –900 mV for prestressing steel.

NOTE 1: Prestressing steel may be sensitive to hydrogen embrittlement and, due to the high tensile loading, failure can be catastrophic. It is essential that caution is exercised in any application of cathodic protection to prestressed elements.

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For any atmospherically exposed structure, any representative point shall meet any one of the criteria given in items a) to c).

a) An instant off potential (measured between 0,1 s and 1 s after switching the d.c. circuit open) more negative than –720 mV with respect to Ag/AgCl/0,5 M KCl.

b) A potential decay over a maximum of 24 h of at least 100 mV from instant off.

c) A potential decay over an extended period (typically 24 h or longer) of at least 150 mV from the instant off subject to a continuing decay and the use of reference electrodes (not potential decay sensors) for the measurement extended beyond 24 hours.

NOTE 2: In systems where activated titanium anodes are used, the steel/concrete potential limit (-1 100 mV or –900 mV) as above may be verified by measurement of the anode/concrete potential and the transformer-rectifier output voltage, taking account of cable volt drop values.

NOTE 3: Criteria, a), b) and c) are not necessarily supported by theoretical considerations but are a non-exhaustive, practical series of criteria to indicate adequate polarization which will lead to the maintenance or re-establishment of protective conditions for the steel within the concrete.

NOTE 4: As an investigation criterion it may be considered appropriate to seek a potential on a fully depolarized electrode after the cathodic protection system has been switched off for a long period (typically 7 days or longer) less negative than -150 mV with respect to Ag/AgCl/0,5 M KCl.

NOTE 5: These criteria, as discussed in items a), b) and c) above, may be disrupted by the presence of concrete repairs encompassing reinforcement within 0,5 m of the point of measurement of potential. This should be avoided by locating reference electrodes and other sensors away from concrete repairs wherever possible.

NOTE 6: The criteria given in items b) and c) above may be invalidated by variations in temperature, and moisture content between the first and second measurements. Such variations, themselves, can be the cause of significant changes in steel/concrete potentials.

8.7 Adjustment of protection current

If the interpretation of the performance assessment data in accordance with 8.6 indicates that the criteria of protection are achieved no immediate measures are necessary, subject to the requirements of clause 10. If the criteria of protection are not achieved or are judged to be at risk of not being achieved in the future, further adjustments of the current output shall be made, to be followed, a minimum of 28 days thereafter, by repeat performance assessments as specified in 8.5 and 8.6.

NOTE: It is emphasized that long-term polarization arising from long term cathodic protection will result in a reduction in the requirement for current and a reduction in the rate of potential decay occurring when switching off the system.

9 System records and documentation

9.1 Quality and test records

The quality plan, the quality documents arising therefrom and the visual inspection and test results shall all form part of the permanent records of the installation of the system.

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9.2 Installation and commissioning report

An installation and commissioning report for the cathodic protection system shall be prepared and shall incorporate as a minimum the following.

a) A general description of the works, the parties associated with the works [e.g. client, design engineer, supervising engineer, contractor, subcontractor(s)] and the key personnel responsible for the design, supervision and commissioning of the cathodic protection system and their respective responsibilities.

b) A copy of the method statements and/or specification and drawings in accordance with which the system was installed and commissioned indicating all deviations or variations therefrom and a copy of the design data calculations [see 4.3 a)] if available.

c) A detailed description of the installation and commissioning works including key data.

d) As-built drawings detailing the installation and its components in sufficient detail to facilitate all future requirements for inspection, maintenance, and reconstruction of the system and its major components.

e) All measurements/test data taken before and while the system was energized and during the initial system performance assessment, together with the performance assessment data used and the interpretation of the data.

f) A record of the ‘as left’ operating conditions of the system.

g) A copy of the permanent records (specified in 9.1).

h) Recommendations for any revisions to the cathodic protection system.

NOTE: Other documents may also be included as considered necessary.

9.3 Operation and maintenance manual

An operation and maintenance manual for the cathodic protection system shall be prepared and shall incorporate as a minimum the following.

a) A detailed description of the system and a set of the ‘as built’ drawings.

b) Details of recommended routine maintenance and inspection intervals and procedures (see clause 10).

c) Recommended intervals and procedures for future performance assessments and the interpretation of the data therefrom.

d) Proformas or computer data formats for all recommended routine maintenance, inspection and performance assessment activities.

e) Error finding procedures for errors within the cathodic protection electrical power supply (a.c. and d.c.), and for short circuits and open circuits in the cathodic protection system.
Maintenance/repair procedures for the electrical power supply equipment, any data logging/control equipment and the anode system with any overlay, sealant or decorative coating.

g) A list of the major components of the cathodic protection system with data sheets and the source(s) of spare parts and/or maintenance for these components and for the overall system.

NOTE: Other information may also be included as considered necessary.

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10 Operation and maintenance

10.1 Intervals and procedures

The operation and maintenance inspection and testing intervals and procedures shall be as recommended in the operation and maintenance manual (see 0) or as subsequently modified based upon performance of the system.

NOTE 1: The intervals and procedures for routine inspection and testing vary from one cathodic protection system to another dependant upon, the structure type, the cathodic protection system type, the reliability of power supplies, the environment and the vulnerability to accidental or deliberate mechanical or electrical damage.

Those systems provided with electronically data logged or electronically data transmitted performance monitoring systems may require less frequent physical inspection as the routine testing can be undertaken automatically.

It can be considered to extend the intervals between routine inspection and testing if no errors, damage or significant variation in system performance are indicated by successives inspections/tests.

NOTE 2: Long periods of satisfactory operation result in significant polarization and repassivation of the steel in concrete.

Routine inspection procedures shall be as follows:

a) Functional check of the following:
   1. Confirmation that all systems are functioning;
   2. Measurement of output voltage and current to each zone of the cathodic protection system.
   3. Assessment of data.

b) Performance assessment of the following:
   1. Measurement of ‘instantaneous off’ polarized potentials;
   2. Measurement of potential decay;
   3. Measurement of parameters from any other sensors installed as part of the performance monitoring system;
   4. A full visual inspection of the cathodic protection system;
   5. Assessment of data;
   6. Adjustment of current output.

All inspections and testing shall be in accordance with clause 8.

NOTE 3: Typically, the functional check shall be undertaken monthly in the first year of operation and, subject to satisfactory performance, thereafter at 3 month intervals. Typically the performance assessment shall be undertaken at 3 month intervals in the first year of operation and, subject to satisfactory performance and review at 6 month to 12 month intervals thereafter.

NOTE 4: At concrete temperatures below 0 °C potential monitoring may be impossible. The dates for performance monitoring should be selected to avoid measurements at such cold weather.

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10.2 System review

The inspection and testing works shall comprise the following at maximum intervals of 12 months:

a) a review of all test data and inspection records since the previous review;

b) performance assessment in accordance with 10.1 b);

c) visual inspection of the cathodic protection system

d) a review and interpretation of the data generally in accordance with clause 8;

e) adjustment of the current output if necessary in accordance with clause 8;

f) preparation of a system review report in accordance with 10.3.

10.3 System review report

The report shall detail the following:

a) the work undertaken;

b) the data collected;

c) recommendations for any changes to the operation and maintenance or system review intervals and procedures;

d) recommendations for any changes to the cathodic protection system.

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Annex A (informative)

Principles of cathodic protection and its application to steel in concrete

A.1 General

Steel in concrete is usually protected against corrosion by passivation of the steel arising from the high alkalinity of the pore solutions within the concrete. A stable oxide layer is formed on the steel surface which prevents the anodic dissolution of iron. The necessity for additional protective measures arises if this stable oxide layer is rendered unstable (if depassivation occurs) due to the ingress of chlorides to the steel/concrete interface or carbonation of the concrete reducing the alkalinity of the pore solution at the steel/concrete interface.

In the case of chloride contamination of concrete, the chloride ions initiate depassivation which leads to corrosion if there is access of oxygen to the remaining passive areas.

Depassivation and hence corrosion can be obtained by the establishing of a specific steel/concrete potential, the pitting potential E_{pit}. At potentials more positive than E_{pit} a sharp increase in the iron dissolution rate leads to high corrosion rates in small localized areas of the steel surface whereas, at lower potentials than E_{pit} (i.e. more negative) the corrosion rate decreases. The objective of cathodic protection is to shift the steel/concrete potential into a region where:

a) the initiation of corrosion; or

b) if corrosion has already started, the continuation/propagation of corrosion;

is so far suppressed that a corrosion failure is unlikely during the lifetime of the structure.

In the case of reinforced concrete a corrosion failure can include cracking and delamination of the covering concrete which may arise from as little as 50 µm of metal loss from an area of reinforcement, due to the bursting stresses generated by high volume corrosion products.

In steel reinforced concrete structures cathodic protection can be achieved by polarizing the reinforcement with an ‘external’ current. For this purpose anodes are surface mounted, painted on to or embedded in the concrete and connected to the positive pole of a d.c. power supply in the case of impressed current protection. Some applications of sacrificial (galvanic) anode cathodic protection have been reported as successful in lower resistivity concretes; no d.c. power supply is required for such applications as the preferential corrosion of the sacrificial anode (typically zinc) provides the ‘external’ current for cathodic protection.

The system cathode is formed by the steel reinforcement. In the case of impressed current, the negative pole of the d.c. power supply is connected to the steel reinforcement. In the case of sacrificial anode cathodic protection the sacrificial anode (typically zinc) is connected directly to the steel reinforcement.

The concrete, in particular the pore solution, provides the electrolyte to allow current flow and the associated ionic movement. The change of steel/concrete potential is indicated by electrodes which are embedded in the concrete or placed on the surface of the concrete and used, in conjunction with suitable instrumentation and connections to the reinforcement, to measure steel/concrete/electrode potentials.

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A.2 Criteria for Protection

If environmental conditions which favour the occurrence of corrosion of the reinforcement are likely to occur during the lifetime of the structure, or occur during service, cathodic protection is one method of preventing corrosion of steel in concrete. Sufficient corrosion protection is given if specific criteria of protection are met at representative points on the structure. The criteria of protection in this standard are based on electrochemical considerations regarding corrosion processes and on practical experience.

In practice two cases are distinguishable. If the aim of cathodic protection is improvement of the corrosion resistance of steel in reinforced and prestressed concrete structures that are expected to become contaminated by chlorides during their service life, a small cathodic polarization of the steel/concrete interface should be applied from early in the service life. This polarization should maintain the steel/concrete potential lower than (more negative than) E_{pit} to prevent the initiation of corrosion. The negative polarization achieved also limits or prevents migration of the chloride ions to the steel reinforcement thereby preventing them from depassivating the steel if the cathodic protection anode system is on the surface through which the contamination will arise. This precautionary protection measure is sometimes called ‘cathodic prevention’ and applies to new structures or structures in service where the chloride ions have not reached the steel and depassivation has not yet occurred.

In older structures with corroding steel reinforcement, cathodic protection is part of the rehabilitation concept and is aimed at decreasing the corrosion rate of the reinforcement from significant to negligible values. For this purpose the steel/concrete potential should be lowered to values in the range of the protection potential E_{prot}. The corrosion potential E_{corr} and the protection potential E_{prot} are dependent upon environmental conditions (chloride content, pH at local anodic sites, temperature, oxygen content, humidity). Based upon the complex interaction of these factors and also practical experience the definition of one typical protection potential is impossible and also unnecessary for cathodic protection of steel in concrete.

It is this complex interaction of factors that dictates that a range of criteria are properly required for cathodic protection of steel in concrete as is reflected in 8.6.

Figures A.1 to A.3 illustrate these factors.

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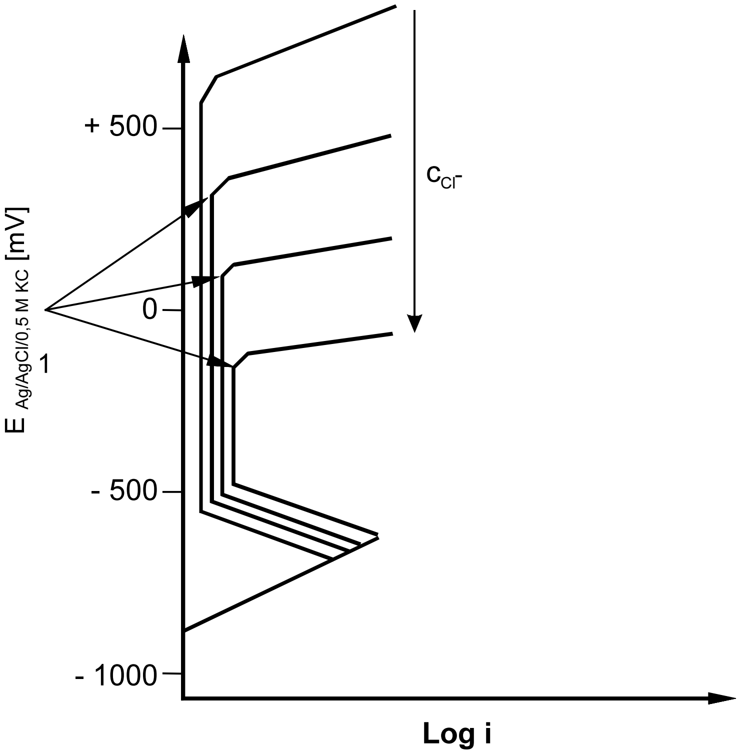
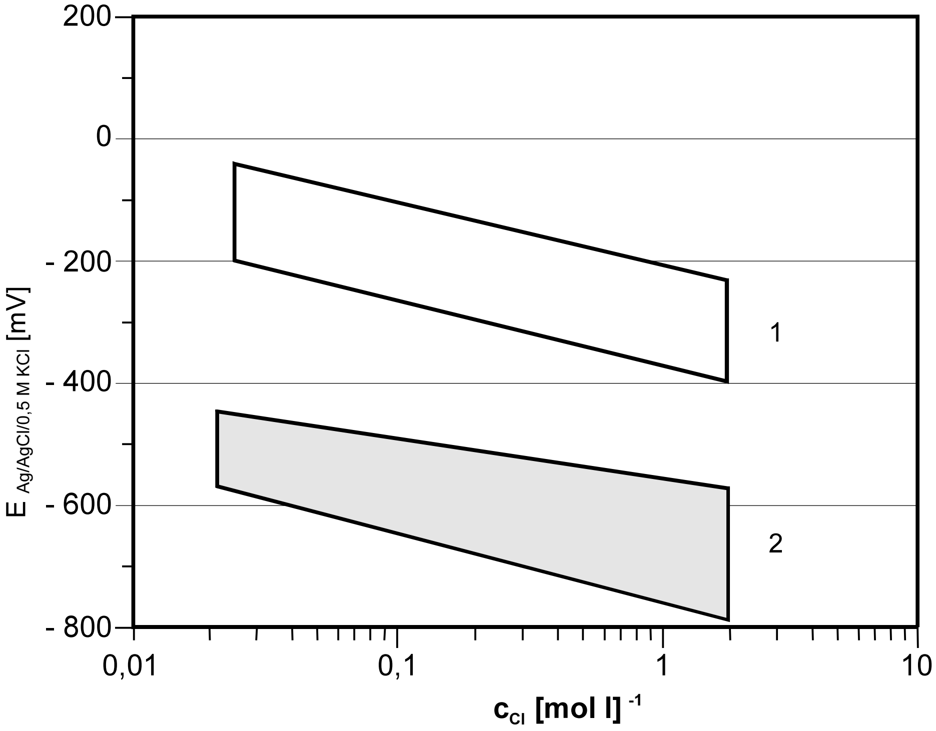


Key

1 E_{pit}

Figure A.1 - Schematic illustration of the anodic behaviour of steel in the presence of chloride



Key

1 E_{pit}
2 E_{prot}

Figure A.2 - Values of E_{pit} and E_{prot} measured on steels buried in sand, covered with saturated $Ca(OH)_2$ solution (pH = 12,6) at 20 °C, after Pedeferri [2]

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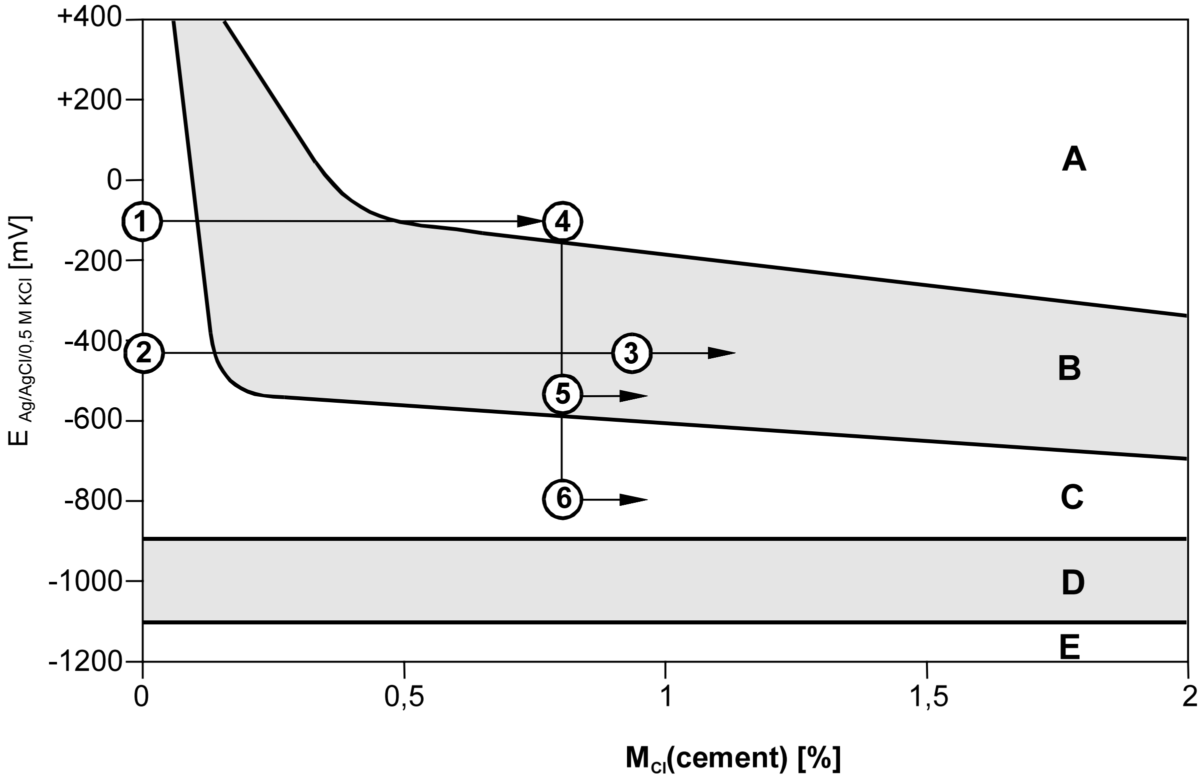

Schematic illustration of evaluation paths of potential and chloride content on steel reinforcement surface during service life for:

Area A:	Pitting initiates and propagates
Area B:	Pitting does not initiate but propagate
Area C:	Pitting does not initiate and propagate
Area D:	Hydrogen embrittlement risk to high strength steels
Area E:	Reduction of steel/concrete bond.

Cathodic Prevention (1 → 2 → 3)
Cathodic Protection restoring passivity (1 → 4 → 5)
Cathodic Protection reducing corrosion rate (1 → 4 → 6)

Cathodic Prevention is applied from the beginning at 1, Cathodic Protection only after corrosion has initiated at 4.

Figure A.3 - Pitting Potential vs. Chloride Content in weight % of cement, after Pedeferri [2]

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A.3 Current density required for ‘cathodic prevention’ and ‘cathodic protection’

‘Cathodic prevention’ current density is approximately one order of magnitude lower than that required for cathodic protection. This is not only because the steel/concrete potentials required for cathodic prevention are less negative than those required for cathodic protection but also because passive steel is more easily polarized.

Typical cathodic prevention current densities range between 0,2 mA/m² and 2 mA/m² compared with 2 mA/m² to 20 mA/m² for cathodic protection on uncoated steel. For organic coated steel these current densities are reduced further as determined by the coating conductance and the extent of any coating damage. Coating deterioration may continue.

A.4 Prestressing steel and the risk of hydrogen embrittlement

Due to the possible occurrence of hydrogen embrittlement high strength steels should not be exposed to a potential more negative than -900 mV (SCE). Prestressing steel may be sensitive to hydrogen embrittlement and, due to the high tensile loading of prestressing members, failure can be catastrophic. It is essential that caution is exercised in any application of cathodic protection to prestressed elements.

A.5 Alkali Silica Reaction

Cathodic protection applied in accordance with this standard has been demonstrated to have no influence on alkali silica reaction/alkali aggregate reaction (ASR/AAR).

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Annex B (informative)

Design process

B.1 Conceptual design

Following feasibility assessment and confirmation of cathodic protection as the repair option, perform preliminary location and sizing of anode zones, based on factors including, but not limited to, concrete chloride content, concrete resistivity, concrete moisture content, reinforcement surface area, distribution and estimated current demand, lifetime requirements, service environment, weight, installation sequence and constraints; similarly give preliminary consideration to anode type, cable routing and possible transformer-rectifier location(s).

B.2 Anode system type

Using the reinforcement surface area and distribution and assumed or measured cathodic current density for desired level of protection, calculate the cathodic current requirements and then the operating anodic current density on each anode. Use this value to confirm the anode type, taking into account the factors given in B.1 to select the overlay material where appropriate.

B.3 Anode system layout

Plan the anode zone size and layout and calculate the feeder spacing to ensure that local cathode current requirements are met and to minimize the voltage differentials within zones. Select the primary anode material and cross section, its distribution and primary anode/'positive cable' connections to provide the required redundancy and to minimize voltage drops.

B.4 Current provision

Using the operating current demand and reserve capacity required, calculate the total current provision.

Typical current demands are 2 mA/m² to 20 mA/m² (of steel) for steel in chloride contaminated concrete (for cathodic protection) and 0,2 mA/m² to 2 mA/m² for passive steel in non-chloride contaminated concrete (for cathodic prevention).

Due to polarization (chemical changes at and around the steel/concrete interface) the current demand for cathodic protection will decline with time.

The reinforcement closest to the anode, will receive a higher cathode current density than steel more remote from the anode.

B.5 Reinforcement connections

Design the connection to the reinforcement, both for current circuits and for monitoring circuits, and calculate the number and location of connections to provide required redundancy and to minimize voltage drops.

B.6 Cabling

Determine the cross-sectional areas and routes for positive and negative cabling to provide redundancy and to minimize voltage differences, similarly, determine the locations of any junction boxes.

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B.7 Transformer-rectifier

Based on operating current and reserve capacity, use circuit resistance to calculate transformer-rectifier output voltage; also determine ancillary transformer-rectifier facilities required for monitoring etc. and to provide a.c. supply requirements.

B.8 Monitoring

Determine the type, frequency and positions of sensors and the appropriate instrumentation for the level of monitoring and control required; also determine the data management requirements.

B.9 Documentation

Document the design, specification of materials/components, the installation procedures and layout of the system, along with the quality plan detailing the testing required at various stages of the work and the commissioning procedure.

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Annex C (informative)

Notes on Anode Systems

C.1 Conductive Coatings

C.1.1 Organic Coatings

The coating may be suitable for application by brush, roller or airless spray.

Conductive coatings generally operate at a current density of up to 20 mA/m² although for short periods (i.e. weeks) current densities of up to 30 mA/m² may be sustained without significant damage to the coating or its interface with the concrete. Conductive coatings vary in performance but have a range of anticipated life time of 5 years to 15 years if properly applied. They are susceptible to environmental factors and do not withstand continuous wetting. They are not suitable for marine applications unless well above the splash and spray zone and are unlikely to perform well in areas of permanent condensation. They do not withstand wear or abrasion. They may be protected or planned regular recoating may be appropriate in environments where they are subjected to wear or abrasion.

As the coating and its interface with the concrete ages small defects appear. Isolated defects of typically smaller than 100 mm x 100 mm per m² do not affect performance but deterioration may accelerate.

No defects other than pinholes should be observed after installation. Localized defects may rapidly occur after energizing due to local high current density requirements. These can be repaired within a few months of initial energizing and, due to progressive polarization and reduction in localized current demand, these repair areas may perform adequately for the remaining life of the system.

Organic conductive coatings are normally applied to a dry film thickness in the range 0,25 mm to 0,5 mm.

The carbon conductor in the coating is consumed by the anodic reaction, but the amount of carbon available should be well in excess of both that required for conduction and the theoretical amounts required for the full lifetime. The normal failure mechanisms are loss of adhesion and flaking of the coating due to anodic reaction products (acidic) attacking the concrete, or local wetting leading to disbondment.

C.1.2 Metallic Coatings

Conductive coatings of thermally sprayed zinc applied by arc or flame spraying may be used as anodes for cathodic protection of steel in atmospherically exposed concrete. Aluminium zinc indium alloys as well as titanium subsequently activated with a strong oxidizing agent have been used in trials.

Multiple connectors are used with typically one per 10 m².

There is an optimum thickness for metallic zinc applied to concrete which for arc spraying is in the range from 0,15 mm to 0,2 mm. Thicknesses below the optimum result in short life and/or resistive coatings. Applications above the optimum thickness result in poor adhesion to the concrete.

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The current density and life performance of thermally sprayed zinc are similar to those for conductive organic coatings given in C.1.1. The significant differences are that the performance of thermally sprayed zinc may be superior to conductive organic coatings when applied to concrete surfaces which are somewhat moist as the thermally sprayed zinc coatings appear to have a greater tolerance to these application conditions. However, the calculated ampere hour capacity of 0,2 mm thickness of zinc is less than 6 years at 20 mA/m², considerably less than the calculated capacity of carbon in conductive organic coatings.

Thermally sprayed zinc has been successfully used as a sacrificial (galvanic) anode in limited trials in warm marine applications. The application is directly to exposed reinforcement and concrete cover.

C.1.3 Activated Titanium

The life of the coating is determined by its composition and the amount of coating deposited on the substrate, the ‘coating loading’.

Test procedures are available for this anode type which enable accelerated testing to demonstrate that the anode life is equivalent to the design life at the maximum design anode current density plus any safety margin determined necessary by the design in respect of possible non-uniform distribution of current.

For all forms of anode of this type, a minimum anode/reinforcement path length of 15 mm should be maintained.

The titanium substrate may be in the form of an expanded mesh, a strip, wire, tube, etc. as required by the design and the magnitude and distribution of current. The coatings are proprietary, wholly or in part protected by patents and frequently their composition is not disclosed.

Activated titanium anodes may be operated at current densities of up to 400 mA/m² of anode surface area for short periods; the limiting factor is acid attack of the surrounding concrete. Generally the anode current density is limited by design to a long-term maximum of 110 mA/m² but for short-term periods (i.e. months) current densities of up to 220 mA/m² may be permitted. Dependent upon electrocatalytic coating loading, the calculated life of the anode is in the range 25 years to 100 years. Anode life-time should be determined considering a non-uniform current distribution.

Surface mounted activated titanium mesh and grid anodes require cementitious overlays and the surface preparation, pre-treatment, design and application of the cementitious overlay is critical to the total performance of the system (see clauses 6 and 7). Some failures have occurred due to disbondment of the overlay; these failures are generally accepted to be attributable to deficiencies in substrate surface preparation, pre-treatment and/or application procedures not related to cathodic protection.

C.1.4 Other Anode Systems

C.1.4.1 Conductive Overlays

Track record of successful long-time use of conductive asphalt overlays in North America, since the late 1970s can be obtained from the Ontario Ministry of Transportation.

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C.1.4.2 Conductive Polymers

Conductive polymers have been used in several forms. One form is used as a backfill in slots cut into the concrete with primary anode wires of electrocatalytic or platinum coated titanium or niobium and secondary anodes of carbon fibres applied. The reported durability is poor. A related form utilises the same anode materials and mounts them on to the concrete surface with a concrete overlay. This system has minor advantages by way of a greater anode surface area.

A conductive polymer overlay has been applied experimentally to decks and a sprayed version has been applied to substructures.

Conductive polymer cable anodes were widely used but have been withdrawn from the market following significant failures.

C.1.4.3 Conductive Ceramics

Conductive ceramics have been used in tile form in trials since 1987. These were fitted to the concrete surface and current was distributed to them using titanium strips. The material was durable but this method of application has not been commercialized.

This material is now available as a tubular anode for embedded applications.

C.1.4.4 Conductive Cementitious Materials

Conductive cementitious anodes have been used containing either granular carbon and carbon fibre with a metallic coating as the conductive medium.

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Bibliography

[1] ASTM B 338-83: Seamless and welded titanium alloy tubes for condensers and heat exchangers (Grade 1 for anode grade titanium) 1995

[2] P. Pedeferri, Cathodic Protection and Cathodic Prevention, Construction and Building Materials, Vol. 10, No. 5, p. 391 - 402, 1996

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