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Corrosion & CP Specialists

Assessment, Monitoring and Investigation of Existing Galvanic Anode Corrosion Mitigation Systems for Atmospherically Exposed Reinforced Concrete

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Content

SECTION 1 OVERVIEW

This document has been developed and published by SegCorr Ltd, to provide guidance to owners and operators, on how to evaluate existing galvanic anode based, corrosion mitigation systems which have been installed onto / into atmospherically exposed reinforced concrete structures.

It is recommended that owners and operators appoint technical specialists who hold certification to BS EN ISO 15257 Competence Levels and Certification of Cathodic Protection Personnel level 4 for concrete, to lead and support the assessment, monitoring and investigation activities as detailed herein.

SECTION 2 CORROSION MITIGATION VS CORROSION CONTROL AND CORROSION PREVENTION

2.1 Corrosion mitigation systems

For the purposes of this document, galvanic corrosion mitigation systems are defined as systems installed to slow down the rate of structural deterioration of atmospherically exposed reinforced concrete structures.

Typically, these systems are not designed to meet the criteria listed within BS EN ISO 12696 Cathodic Protection of Steel in Concrete section 8.6, or are not installed with monitoring equipment as per the requirements of BS EN ISO 12696.
If monitoring equipment is provided, these systems do not necessarily meet the requirements listed within BS EN ISO 12696 for demonstrating full cathodic protection.

Under these circumstances additional risk based assessment of the structural element is required to ensure that the rate of deterioration, is acceptable or to identify when addition remediation or strengthening measures are required.

Corrosion mitigation systems are most suitable for low risk, easily accessible structures such as abutment walls and piers, which support direct access to the structure and enable risk based assessment and future remediation activities.

They are less suitable for structural components, such as half joints, bearing shelves and other difficult to access and structurally critical areas where the consequences of ongoing corrosion are more significant and where detailed assessment is difficult or impossible.

Risk based assessment is required following the installation of galvanic anodes in order to evaluate the extent of corrosion mitigation, to identify the onset of any reinforcement corrosion and to assess the progression of any structural deterioration.

2.2 Corrosion control systems

Corrosion control systems are used to control the rate of corrosion of the embedded reinforcement within structures to a level that will stop or make negligible, structural deterioration associated with reinforcement corrosion.

These systems are designed in accordance with BS EN ISO 12696 Cathodic Protection of Steel in Concrete, installed with embedded monitoring equipment and are wired up to enable testing and evaluation against the performance criteria within BS EN ISO 12696.

Evidence of compliance with the specific protection criteria listed within BS EN ISO 12696, demonstrates effective cathodic protection and corrosion control of the embedded reinforcement.

BS EN ISO 12696 has three criteria that demonstrate protection (criteria a to c). Criterion b (100mV decay over 24 hours) is the commonest applied to atmospherically exposed steel in concrete.

Under these circumstances the monitoring evidence can be used to demonstrate corrosion risk mitigation and corrosion risk control, under continuous exposure to aggressive environments, without the need for additional risk based inspection and assessment.

Risk based inspection and deterioration assessment resulting from other non-corrosion related deterioration may still be required.

SECTION 3 TYPES OF CORROSION MITIGATION SYSTEMS

Galvanic corrosion mitigation systems can be divided into two groups, based on the area of protection and application method.

- Galvanic patch repair enhancers
- Galvanic corrosion mitigation systems

These techniques promote electrochemical reactions on the embedded reinforcement surfaces, which slows corrosion, reducing the rate of reinforcement section loss and the associated expansive corrosion product formation, thereby reducing the risk of cracking and spalling of the concrete.

3.1 Galvanic anode - patch repair enhancers

Galvanic anode repair enhancers for atmospherically exposed reinforced concrete are installed into concrete repairs to provide localised corrosion mitigation of the reinforcement within the undamaged, typically chloride contaminated parent concrete immediately adjacent to the concrete patch repair.

The galvanic anodes installed within the repair provide localised corrosion deterioration mitigation, by reducing the rate of corrosion of the steel within the old undamaged chloride contaminated concrete and inhibit the formation of concentration cells (incipient anodes)[1] in the area immediately adjacent to concrete patch repairs.

Reinforcement embedded in old undamaged chloride contaminated concrete away from the active anode surface and the patch repairs, may not receive any benefit and may corrode. The rate of corrosion will be dictated by environmental exposure, anode composition and material resistivity conditions. If corrosion occurs and expansive corrosion products reach critical levels, then concrete cracking followed by concrete spalling can be expected to occur.

Galvanic anode patch repair enhancing systems include discrete galvanic anodes which are fixed and made electrically continuous to the reinforcement within the concrete repair areas and are then fully embedded within the new repair concrete or installed adjacent to the repair within the undamaged parent concrete surrounding the patch repair.

Other systems are based on providing a zinc rich coating or metallic zinc foil directly to the exposed reinforcement within the concrete repair areas which are then fully embedded within the new repair concrete.

Due to the localised nature of concrete patch repair which include galvanic anode enhancers, these systems are typically not provided with any monitoring facilities.

3.2 Galvanic anode - corrosion mitigation systems

Galvanic anode corrosion mitigation systems for atmospherically exposed reinforced concrete are typically installed over larger areas of the un-damaged but chloride contaminated structures and are not restricted to concrete repair areas.

Galvanic anode corrosion mitigation systems consist of either embedded anode types or surface mounted anode types.

- Embedded types consist of individual galvanic anode elements which are installed into drilled holes or fixed onto exposed reinforcement cages of old structures and embedded within the structure using purposely formulated cementitious repair material and connected to the embedded reinforcement.

- Surface applied types consist of either adhesive metallic foil, thermally applied metallic coatings or zinc/zinc alloy rich particles bound within an organic coating system, which are applied or fixed directly to the concrete surfaces and connected to the embedded reinforcement.

3.2.1 Embedded anode systems

The embedded types are effective in the areas adjacent to the active anode surface into the old undamaged concrete and provide localised corrosion deterioration mitigation within undamaged chloride contaminated concrete and inhibit the formation of concentration cells (incipient anodes).

Reinforcement embedded in old undamaged chloride contaminated concrete, which are away from the active anode surface may not receive any benefit and may corrode. The rate of corrosion will be dictated by environmental exposure, anode composition and material resistivity conditions. If corrosion occurs and expansive corrosion products reach critical levels, then concrete cracking followed by concrete spalling can be expected to occur.

Typically, these anodes are installed into a grid configuration, with each anode connected either directly to the reinforcement or wired together to form anode zones. Anode sizing and spread recommendations can be found in the manufacturer's literature or can be calculated by a suitably qualified and experienced cathodic protection designer.

Historically these systems, have been installed without monitoring facilities. However, in order to meet the requirements of BS EN ISO 12696, embedded monitoring probes, anode test panels or other testing and monitoring facilities are required, to enable system performance assessment.

3.2.2 Surface applied anode systems

The surface applied systems are applied directly to the concrete surface and can be divided into three main categories:

- Adhesive lined foil – fixed to the concrete surface
- Thermal applied metallizing – molten metal droplets sprayed directly onto the concrete surfaces
- Organic based coating systems containing zinc or zinc alloy particles – brush or airless spray applied directly to the concrete surfaces

The surface applied anode types are effective from the surface of the anode into the old, undamaged concrete and provide localised corrosion deterioration mitigation within undamaged chloride contaminated concrete and inhibit the formation of concentration cells (incipient anodes).

The surface applied anode types are most effective for reinforcing close to the concrete surface and may be less effective for deeper reinforcement.

In addition to the electrochemical reactions which occur on the embedded reinforcement surfaces, these systems provide additional barrier effects between the external environment (water, oxygen and chlorides) and the concrete.
Both effects act to slow down the corrosion of the embedded steel, reducing the rate of expansive corrosion product formation, thereby preventing cracking and spalling of the concrete.

These systems can be applied to localised areas or over the entire concrete surface, with connections made directly to the reinforcement using surface mounted connection plates or wired up to form anode zones.

Historically these systems are installed without monitoring facilities. However, in order to meet the requirements of BS EN ISO 12696, embedded monitoring probes, anode test panels or other testing and monitoring facilities are required, to enable system performance assessment.

SECTION 4 ASSESSMENT AND MONITORING OF GALVANIC CORROSION MITIGATION SYSTEMS

The main objective of galvanic corrosion mitigation systems is to slow down the deterioration of reinforced concrete structures. They are not intended to fully stop or prevent reinforcement corrosion under prevailing conditions, and as such do not achieve full cathodic protection as defined within BS EN ISO 12696.

These systems which include galvanic patch repair enhancers and galvanic mitigation systems are not normally compliant with BS EN ISO 12696 for assessing corrosion mitigation and corrosion control and as such, conventional[2] risk based structural and concrete inspections (as referenced in TR60[3] and BA35[4]) are the only way to evaluate the benefit of these systems and help identify when additional structural maintenance is required.

4.1 Assessment and monitoring options – embedded galvanic anodes

Embedded galvanic anodes may have an influence on conventional deterioration assessment techniques such as corrosion potential mapping, cover surveys, chloride sampling, and corrosion rate measurements. It is vital to retain as-built records of where the anodes have been installed to reduce the risk of misinterpretation of data.

Where existing galvanic anode systems have been installed then it is recommended that the following assessment techniques are used where applicable.

4.1.1 Visual survey

Visual assessment of the entire structure should be undertaken, with emphasis on existing patch repairs, noting any evidence of cracking, water or rust staining, deposits or other surface discoloration. A visual survey from ground level using binoculars where necessary should be undertaken at a two-year interval, with a close up "touching distance" survey every 6 years or as recommended by suitably qualified and experienced personnel (e.g. as defined under IAN 192/16[5] for bridge inspectors). The two and six year intervals align with the requirements for inspection of highway structures on the strategic road network as defined in BD 63/17[6] although that can be adjusted as described in IAN 171[7] for risk based inspections.

4.1.2 Delamination survey

Delamination surveys of the entire structure should be undertaken, with emphasis on areas surrounding the existing patch repairs, identify and noting any delaminated areas. This should be carried out with the "touching distance visual survey".

4.1.3 Cover surveys

Cover surveys are required for the interpretation of chloride profile and the location of reinforcement for subsequent investigations. Conventional cover meters may not identify the location of existing embedded galvanic anodes, specialist equipment may be able to identify existing anode locations (e.g. Hilti PS 1000).

For all equipment, it is recommended that a site calibration is conducted prior to use. This may include locally exposing reinforcement or embedded anodes and measuring the actual cover depth and bar or anode dimensions to ensure accuracy of the measurements.

Concrete cover and embedded anode locations will not change with time, so repeated cover surveys are not normally required at each visit.

4.1.4 Corrosion potential

When carrying out corrosion potential surveys (to ASTM C876 [8] and Concrete Society TR60), galvanic anodes and the steel reinforcement close to and connected to the anodes can be expected to present a more negative potential, following anode installation and in the early life of the repair, compared with the reinforcement potentials, prior to anode installation and concrete repairs. With time, a positive potential shift may be expected following anode consumption and localised re-passivation of the reinforcement.

Corrosion potential assessment of the structure should be instigated at the same six yearly intervals as for the “touching distance visual survey”, specifically noting locations and dimensions of existing patch repairs and if possible galvanic anode locations.

The assessment of the data should target overall potential trends and changes with time, to identify areas requiring further assessment, such as areas of increased negative potential within the old unrepaired parent concrete at locations not expected to benefit from the existing embedded galvanic anodes.

The following should be considered in the data assessment which may be used to justify detailed destructive assessment locations

- Identify areas of increased positive potential within the parent / old concrete directly adjacent to repairs, to evaluate the state of embedded reinforcement at the old / new concrete interface
- Identify areas of increased positive potential within the repaired concrete to identify possible anode locations for removal and assessment of remaining anode material and concrete integrity around the anode.
- If possible, historical corrosion potential (half-cell) data taken prior to installation of the galvanic anodes and concrete repairs, should be obtained and used to compare against the new corrosion potential data to provide performance evidence of the embedded anodes and allow for end of anode life identification.

Where anode to cathode zone isolation facilities are provided, then additional corrosion potential assessments are recommended, subject to site constraints, to help evaluate system performance and deterioration risk:

- As found On steel/concrete/reference electrode potential – with the anodes connected
- Instant off potential – between 0.1 and 1second after disconnecting all the anodes
- Near Instant off potential –typically 5 to 30 minutes and up to 1-2 hours after of disconnecting the anodes

- 24 hour Off potential - with the anodes disconnected
- 1 week Off potential - with the anodes disconnected
- On potential – with all anodes re-connected between 1-2 hours of re-connecting all the anodes
- 1 week On potential – with all anodes re-connected

The assessment of the data following anode to cathode isolation should target overall potential trends and changes with time, to identify system performance or lack of performance and areas requiring further assessment.

4.1.5 Chloride sampling

When carrying out chloride sampling, the galvanic anodes may influence the concentration and distribution of chlorides within the concrete. For structures containing existing galvanic anode repair enhancers or embedded galvanic anodes, chloride sampling should be targeted at areas located within the parent / old un-repaired concrete, at high and low risk areas (identified from potential surveys) and should avoid direct contact with embedded anodes.
Chloride sampling of the structure should be instigated at the same intervals as "touching distance visual survey".

4.1.6 Corrosion rate monitoring

Corrosion rate monitoring, using either temporary or permanent embedded equipment may be used to provide an indication of the rate of reinforcement corrosion prior to and following anode installation (Concrete Society TR 60). Corrosion rate data collection and interpretation may be subject to errors and should not be used in isolation to demonstrate corrosion mitigation. It is recommended that, where selected, this technique should be used in conjunction with the techniques listed above to support the overall corrosion risk assessment.

4.1.7 Performance assessment

Where monitoring facilities have been provided, such as embedded reference electrodes and anode to cathode isolation facilities, then detailed performance assessment should be instigated annually subject to site constraints or where possible, at the frequency listed within the BS EN ISO 12696.

Where such evidence of system performance can be demonstrated, then the operator may be able to offset the need for some of the destructive assessment techniques, such as removing anodes to evaluate anode functionality, evaluating residual anode life and exposing reinforcement for evaluating the extent of reinforcement corrosion.

Where monitoring facilities are provided and subject to site constraints, the following measurements are recommended.

In monitoring boxes on the anode and cathode wires:

- Anode to cathode as found instant Off voltage (Volts)
- Anode to cathode as found current (Amps)

- Anode to cathode long term Off voltage (Volts) following a week or more with the anodes disconnected
- Anode to cathode instant On current (Amps) following a week or more with the anodes disconnected

In monitoring boxes measuring steel/concrete potential with respect to the embedded reference electrode cables:

- As found On potential – with all anodes connected
- Instant off potential – between 0.1 and 1 second after disconnecting all the anodes
- Near Instant off potential –typically 5 to 30 minutes and up to 1-2 hours after of disconnecting the anodes
- 24 hour Off potential– following anode zone disconnection
- 1 week Off potential – following anode zone disconnection
- Instant On potential – with all anodes re-connected
- 1 week On potential – with all anodes re-connected

A record should be made of the anode zone interrupted, the location of the reference electrode(s) within the zone and the proximity of non-interruptible anodes to the zone and to the locations of the reference electrode(s)

The findings of the results can be used to evaluate the following

- Anode performance (driving voltage, anode to cathode current, calculated circuit resistance)
- Anode consumption (the anode to cathode current can be used to calculate the rate of anode consumption and predict a theoretical anode life, based on the original anode mass and an assumed utilisation factor and efficiency. This data can then be compared against the actual residual anode mass identified following destructive assessment).
- Initial and steady state driving voltages and changes in driving voltage with changing environmental conditions
- Initial and steady state anode to cathode current and changes in current with changing environmental conditions
- Where as-built reinforcement and anode locations are available, using the measured steady state anode to cathode current, calculate the expected current density at the steel surface

4.1.8 Destructive evaluation

Data from the non-destructive testing can be used to identify areas which may require more detailed assessment and investigation, such as high corrosion risk locations identified in the potential assessment, corrosion staining, concrete cracking and delaminated areas.

The destructive assessments will entail localised concrete removal to expose the embedded reinforcement to enable assessment of the extent and depth of concrete cracking or delamination and the extent of reinforcement section loss. Destructive assessment of the structure should be instigated at the same intervals as “touching distance visual survey”.

Destructive assessment of embedded galvanic anodes requires specific assessment techniques which are yet to be fully developed and detailed within the industry. These may include:

- removal of anodes to evaluate residual anode capacity (weight), corrosion morphology, anode utilisation factor (the % of original anode alloy anticipated to have been constructively consumed, having maintained contact with the anode wire and delivered current at end of life)
- evaluation of corrosion product migration, concrete pore blocking and changes to concrete resistivity or concrete porosity
- anode activation, passivation, and rate of anode consumption under local conditions.

Where destructive assessment is instigated, all testing should be performed by a UKAS accredited laboratory in accordance with current standards.

4.2 Assessment and monitoring options – surface applied galvanic anodes

Surface applied galvanic anode corrosion mitigation systems prevent direct access to the concrete surfaces, impacting deterioration assessment techniques such as visual assessment, corrosion potential mapping, cover surveys, chloride sampling, and corrosion rate measurements. Those systems consisting of thin (e.g. arc sprayed) coatings will allow more direct visual assessment when compared with foil or other heavy overlays.

4.2.1 Visual survey

Visual assessment of the entire structure with emphasis on the state of the surface applied system, noting any evidence of de-bonded coating areas, concrete cracking, water or rust staining, corrosion deposits or other surface discoloration. A visual survey from ground level using binoculars where necessary should be undertaken at a two year interval, with a close up "touching distance" survey every 6 years or as recommended by a suitably qualified and experienced personnel (e.g. as defined under IAN 192/16 for bridge inspectors). The two and six year intervals align with the requirements for inspection of highway structures on the strategic road network as defined in BD 63/17 although that can be adjusted as described in IAN 171 for risk based inspections.

4.2.2 Delamination survey

Delamination surveys of the structure and assessment of surface applied systems should focus on identifying delaminated or de-bonded foil anode, metallizing or organic coating systems as any air gaps between the anode and the concrete surfaces will render the system ineffective.

It should be noted that foil and metallizing systems may prevent accurate assessment of delaminated concrete areas located under the anode surface, whereas organic coating systems may enable assessment of the concrete surfaces underlying coating system.

4.2.3 Cover surveys

Cover surveys are required for the interpretation of chloride profile and the location of reinforcement for subsequent investigations. Surface applied galvanic corrosion mitigation systems consisting of non-magnetic zinc or zinc alloys are not expected to influence or impact the performance of conventional cover meters, however, specialist equipment may be required.

For all equipment, it is recommended that a site calibration is conducted prior to use, this may include locally exposing reinforcement and measuring the actual cover depth and bar dimensions to ensure accuracy of the measurements.

Concrete cover and embedded anode locations will not change with time, so repeated cover surveys are not normally required at each visit.

4.2.4 Corrosion potential

Surface applied galvanic corrosion mitigation systems prevent direct access to the concrete surfaces which prevent corrosion potential assessment. The reference electrodes used for corrosion potential assessment, requires direct contact with the concrete surfaces with no peripheral contact with the anode material.

It may be possible to locally remove the surface coatings or anodes, to provide clean concrete inspection windows, which can then be used to perform potential surveys of the embedded reinforcement. Corrosion potential assessment of the structure should be instigated at the same intervals as “touching distance visual survey”.

The benefit of corrosion potential assessment is considered minimal, where direct electrical contact between the surface applied anode system and the embedded reinforcement are present or installed without the facility to isolate the anode from the cathode.

The surface applied coating systems are also expected to reduce the relative humidity within the concrete, which will affect the corrosion potential readings, presenting more positive readings when compared with an uncoated structure exposed to prevailing environmental conditions and relative humidity.

For systems which have been provided with anode to cathode zone isolation facilities or where complete removal and replacement of the surface system is scheduled, then this survey technique may prove more useful. Data analysis and interpretation should consider the impact and effects of concrete drying on the recorded potentials.

4.2.5 Chloride sampling

Surface applied galvanic corrosion mitigation systems may influence the concentration and distribution of chlorides within the concrete, by presenting increase chloride concentration in the concrete surfaces close to the anode.

Given the lack of visual access and difficulties associated with corrosion potential surveys, locating areas for additional chloride sampling is likely to be restricted to areas of coating failure, new leakage areas or following complete removal of the

surface system for renewal. Chloride sampling should be targeted at areas located within the parent / old un-repaired concrete, at high and low risk areas identified from potential surveys.
Chloride sampling of the structure should be instigated at the same intervals as "touching distance visual survey".

4.2.6 Performance assessment

Where monitoring facilities have been provided, such as embedded reference electrodes and anode to cathode isolation facilities, then detailed performance assessment should be instigated annually subject to site constraints or where possible, at the frequency listed within the BS EN ISO 12696.

Where such evidence of system performance can be demonstrated, then the operator may be able to offset the need for some of the destructive assessment techniques, such as removing anodes to evaluate anode functionality, evaluating residual anode life and exposing reinforcement for evaluating the extend of reinforcement corrosion.

Where monitoring facilities are provided then the testing and measurements listed within section 4.1.6 is recommended.

4.2.7 Destructive evaluation

Data from the non-destructive testing can be used to identify areas which may require more detailed assessment and investigation, such as de-bonded or consumed surface coatings, passive or fully consumed anodes, high corrosion risk locations, corrosion staining, concrete cracking and delaminated areas.

The destructive assessments will entail localised concrete removal to expose the embedded reinforcement to enable assessment of the extent and depth of concrete cracking or delamination and the extent of reinforcement section loss. Destructive assessment of the structure should be instigated at the same intervals as "touching distance visual survey".

Destructive assessment of surface applied galvanic anodes requires specific assessment techniques which are yet to be fully developed and detailed within the industry, these include:

- removal of anodes to evaluating residual anode capacity (weight per unit area), anode utilisation and overall anode efficacy
- adhesion and ionic permeability at the anode / concrete interface
- evaluation of corrosion product migration, concrete pore blocking and changes to concrete resistivity or concrete porosity
- anode activation, passivation, uniformity and rate of anode consumption under local conditions.
- atmospherically exposed anode surface and atmospheric anode consumption of the anode material
- stability of organic binder, adhesives and atmospheric protective coating systems

Please see the following documents for illustrations and pictures of typical installations, assessment techniques and results.

[1] CPA Technical Note No: 6 The Principles and Practice of Galvanic Cathodic Protection for Reinforced Concrete Structures
[2] CPA Technical Note 27 Corrosion Testing of Concrete Structures
[3] Concrete Society TR60 - Electrochemical tests for reinforcement corrosion
[4] Highways England BA35 Inspection and Repair of Concrete Highway Structures
[5] Highways England Interim Advice Note 192/16 Structures Inspector Competencies and Certification
[6] Highways England DB63/07 Volume 3 Highway Structures: Inspection and maintenance of highway structures
[7] IAN 171 Interim Advice Note 171/12 Risk Based Principal Inspection Intervals
[8] ASTM C876 Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete