



Engineering Standard

SAES-X-800

18 February 2013

Cathodic Protection for Existing Reinforced Concrete Structures

Document Responsibility: Cathodic Protection Standards Committee

Saudi Aramco DeskTop Standards

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1 Scope

This standard prescribes the minimum mandatory requirements governing the design and installation of mesh anode impressed current cathodic protection systems for bare steel reinforcement in existing concrete structures exposed to corrosive environment.

The Proponent Department and Consulting Services Department (CSD) shall assess the suitability of a structure to receive cathodic protection. Other repair methods shall also be considered before deciding whether or not to use cathodic protection.

Consider conventional impressed current and sacrificial anodes cathodic protection for the protection of submerged or buried reinforced concrete. Apply other applicable cathodic protection engineering standards for such applications.

2 Conflicts and Deviations

- 2.1 Any conflicts between this standard and other applicable Company Engineering Standards, Materials System Specifications, Standard Drawings, or forms shall be resolved in writing by the Design Agency representative through the Company Cathodic Protection (CP) Subject Matter Expert (SME).
- 2.2 Requests to deviate from this standard shall be submitted electronically through the SAP Waiver Process in accordance with [SAEP-302](#), "Instructions for Obtaining a Waiver of a Mandatory Saudi Aramco Engineering Requirement."

3 References

The selection of material and equipment, design, construction, maintenance, and repair of equipment and facilities covered by this standard shall comply with the latest edition of the references listed below, unless otherwise noted.

- Saudi Aramco References

Saudi Aramco Engineering Procedure

[SAEP-302](#)

*Instructions for Obtaining a Waiver of a Mandatory
Saudi Aramco Engineering Requirement*

Saudi Aramco Engineering Standard

[SAES-Q-001](#)

*Criteria for Design & Construction of Concrete
Structures*

Saudi Aramco Materials System Specifications

[09-SAMSS-097](#)

Ready Mix Portland Cement Concrete

[17-SAMSS-017](#)*Impressed Current Cathodic Protection Cables*[17-SAMSS-018](#)*Remote Monitoring System for Cathodic Protection*

Saudi Aramco Best Practice

[SABP-X-003](#)*Cathodic Protection Installation Requirements*

4 Testing and Repair Prior to Cathodic Protection Application

4.1 Site History and Environmental Survey

Conduct a site survey to determine the following:

- a) For buried concrete: Soil condition, pH and resistivity
- b) For submerged concrete: Water soluble chloride content, splash line and tide levels
- c) Average seasonal temperature and humidity
- d) Utilization of the concrete structure

4.2 Tests Prior to Cathodic Protection Application

4.2.1 Chloride Content

Record the chloride level from core samples collected in a 25 mm increment of depth of concrete to a level of 25 mm beyond the reinforcement.

4.2.2 Electrical Continuity

- 4.2.2.1 Perform continuity survey between reinforcement cage and all steelworks that might be affected by the CP system, and between different sections of reinforcement.
 - 4.2.2.2 Ensure that all the steel reinforcement layers, including links, tie bars, saddles, and any other embedded metallic fixtures within the structure, are electrically continuous.
 - 4.2.2.3 Measure DC resistance of the reinforcement at a minimum of two locations per 100 m² of concrete surface area.
 - 4.2.2.4 Use a DC ohmmeter with a resolution of 0.1 ohm or less for all continuity testing.
 - 4.2.2.5 Clean the reinforcement steel to be used as a contact point to a bright steel surface.
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4.2.2.6 Discontinuous steel is indicated by one of the following:

- a) Resistance readings that change more than 0.5 ohms in 15 seconds.
- b) Unstable resistance readings on the test meter.
- c) Resistance readings greater than 1 ohm.
- d) Any resistance reading that changes by more than 1 ohm when the leads are reversed.

4.2.2.7 Bond discontinuous steel to the continuous section of the reinforcement utilizing the negative connection procedures discussed in [SABP-X-003](#), paragraph 4.4.3.

4.2.2.8 Re-measure the new resistance following bonding at these locations.

4.2.3 Potential Mapping

4.2.3.1 Carry out potential mapping of the structure prior to any work if requested by the Proponent Department or CSD. Ensure that the relevant structural sections are electrical continuous before conducting potential mapping.

4.2.3.2 Record readings over the entire reinforcement surface on a grid pattern with maximum spacing of 500 mm.

4.2.3.3 Use Ag/AgCl mapping reference electrode for the testing. Prior to testing, adequately wet the surface with potable water to ensure correct results. When wetting is completed, conduct the following test to ensure adequacy:

- a) Position the electrode at a fixed location and record the potential. This shall be a stable value with no change with time.
- b) Apply an additional quantity of water to the surface and repeat the test. If wetting is adequate, the potential will not change.

4.2.3.4 The results of the potential mapping shall provide base line comparison data and assist in determining most anodic areas for embedded reference electrode placement.

4.2.4 Concrete Cover Thickness

Record concrete cover thickness for each section of the concrete structure.

4.2.5 Structural Survey

Assess each candidate structure from a structural standpoint to the satisfaction of the Proponent Department and Civil Engineering Unit of CSD to ensure that it is structurally sound before deciding on a cathodic protection measure.

Commentary Note:

Cathodic protection will not restore to the structure any structural capacity, which may have been lost due to corrosion.

4.2.6 De-lamination Survey

4.2.6.1 Conduct a delamination survey of the entire concrete surface.

4.2.6.2 Mark and repair all delaminated surfaces according to section 4.3 of this standard prior to the application of cathodic protection.

Commentary Note:

Cathodic protection current cannot penetrate a delamination unless the delamination is permanently submerged and therefore full of water.

4.3 Repair Prior to Cathodic Protection

4.3.1 Carry out full concrete repair on all areas where cathodic protection is to be installed. Determine the repair scale from the concrete damage assessment.

4.3.2 The proponent or CSD civil engineers shall review and approve the repair requirements and procedures.

4.3.3 Minimize the use of additives that might increase the resistivity of the repair concrete.

4.3.4 Repairs shall be carried out in accordance with the applicable Saudi Aramco civil engineering standards.

5 Design Considerations for Cathodic Protection

5.1 Design Life

Design the cathodic protection system for 40 years life or the remaining life of the structure, whichever is less.

5.2 Protection Criteria

5.2.1 Use protection criteria as described in Section 7.2 (I). The decay shall be measured from the instantaneous OFF up to one week.

5.2.2 Obtain the instantaneous OFF readings not more than 1 second following interruption of the DC source.

5.3 Current Density Criteria

5.3.1 Design the system for a current density of 20 mA/m² of reinforcing steel surface and embedded or surface mounted steel.

5.3.2 Do not exceed the maximum anode current density of 110 mA/m² at the anode-concrete interface.

5.3.3 Include the following in the current density calculation:

- a) Total surface area of the reinforcement,
- b) Any steelworks which lie in, or are mounted on the concrete surface, and
- c) Embedded metallic fixtures within the concrete structure

5.4 Zones and Sub-Zones

5.4.1 Ensure similar environmental exposure for sections of concrete structure, which may be combined together into a single zone.

5.4.2 Restrict the combinations of sub-zones to those areas, which experience similar conditions of rebar density and concrete quality.

5.4.3 Do not exceed a current requirement of 5.0 Amps for a single zone.

5.4.4 Connect at least two positive and two negative connections per zone or sub-zone.

5.4.5 In a single zone, do not connect together areas with cover thickness more than double the cover thickness of other areas.

Commentary Note:

A zone is defined as a discrete section of structure powered by an independently controlled output from a transformer rectifier. A zone may be divided into sub-zones, comprising different sections of the concrete structure.

5.5 Anode Design

- 5.5.1 Use embedded anode system with coated mixed metal oxide expanded titanium mesh anode laid in a cementitious overlay.
- 5.5.2 Ensure that the anode materials and type have a proven history in use in concrete and shall be approved by Consulting Services Department.
- 5.5.3 Determine the grade of mesh selected based on the steel surface area and the current requirement of a zone or sub-zone.
- 5.5.4 Allow for a spare capacity of 20% of the required current density in the design of the anode system.
- 5.5.5 Allow for sufficient redundancy so that any single random break in a power feeder or two random breaks in anode materials shall not result in:
 - a) Reducing the output of any one anode zone by more than 5%.
 - b) Disconnecting more than 5% of the area of any anode zone.
- 5.5.6 Ensure that the anode materials do not cross an expansion or construction joints. Operate concrete structure with such joints independently of all other sections by using independent zones or sub-zones. Make connection of anode systems within such elements in the junction boxes and not within the concrete.
- 5.5.7 Design the distribution of anode mesh within each zone by calculating the current requirement of the steel reinforcement under the following conditions:
 - a) The maximum allowable separation distance between any reinforcement and any anode shall be 400 mm.
 - b) The maximum allowable distance any reinforcement can extend after the edge of the anode in the horizontal direction shall be 150 mm.

Commentary Notes:

- 1. Pay particular attention to reinforcement at the corners and edges of the structure. The distance between the reinforcement most diagonally remote and the anode shall not exceed 400 mm.*
- 2. For structures with one layer of anode, if the side most remote from the anode is in an environmental condition such that drying may take effect. Consider applying a waterproof membrane on the remote side. The waterproof membrane is not required if the remote side is exposed to water or increased humidity.*

- 5.5.8 Calculate cathode current density for all sections of structure. Consider localized increases in reinforcement if it extends for a distance of greater than 400 mm across the surface

5.6 Overlay

- 5.6.1 Ensure that the overlay material to be used has a verifiable history in applications for concrete repair and cathodic protection.
- 5.6.2 The minimum overlay thickness is 40 mm.
- 5.6.3 Maximum electrical resistivity of the overlay material shall be less than 50,000 ohm-cm (500 ohm-m.) after 28 days (to be measured with pre-calibrated instruments using the Wenner four pin method or equivalent).
- 5.6.4 Apply the overlay material as soon as possible after fixing and testing of anodes, conductor bars, reference electrodes, etc.
- 5.6.5 The overlay materials shall comply with [SAES-Q-001](#) and [09-SAMSS-097](#).
- 5.6.6 Compressive Strength, Chloride Content, Cement Content, and Water/Cement Ratio shall comply with [SAES-Q-001](#) and [09-SAMSS-097](#).
- 5.6.7 Perform the bond Strength by direct pull-off testing a mean value of 1.25 MPa at 7 days with no single value less than 1.0 MPa.
- 5.6.8 Alkali Content shall be less than 3 kg/m³
- 5.6.9 Cure the concrete with sweet water for a minimum of 28 days.

5.7 Circuit and Cable Resistance

- 5.7.1 Do not exceed within a zone a voltage drop of 300 mV from the power supply terminals to the furthest point in the circuit.
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- 5.7.2 Ensure that the combined resistances of the positive and negative cables in a given zone or sub-zone is not more than 20% of the combined resistance of other positive and negative cables in the same zone or sub-zone.

5.8 Rectifier

- 5.8.1 Ensure that the rectifier has a verifiable history and get it approved by Consulting Services Department.
- 5.8.2 Remote monitoring of the rectifier shall be provided if requested by the Proponent Department.
- 5.8.3 The rectifier shall be a multi-channel unit. It shall be rated for an ambient temperature of 55°C.
- 5.8.4 Each channel shall have a maximum rated operating voltage of not more than 10 volts.
- 5.8.5 Insulate the anode circuit of each rectifier from the others, if more than one rectifier is installed.

5.9 Remote Monitoring and Control Units

The remote monitoring system shall comply with [17-SAMSS-018](#).

5.10 Cables

- 5.10.1 Minimum cable size shall be 4 mm².
- 5.10.2 Color code the positive and negative cables. Color coding shall be the same for all areas. Use the following colors:
- Red for positive cables
 - Black for negative cables
 - Different colors for reference cell and instrument cables
- 5.10.3 DC cables shall comply with section 1 through 4 of [17-SAMSS-017](#).
- 5.10.4 Label all cables with permanent engraved name tags.
- 5.10.5 All cables shall be of sufficient length to run from its point of origin to the junction box without a splice.
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5.11 Reference Electrodes

- 5.11.1 Ensure that the reference electrode has a verifiable history for use in concrete and get it approved by Consulting Services Department.
- 5.11.2 Use silver/silver chloride reference electrodes. You can use other types of electrodes if approved by Consulting Services Department. In general, any reference electrode shall have a proven track record for use in concrete and shall be approved by Consulting Services Department.
- 5.11.3 Each zone shall contain a minimum of two reference electrodes. Where a zone consists of two or more sub-zones then one reference electrode shall be provided in every sub-zone up to 100 m² in area, and two reference electrodes shall be provided in every sub-zone, above 100 m² in area.
- 5.11.4 Position the reference electrodes such that they represent the most exacting geometric configuration for each zone or sub-zone, such as diametric opposition.
- 5.11.5 Position the reference electrodes not more than 40 mm from the reinforcement.
- 5.11.6 Install a separate connection to the reinforcement cage positioned adjacent to the reference electrode and lies away from the reading face of the electrode.
- 5.11.7 The reference electrodes shall have suitable length of cable, such that no splices are required within the cementitious anode overlay.
- 5.11.8 The reference electrode shall be rated for an ambient temperature of 55°C.

5.12 Interference

Bond to the system all metallic structures embedded in or mounted on the concrete surface that might be interfered with the CP system.

5.13 Documentation

- 5.13.1 The proponent and Consulting Services Departments shall approve the final construction design package in writing before the start of construction.
 - 5.13.2 The design package shall include complete design drawings that clearly detail the following:
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- a. Overall layout of the structure to be protected
- b. Overall layout of the cathodic protection system including anodes, negative and positive connection, reference electrodes, junction boxes, test stations, electrical bonds, electrical insulators, all cables, and adjacent metallic components.
- c. Detailed anode layout and relevant typical cross sections location of the components within the protected structures

5.13.3 The design package shall include detailed calculations of the design that include the following:

- a. Reinforcement steel density
- b. Cathode current requirement
- c. Anode size and positioning
- d. Zone and sub-zone sizes and current requirements
- e. Circuit resistance of each component
- f. Rectifier rating

5.13.4 The design package shall also include:

- a. Installation procedures
- b. Materials specification, procurement and handling
- c. QA/QC document
- d. Commissioning requirement

6 Installation, Records, Commissioning and Inspection

Refer to Saudi Aramco Best Practice [SABP-X-003](#). [SABP-X-003](#) shall be deemed a mandatory document for this standard.

7 Contractor Expertise

- 7.1 Assign all works associated with design preparations and calculations to qualified design contractor with minimum of 5 years documented experience in the design of cathodic protection systems for concrete structures.
 - 7.2 Assign only qualified project contractor to perform the installation and construction of cathodic protection on reinforced concrete structures.
 - 7.3 Assign qualified project engineer and inspector on a full time basis to handle this project. The project engineer and inspector shall have minimum of two
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years documented experience in the field of cathodic protection for concrete structures.

- 7.4 Consulting Services Department shall review and approve the qualification of the design contractor, construction contractor, project engineer and inspector prior to the start of the project.

Revision Summary

18 February 2013

Revised the "Next Planned Update." Reaffirmed the content of the document, and reissued with some editorial changes.