Engineering Standard

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Cathodic Protection for Existing
Reinforced Concrete Structures

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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 The Company or Buyer Representative shall resolve in writing through the Manager, Consulting Services Department of Saudi Aramco, Dhahran any conflicts between this standard and other applicable Saudi Aramco Engineering Standards (SAESs), Materials System Specifications (SAMSSs), Standard Drawings (SASDs), or industry standards, codes, and forms.

2.2 Direct all requests to deviate from this standard in writing to the Saudi Aramco or Buyer Representative, who shall follow internal Saudi Aramco procedure SAEP-302 and forward such requests to the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

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.

3.1 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*

3.2 Industry Codes and Standards

American Concrete Institute Standards

ACI 506.2-95	*Specification for Shotcrete*
ACI 506R-90	*Guide to Shotcrete*

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.

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 section 6.3.

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 (l). 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/m^2 of reinforcing steel surface and embedded or surface mounted steel.

5.3.2 Do not exceed the maximum anode current density of 110 mA/m^2 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/m^3

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.

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 mm^2.

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 1through 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.

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 m^2 in area, and two reference electrodes shall be provided in every sub-zone, above 100 m^2 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:

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

6.1 Anode Installation

6.1.1 Clean and prepare the surface according to section 6.5.2 of this standard and the requirements of the cementitious overlay prior to anode installation.

6.1.2 Place anode mesh panels as designed and interconnect them with current distributor bars. Install the current distribution on the concrete surface and the anode mesh placed on top.

6.1.3 Weld the current distribution bars to the mesh at every mesh strand crossing.

6.1.4 Do not exceed a distance of 100 mm between adjacent anode mesh panels.

6.1.5 Securely fasten the anode mesh to the concrete surface using non-metallic fasteners to prevent movement during overlay placement.

6.1.6 Do not exceed a distance of 100 mm in each direction for interconnection welds if overlapping of anode mesh panels is required.

6.2 Positive Connections

6.2.1 Weld the positive connections to each current distribution bar in the following manner:

a) Prepare a 150 mm long, 3.175-mm diameter titanium rod.

b) Connect the pre-stripped copper core of the positive cable to the titanium rod by compression crimped.

c) Encapsulate the assembly with a suitable, mechanically strong adhesive lined heat shrink tube, which extends 50 mm either side of the crimp. Care shall be taken during the heat shrink operation to ensure no damage results to the cable insulation.

d) At the proposed locations for each current distribution bar, connect the assembly along the bar in the manner as described below:

- Position the assembly in the correct orientation and secure it to the current distribution bar.

- Fasten the positive cable to the current distribution bar and then to the concrete surface using non-metallic cable ties.

- Make the connection between the assembly and current distribution bar by tack welding (minimum of 6 welds). Take care to ensure that the process in no way damages the current distribution bar or the cable connection.

6.2.2 Inspect the system positive connections and get Saudi Aramco representative approval prior to overlay placement.

6.3 Negative Connections

6.3.1 At the locations of the negative connection, clean the reinforcement thoroughly to expose clean bright steel around its full circumference. Then, connect the system negative to the reinforcing steel by welding.

6.3.2 Construct the connection as follows:

a) Drill a 30 mm deep hole off-center in the end of a 10 mm diameter rebar which is 100 mm long.

b) Place the pre-stripped copper core of the negative cable inside the hole and braze welded to the rebar.

c) Encapsulate the connection with a suitable, mechanically strong, adhesive lined heat shrink tube extending 50 mm either side of the connection point.

d) Weld the bare portion of the rebar along the designated steel reinforcement of the structure to be protected.

6.3.3 Record the DC resistance between and within zones, the DC resistance shall be less than 2 ohms. If the resistance is more than 2 ohms, install more connections until a value less than 2 ohm resistance is achieved. Then, record the resistance between any one single cable and the remaining cables.

6.3.4 Inspect the system negative connections and get Saudi Aramco representative approval prior to overlay placement.

6.4 Reference Electrodes

6.4.1 Install the reference electrodes at the predetermined locations.

6.4.2 Place the reference electrode at the level of, and parallel to the reinforcing steel.

6.4.3 Provide instrument negative connection at the location. The connection shall follow the same procedure described for the system negative connections.

6.4.4 Mark all reference electrodes on the electrode case and at the cable termination point

6.4.5 Pre-cast each reference electrode into concrete similar to the overlay materials with the addition of 3% sodium chloride to the mix water to facilitate a low resistivity connection. The concrete cover shall be 20 mm all round the electrode. The encapsulation shall occur at least three days prior to the placement. Rough the surface of the encapsulation prior to placement to prevent a shrinkage interface being formed.

6.5 Overlay

6.5.1 General

6.5.1.1 Extend the overlay over the whole of the area covered by cathodic protection anodes.

6.5.1.2 Ensure that application of overlay does not damage any anode, cables, etc. either within the pouring panel or on adjacent panels.

6.5.1.3 Protect all items which are not designated for total encapsulation during installation.

6.5.2 Surface Preparation

6.5.2.1 Remove all traces of laitance to expose clean aggregate by scabbling, chipping or abrasive blasting.

6.5.2.2 The prepared profile shall be a minimum of 50% of the aggregate size or 8 mm peak, which ever shall be greater.

6.5.2.3 Carry out surface preparation to all surfaces to which anode is to be installed irrespective of whether the substrate is original concrete or repair material.

6.5.2.4 Ensure that the surface preparation activities do not cause weakness of the interface due to the fracture of aggregate or loosening of the bond. If this does occur, carry out further surface preparation by grit blasting or water blasting only until this situation is remedied.

6.5.3 Overlay Application

6.5.3.1 Following preparation and anode installation, pre wet the surfaces with potable water for 24 hours immediately prior to overlay application to reduce absorption of curing water by the substrate concrete. Where considered necessary,

take additional precautions such as shading or polythene sheeting, in order to assist the saturation of the existing concrete before application.

6.5.3.2 Maximum time between mixing and application shall be 20 minutes.

6.5.3.3 Use external surface vibrators to compact the concrete, if the overlay will be poured onto the deck areas on top of the anodes.

6.5.3.4 Apply the poured overlay in a single layer of nominal thickness. Control the time between pours to avoid cold joints.

6.5.3.5 Fix formwork securely to the base substrate and it shall be rigid and watertight. They shall be sufficient to prevent bulging and sagging during pouring.

6.5.3.6 Use a form oil to prevent surface blemishes being created on form removal. If such blemishes do arise, repair them by hand application of a similar mix to the pour with due consideration for aggregate size.

6.5.3.7 For sprayed concrete, the application shall conform to the requirements of ACI 506.2-95 "Specification for Shotcrete" and ACI 506R-90 "Guide to Shotcrete".

6.5.3.8 CONTRACTOR shall install a test panel of his proposed mix and procedure to ensure compliance with the specification. Perform all tests on site and get Saudi Aramco representative to witness the test.

6.5.3.9 Follow the manufacturers instruction totally if proprietary materials are to be used.

6.5.3.10 Cure all concrete overlays with potable water for 28 days minimum. Provide shading for surfaces in direct exposure to sunlight.

6.5.3.11 Do not use curing agents.

6.5.4 Weather Precautions

Refer to SAES-Q-001 for hot weather precautions.

6.5.5 Repair of Defects

Remove, discard and replace any overlay which lacks uniformity, exhibits segregation, honeycombing, lamination or which contains dry patches, voids or sand pockets.

7 Commissioning

7.1 Assign only qualified CP specialist with minimum of two years experience to carry out the commissioning work. Consulting Service Department shall review and approve his qualification.

7.2 Commissioning Procedure

Conduct the commissioning after 28 days using the following procedure:

a) Measure the natural potentials of rebars prior to energizing the rectifier relative to the embedded reference electrodes and portable surface electrodes using a grid pattern of 1m by 1m where applicable.

b) Check correct wiring polarity in the rectifier.

c) Energize each rectifier output channel separately with controls at zero.

d) Increase voltage to achieve 10 ma/m² of steel surface area.

e) Record 'ON' potentials after 5 minutes. There should be an increase of between 100-200 mV from natural potentials. If not, increase current density by 50% of it's set output.

f) Following energizing of units as above, carry out interference testing if applicable.

g) Leave the system energized for 24 hours to stabilize.

h) After 24 hours, record volts, amps, back EMF, 'ON' and instantaneous 'OFF' potentials for each channel. Instantaneous 'OFF' potentials should be 100 mV or more shifted from natural potentials. If this requirement is not achieved, increase operating conditions as defined in e & g.

i) Once you achieve the 100 mV shifts from the natural potentials, keep the systems energized and allow it to polarize for a period of 28 days.

j) Maintain the output settings at the initial levels each day.

k) Record the 'ON' and instantaneous 'OFF' potentials after 28 days. Then re-energize the transformer rectifier and record the 'ON' and instantaneous 'OFF' potentials after 4, 24, 48, 72 and 168 hours.

l) Consider each system as operating satisfactorily when both the following criteria are met at all locations associated with its particular transformer rectifier unit:

1. 100 mV decay or more measured up to 24 hours from instantaneous 'OFF'.
2. 150 mV decay or more measured up to 168 hours from instantaneous 'OFF'.
3. The instantaneous 'OFF' potentials Shall not be more negative than1050 mV vs. Ag/AgCl.

m) Repeat the above depolarization test after 1, 3, 6 and 12 months of operation, after the system is considered to be operating satisfactorily.

n) If the 100 mV criteria is not achieved at all locations or for any one channel, then increase the output of the relevant rectifier channel by increments of not greater than 20% of present current output and the above tests shall be repeated until the criteria is met. If the upper limit is exceeded, then reduce the output by 20%.

o) If the criteria is not achieved within three months of initial energizing of the system, the contractor shall conduct further investigation and repair of the installed system until the criteria is achieved. The investigation may include but not limited to: checking all connections, reviewing all records and conducting potential scan of the relevant structure components.

p) Submit all commissioning data as part of the as-built documentation prior to final acceptance.

8 Records

Provide the following documents to the Proponent Department and Consulting Services Department:

a. Description of Structure and Systems
b. As-Built Drawings of Cathodic Protection System
c. Commissioning Data
d. Periodic Inspection Requirements and Monitoring Method Statement
e. System Output Parameter
f. Rectifier Operating Instructions and Maintenance Requirements
g. Rectifier circuit drawings
h. Reinforcement and Permanent Reference Electrode Potential Data
i. Electrical Continuity and Electrical Isolating Data
j. Current Requirement Data

k. Chloride Test Results and Other Chemical and Physical Analyses

l. Delamination Survey Data

m. Depth of Cover Data

9 Contractor Expertise

9.1 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.

9.2 Assign only qualified project contractor to perform the installation and construction of cathodic protection on reinforced concrete structures.

9.3 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 years documented experience in the field of cathodic protection for concrete structures.

9.4 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

28 April, 2004	Revised the "Next Planned Update". Reaffirmed the contents of the document, and reissued with minor changes.