

## **Standard Specification for Electrochemical Chloride Extraction**

AASHTO Designation:

**1. Introduction** - This standard provides a specification for Electrochemical Chloride Extraction (ECE) of a chloride contaminated concrete structure, i.e. a bridge sub-structure or a bridge deck.

### **2. Scope**

2.1 This standard provides installation and operation specifications for Electrochemical Chloride Extraction of chloride contaminated concrete structures.

2.2 *This standard may involve hazardous materials, operations, and equipment. It does not purport to address all of the safety problems associated with its use. It is the responsibility of whomever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

### **3. Referenced Documents**

#### 3.1 AASHTO Designations

T 260-94 Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials

R 18 Establishing and Implementing A Quality System for Construction Materials Testing Laboratories

#### 3.2 ASTM Standards

C876-91 Measurement and Interpretation of Half-Cell Potentials of Reinforcing Steel in Concrete

### **4. Terminology**

4.1 Alternating Current (AC) - Electric current which repeatedly reverses direction on a periodic cycle, usually at a frequency of 60 cycles per second (60 Hz).

4.2 A.C. Service - Alternating current supply to the rectifier; 240 or 480 volts AC.

4.3 Anode - The electrode at which oxidation reactions (i.e. corrosion reactions) occur, and to which negatively charged ions migrate when an electric current is passed through an electrolyte. The anode may be any material that distributes the ECE current to the entire surface to be treated. Anode used for ECE shall be either catalyzed titanium, or steel as specified.

4.4 Anode Subzone - An electrically isolated anode circuit within an Anode Zone occupying an area not exceeding 200 ft<sup>2</sup>. All subzones within a zone operate in parallel.

4.5 Anode Zone - An isolated anode circuit on the concrete surface occupying an area not exceeding 1,500 ft<sup>2</sup>.

4.6 Cathode - The electrode at which reduction occurs, and to which positively charged ions migrate when an electric current is passed through an electrolyte. When applying ECE systems, the cathode is the embedded reinforcing steel.

4.7 Cell - An electrochemical system consisting of an anode and a cathode in metallic contact and immersed in an electrolyte. The anode and cathode may be different metals.

4.8 Constant Current - An operating mode in a rectifier in which the current is set at a fixed level, and the voltage varies. Variations in the rectifier output voltage and current will occur with the changes in the concrete resistance and AC line voltage.

4.9 Constant Voltage - An operation mode in a rectifier in which the voltage is set at a fixed level, and the current varies. Variations in the rectifier output voltage and current will occur with the changes in the bridge deck resistance and AC line voltage.

4.10 Corrosion - The natural tendency of a metal to revert to its native state because of a reaction with its environment. In order for corrosion to occur there must be an anode, a cathode, an electrolyte and a conductive path between the anode and cathode.

4.11 Current - A movement of electricity through a solid or solution; commonly measured in amperes or milliamperes. In an ECE system, the direct current flow

is ionic (through the electrolyte) and electronic (through the metallic paths).

4.12 Current Density - The current per unit area of surface of metal or concrete. A common unit is  $A/m^2$  (amperes per square meter).

4.13 Direct Current (D.C.) - Electric current that flows in only one direction.

4.14 D.C. Wiring - All insulated conductors necessary for connecting the anode zones, reinforcing steel and other instrumentation with the rectifier and/or junction box.

4.15 ECE Installation Supervisor (IS) - Representative who is familiar with all aspects of the ECE process and its installation.

Note 1 - The IS gives advice in the field regarding the installation and operation of the ECE process and may perform necessary quality control field tests to ensure proper system operation. The IS should have a minimum 1 year of relevant experience with Electrochemical Chloride Extraction systems.

4.16 Electrical Continuity - A closed circuit (unbroken electrical path) between metal components under consideration. For ECE of concrete structures, continuity typically refers to the electrical connection of reinforcing steel.

4.17 Electrical Discontinuity - The physical separation between metal components under consideration. For ECE of concrete structures, electrical discontinuity typically refers to discontinuous or unconnected reinforcing steel.

4.18 Electrolysis - Chemical changes in an electrolyte brought about by the passage of an impressed electric current.

4.19 Electrolyte - Any medium which serves as a conductor for the passage of ionic current (i.e. concrete, soil and water).

4.20 Energize - (turn on) The process of initially applying power to an ECE system.

4.21 Engineer - The owner's representative or project engineer.

4.22 Filter - A device used to increase the conversion

efficiency of a rectifier. Filters typically consist of an inductor or choke, which is used to reduce the ripple component in the D.C. output.

4.23 Half-Cell - A single electrode in contact with an electrolyte and which, in contact with another half-cell, forms a full electrochemical cell. This term is sometimes used to designate a reference electrode or reference cell.

4.24 Ion - An atom or group of atoms that have lost or gained one or more electrons, and have therefore acquired an electric charge (i.e.  $Cl^-$ ,  $OH^-$ ,  $H^+$ ,  $Na^+$ ).

4.25 Macro Cell - A corrosion cell with a large anode to cathode relationship.

4.26 Meter - An instrument which is used for measuring and recording such as in the case of rectifier voltage, current and half-cell potential. Rectifier meters may be analog or digital.

4.27 Micro Cell - A corrosion cell with a small anode to cathode relationship.

4.28 Ohm's Law - The relationship between voltage, current and resistance ( $E = IR$ ).

4.29 pH - A value taken to represent the acidity or alkalinity of a solution. A pH of seven is considered 'neutral', with lower numbers representing solutions which are acidic and higher numbers solutions which are basic or alkaline.

4.30 Potential - A voltage measurement (i.e. half-cell potential).

4.31 Potential Survey - obtaining half-cell potentials at multiple locations on the surface of a structure.

4.32 Remote Monitoring System - A device used to collect and transfer rectifier operating data to a remote computer terminal, thus eliminating the need for regular inspections of the ECE system during the treatment process. The remote monitoring system typically consisting of a data recorder, modem, telephone service and personal computer at the receiving end.

4.33 Resistance - Opposition offered by a conductor to the passage of electrical current, measured in ohms.

4.34 Resistivity - The electrical resistance of a substance (i.e. concrete, water and soil) commonly measured in ohm-centimeters (ohm-cm). Concrete of lower resistivity is likely to be more corrosive than

concrete of higher resistivity.

4.35 Rectifier - A device used to convert alternating current to direct current. In an ECE system the rectifier is used to control the voltage and current output to each zone.

4.36 Ripple - Percent ripple =  $\frac{\text{Ripple Voltage (RMS)}}{\text{Volts DC}} \times 100$ . Ripple voltage shall be measured across the output terminals of the rectifier with a true RMS AC voltmeter. Volts DC shall be measured across the output terminals of the rectifier with a DC voltmeter.

4.37 System Negative Connections - Cable connections to the reinforcing steel from the rectifier negative (-) output.

4.38 Voltage - Difference of potential expressed in volts or millivolts (1 volt = 1,000 millivolts).

## 5. Summary

5.1 This standard presents specifications for the installation and operation of Electrochemical Chloride Extraction (ECE) systems for chloride contaminated concrete structures. It incorporates the use of other available standards which are applicable to the accomplishment of this task. The procedure allows adjustments to accommodate the needs of individual agencies.

5.2 The specifications and procedures consist of three major sections: (1) general requirements for all Electrochemical Chloride Extraction installations, (2) specific requirements for application to vertical and overhead surfaces, (3) specific requirements for application to horizontal surfaces.

## 6. Significance and Use

6.1 Significance - Electrochemical Chloride Extraction (ECE) was designated as one of the most important technologies to come out of the SHRP program. Initial research of ECE began in the U.S. in the 1970's. A Norwegian company developed a commercial system in the 1980's. SHRP then evaluated the technology during the 1980's and early 1990's. ECE is a treatment process typically taking 6 to 8 weeks. It is a non-destructive treatment that does not alter the final appearance of the structure to which it is applied. ECE halts corrosion by migrating chlorides, the source

of the corrosion, away from embedded reinforcement. At the same time, electrolysis at the reinforcement surface produces a high pH environment, repassivating the steel reinforcing. Variations of the ECE system which are available include the Traffic Bearing System for situations that require full traffic access during treatment, Realkalisation to increase the pH of carbonated concrete, and electrochemical lithium migration to treat ASR affected concrete.

## 6.2 Use

6.2.1 Electrochemical Chloride Extraction applied to a vertical or overhead surface typically employs a steel anode fastened to the concrete. Titanium anodes are generally specified for architectural applications where rusting of the anode is unacceptable. A spacer is used to keep the anode from being in direct contact with the concrete, allowing room for the electrolyte media between the anode and the concrete. The electrolyte media usually consists of a sprayed on cellulose fiber mixture, which is easily applied to vertical and overhead surfaces. The electrolyte media is designed to retain moisture. The system is then wrapped with plastic to help retain moisture, and is continuously wetted. The treatment duration is typically 6 to 8 weeks, after which time all materials are removed from the concrete surface. When steel anode is used there will be some rust staining. Abrasive blast cleaning is generally specified to remove the rust staining and prepare the surface for the application of an appropriate sealer or coating.

6.2.2 Electrochemical Chloride Extraction when applied to a horizontal surface also employs an anode. Typically the anode used for these applications is catalyzed titanium. The electrolyte media is generally made up of two layers of absorbent felt, although cellulose fiber can be used. The anode is sandwiched between the two layers of felt and laid on the concrete surface. The system is then covered with plastic to help retain moisture, and is continuously wetted. The treatment duration is typically 6 to 8 weeks, after which time all materials are removed from the concrete surface. Moisture and pH conditions are controlled to prevent the generation of acid and etching of the concrete surface if catalyzed titanium anode is used. Abrasive blast cleaning is conducted to prepare the surface after treatment for an appropriate sealer, coating or overlay.

## 7. Laboratory Apparatus and Materials

7.1 Personal safety equipment required by the

specified test method.

7.2 Testing equipment required by the specified test method.

## **8. Field Apparatus and Materials**

8.1 Personal safety equipment required by the laboratory, field organization, or OSHA for work in the ECE installation area.

8.2 Materials for Concrete Repair - Materials for Concrete Repair shall meet the requirements of sections 8.2.1 through 8.2.2.

8.2.1 The material used in concrete repairs shall be Portland cement concrete or mortars having an appropriate electrical resistivity.

8.2.2 Bonding agents or additives that are non conductive or electrically insulating in nature shall not be used.

8.3 Anode System - The Anode System shall meet the requirements of sections 8.3.1 through 8.3.5

8.3.1 The anode system shall consist of an anode embedded in an electrolyte reservoir on the concrete surface. The electrolyte reservoir may consist of either cellulose fiber or felt cloth, saturated with an electrolyte.

8.3.2 Anode - Catalyzed titanium or steel may be used. The use of steel anode may be suitable for applications where rust staining produced by the steel can be removed without disrupting the client.

8.3.3 Cellulose Fiber - Sprayed on Cellulose Fiber material shall have excellent adhesion to overhead and vertical surfaces, high moisture retention properties, and a proven track record. Contractor to supply references of use of the proposed material on a minimum of three previous projects. Prior to spraying of the cellulose fibers onto the concrete surface to be treated, wooden battens if used or suitable spacers shall be installed.

8.3.4 Felt cloth - In order to provide appropriate spacing and moisture retention, each layer of felt cloth shall be no less than 3mm thick, and shall be primarily used on horizontal or deck surfaces.

8.3.5 Electrolyte - The electrolyte shall consist of potable water. Calcium Hydroxide may be added if deemed necessary. Lithium based electrolyte may be

used if specified for cases where concrete suffering from ASR is identified.

8.4 Electrical Insulating Material - Electrical Insulating Material used to cover all electrical connections shall be waterproof.

8.5 AC Power Supply - the AC Power Supply shall be sufficient to operate the required number of DC power rectifiers.

8.6 DC Power Supply - DC Power Supply shall meet requirements of sections 8.6.1 through 8.6.4.

8.6.1 Each AC/DC rectifier shall be rated to provide total output current and voltage to meet the current demand of the individual zone. A current distribution box shall be provided for each zone, such that each zone shall be divided into subzones that operate electrically in parallel. The DC voltage side shall be limited to approximately 40 VDC. Rectifiers shall be rated to operate continuously at maximum output under site conditions of temperature and relative humidity.

8.6.2 Enclosures - The rectifiers shall be housed in vandal-proof enclosures suitable for site conditions.

8.6.3 Controls and connections - Each AC/DC rectifier shall be provided with: (i) All output controls, (ii) One output voltmeter and one output ammeter, (iii) Provision for direct measurement of output voltage with an external meter, (iv) Easy access to the positive and negative terminals of each output, which shall be clearly marked "+VE Anode" and "- VE Rebars". All output terminals shall be fully insulated from the chassis or its enclosure, (v) An adequately rated circuit breaker or fuse, on the main input to ensure protection against short circuit and thermal overload, (vi) AC cable connections shall conform to all relevant NEC codes and standards.

8.6.4 Electrical components - Electrical Components of AC/DC rectifiers shall meet the requirements of sections 8.6.4.1 through 8.6.4.4.

8.6.4.1 All electronic component subassemblies shall be encapsulated in epoxy resin or varnishes, which shall be recommended by the component manufacturers.

8.6.4.2 The rectifiers shall be suitable for continuous operation at the specified output ratings, with a peak inverse voltage of at least 800 volts. Rectifiers shall have double windings, which must be separated by a grounded metallic screen or mounted on separate limbs

of a grounded core.

8.6.4.3 Rectifiers shall be of the silicon type with suitable AC surge protection. Fuses shall be used to protect the rectifiers on the DC output side.

8.6.4.4 AC ripple on DC output of all rectifiers shall not exceed 2V at all output settings from 10 to 100% of rated voltage and current.

8.7 Cables and Wiring - Cables and Wiring shall meet requirements of sections 8.7.1 through 8.7.4.

8.7.1 All AC Cables or wiring shall be stranded copper conductors. The cables shall be insulated with cross linked polyethylene listed by UL.

8.7.2 DC Cables for connection to the anode (positive) shall be identified by red insulation and shall have a minimum gauge of 10 AWG.

8.7.3 DC Cables for connection to the reinforcing steel (negative) shall be identified by black insulation and shall have a minimum gauge of 6 AWG.

8.7.4 Each DC cable shall be labelled according to the zone or portion of a concrete structure to which it is connected.

8.8 Digital Voltmeter - A battery-operated Digital Voltmeter (DVM) shall be provided to enable testing and monitoring during the treatment period. Spare batteries shall be provided. The DVM shall, have a minimum 3.5 digit display, resolution of 1 mV, and an error of no more than 1 digit. The input impedance of the DVM shall be at least 10 M $\Omega$ .

8.9 Current Probes - A battery-operated current tong probe, with spare batteries, shall be provided for current readings during the treatment period. The error of the probe shall be no more than + 5%.

8.10 Corrosion Potential Half-Cell - A suitable half-cell such as copper-copper sulphate shall be used to measure corrosion potentials of the concrete structure.

8.11 Apparatus for Monitoring Chloride Concentrations - Core or rotary impact drills are to be used to obtain concrete samples to monitor the chloride concentrations

## 9. Testing

9.1 Half-Cell Corrosion Potential Survey - Half-Cell Corrosion Potential Survey as specified to be conducted in accordance to ASTM C 876-91.

9.2 Chloride Analysis - Chloride Analysis to determine the residual water-soluble chloride content in the concrete shall be in accordance with AASHTO T260-94. Measurements may be made using the rapid chloride test method.

9.3 Sampling - Sampling of concrete for chloride analysis is performed by drilling either powder or core samples. Powder samples may be collected directly from drill cuttings at selected depths. If cores are selected, they shall be cut into slices and crushed to fine powder.

9.3.1 Sampling of the concrete before and after treatment should be carried out by experienced personnel. Care shall be taken to prevent cross contamination between samples.

9.3.2 Chlorides in unreinforced concrete do not cause any deterioration of the concrete. It is therefore important that testing is performed in the concrete area directly in the vicinity of the reinforcing steel. The exact location of the reinforcing steels, in the area to be tested, shall be located with a cover meter, pachometer, or other suitable reinforcing steel-locating device. Core samples shall be taken directly over a single reinforcing steel while dust samples may be drilled adjacent to the intersection of two reinforcing steels.

9.3.3 The samples shall be extracted by taking cores no greater than 50mm in diameter down to the depth of the reinforcing steel and if permitted by the Engineer, through the reinforcing steel. Alternatively, dust samples may be extracted with the use of a hammer drill. The drill bit should be the smaller of 1.5 times the diameter of the reinforcing steel in the location being tested, or 25mm. Samples shall be taken within 1.5 times the diameter of the rebar or 1 inch of the nearest rebar. To eliminate surface variability, the concrete shall be drilled to a depth of 6mm and the dust discarded. Dust samples shall be taken in standard increments from the surface to the depth of the reinforcing steel. To avoid cross contamination the drill bit shall be cleaned or changed to one of a smaller diameter for the subsequent increment. The hole shall be thoroughly cleaned with compressed air at each increment.

9.3.4 Samples shall immediately be placed into sealed airtight bags, or other suitable containers. They should then be clearly marked with the contract name, the date,

the location of the sample, the depth from which the sample was removed, the cover depth of the reinforcing steel at that location, and the lateral distance to the nearest reinforcing bar.

## **10. Hazards**

10.1 Observe the safety procedures required by the Laboratory and/or Field Agency and/or OSHA for each laboratory and field operation as applicable.

10.2 Obtain a material safety data sheet for all materials that require one, and plans for storage, handling, and placement, prior to receiving such materials at the jobsite.

## **11. Preparations**

11.1 Pre-Project Submittal - A Pre-Project Submittal shall be made before the commencement of any Electrochemical Chloride Extraction project. The Pre-Project Submittal shall include items identified in sections 11.1.1 through 11.1.6.

11.1.1 Project name and location.

11.1.2 The type of anode to used, whether steel or titanium or a combination of the two.

11.1.3 The electrolyte materials to be used, including cellulose, felt, water, chemical additives, etc...

11.1.4 Approximate size and layout of zones and subzones.

11.1.5 AC power requirements if power is to be provided by the owner.

11.1.6 Approximate project schedule.

## **12. Standardization**

12.1 Laboratories conducting inspections or testing in accordance with this standard shall comply with the requirements of AASHTO R18.

12.2 Verify the calibration of instruments used for testing components or systems as designated in this standard in accordance with the requirements of the standard used for testing.

## **13. General Requirements for all Electrochemical Chloride Extraction Installations**

13.1 Installation Procedure - Installation Procedure shall conform to items identified in sections 13.1.1 through 13.1.5.

13.1.1 Preparation of the concrete for Electrochemical Chloride Extraction treatment shall include items identified in sections 13.1.1.1 through 13.1.1.8.

13.1.1.1 Preparation of the Concrete Surface - The surface of the concrete shall be cleaned of any grease, coating, etc., that may interfere with the passage of electrical current, to ensure optimum treatment efficiency. Sandblasting or water jetting may be required to achieve this. The specification shall state whether pre-cleaning of the concrete surface is required and a separate bid item shall be provided as required.

13.1.1.2 Pre-installation survey - Visual and sounding surveys shall be carried out over the full surface area of the structure to determine where delaminations and previous repairs have been carried out. In addition, areas where concrete cover over the rebars is insufficient (i.e., less than 10 mm) shall be located, by means of a cover meter / pachometer survey and selective chip-outs. Also a pre treatment corrosion potential survey shall be performed if specified throughout the surface area which will be repeated not less than three months after completion of the treatment. The specification shall state whether the tests (survey) are to be performed by the Owner, Engineer, or Contractor and a separate bid item shall be provided as required.

13.1.1.3 Removal and replacement of delaminated concrete - Delaminated and spalled concrete areas shall be repaired before beginning the ECE treatment, and are not considered part of the ECE treatment itself.

13.1.1.4 Remediation for insufficient concrete cover - Cement-based mortar shall be applied over all areas determined to have insufficient concrete cover until the total cover at each area is at least 10 mm or has comparable resistance to 10mm of concrete. Alternatively, localized areas may be isolated by applying an epoxy or other non-conductive coating to the affected area.

13.1.1.5 Insulation of visible or shallow metal components - Any tie wires, nails, or other metal

components, that are close to the surface or visible on the surface of the concrete, shall be removed or insulated with silicon rubber or non-conductive epoxy. If necessary, these may be cut back to not less than 10 mm below the surface, then patched with a cement-based mortar.

13.1.1.6 Reinforcement continuity - The top-layer of reinforcing steel in the structure shall be checked for electrical continuity prior to treatment. This can be done either at existing spall locations, or at cathode (reinforcing steel) connection points. If necessary additional holes can be drilled or chipped to access the reinforcing steel. If the voltage difference between any two reinforcement steel locations (from different locations in the structure) is less than 1.0 mV (when measured with a high input impedance voltmeter with a resolution of no less than 0.1 mV), or resistance is less than 5 Ohms (when measured in Ohms with a multimeter) these reinforcement steels are considered to be continuous. Drawings of the structure showing reinforcement details shall be inspected to locate areas where continuity might not exist, and direct measurements of voltage differences or resistance between rebars in these areas and other areas in the structure shall be made. In addition, measurement points shall include the perimeters and the middle of each structural component. Records of the locations of measurement points and the measured voltage/resistance differences shall be submitted to the Engineer with the final report, or sooner if requested. Where any electrical discontinuity is identified, proposals for providing continuity shall be submitted to the Owner for approval before proceeding. Compensation for insulation of shallow metal, remediation of insufficient cover, continuity bonding and the correction of other hidden defects is generally by separate bid item or based on force account rates.

13.1.1.7 Reinforcement (negative) connections - There shall be at least 1 reinforcing steel connection per 50m<sup>2</sup> of concrete surface area, and never less than two connections per zone. Reinforcing steel connections shall be installed and tested for continuity. Immediately after a connection has been made, the reinforcement connection shall be coated with a non-conductive material, such as silicon rubber, or the hole may be sealed with an approved patch repair mortar.

13.1.1.8 Connection of Metal Fixtures - Any metal fixtures attached to the concrete structure must be protected against corrosion by electrical connection to the reinforcement. Any cable used in providing electrical connections shall comply with the

requirements of sections 8.7.3 through 8.7.4 and the sheathing shall be color coded black.

13.1.2 Installation of the anode system shall meet the requirements of sections 13.1.2.1 through 13.1.2.3.

13.1.2.1 To prevent short circuits, any exposed steel, in or on the surface of the concrete, shall be adequately masked and, if necessary, connected to the reinforcement or removed, before applying the anode system.

13.1.2.2 Anode Zones - The concrete surface to be treated shall be divided into isolated Anode Zones. The Anode Zones may then be divided into anode subzones. Anode subzones should be of approximately equal resistance, size, and geometry where possible. Anode zones and subzones should be spaced 50mm to 100mm apart to ensure electrical isolation from each other.

13.1.2.3 Electrolyte Media - The anode shall be embedded within electrolyte-saturated media. Different combinations of anode and electrolyte media may be used for different applications.

13.1.3 Connection of Cables - All DC cables shall be placed and connected so they do not cause any unnecessary inconvenience. Cable insulation shall be checked; any damaged insulation shall be repaired using a generous amount of an appropriate insulation material, or by making new joints.

13.1.4 Placement of the AC/DC Rectifiers - A suitable location for placement of the AC/DC rectifiers shall be chosen to provide minimal disturbance. The chassis of the AC/DC rectifiers shall be grounded in accordance with relevant NEC codes and standards. All AC power cables shall be installed in accordance with relevant NEC codes and standards.

13.1.5 Inspection of the Installation - The installed anode system, its electrical connections, and power cables shall be inspected prior to the initiation of the ECE treatment. AC power shall be connected by a certified electrician as required by relevant NEC codes and standards.

13.2 System Operation and Maintenance - System Operation and Maintenance shall meet the requirements of sections 13.2.1 through 13.2.3.

13.2.1 System Start-Up - System Start-Up procedures shall meet requirements of sections 13.2.1.1 through 13.2.1.2.

13.2.1.1 Circuit Verification - Prior to start-up or energization of power, tests shall be undertaken to ensure that all measurements, and power distribution circuits are correctly wired, connected and labelled. Where appropriate, the circuits shall have the expected resistances. Using a suitable voltmeter, the polarity of the reinforcement shall be ascertained when the power sources are switched on.

13.2.1.2 Adjustment of current output - The initial current used for the ECE treatment shall generally be between  $1A/m^2$  to  $2A/m^2$  and shall not exceed  $5 A/m^2$ . During the treatment, the current output shall be measured individually in each anode cable (as detailed in section 13.2.2). The total current can be adjusted by decreasing or increasing the applied voltage. If the results indicate an unexpected current distribution, an inspection shall be carried out to determine the reason, and remedial action shall be taken.

13.2.2 Monitoring of System Operation - Monitoring of System Operation shall meet requirements of sections 13.2.2.1 through 13.2.2.2.

13.2.2.1 Inspections - During the treatment, the operation of the system shall be checked regularly and the following records shall be made: (i) date and time, (ii) current (to each zone and subzone as appropriate), (iii) voltage (to each zone). Any problems that develop shall be identified, recorded, solved, and reported. Visual inspection of cable connections, cable insulation, anode condition, and wetting of the electrolyte media shall be conducted regularly. Any interruption in the operation shall be recorded and reported.

13.2.2.2 Determination of chloride content - In addition to the regular inspection, determination of the residual water-soluble chloride (Cl) in the concrete adjacent to the steel (per AASHTO T 260-94) shall be carried out as deemed necessary during the treatment. The determination shall be conducted on concrete samples to be taken at pre determined points in the vicinity of the rebar. These locations shall be submitted to the Owner for approval prior to commencement of treatment. If the results of any of these analyses indicate that the system is not operating properly, the Contractor shall determine the cause and rectify the situation.

13.2.3 Remedial Work - During the treatment, remedial work shall be conducted whenever any inspection indicates the system is not performing properly. This remedial work shall include, but not necessarily be limited to, the following: (i) repair or replacement of defective components of the system, (ii)

modification to correct any electrical short circuits or to prevent stray currents. The materials and workmanship for remedial works shall be in accordance with standard concrete repair practices, except where otherwise agreed.

13.3 Termination of the ECE Treatment - The ECE treatment shall be performed: (i) for approximately 60 days, or (ii) until a total of  $600A\text{-hrs}/m^2$  has been passed, or (iii) until the chloride in the concrete in the vicinity of the reinforcing steel has decreased to 0.03% by weight of concrete after correction for background chlorides, whichever is the earliest.

13.4 Dismantlement and Disposal of The System - After the system is shut down, remove all electrical cables, conduits, hangers, and power supplies from the site. The anode, electrolyte media and wooden battens or dams (if used) shall also be removed from the site or be disposed in accordance with applicable disposal and safety regulations.

13.5 Post Treatment Surface Cleaning and Patching of the Concrete - The surface of all treated concrete shall be either washed with pressure cleaning, using clean water, or light abrasive blasting as preparation for the application of the specified surface treatment/protective coating. The entire treated structure shall then be inspected; the occurrence, location, and extent of any physical damage or changes to the concrete shall be noted. Any such defects such as core and sample holes made in the concrete shall then be repaired. The surface of all the treated and prepared concrete shall be treated with a penetrant sealer or coating as defined elsewhere in the design specifications. The site shall be clean at the end of the job.

## **14. Specific Requirements for Vertical and Overhead Surfaces**

14.1 Installation of the anode system for vertical and overhead surfaces shall meet the requirements of sections 14.1.1 through 14.1.3.

14.1.1 Anode - The Anode for vertical and overhead surfaces unless otherwise specified shall be welded wire steel mesh. Spacers such as wooden battens shall be used to keep the anode from coming in direct contact with the concrete surface and to allow room for the electrolyte media between the anode and the concrete surface. The Anode shall be securely fastened to the concrete surface via insulated anchors to prevent any shorting of the system.

14.1.2 Electrolyte Media - The Electrolyte Media shall be sprayed cellulose fiber unless otherwise specified. The cellulose fiber material shall provide high moisture retention and be easily applied to awkward and uneven surfaces. The cellulose fiber and the electrolyte shall be delivered through separate hoses, then mixed at a nozzle and sprayed directly onto the concrete surface. The fiber-electrolyte mixture shall be applied only after the anode is securely installed. The fiber-electrolyte layer shall be approximately 1.5 to 2" thick.

14.1.3 Wetting of Electrolyte Media - The Electrolyte Media must be kept 'wet' at all times. The treatment areas can be wrapped in plastic to minimize moisture loss due to evaporation. An irrigation system with a continuous supply of electrolyte can be set up to ensure all surfaces are continuously wetted.

## 15. Specific Requirements for Horizontal Surfaces

15.1 Installation of the anode system for horizontal surfaces shall meet the requirements of sections 15.1.1 through 15.1.3.

15.1.1 Anode - The Anode for horizontal surfaces shall be a catalyzed titanium unless otherwise specified. This mesh is suitable to apply to horizontal surfaces and will not produce any rust staining. Steel anode may be used with the appropriate electrolyte media.

15.1.2 Electrolyte Media - The Electrolyte Media for horizontal surfaces can be either a cellulose fiber, as in section 14.1.2, or multiple layers of felt cloth. In most applications felt cloth can be used as the electrolyte media. Using this system, a layer of felt will be followed by the titanium and covered with a top layer of felt, thus producing a felt/titanium/felt sandwich. If a titanium anode is utilized, a proposal for mitigating acid generation at the titanium shall be submitted by the contractor. The proposal shall contain a minimum of three reference projects where the proposed method has been used by the contractor.

15.1.3 Wetting of the Electrolyte Media - A small watertight barrier (min 40mm in height) shall be erected around the perimeter of the horizontal surface to be treated. To continuously wet the electrolyte media, the area inside the barrier shall be flooded with electrolyte. To keep the electrolyte media saturated a irrigation system may be utilized. Also, covering the surface with plastic will reduce evaporation and retain moisture.

**16. Report and Data Sheets** - After completion of the work, the contractor shall prepare a final report as defined below. The final report shall include the following information on the ECE project:

16.1 Project name and location.

16.2 Reinforcing steel continuity testing completed on the structure and locations of any continuity bondings made.

16.3 Surface preparation performed before treatment.

16.4 Description of the ECE installation and procedure used.

16.5 Materials used with manufacturers' data sheets.

16.6 Description of test locations and test procedures.

16.7 Current and voltage readings during treatment.

16.8 All test results including pre and post Cl<sup>-</sup> levels.

16.9 Pre treatment corrosion potential survey measurements if specified. In order to allow sufficient depolarization of the structure, post treatment corrosion potential survey may not be taken prior to 3 to 6 months after treatment..

16.10 Locations and repair of any damage to the concrete arising from the treatment.

16.11 Discussion of results, including consideration of any local anomalies or variations in results.

16.12 Statement on the effectiveness of the treatment.

**17. Key Words** - Electrochemical Chloride Extraction, ECE, bridge sub-structure repair, bridge deck repair, concrete repair, corrosion remediation, corrosion mitigation