# SECTION 10 – STRAY CURRENT/CORROSION CONTROL

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### 10.1.0 GENERAL

This section describes the design criteria necessary to provide corrosion control measures. Corrosion control measures are required to prevent premature corrosion failures on transit system fixed facilities and other underground structures. Such measures will also minimize stray current levels and their effects on underground and above grade structures. Corrosion control systems should be economical to install operate, and maintain.

#### 10.1.1 Scope

Corrosion control design criteria encompass all engineering disciplines applied to the project. The criteria are separated into three areas: soil corrosion, stray current corrosion and atmospheric corrosion. The design criteria for each of these categories, and their implementation, shall meet the following objectives:

- Realize the design life of system facilities by avoiding premature failure caused by corrosion;
- Minimize annual operating and maintenance costs associated with material deterioration;
- Provide continuity of operations by reducing or eliminating corrosion related failures of systems and subsystems; and
- Minimize detrimental effects to facilities belonging to others as may be caused by stray earth currents from transit operations.

#### 10.1.2 System Interfaces

Corrosion control engineering shall be coordinated with the other disciplines, including mechanical, utility, electrical, civil, structural, trackwork, electrification, signaling and communications designs.

#### 10.1.3 Codes and Standards

All design relating to implementation of the corrosion control requirements shall conform to or exceed the requirements of the latest versions of codes and standards identified in these criteria.

#### 10.1.4 Requirements

Soil Corrosion Control

Criteria in this category apply to systems or measures installed to mitigate corrosion caused by soil/rock and groundwater.

Soil/rock samples should be obtained in conjunction with geotechnical testing in areas of extensive below grade construction. The samples should be analyzed for resistivity (or conductivity), moisture content, pH, chloride and sulfate ion concentrations, and for the presence of sulfides.

Structures shall be protected against environmental conditions by the use of coatings, insulation, cathodic protection, electrical continuity or a combination of the preceding, as appropriate.

Stray Current Corrosion Control

Criteria in this category apply to measures installed with the traction power system and trackwork to assure that stray earth currents which may be produced by the traction electrification system do not exceed maximum acceptable levels, $10^{14}$ ohms-cm. These levels are based on system characteristics and the characteristics of underground structures.

These criteria also apply to measures installed with fixed facilities, and to facilities belonging to others. They are based on anticipated stray earth current levels and the characteristics of fixed facilities and other buried structures.

Atmospheric Corrosion Control

Criteria in this category apply to systems or measures installed to mitigate corrosion caused by local climatological conditions and air pollutants.

## 10.2.0 SOIL CORROSION CONTROL

This section provides criteria for the design of systems and measures to prevent corrosion of transit system fixed facilities due to contact with area soil/rock and groundwater. Designs shall be based on achieving a minimum 50 year design life for buried structures, with exception of a 100 year design life for the stations, through consideration of the factors given below.

### 10.2.1 Materials of Construction

All pressure and non-pressure piping and conduit shall be non-metallic, unless metallic materials are required for specific engineering purposes.

Aluminum and aluminum alloys shall not be used in direct burial applications. If non-native fill is to be used for backfilling concrete or ferrous structures, then it shall meet the following criteria:

- pH 6 to 8 (ASTM G-51)
- Maximum chloride ion concentration of 250 ppm (ASTM D-512)
- Maximum sulfate ion concentration of 200 ppm (ASTM D-516)

Test reports shall be submitted for approval of all imported backfill.

Use of fill material, which does not meet one or any of the preceding criterion, may be acceptable after review and approval by RTD.

### 10.2.2 Safety and Continuity of Operations

Corrosion control protection shall be required for those facilities where failure of such facilities caused by corrosion may affect the safety, or interrupt the continuity of operations.

### 10.2.3 Accessibility of Installations

Permanent test facilities installed with certain corrosion control provisions shall be accessible after installation, allowing for periodic maintenance and monitoring.

### 10.2.4 Special Considerations

Installation of corrosion control measures for facilities owned by others, but designed as part of the transit project, shall be coordinated through RTD or its representative. This coordination shall resolve design and construction conflicts to minimize the impact on other system elements.

### 10.2.5 Materials and Methods

The following paragraphs establish the materials and methods to be used for soil corrosion control.

#### 10.2.5.1 Coatings

Coatings specified for corrosion control of buried metallic or concrete facilities shall satisfy the following criteria:

- Minimum volume resistivity of $10^{10}$ ohm-centimeters (10 Billion ohm-centimeters) (ASTM D-257).
- Minimum thickness as recommended for the specific system, but not less than 15 mils.
- A chemical or mechanical bond to the metal or concrete surface. Pressure-sensitive systems are not acceptable; non-bonding systems may be used in special instances, after review and approval by the RTD
- Minimum 5 year performance record for the intended service.
- Mill application wherever possible, with field application of a compatible paint or tape system.

- Mechanical characteristics capable of withstanding reasonable abuse during handling and earth pressure after installation for the design life of the system.

Generic coating systems include but are not limited to the following:

- Extruded polyethylene/butyl based system
- Coal-tar epoxies (two component systems)
- Polyethylene-backed butyl mastic tapes (cold applied)
- Bituminous mastics (airless spray)

#### 10.2.5.2 Electrical Insulation of Piping

Devices used for electrical insulators for corrosion control shall include nonmetallic inserts, insulating flanges, couplings, unions, and/or concentric support spacers. Devices shall meet the following criteria:

- A minimum resistance of 10 megohms prior to installation.
- Sufficient electrical resistance after insertion into the operating piping system such that no more than 2 percent of a test current applied across the device flows through the insulator, including flow through conductive fluids if present.
- Mechanical and temperature ratings equivalent to the structure in which they are installed.
- Internal coating (except complete non-metallic units) with a polyamide epoxy for a distance on each side of the insulator equal to two times the diameter of the pipe in which they are used. Where conductive fluids with a resistivity of less than 2,000 ohm-centimeters are present, internal coating requirements shall be based on separate evaluation.
- Devices (except non-metallic units) buried in soils shall be encased in a protective coating.
- Devices (except non-metallic units) installed in chambers or otherwise exposed to partial immersion or high humidity shall have a protective coating applied over all components.
- Inaccessible insulating devices, such as buried or elevated insulators, shall be equipped with accessible permanent test facilities.
- A minimum clearance of 12 inches shall be provided between new and existing metallic structures. When

conditions do not allow a 12 inch clearance, the design shall include special provisions to prevent electrical contact with existing structure(s).

#### 10.2.5.3 Electrical Continuity of Piping

Electrical continuity shall be provided for all non-welded metallic pipe joints and shall meet the following criteria:

- Use direct burial, insulated, stranded, copper wire with the minimum length necessary to span the joint being bonded.
- Wire size shall be based on the electrical characteristics of the structure and resulting electrical network to minimize attenuation and allow for cathodic protection.
- Use a minimum of two wires per joint for redundancy.
- Surface preparation of the structure to be coated shall be required in accordance with the coating manufacturer's recommendations.

#### 10.2.5.4 Cathodic Protection

The design of cathodic protection shall be by a NACE International certified Corrosion Specialist or Cathodic Protection Specialist. Cathodic protection shall be accomplished by sacrificial galvanic anodes to minimize corrosion interaction with other underground utilities. Impressed current systems shall be used only when the use of sacrificial systems is not technically and/or economically feasible. Cathodic protection schemes that require connection to the transit system negative return system, in lieu of using a separate isolated anode ground bed, shall not be permitted.

Cathodic protection system design shall be based on industrial standards (NACE International), recommended practices, and criteria on theoretical calculations. Theoretical calculations shall include the following parameters:

- Estimated percentage of bare surface area (minimum 1 percent)
- Cathodic protection current density (minimum of 1.0 $ma/ft^2$ of bare surface area)
- Estimated current output per anode
- Estimated total number of anodes, size and spacing
- Minimum anode life of 25 years (minimum 50 percent efficiency)
- Estimated anode ground bed resistance

Impressed current rectifier systems shall be designed using potentially controlled rectifiers with permanent reference electrode facilities. Rectifiers shall be rated at a minimum of 50% above calculated operating levels to overcome a higher-than-anticipated anode ground bed resistance, lower-than-anticipated coating resistance, or presence of interference mitigation bonds. Other conditions which may result in increased voltage and current requirements shall be considered.

Test facilities consisting of a minimum of two structure connections, one reference electrode connection, conduits and termination boxes shall be designed to permit initial and periodic testing of cathodic protection levels, interference currents and system components (anodes, insulating devices and continuity bonds). The Design Engineer shall specify the locations and types of test facilities for each cathodic protection system.

### 10.2.6 Structures and Facilities

The following paragraphs establish the protective measures to be considered for utilities and buried structures.

#### 10.2.6.1 Ferrous Pressure Piping

All new buried cast iron, ductile iron and steel pressure piping shall be cathodically protected. System design shall satisfy the following minimum criteria:

- Conformance with existing standards and specifications of the Owner.
- Conformance with federal, state and local codes for regulated piping.
- Application of a protective coating to the external surface of the pipe (see Section 10.2.5.1).
- Electrical insulation of pipe from interconnecting pipe, casings, other structures and segregation into discrete electrically isolated sections depending upon the total length of piping (see Section 10.2.5.2).
- Electrical continuity through the installation of copper wires across all mechanical pipe joints other than intended insulators (see Section 10.2.5.3).
- Permanent test/access facilities to allow for verification of electrical continuity, electrical effectiveness of insulators and coating, and evaluation of cathodic protection levels, installed at all insulated connections. Additional test/access facilities shall be installed at intermediate locations, either at intervals not greater than 200 feet, or at greater

intervals determined on an individual structure basis (see Section 10.2.5.4).

- Number and location of anodes and size of rectifier (if required) shall be determined on an individual structure basis.

#### 10.2.6.2 Copper Piping

Buried copper pipe shall be electrically isolated from non-buried piping, such as that contained in a station structure, through use of an accessible insulating union installed where the piping enters through a wall or floor. Pipe penetrations through the walls and floors shall be electrically isolated from building structural elements. The insulator should be located inside the structure and not buried.

#### 10.2.6.3 Gravity Flow Piping (Non-Pressured)

Corrugated steel piping shall be internally and externally coated with a sacrificial metallic coating and a protective organic coating.

Cast or ductile iron piping shall be designed and fabricated to include the following provisions:

- An internal mortar lining with a bituminous coating on ductile iron pipe only (not required for cast iron soil pipe)
- A bonded protective coating or unbonded dielectric encasement on the external surfaces in contact with soils (AWWA Standard C105)
- A bituminous mastic coating on the external surfaces of pipe 6 inches on each side of a concrete/soil interface

Reinforced concrete non-pressure piping shall include the following provisions:

- Water/cement ratios meeting the minimum provisions of AWWA
- Maximum 250 ppm chloride concentration in the total concrete mix (mixing water, cement, admixture and aggregates)
- Use Type 1 cement, except as noted in Table 10-A.

**TABLE 10-A- ACCEPTABLE CEMENT TYPE BASED ON SULFATE CONCENTRATIONS OF SOIL AND GROUNDWATER**

| Acceptable Cement Type | Percent Water Soluble Sulfate (As $SO_4$) In Soil Samples | Sulfate (as $SO_4$) in Groundwater (ppm) |
|---|---|---|
| Type I | 0 to 0.10 | 0 to 150 |
| Type II | 0.10 to 0.20 | 150 to 1,000 |
| Type V | Over 0.20 | Over 1,000 |

**10.2.6.4 Electrical Conduits**

Buried metallic conduits shall include the following provisions:

- Galvanized steel with PVC or other coating acceptable for direct burial, including couplings and fittings. The PVC coating is not required when conduits are installed in concrete.
- Electrical continuity through use of standard threaded joints or bond wires installed across non-threaded joints.

**10.2.6.5 Buried Concrete/Reinforced Concrete Structures**

The design of cast-in-place concrete structures shall be based on the following provisions.

- Use Type I cement, except as noted in Table 10-A. Use of a concrete mix with a cement type not specifically listed in Table 10-A must be reviewed and approved by RTD. ASTM C 452-75 and American Concrete Institute (ACI) Publication SP-77 "Sulfate Resistance of Concrete" should be used as guidelines for evaluating the sulfate resistance of concrete mixes with non-standard cement types.
- Water/cement ratio and air entrainment admixture in accordance with specifications presented in the structural criteria to establish a dense, low permeability concrete. Refer to applicable sections of ACI 201.2R "Guide to Durable Concrete".
- Maximum chloride concentration of 250 ppm in the total mix (mixing water, aggregate, cement, and admixtures). The concrete mix should be such that the water soluble and acid soluble chloride concentrations, at the concrete/reinforcing steel interface, do not exceed 0.15

and 0.2% by weight of cement, respectively, over the life of the structure. Refer to applicable sections of ACI 222R "Corrosion of Metals in Concrete".

- Concrete cover over reinforcing steel shall comply with ACI codes and provide a minimum of 2 inches of cover on the soil/rock side of reinforcement when pouring within a form and a minimum of 3 inches of cover when pouring directly against soil/rock.
- The need for additional measures, as a result of localized special conditions, shall be determined on an individual basis. Additional measures may include application of protective coating to concrete, reinforcing steel, or both.

Precast standardized facilities, such as vaults and manholes, must be reviewed on an individual basis to determine alternative criteria when they cannot be practically modified to meet some or all of the provisions specified herein.

Precast segmented concrete ring construction shall meet the requirements of this Section or be reviewed on an individual basis to determine alternative criteria when they cannot be practically modified to meet some or all of the provisions specified.

Below Grade Shotcrete

- Below grade shotcrete used for permanent support shall be in accordance with ACI 506.2 and applicable provisions specified in this Section. In the case of conflicting specifications, the more rigid or conservative specification shall be applicable.
- No special corrosion control measures are required for shotcrete applications, which are not considered as providing permanent support.

#### 10.2.6.6 Support Pilings

The following is applicable only to support piling systems, which are to provide permanent support. Pilings used for temporary support do not require corrosion control provisions.

Designs based on the use of metallic supports exposed to the environment, such as H or soldier piles, shall include the use of a barrier coating. The need for special measures, such as cathodic protection, shall be determined on an individual basis, based on type of structure, analysis of soil borings for corrosive characteristics, and the degree of anticipated structural deterioration caused by corrosion.

Reinforced concrete piling, including fabrications with prestressed members, shall be designed to meet the following minimum criteria:

- Water/cement ratio and cement types in accordance with Section 10.2.6.5.
- Chloride restrictions for concrete with non-prestressed members shall be in accordance with Section 10.2.6.5.
- Chloride restrictions for concrete with prestressed members shall be in accordance with Section 10.2.6.5, with exception that the concrete mix should be such that the water soluble and acid soluble chloride concentrations, at the concrete/prestressed steel interface, do not exceed 0.06 and 0.08 percent by weight of cement, respectively, over the life of the structure. Refer to ACI 222R "Corrosion of Metals in Concrete".
- A minimum of 3 inches of concrete cover over the outermost reinforcing steel, including prestressing wires, if present.

Concrete-filled steel cylinder columns, where the steel is an integral part of the load bearing characteristics of the support structure, shall be designed considering the need for special measures, such as increased cylinder wall thickness, external coating system, and/or cathodic protection. The design shall be determined on an individual basis, based on type of structure, analysis of soil borings for corrosive characteristics and the degree of anticipated structural deterioration caused by corrosion. Chloride restrictions shall be in accordance with Section 10.2.6.5.

#### 10.2.6.7 Reinforced Concrete Retaining Walls

Cast-in-place concrete retaining walls shall be in accordance with the requirements in Section 10.2.6.5.

Modular-type retaining walls with restraining devices or reinforcing strips placed beneath the LRT tracks shall meet the requirements in Section 10.2.6.5, FHWA Publication No. FHWA-SA-96-072, and require special consideration for stray current mitigation due to the location of critical structural components. Designers must provide for stray current and soil corrosion control for modular retaining walls with structural support components beneath the LRT tracks.

Modular-type retaining walls that do not place critical structural components beneath the tracks shall meet the requirements in Section 10.2.6 5, FHWA Publication No. FHWA-SA-96-072, and the following or be reviewed on an individual basis to determine alternative criteria when they can not practically modified to meet some or all of the provisions specified below.

- Embedded and buried steel reinforcing members of the modules should be constructed without special provisions for establishing electrical continuity.
- Steel reinforcing strips of adjacent modules should not be electrically interconnected. The reinforcing strips should be coated with a fluidized bed epoxy resin system or coal tar epoxy system.
- Tie-strips should be coated with a fluidized bed epoxy resin system or coal tar epoxy system prior to module construction.
- The tie-strips should not make electrical contact to the reinforcement steel in each module. A minimum 1 inch separation should be maintained.
- Longitudinal reinforcing steel within precast concrete parapets and cast-in-place junction slabs should not be made electrically continuous.

Pre-stressed/post-tensioned concrete cylinder pressure pipe shall not be designed for use in the vicinity of the LRT tracks or substations without review on an individual basis to determine alternate materials of construction. If these types of piping are used, the following items shall be addressed in the design.

- Possibility of hydrogen embrittlement of highly stressed steel components
- Provisions for electrical continuity within the manufactured pipe
- Provisions for electrical continuity of mechanical fittings and pipe joints
- Provisions for monitoring stray currents and hydrogen over voltages
- Provisions for reducing stray currents through the use of dielectric coatings or encasements
- Possible consequences of a failure of the pipe

## 10.3.0 STRAY CURRENT CORROSION CONTROL

This section provides criteria for designs to minimize the corrosive effect of stray earth traction currents from transit operations on transit structures and adjacent structures owned by others.

Stray current control shall reduce or limit the level of stray currents at the source, under normal operating conditions, rather than trying to mitigate the corresponding effects (possibly detrimental), which may otherwise occur on transit facilities and other underground structures. The basic requirements for stray current control are as follows:

- Operate the mainline system with no direct or indirect electrical connections between the positive and negative traction power distribution circuits and ground.
- Design the traction power system and trackwork to minimize stray earth currents during normal revenue operations.

### 10.3.1 Traction Power System

Traction power supply system shall be designed as a dedicated system, providing power solely to the light rail line. Joint use of traction power facilities, except for common civil structures, is not permitted. Individual traction power supply system for the light rail line shall be designed with two electrically isolated, independent subsystems for mainline and shop.

#### 10.3.1.1 Traction Power Substations (Mainline)

Traction power substations shall be spaced at intervals such that maximum track-to-earth potentials do not exceed 50 volts during normal operations.

Substations shall be provided with stray current facilities to allow the connection of the negative bus to the station ground mat through a relay (normally open) and a current monitoring shunt. The test facility should be implemented to allow for periodic monitoring of the stray current return to identify changing conditions associated with the track-to-earth resistance.

Substations shall be provided remote monitoring systems to record the negative bus-to-earth potential, negative return shunt and the stray current return circuit. The remote monitoring system shall consist of either a stand-alone data acquisition module and communications package or SCADA interface.

Provisions shall be included to monitor track-to-earth potentials on a continuous basis at intervals not greater than 3.0 miles. Monitoring facilities shall be located at traction power substations and at intermediate locations, such as passenger stations, to maintain the recommended spacing. Permanently installed recorders or provisions for connection to the SCADA system shall be considered.

Space should be provided in each substation for future installation of stray current mitigation drainage devices. Additional requirements for this area are as follows:

- The designated area should have direct access to the DC negative bus or have access through a 3 inch PVC conduit or cable run. Installation of a separate drainage bus would be a preferred alternative. A suitable drainage bus would be a copper plate 6 inches high, 24 inches wide, and 1/2 inch thick, with two 250 MCM cables connected between the copper plate and DC negative bus.
- The drainage bus must be electrically isolated from other grounded facilities in the substation.
- Four 3 inch PVC conduit stubouts from the area to a manhole or weathertight enclosure conveniently located outside the substation.
- The dedicated area inside the substation should have easy access for test personnel.

#### 10.3.1.2 Positive Distribution System

Positive distribution system shall be normally operated as an electrically continuous bus, with no breaks, except during emergency or fault conditions. Intentional electrical segregation of mainline, yard and shop positive distribution systems is the only type of segregation permitted.

Overhead contact systems (OCS), consisting primarily of support poles, the contact wire and, where applicable, the messenger wire, shall be designed to meet the following minimum requirements and include the following minimum provisions:

- A maximum leakage current to ground of 2.5 milliamperes per mile of single track OCS with 2,500 volts DC applied between the OCS and ground.
- Discrete grounding of individual at-grade support poles, in lieu of interconnecting poles to each other or to a common ground electrode system. Establish electrical continuity of reinforcing steel in OCS support poles as described in Section 10.3.1.3 and electrically connect support poles to the foundation reinforcing steel.
- Common grounding of support poles on aerial structures through electrical connection to either bonded (welded) reinforcing steel in the deck or to each other and a common ground electrode system, when present. Establish electrical connections as described in Section 10.3.2.2 for OCS poles on aerial structures.

#### 10.3.1.3 Mainline Negative Return System

Running Rails

The mainline running rails, including special trackwork, grade crossings and all ancillary system connections, shall be designed to have a minimum, uniformly distributed, in-service track-to-earth resistance as determined by the following requirements:

- The use of a computerized simulation of the traction power system to determine the level of stray current generated at a minimum of two levels of track-to-earth resistance. The simulation shall be performed with train operations at each passenger station along the ROW and any special conditions as noted by the traction power designer.
- The use of soil layer resistivity (ASTM G-57) along the entire ROW at a maximum spacing of 500-feet between measurement locations and to a minimum depth of 15-feet. This information shall be incorporated into the stray current simulation to determine the earth potential gradients anticipated along the ROW.
- Under no circumstances shall the allowable track-to-earth resistance level be less than the following:
  - o Special trackwork and concrete tie & ballast track: 250 ohm- 1000-feet (4 rails)
  - o Direct fixation track: 250 ohm-1000-feet (4 rails)

The criteria shall be met through the use of appropriately designed insulating track fastening devices, such as insulated tie plates, insulated rail clips, direct fixation fasteners, rail fastener coating or other approved methods.

Ballasted track construction shall meet the following minimum provisions:

- Use of a hard rock, non-porous, well drained ballast material free of dirt or debris.

A minimum 1 inch clearance between the ballast material and all metallic surfaces of the rail and metallic track components in electrical contact with the rail.

Mainline track shall be electrically insulated from the shop tracks by use of insulated rail joints in both rails of each track. Location of the insulating joints shall be chosen to reduce the possibility of a vehicle bridging the insulator for a time period longer than that required to move a vehicle into or out of the shop.

Mainline track shall be electrically insulated from foreign railroad connections (sidings) by use of insulating rail joints. Location of the insulating joints shall be chosen to reduce the possibility of a vehicle bridging the insulator(s) for a time period larger than required to move onto or off of mainline.

Special trackwork shall include the following: embedded trackwork at stations, embedded crosswalks, turnouts, crossovers, grade crossings. The special trackwork shall meet the following minimum provisions:

- Electrical isolation shall be provided between the rail and all embedment materials including, grade crossings, exhibiting a minimum volume resistivity of $1 \times 10^{14}$ Ohm-Centimeters as measured in accordance with ASTM D-257.
- The surface profile of the finished grade adjacent to the rails shall be sloped away from the rail to allow for drainage and reduced accumulation of debris.
- The surface profile of the finished grade within 6-inches of the rail shall be a smooth finish to support maintenance and cleaning.

Ancillary Systems

Switch machines, signaling devices, train communication systems, and other devices or systems which may contact the rails shall be electrically isolated from earth. The criteria shall be met through the use of dielectric materials electrically separating the devices/systems from earth, such that the criterion given in Section 10.3.1.3 is met.

Electrical Continuity

The running rails shall be constructed as an electrically continuous power distribution circuit through use of either rail joint bonds, impedance bonds, continuously welded rail or a combination of the three, except for the use of insulated rail joints at the locations noted in Sections 10.3.1.3 and 10.3.1.4.

#### 10.3.1.4 Maintenance Shop

Shop traction power shall be provided by a separate dedicated DC power supply electrically segregated in both the positive and negative DC power circuits from the yard traction power system and the mainline system.

Shop track shall be electrically connected to the shop building and shop grounding system.

Other electrically grounded track, such as blowdown pit tracks, car wash tracks and interconnecting switching tracks between these facilities shall be electrically insulated from the yard tracks and powered from the shop traction power supply.

#### 10.3.1.5 Water Drainage

Below grade sections shall be designed to prevent water from dropping or running onto the running rails and rail appurtenances and shall be designed to prevent the accumulation of freestanding water.

Water drainage systems for sections exposed to the environment shall be designed to prevent water accumulation from contacting the rails and rail appurtenances.

### 10.3.2 Transit Fixed Facilities

#### 10.3.2.1 Aerial Trackway Structures

<u>Column and Bearing Assemblies, Direct Fixation</u>

This section applies to aerial structures and bridges that use a column and bearing assembly that can be electrically insulated from deck or girder reinforcing steel and will have insulated trackwork construction.

- Provide electrical continuity of top layer reinforcing steel in the deck/girder by welding all longitudinal lap splices.
- Electrically interconnect all top layer longitudinal reinforcing steel by welding to transverse collector bars installed at breaks in longitudinal reinforcing steel, such as at expansion joints, hinges and at abutments. Connect collector bars installed on each side of a break with a minimum of two cables.
- Provide additional transverse collector bars at intermediate locations to maintain a maximum spacing of 500 feet between collector bars.
- Provide a ground electrode system at each end of the structure and at intermediate locations to maintain a maximum spacing between ground electrode systems of 1,500 feet. The number, location and earth resistance of the ground electrode system must be determined on an individual structure basis.
- Provide test facilities at each end of the structure and at intermediate locations to maintain a maximum spacing of 500 feet between test points. The facilities will house test

wires from the collector bars and ground electrode system, if present.

- Provide electrical isolation of reinforcing steel in deck/girders from columns, abutments and other grounded elements. Isolation can be established through the use of insulating elastomeric bearing pads, dielectric sleeves and washers for anchor bolts, and dielectric coatings on selected components.
- All copper to steel weld locations (bond cables) shall require coating with a cold applied, fast drying mastic consisting of bituminous resins and solvents.
- An alternate method to the use of electrical continuity is the use of epoxy coated reinforcing steel. RTD approval is required prior to the use of the alternate system.

Column and Bearing Assemblies, Tie and Ballast

This section covers the same type of aerial structures covered above, but with tie and ballast track construction. Welding of reinforcing steel in the deck is not required for this configuration.

- Provide a waterproofing, electrically insulating membrane (with protection board) over the entire surface of the deck that will be in contact with the ballast. The membrane system shall have a minimum volume resistivity of $10^{10}$ (10 billion) ohm-centimeters.
- Provide an electrically continuous collector grid, such as steel welded wire fabric, directly on top of the protection board over the waterproofing membrane and beneath the ballast. The collector grid shall extend the full width of the trackway.
- Provide a ground electrode system at each end of the structure and at intermediate locations to maintain a maximum spacing between ground electrode systems of 1,500 feet. The number, location, and earth resistance of the ground electrode system must be determined on an individual structure basis.
- Provide test facilities at each end of the structure and at intermediate locations to maintain a maximum spacing of 500 feet between test points. The facilities will house test wires from the collector grid and ground electrode system, if present.
- Provide electrical isolation of reinforcing steel in deck/girders from columns, abutments, and other grounded elements. Isolation can be established through the use of insulating elastomeric bearing pads, dielectric sleeves and

washers for anchor bolts and dielectric coatings on selected components.

- All copper to steel weld locations (bond cables) shall require coating with a cold applied, fast drying mastic consisting of bituminous resins and solvents.
- An alternate method to the use of insulating membrane (with protection board) is the use of spray applied polyurea. RTD approval is required prior to the use of the alternate system.

Bents and Girders, Direct Fixation

This section applies to aerial structures that use bent type supports with reinforcing steel extending into the deck/girders.

Girders can be pre or post tensioned. This type of construction precludes the electrical isolation of deck/girder steel from bent/column steel. Ground electrode systems are not required for these types of structures.

Provide electrical continuity of top layer reinforcing steel in the deck/girder by welding all longitudinal lap splices.

Electrically interconnect all top layer longitudinal reinforcing steel by welding to transverse collector bars installed at bents and on each side of breaks in longitudinal reinforcing steel, such as at expansion joints, hinges and at abutments (deck side only). Connect collector bars installed on each side of a break with a minimum of two bond cables.

- Provide electrical continuity of all column/bent steel by welding appropriate reinforcing to at least two vertical column bars. Make these connections to each of the two vertical bars at the top and bottom of the column/bent.
- Electrically interconnect column/bent steel to deck/girder steel by welding at least two vertical column bars to collector bars installed at bents.
- Electrically interconnect column/bent steel to footing steel when column/bent steel penetrates the footing. Weld at least two vertical column/bent bars to footing reinforcing steel.
- Electrically interconnect pre or post tensioned cables to continuous longitudinal reinforcing steel by welding a cable between each anchor plate and the longitudinal reinforcing steel.
- Provide test facilities at each hinge and expansion joint and at every Provide other column/bent, starting with the first

column/bent from an abutment. Test facilities at hinges and expansion joints will house bonding cables from adjacent collector bars on each side of the hinge/joint. Facilities at columns/bents will house two wires from vertical column/bent steel and from the collector bar at the top of the bent.

- All copper to steel weld locations (bond cables) shall require coating with cold applied, fast drying mastic consisting of bituminous resins and solvents.
- An alternate method to the use of electrical continuity is the use of epoxy coated reinforcing steel. RTD approval is required prior to the use of the alternate system.

Bents and Girders, Tie and Ballast

This section covers the same type of aerial structures covered above, but with tie and ballast track construction.

- Provide the same features as described in the bullet points above for direct fixation and the following additional item.
- Provide a waterproofing, electrically insulating membrane over the entire surface of the deck that will be in contact with the ballast. The membrane system shall have a minimum volume resistivity of $10^{10}$ (10 billion) ohm-centimeters.
- All copper to steel weld locations (bond cables) shall require coating with a cold applied, fast drying mastic consisting of bituminous resins and solvents.
- An alternate method to the use of insulating membrane (with protection board) is the use of spray applied polyurea. RTD approval is required prior to the use of the alternate system.

Concrete Deck/Exposed Steel, Direct Fixation

This section applies to bridge structures that use a reinforced concrete deck with exposed steel superstructure and will have insulated trackwork construction. This type of construction precludes the electrical insulation of deck reinforcing steel from superstructure steel.

- Provide electrical continuity of top layer reinforcing steel in the deck/girder by welding all longitudinal lap splices.
- Electrically interconnect all top layer longitudinal reinforcing steel by welding to transverse collector bars installed at breaks in longitudinal reinforcing steel, such as at expansion joints, hinges, and abutments. Connect collector

bars installed on each side of a break with a minimum of two cables.

- Provide additional transverse collector bars at intermediate locations to maintain a maximum spacing of 500 feet between collector bars.
- If the total structure length exceeds 250 feet, provide a ground electrode system at each end of the structure and at intermediate locations to maintain a maximum spacing between ground electrode systems of 1,500 feet. The number, location and earth resistance of the ground electrode system must be determined on an individual structure basis.
- Provide test facilities at each end of the structure and at intermediate locations to maintain a maximum spacing of 500 feet between test points. The facilities will house test wires from the collector bars and ground electrode system, if present.
- Provide electrical isolation of reinforcing steel in the deck and superstructure steel from columns, abutments, and other grounded elements. Isolation can be established through the use of insulating elastomeric bearing pads, dielectric sleeves and washers for anchor bolts, and dielectric coatings on selected components.
- If electrical isolation of reinforcing steel in the deck and superstructure steel from columns, abutments and other grounded elements cannot be obtained, then electrical continuity of metallic components within these latter elements must be established by appropriate welding and bonding procedures.
- All copper to steel weld locations (bond cables) shall require coating with a cold applied, fast drying mastic consisting of bituminous resins and solvents.
- An alternate method to the use of electrical continuity is the use of epoxy coated reinforcing steel. RTD approval is required prior to the use of the alternate system.

Concrete Deck/Exposed Steel, Tie and Ballast

This section covers the same type of aerial structures covered above, but with tie and ballast track construction. Welding of reinforcing steel in the deck is not required for this configuration.

- Provide a waterproofing, electrically insulating membrane (with protection board) over the entire surface of the deck that will be in contact with the ballast. The membrane system shall have a minimum volume resistivity of $10^{10}$ (10 billion) ohm-centimeters.

- Provide an electrically continuous collector grid, such as steel welded wire fabric, directly on top of the protection board over the waterproofing membrane and beneath the ballast. The collector grid shall extend the full width of the trackway.
- Provide a ground electrode system at each end of the structure and at intermediate locations to maintain a maximum spacing between ground electrode systems of 1,500 feet. The number, location and earth resistance of the ground electrode system must be determined on an individual structure basis.
- Provide test facilities at each end of the structure and at intermediate locations to maintain a maximum spacing of 500 feet between test points. The facilities will house test wires from the collector grid and ground electrode system, if present.
- Provide electrical isolation of reinforcing steel in the deck and superstructure steel from columns, abutments and other grounded elements. Isolation can be established through the use of insulating elastomeric bearing pads, dielectric sleeves and washers for anchor bolts, and dielectric coatings on selected components.
- If electrical isolation of reinforcing steel in the deck and superstructure steel from columns, abutments, and other grounded elements cannot be obtained, then electrical continuity of metallic components within these latter elements must be established by appropriate welding and bonding procedures.
- All copper to steel weld locations (bond cables) shall require coating with a cold applied, fast drying mastic consisting of bituminous resins and solvents.
- An alternate method to the use of insulating membrane (with protection board) is the use of spray applied polyurea.  RTD approval is required prior to the use of the alternate system.

<u>Existing Concrete Deck Structures, Tie and Ballast</u>

This section applies to existing aerial structures used for LRT installation. Stay current corrosion control for existing aerial type structures shall be addressed by limiting earth current levels at the source (running rails). Meeting the criteria established in Section 10.3.1 and those items indicated below will provide the primary stray current control for these facilities.

- Provide a waterproofing, electrically insulating membrane (with protection board) over the entire surface of the deck that will be in contact with the ballast. The membrane system shall have a minimum volume resistivity of $10^{10}$ (10 billion) ohm-centimeters.
- Provide an electrically continuous collector grid, such as steel welded wire fabric, directly on top of the protection board over the waterproofing membrane and beneath the ballast. The collector grid shall extend the full width of the trackway.
- Provide a ground electrode system at each end of the structure and at intermediate locations to maintain a maximum spacing between ground electrode systems of 1,500 feet. The number, location and earth resistance of the ground electrode system must be determined on an individual structure basis.
- Provide test facilities at each end of the structure and at intermediate locations to maintain a maximum spacing of 500 feet between test points. The facilities will house test wires from the collector grid and ground electrode system, if present.
- An alternate method to the use of insulating membrane (with protection board) is the use of spray applied polyurea. RTD approval is required prior to the use of the alternate system.

#### 10.3.2.2 Overhead Contact System (OCS) Pole Foundation Grounding

All metallic components, inclusive of the pole baseplate, that will be partially embedded or come in contact with concrete surfaces shall be coated with a sacrificial or barrier coating. The sacrificial coating shall be applied to the entire component. The barrier coating shall extend a minimum of 6 inches into the concrete and a minimum of ½ inch above the surface of the concrete.

At-Grade OCS Support Poles

- Electrical continuity of reinforcing steel within support pole foundations shall be established to provide an adequate means for dissipating any leakage current from the contact wire and, where applicable, the messenger wire. The following minimum provisions shall be included with design:
  - o The outermost layer of vertical reinforcing steel within the concrete foundation shall be tack welded at all intermediate vertical lap joints and to reinforcing bar

    - collector rings (two) installed at the top and bottom of the reinforcing bar cage.
    - A copper cable shall be connected between the base of the catenary support pole and the foundation reinforcing steel. The cable shall be thermite welded or brazed to the support pole and routed in such a manner that it will not be susceptible to damage during construction or after installation is complete.
    - The copper cable shall be sized based upon anticipated fault current and fault clearing time.
- Different electrical continuity requirements may be necessary depending on the actual reinforcing configuration for the support pole foundations.
- All copper to steel weld locations (bond cables) shall require coating with a cold applied, fast drying mastic consisting of bituminous resins and solvents.

OCS Poles on Aerial Structures. OCS poles located on aerial structures shall include either of the following minimum set of provisions, depending on the type of aerial structure.

- Where the aerial structure includes welded deck reinforcing steel connected to a ground electrode system, electrically interconnect the OCS support poles on the structure and connect these poles to the ground electrode system.
    - Cabling used to interconnect the poles and the ground electrode system shall be sized based upon anticipated fault current and fault clearing time.
    - The cabling shall be routed in conduit and terminated in junction boxes or test cabinets that also house wires from the deck reinforcing steel and the ground electrode system.
    - Cabling shall be designed to allow for connection of interconnected OCS poles along the aerial structure to all ground electrode systems installed with a particular aerial structure.
- Where the aerial structure has welded deck reinforcing steel but does not include a ground electrode system, electrically connect the OCS support poles to the welded deck reinforcing steel.
    - Provide a copper cable from each OCS support pole to the deck reinforcing steel. The copper cable shall be sized based upon anticipated fault current and fault clearing time.

- Thermite weld or braze the cable to the OCS support pole and preferably to the nearest transverse collector bar installed in the aerial structure deck.
- Where it is not practical to connect an OCS pole directly to a transverse collector bar, because of excessive distance or other factors, connect the pole to a local transverse reinforcing bar using a copper cable and weld the transverse reinforcing bar to at least three upper layer longitudinal reinforcing bars in the deck.

- All copper to steel weld locations (bond cables) shall require coating with a cold applied, fast drying mastic consisting of bituminous resins and solvents.

#### 10.3.2.3 Utility Structures

All piping and conduit shall be non-metallic, unless metallic facilities are required for specific engineering purposes. There are no special provisions required if nonmetallic materials are used.

Metallic Facilities (System wide)

- Pressure or non-pressure piping exposed within crawl spaces or embedded in concrete inverts shall not require special provisions.
- Pressure piping that penetrates station walls shall be electrically insulated from the external piping to which it connects, wall reinforcing steel, and from watertight wall sleeves.

Metallic Facilities (Shop)

All reinforcing steel, structural steel, and rails within the shop building shall be electrically connected to a common grounding grid.

- All pressure piping within the shop building or perimeter of the shop foundation or foundation slab shall have the following minimum provisions:
    - Designed to be run above or within the foundation slab. Below slab installations must be reviewed on an individual basis to determine the need for special measures.
    - Electrical insulation from interconnecting pressure piping located outside the shop building or perimeter of the foundation/foundation slab. Locate insulating devices above grade or inside the building, in lieu of burying directly.

- o Electrical insulation from watertight wall/floor sleeves and wall reinforcement.
- o Electrical connection to the shop common ground grid at sufficient locations, such that there will be only negligible potential differences between the piping and grounding network during fault and normal conditions.

<u>Metallic Facilities (Yard)</u>

- All buried pressurized piping shall meet the criteria of Section 10.2.0 and include the following minimum provisions:
    - o Electrical continuity as described in Section 10.2.5.3.
    - o Electrical insulation from interconnecting non-transit facilities and possibly additional insulation to establish discrete electrical units.
    - o Test/access facilities installed at all insulated connections and at intermediate locations as determined during final design.
- Metallic fencing surrounding the yard perimeter shall be made electrically continuous and grounded.

### 10.3.3 Facilities Owned by Others

#### 10.3.3.1 Replacement/Relocated Facilities

Corrosion control requirements for buried utilities installed by a utility owner/operator as part of transit construction shall be the responsibility of the individual utility owner/operator. Minimum stray current corrosion control criteria, when guidance is requested by the utility owner/operator, shall be in accordance with Section 10.3.3.2.

Relocated or replaced utilities, installed by transit contractors as part of contractual agreement between the transit agency and the utility, shall be installed in accordance with the utility owner specifications and shall include the following minimum provisions. These provisions are applicable to ferrous and reinforced concrete pressure piping. Other materials and structures will require individual review.

- Electrical continuity through the installation of insulated copper wires across all mechanical joints for which electrical continuity cannot be assured and shall be evaluated on a case by case basis.

- The requirement for electrical access to the utility structure via test facilities shall be evaluated on a case by case basis.
- The need for additional measures, such as electrical isolation, application of a protective coating system, installation of cathodic protection or any combination of the preceding, shall be based on the characteristics of the specific structure and to not adversely effect the existing performance within the environment.

#### 10.3.3.2 Existing Utility Structures

The need for stray current monitoring facilities shall be jointly determined by RTD and the utility operators. If utilities require assistance, the following minimum provisions shall be suggested.

- Test facilities may be installed at select locations for the purpose of evaluating stray earth current effects during start-up and revenue operations. Guidelines for location of test facilities shall be as follows:
    - At all utility crossings with the system, and on structures that are within 300 feet and parallel to the system ROW.
    - At locations on specific utility structures that are within 300 feet of the system traction power substations.

#### 10.3.3.3 Existing Bridge Structures

Stray current corrosion control for existing bridge structures shall be addressed by limiting earth current levels at the source (running rails). Meeting the criteria established in Sections 10.3.1.1, 10.3.1.2, 10.3.1.3, and 10.3.2.2 will provide the primary stray current control for these facilities.

## 10.4.0 MISCELLANEOUS CORROSION CONTROL CONSIDERATIONS (COATINGS)

Coatings shall have established performance records for the intended service and be compatible with the base metal to which they are applied.

Coatings shall be able to demonstrate satisfactory gloss retention, color retention and resistance to chalking over their minimum life expectancies.

Coatings shall have minimum life expectancies, defined as the time prior to major maintenance or reapplication, of 15 to 20 years.

### 10.4.1 Metallic-Sacrificial Coatings

Acceptable coatings for carbon and alloy steels for use in tunnels, crawlspaces, vaults or above grade are as follows:

- Zinc (hot-dip galvanizing [2 oz. per sq ft] or flame sprayed)
- Aluminum (hot-dip galvanizing [2 mil thickness] or flame sprayed)
- Aluminum-zinc
- Cadmium and electroplated zinc (sheltered areas only)
- Inorganic zinc (as a primer)

### 10.4.2 Organic Coatings

Organic coating systems shall consist of a wash primer (for galvanized and aluminum substrates only), a primer, intermediate coat(s) and a finish coat. Acceptable organic coatings, for exposure to the atmosphere, are as follows:

- Aliphatic polyurethanes
- Vinyl copolymers
- Fusion-bonded epoxy polyesters, polyethylenes and nylons
- Acrylics, where not exposed to direct sunlight
- Alkyds, where not exposed to direct sunlight
- Epoxy as a primer where exposed to the atmosphere or as the complete system where sheltered from sunlight

### 10.4.3 Conversion Coatings

Conversion coatings, such as phosphate and chromate coatings shall be used as pretreatments only for further application of organic coatings.

### 10.4.4 Ceramic-Metallic Coatings (Cermets)

This hybrid-type coating system is acceptable for use on metal panels and fastening hardware.

### 10.4.5 Sealants

Seal all crevices with a polysulfide, polyurethane or silicone sealant.

### 10.4.6 Barrier Coating System

Use one of the following barrier coating systems where corrosion protection is needed but appearance is not a primary concern:

- Near white blast surface according to SSPC-SP 10. Follow with a three coat epoxy system.

- Commercial blast surface according to SSPC-SP 6. Follow with a two coat inorganic zinc and high build epoxy system.
- Near white blast surface according to SSPC-SP 10. Follow with a three coat epoxy zinc, high build epoxy system.
- Apply all coatings according to manufacturer's specifications.

Use one of the following barrier coating systems where corrosion protection and good appearance are needed.

- Near white blast surface according to SSPC-SP 10. Follow with a three coat inorganic zinc, high build epoxy, and polyester urethane system.
- Near white blast surface according to SSPC-SP 10. Follow with a three coat vinyl system.
- Commercial blast surface according to SSPC-SP 6. Follow with a three coat epoxy zinc, high build epoxy, and polyester urethane system.
- Commercial blast surface according to SSPC-SP 6. Follow with a three coat epoxy zinc, high build epoxy, and acrylic urethane system.
- Apply all coating according to manufacturer's specifications.

## 10.5.0 QUALITY CONTROL TESTING

### 10.5.1 Electric Continuity

The electrical continuity of reinforcement and utility structures is required by the design criteria. The requirements for determining the proper electrical characteristics of these structures shall be incorporated into the design of the structure. The following paragraphs establish the guidelines for developing the quality control test procedures for electrical continuity.

- All structures that are to be made electrically continuous shall be tested for electrical continuity, compared to theoretically based criteria, and meet or exceed the accepted criteria.
- Incorporate a specific set of test procedures and acceptance criteria to be followed for the electrical continuity testing into the project specifications.
- Incorporate selection criteria for the test entities to perform the quality control testing including the qualifications of the agency, personnel requirements and equipment requirements. A minimum of 5 years of experience performing this work is required.
- Incorporate specific reporting requirements for the electrical continuity testing.

### 10.5.2 Cathodic Protection

The application of cathodic protection on the underground utility structures is required by the design criteria. The requirements for determining proper application of cathodic protection include the verification of electrical continuity (Section 10.5.1) and verification of cathodic protection compliance with industry standards (NACE International). The following paragraphs establish the guidelines for developing the quality control test procedures for verification of proper cathodic protection levels.

- All structures that are required to have cathodic protection shall be tested in accordance with NACE International RP0169.
- A test plan shall be submitted by the testing agency to be approved by the RTD.
- Incorporate specific reporting requirements for the cathodic protection testing.
- Incorporate selection criteria for the testing entities to perform the quality control testing including the qualifications of the agency, personnel requirements, and equipment requirements. A minimum of 5 years of experience performing this work is required.

### 10.5.3 Coatings

The quality control measures required for the verification of proper application and handling vary greatly depending on the coating type. The following guidelines establish general procedures for the quality control testing.

- Coatings shall be tested in accordance with the manufacturer's recommendations and in accordance with NACE International Recommended Practices.
- A quality control test plan shall be required for the application and testing of all coated surfaces. The test plan shall address the allowable coating thickness measurements, adhesion requirements, hold points for test, test procedures to be used in the quality control process, and the reporting and acceptance requirements for each specific type of coating system being used.
- All shop coated surfaces shall first be tested, witnessed, and accepted at the coating facility. Additional field quality control hold points shall be required.
- Incorporate selection criteria for the testing entities to perform the quality control testing including the qualifications of the agency, personnel requirements, and equipment requirements. A minimum of 10 years of experience performing this work is required.

### 10.5.4 Track-to-Earth Resistance Testing

The track-to-earth resistance of the running rails is the primary barrier for the control of stray current discharge from the negative system. The requirements for conducting this testing are as follows:

- Incorporate a specific set of test procedures and acceptance criteria to be followed for the track-to-earth testing into the project specifications.
- Incorporate selection criteria for the testing entities to perform the quality control testing including the qualifications of the agency, personnel requirements, and equipment requirements. A minimum of 10 years of experience performing this work is required.
- Incorporate specific reporting requirements for the track-to-earth resistance testing.