ABSTRACT:
This paper summarizes corrosion control measures for stray current encountered in an electrified rail-transit environment. Methods developed to protect various metallic and reinforced concrete infrastructure based on the type of track structure will be evaluated:

1. Tie and Ballast
2. Direct Fixation
3. Embedded Tracks
4. Tracks in Aerial Structures
5. Tracks in Tunnels
6. Green Tracks

For each of these trackwork systems, corrosion control measures to mitigate stray currents will be presented. The magnitude of stray current is affected largely by the rail-to-ground resistance. Generally, the lower this resistance, the less isolated the rails are and the lower the voltage drop will be along the rail. Since the running rails are typically the primary traction power return current path for an electrified system, leakage from the rails into the surrounding track structure is more likely to occur. Serious safety and/or stray current corrosion problems can arise if this phenomenon is ignored. A high track-to-earth resistance (i.e. well isolated rails) is one is the most important aspects of stray current control. Careful attention to trackwork design and construction can ensure both well-isolated rails and high track-to-earth resistance. Increasing the resistance of the running rails to earth is one is the most effective methods of reducing stray current levels on transit and neighboring infrastructure. Tables with recommended rail-to-earth resistance criteria for each track system will be provided.

The criteria shall be met through the use of appropriately designed isolating track fastening devices, such as isolated tie plates, isolated rail clips, plastic ties, isolated direct fixation fasteners, rail fastener coating or other approved methods. Test facilities shall be included, to the extent necessary, to determine rail-to-earth resistance levels during construction and operations.

Corrosion control measures to mitigate stray current on metallic and reinforced concrete facilities neighboring track systems are recommended. There are two basic methods to minimize stray currents on structures to a reasonable level: 1) ensure that structures close to the tracks are electrically continuous and 2) properly isolate structures from tracks. Both methods are presented for each type of track structure.

All prevention, mitigation and control measures should be installed, operated and maintained in a cost-effective manner. Cost estimates for corrosion control measures for each track system should also be
1. INTRODUCTION

Electrified rail transit systems, both light and heavy rail, typically utilize the running rails as the negative side of the electrical circuit in the system’s traction power network. The positive side, which carries direct current (DC) from the substation to the transit vehicle, is an overhead wire system or third power rail. Because perfect electrical insulators do not exist, electrical currents will leak out of this circuit and escape into the soil to find the path of least resistance back to the substation. Stray currents from the track, are common and can get quite large due in no small part to the proximity of the track to the ground. Once in the soil, stray currents will follow any available conductor to get back to the traction power substation. These paths can include the soil itself; buried utility pipelines and cables; and other metallic structures, such as bridges, along the way. If an alternative path offers less electrical resistance than another route, then the better conductor will carry proportionally more of the stray current. In extreme examples, particularly when the electrical continuity of the track structure is poor, more electricity will return as stray current than through the running rails. Some older elevated railway systems were actually designed for this occurrence. The amount of such stray currents will be inversely proportional to the efficacy of the electrical insulation provided and directly related to the conductivity of the soil and any alternative current paths back to the substation such as pipes, cables, reinforcing steel, etc. Where this current leaves a conductor to go to another, corrosion occurs by electrolysis.

In addition to stray current that originates at an electrified rail transit line, other sources of stray current can be found in virtually any metropolitan area. It is important to identify these so that the contributions from each source can be analyzed and appropriate mitigation measures be implemented. For the same reason, regular monitoring of the structures for stray current and corrective maintenance of any leaks are both extremely important.

While corrosion can occur for many reasons, stray current is responsible for a significant proportion of the corrosion damage that occurs on DC electrified rail transit systems. Controlling that damage requires controlling the stray current at its source—the track structure. The track engineer, working together with other disciplines, plays a key role in that mission.

An extremely important part of designing a proper traction system is to keep the resistance of the negative current return as low as possible. This is done by providing a metallic, low-resistance path so the current will return to the traction power substation through the intended conductors. The two running rails are normally used for this purpose. Other designs, such as continuously welding the running rails and crossbonding the two running rails, also decreases the resistance of the negative return path. Unfortunately, other return paths of varying resistance along the transit system exist for the negative current to follow. If these parallel return paths have a sufficiently low resistance, or the equivalent parallel resistance is low, some of the current will return via these alternative paths as well as by the running rails and thereby propagate stray currents.

2. MAINLINE TRACKS

A. Rail-to-Earth Resistance

The mainline running rails, including special trackwork and ancillary system connections, are recommended to have the following minimum as-constructed rail-to-earth resistances specified, normalized to 1,000 feet of track (two rails):

- Embedded track: 250 Ω.
- Direct-fixation track: 1,000 Ω.
- At-grade ballasted track with concrete ties: 500 Ω.
- At-grade ballasted track with plastic (composite) ties: 500 Ω.
- At-grade ballasted track with wood ties: 250 Ω.
- Green track: 250 Ω.
- Grade crossings: 250 Ω.

The criteria shall be met through the use of appropriately designed isolating track fastening devices, such as isolated tie plates, isolated rail clips, plastic ties, isolated direct-fixation fasteners, rail fastener coating, or other approved methods. Test facilities shall be included, to the extent necessary, to determine rail-to-earth resistance levels during construction and operations. Rail-to-earth resistance shall be periodically monitored during construction to detect variations or decreases in the resistance. Investigations shall be initiated as soon as a low resistance reading is detected and the adverse condition(s) repaired promptly by the contractor. See Figure 1 for a schematic diagram for rail-to-earth resistance testing.

Figure 1 – Schematic Diagram for Rail-to-Earth Resistance Testing

B. Rail Size

Historically, rail size was an issue because electrified-transit systems were often built on existing trolley track used for horse-drawn trolley cars. These running rails were small and did not provide a sufficiently low-resistance return for the current. Today, all transit systems use similar size running rails ranging from 90 to 120 pounds per yard of rail, which provides a sufficient negative return for the currents needed on modern transit systems. Thus, rail size is not a modern design issue.

C. Electrical Continuity

Another important measure to decrease the running-rail resistance is to maintain a continuous electrical path for the negative current return. Running rails shall be constructed as an electrically continuous power distribution circuit through the use of continuously welded rail, impedance bonds, rail joint bonds, or a combination of these methods, except for the use of isolated rail joints.
D. **Rail Isolation Joints**

Mainline track shall be electrically isolated from the yard and shop tracks by use of isolated rail joints in both rails of each track. Similarly, the yard and shop tracks are recommended to be electrically isolated from one another. Location of the isolating joints shall be chosen to reduce the possibility of a vehicle standing or parking at the interface point. The isolated rail joints shall not be bridged for a time period longer than that required to move a train across the interface point. Additional rail isolating joints shall be installed prior to bumping posts.

Mainline track shall be electrically isolated from foreign railroad connections (sidings) by use of isolating rail joints. Location of the isolating joints shall be chosen to reduce the possibility of a portion of train bridging the isolator(s) for a time period longer than required to move onto or off of mainline.

For LRT transit systems the placement of OCS section breaks and mainline negative return system isolated rail joints should be coordinated with the location of the LRV pantographs and tracks.

E. **Track Bonding and Cross-Bonding**

Cross-bonding is to be provided as required to meet criteria for traction power, signaling, EMI limitations, and other considerations. Track cross-bonds shall be provided rail-to-rail and track-to-track between mainline inbound and outbound tracks in order to maintain equal potentials on rails for stray current control. Cross-bonding shall be designed and installed to avoid conflicts with EMI limitations, meet the following minimum requirements, and include the following minimum provisions:

- Cross-bond spacing shall not exceed 2,000 feet wherever possible.
- Cross-bonding shall be installed within 500 feet of passenger station platforms if not covered by other criteria for cross-bonds.
- Rail bond jumpers shall be installed across mechanical rail connections.

F. **Ancillary Systems**

In order to keep traction power current in running rails switch machines, signaling devices, train communication systems, and other devices or systems which may contact the rails should be electrically isolated from earth. The criteria can be met through the use of dielectric materials electrically separating the devices/systems from earth, or by separating the grounded portion of the device from the rails.

G. **Track Ties**

1. **Concrete Ties**

Concrete crossties with an insulating base consisting of a rail pad and clip insulators provide good rail insulation. The rail seat pad is generally constructed of thermo-plastic rubber, ethyl vinyl acetate, or natural rubber. It is approximately 0.25 to 0.62 inches thick and is formed to fit around the iron shoulder embedded in the concrete crosstie. The clip insulator may be a glass reinforced nylon material formed to sit on the rail and under the steel anchoring clip. This affords electrical insulation between the rail and the concrete tie anchoring clip. Insulating the rail base is important because concrete crossties, with their reinforcing steel, are not good insulators.

2. **Timber Ties**

While wood is generally a good insulating material, timber crossties are only marginal insulators both because they are treated with preservative chemicals and they absorb moisture as they age. Traditionally, rails were installed on wood ties treated with creosote to increase the resistance of the wood and to prevent degradation. While they provide sufficient insulation against low-voltage, low-amperage signal system currents, they offer little resistance to high-voltage, high-amperage traction power current.
Timber crossties with insulating components at the fastening plate can be used on main line track and at special trackwork turnouts and crossovers to reduce leakage. Electrical insulation can be achieved by inserting a polyethylene pad between the metal rail plate and the timber tie, installing an insulating collar thimble to electrically isolate the steel plate from the anchoring lag screw, and applying coal tar epoxy to the hole for the lag screw. The insulating pad and collar thimble afford insulation directly between the two materials. Coal tar epoxy applied to the drilled tie hole fills any void between the end of the collar thimble and timber tie and affords some insulation between the lag screw and wood tie. The insulated tie plate pad should extend a minimum of 0.5 inches beyond the tie plate edges to afford a higher resistance path for surface tracking of stray currents. Chemical compatibility between the pad and epoxy material must be verified during design.

While at first glance, timber crossties appear attractive compared to concrete ties on a first cost basis, the costs of materials and labor associated with adding insulated rail fastenings to them can tip the scale toward the use of concrete crossties. This is particularly true if high quality timber ties, are specified. Because of this factor, the longer life expectancy of high quality concrete crossties, and the fact that fewer concrete crossties are usually required, most rail transit projects have concluded that concrete crossties are more economical on a life cycle cost basis.

Wooden ties can, of course, catch fire; as they age they develop cracks that allow sparks to lodge so that they catch fire more easily. In the USA for main line tracks, timber ties have a very limited use.

3. Concrete ties

Concrete ties are cheaper and easier to obtain than timber and better able to carry higher axle-weights and sustain higher speeds. Concrete ties have a longer service life and require less maintenance than timber due to their greater weight, which helps them remain in the correct position longer. Concrete ties need to be installed on a well-prepared subgrade with an adequate depth on free-draining ballast to perform well. Concrete ties amplify wheel noise, so wooden ties are often used in densely populated areas.

From stray current control point of view concrete ties provide higher resistance between rail and ground comparing to wooden ties.

4. Steel Ties

Steel ties are now in widespread use on secondary or lower-speed lines in the Europe where they have been found to be economical to install due their ability to be installed on the existing ballast bed. Steel ties are lighter in weight than concrete and able to stack in compact bundles unlike timber. Steel ties can be installed onto the existing ballast, unlike concrete ties which require a full depth of new ballast. Steel ties are 100% recyclable and require up to 60% less ballast than concrete ties and up to 45% less than wood ties.

Modern steel ties handle heavy loads, have a proven record of performance in signalized track, and handle adverse track conditions. Of high importance to railroad companies is the fact that steel ties are more economical to install in new construction than creosote-treated wood ties and concrete ties.

Steel ties require a proper isolation from the ballast in order to minimize leakage of traction power current to the ground. Because of such leakage which is difficult to stop steel ties have a very limited use in USA electrified railroads.

5. Plastic Ties

Plastic ties become more and more popular around the world. Manufacturers claim a service life longer than wooden ties with an expected lifetime in the range of 30–80 years. In some main track applications, the hybrid plastic tie has a recessed design to be completely surrounded by ballast.
H. Track Ballast

Ballasted track construction should meet the following provisions to minimize stray current:

• 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 metallic surfaces of the rail and metallic track components in electrical contact with the rail.

I. Embedded Tracks

For corrosion control embedded track slabs should be designed with the following provisions:

• Epoxy coated reinforcement steel should not be used for track slabs or other reinforced concrete structures that may be subject to detrimental levels of stray current from the transit system.

• Electrical continuity of top layer reinforcing steel in the slab needs to be provided and can be achieved by welding longitudinal lap splices.

• Top layer longitudinal reinforcing steel can be electrically interconnected by welding to transverse collector bars installed at breaks in longitudinal reinforcing steel, such as at expansion joints, hinges, and abutments. Collector bars, installed on each side of a break, connected by exothermically welding multiple insulated copper jumpers to the collector bar on adjoining track slabs. Jumper cables should be extended to a test station. Where the track slab crosses bridges or other structures and the track slab continues on the other side, then copper jumpers shall be exothermically welded between the two separate track slabs so the slabs are electrically continuous. The jumper cables shall be installed in PVC conduit. The number of cables required shall be determined by the Corrosion Engineer of Record during final design.

• Additional transverse collector bars shall be provided at intermediate locations to maintain a maximum spacing of 500 feet between collector bars.

• A test station shall be provided approximately every 500 feet at collector bar locations and at each end of the slab. Test stations installed at breaks shall be located within the system ROW, preferably on sidewalks or platforms, to allow testing with minimum impact to train and vehicular traffic. The test box shall contain equipment and wiring to enable electrical separation of adjacent track slabs. Test stations installed in accordance with the two previous bullets shall be taken into consideration during the design, when scheduling the breaks between adjacent embedded track slabs.

• Two 4-AWG isolated wires connected to each collector bar. A minimum of 6 feet shall separate wires wherever possible. Wires shall be run to the nearest test box. Wire tags with numbers shall be provided on both ends of the wire and the wires shall be color-coded.

• Copper-to-steel weld locations (bond cables) coated with a cold applied, fast drying mastic consisting of bituminous resins and solvents or an approved epoxy.
• Prior to and after the pouring of the concrete, the rebar system should be tested for continuity. The rebar system resistance shall be within 20% of the theoretical resistance of the system.

J. **Green Tracks**

Green track, which are designed for plant material to grow alongside and between the running rails, should have a minimum rail-to-earth resistance of 250 Ohms per 1,000 feet of track (two rails). Special attention shall be made in the design, construction, and maintenance of the green track in order to maintain a minimum 4-inch horizontal clearance between any plant, growing medium, and/or soil material and metallic surfaces of the rail and/or metallic track components in electrical contact with the rail.

K. **Direct Fixation Tracks**

Direct fixation track is generally located on aerial sections or in tunnels in dc powered transit systems. The direct fixation fasteners provide electrical insulation between the rails and the concrete structure. The typical direct fixation fastener consists of a sandwich of steel plates and rubber pads, with the latter providing both electrical isolation and acoustic attenuation. An elastomer of the proper resistivity provides excellent insulation and deters current leakage. Fastener inserts are often epoxy coated to further isolate the rails from the concrete slab. See direct fixation track system example below:

*Figure 2 – Direct Fixation Track System*

Generally direct fixation considered as the best trackwork system to control stray currents. It becomes more and more popular in USA and around the globe.

L. **Underground Trackway Structures**

For soil corrosion control of underground trackways in tunnel inverts the design of concrete shall include the following provisions:
- Use a maximum water cement ratio by weight in accordance with either ACI Standards or a maximum water/cement ratio of 0.45 by weight, whichever is less.
- Maximum chloride concentration of 250 ppm in the cement,
- A minimum 3 inches of cover on soil side of tunnel structures when pouring directly against soils.

For stray current corrosion control the reinforcing steel in underground trackway in the inverts of subways, portals, and underground stations shall be made electrically continuous. Minimum requirements shall include the following:

- Welding of all longitudinal lap splices in the top layer of first pour reinforcing steel in inverts.
- Welding of all longitudinal top layer members in the first-pour reinforcing steel in inverts to a transverse (collector) bar at each end of the structure, at intervals along the structure not exceeding 500 feet and at each side of electrical (physical) breaks in the longitudinal reinforcing steel, such as at expansion joints. Transverse (collector) bars located on each side of breaks in the longitudinal reinforcing steel shall be interconnected electrically with copper bond cables.
- Electrical continuity in top layer invert reinforcing steel should be maintained across bridging beams located at the interfaces between structures. Top-layer longitudinal steel reinforcement or dowels for bridging beams shall be welded at lap splices and interconnected through welded connections or copper bond cables to adjacent top-layer steel reinforcement in structures located on each side of the bridging beam.
- Test facilities shall be installed on first-pour reinforcing steel at each end of the structure and at transverse collector bars located at intervals along the structure not exceeding 1,000 feet. Test facilities shall consist of insulated copper wires, conduits, and enclosures terminated at an accessible location.

M. Aerial Trackway Structures

Aerial structures and bridges shall be designed for the following provisions against stray current corrosion:

- Electrical continuity of top layer deck/girder reinforcing steel shall be provided by welding all longitudinal lap splices.
- All top layer longitudinal deck/girder reinforcing steel shall be electrically interconnected by welding to transverse collector bars installed at each end of the structure and at each side of breaks in longitudinal reinforcing, such as at expansion joints, hinges and abutments. Transverse collector bars installed on each side of a break shall be electrically interconnected with a minimum of two copper bond cables.
- Additional transverse collector bars shall be provided at intermediate locations along the structure to maintain a maximum spacing of 500 feet between collector bars.
N. Fiber Reinforcing

For many applications, it is becoming increasingly popular to reinforce the concrete with small, randomly distributed fibers. Fibers of various shapes and sizes produced from steel, plastic, glass, and natural materials are being used; however, for most structural and nonstructural purposes, steel fiber is the most commonly used of all the fibers. Compared to plain concrete, fiber reinforced concrete is much tougher and more resistant to impact. Small microfibers stabilize the microcracks and increase the strength – reducing the porosity of concrete. Generally fiber concrete is an excellent option for stray current corrosion control of track slabs. Recently it has been used in several transit projects including East Side Access project of MTA’s Long Island Rail Road.

3. YARD TRACKS

- Yard track including at-grade crossings shall generally not require insulating track fastening devices. Yard track shall be constructed with no direct or indirect electrical connections between the rail and electrically grounded systems. The design of yard track shall include the following minimum provisions:
  - Use of high-resistivity, well-drained ballast material.
  - Minimum 1-inch clearance between the ballast material and metallic surface of the rail and of metallic track components in electrical contact with the rail.
  - Dead-ended tracks shall have isolated joints installed to isolate bumping posts or similar devices that are electrically grounded. Isolated rail joints shall be located to prevent a train from bridging the isolators.
  - Dead-ended track shall have the negative return rails cross-bonded to other negative return rails within 10 feet of the end of the track.
  - Cross-bonding negative return cables shall utilize a main cable run (possibly several cables) with taps to negative power rail(s) as opposed to long runs of individual cables connected to single negative power rails.
  - Yard tracks must be electrically insulated from mainline track.

4. CONCLUSIONS

It is critical for soil and stray current corrosion to be considered during the design of trackwork for dc transit systems. High track-to-earth resistance ensures that much of the traction current stays in the rails which serve as a negative return to traction power substations. This paper provides several methods to effectively control stray current and soil corrosion for different types of trackwork. Fiber reinforcing for track slabs, direct fixation of rails, bonding of steel reinforcing used in trackway are among the methods for successfully controlling corrosion in various track structures.

5. LIST OF FIGURES

Figure 1 – Schematic Diagram for Rail-to-Earth Resistance Testing

Figure 2 – Direct Fixation Track System
REFERENCES:


4. W. Sidoriak, “Rail Isolation on the Baltimore Central Light Rail Line,” MP 32

5. E. Wetzel “Track-to-Earth Resistance, What Does it Mean?” NACE Paper 05242
CORROSION CONTROL/STRAY CURRENT MITIGATION IN VARIOUS TRACK STRUCTURES

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AGENDA

• DC Powered Transit and Corrosion Control
• Types of Corrosion (Affecting DC Powered Systems)
• Trackwork Mitigation Techniques Used
• Important Things To Keep In Mind
Trackwork Systems

• Tie and Ballast
• Direct Fixation
• Embedded Tracks
• Tracks in Aerial Structures
• Tracks in Tunnels
• Green Tracks
Types of Corrosion

• Stray Current Corrosion
  ✓ Refers to the current that leaves the rails and flows through paths other than the intended circuit. The extent of damage or loss of metal is directly proportional to the magnitude of stray current passing through the system. Stray current leaving the rail will cause severe corrosion of the rail.

• Soil and Water Corrosion
  ✓ This type of corrosion is typically results from metals and nonmetals in contact with soluble chloride salts found in the soil or water. Some key factors that influence the severity and rate of corrosion include: the amount of moisture in the soil, the conductivity of the solution, the pH of the solution, and the oxygen concentration within the soil (aeration). Improper track isolation from the ground can cause soil-related corrosion of the rail bottom.
Corroded Rail on Wooden Ties
Stray Current from LRT

- Corrosion will occur at the location where current leaves the rails or any metallic structure. In this case corrosion occurs both on the rail and pipe.
Stray Current Simplified Circuit

- **Load (Train)**
  - $I_G$ to $R_G$

- **Positive Circuit (OCS)**
  - $I_T$

- **Negative Circuit (Rails)**
  - $I_N$

- **TPSS**
  - $I_S$ to $R_S$
Stray Current Mitigation Techniques

• Decreasing the electrical resistance of the return circuit makes current through the ground less likely. This can be done by the following:
  ✓ Use of heavier rail sections
  ✓ Continuously welded rails
  ✓ Improved rail bonding
  ✓ Supplementary negative return cables

• The rail to soil resistance can be increased by using insulators placed between the rails and concrete or wooden ties and by using insulated rail fasteners

• High resistivity concrete for track slabs, e.g. silica fume additive

• Properly isolate rails from neighboring structures

• Track cross-bonding

• Yard electrically isolated from main line
Electrical Continuity of Steel Reinforcement

Steel Reinforcement of Trackway:

• The top layer of steel reinforcing should be made electrically continuous by bonding.
• Installation of test facilities should be placed at regular intervals.

If electrical continuity of steel reinforcement is not provided than the corrosion of steel will cause concrete to crack and spall.
Track Insulation

c. Direct Fixation Fastener on a Wood Tie.
Soil and Water Corrosion Mitigation Techniques

- Want to minimize corrosion of transit systems facilities caused by contact with corrosive soil, rock and groundwater.

- The corrosive tendencies of the soil and groundwater along the rights-of-way (ROW) can be determined by performing a soil analysis.

- Structures and systems can be protected against environmental conditions by the use of coatings, electrical isolation, electrical continuity provisions, cathodic protection or a combination of all.

- The most important factor in modern rail design is to assure that the rail is well drained and free of collecting water that supports the chemical reaction that causes oxidation.
Track-to-Earth Resistances/1000 ft
(Double Rail)

- Embedded track: 250 Ω.
- Direct-fixation track: 1,000 Ω.
- At-grade ballasted track with concrete ties: 500 Ω.
- At-grade ballasted track with plastic (composite) ties: 500 Ω.
- At-grade ballasted track with wood ties: 250 Ω.
- Green track: 250 Ω.
- Grade crossings: 250 Ω.
Rail-to Earth Resistance Test
Things to Keep in Mind

• Rail-to-earth resistance has to be measured in accordance with ASTM G-165 during track installation and immediately after installation.

• Effective corrosion control of dc powered transit systems could be achieved primarily by providing and maintaining high levels of electrical isolation of rail tracks from ground.

• In order to meet the permissible touch voltages most of dc transit systems require the potential of the rails to ground not to exceed a predetermined threshold.

• Track components specifications should include appropriate electrical resistance features to accomplish the goals of the corrosion control plan.