# Design of Reinforced Concrete Bridge Structures to Mitigate Against Stray Current Corrosion Within a Rail Corridor

Colin Morrow, Senior Bridge Engineer, Aurecon, Australia

## ABSTRACT

Electrified direct current traction systems are commonly used to power rail networks in constrained urban environments, these systems can result in stray current leaking in to adjacent reinforced concrete structures. Electrolysis corrosion occurs where these stray currents are discharged from reinforced concrete elements. The corrosion rate is proportional to the current magnitude and can lead to rapid steel section loss.

The risk of stray-current electrolysis corrosion occurring within reinforced concrete bridges and retaining wall structures can be mitigated through the use of various mitigation measures. There are several state and international guidance documents outlining preferred strategies. This paper discusses some of these strategies and provides examples of how their objectives can be met, specifically focusing on the detailing of reinforced concrete structures. These mitigation measures are presented in the context of a recently completed rail grade separation project in Melbourne.

The provision of electrical segregation of reinforced concrete elements reduces the risk of stray current electrolysis occurring. The use of insulating elements is provided at the segregation locations to provide a non-continuous structure. The provision of electrical continuity within reinforced concrete elements also reduces the risk of localised electrolysis corrosion occurring, both within the element and at the discharge locations. The tack welding of steel reinforcement cages should be used to create the electrical continuity, with tie wiring methods typically not accepted by rail authorities. The completed structure must be tested to validate the electrical conductivity assumed.

Overhead wire support structures must also be considered and should be detailed depending on the connection types and support structures. The earthing and bonding strategy for a given project must be developed along with the electrolysis strategy to ensure the best overall solution.

## INTRODUCTION

Electrified direct current (DC) traction systems are commonly used to power suburban train and tram networks. The rail networks are often located close to existing structures and assets, increasing the likelihood of any detrimental rail-structure interaction effects occurring.

DC traction systems result in stray current being leaked from the rail tracks and travelling back to the rail substation through conductive structural elements. Electrolysis corrosion occurs at the location where the current leaves the structural elements which can cause the premature failure of the structure.

This potential failure mechanism is particularly relevant when the existing rail tracks are to be grade separated from a road intersection. In this scenario, the rail is typically elevated over the road on a bridge structure or passes under the road in a trough-like cut involving the use of retaining walls. Adequate consideration must be given to the management and mitigation of electrolysis corrosion for elements constructed near electrified rail.

Several states in Australia have published guidance documents that describe preferred mitigation measures for stray current induced corrosion. The implementation of the measures is still not well understood within the construction industry and is often seen as an unnecessary expense.

This paper gives a brief introduction to electrolysis corrosion and how it may develop within structures adjacent to electrified DC rail. Furthermore, the various strategies which can be employed as electrolysis mitigation measures are discussed. Finally, detailed examples of mitigation measures for reinforced concrete structures are presented.

The examples provided in this paper are referenced form the recently completed Level Crossing Removal Project: Furlong Main Blackburn Heatherdale [5] in Melbourne, Australia. This project involved the construction of four rail-under-road grade separations.

### How Do Stray Currents Occur In A Rail Environment?

Typically, trams and trains are powered by DC traction systems with substations provided at approximately 5km to 15km intervals [2]. The current is received by the train pantograph from the overhead contact wire and returns to the substation via the wheels of the train in contact with the tracks rails.

In ideal circumstances, all of the current will flow directly to the substation through the rails. In reality, as the rails are in contact with the earth which may have some element of conductivity, a portion of the current will leak from the rails and return to the substation through the earth and/or other elements with low resistivity. The current which does not take the direct path to the substation through the rails is known as “Stray Current”, see Figure 1 below. The track is not the only source of stray currents, leakage can occur via faulty (leaky) overhead wire support insulators.

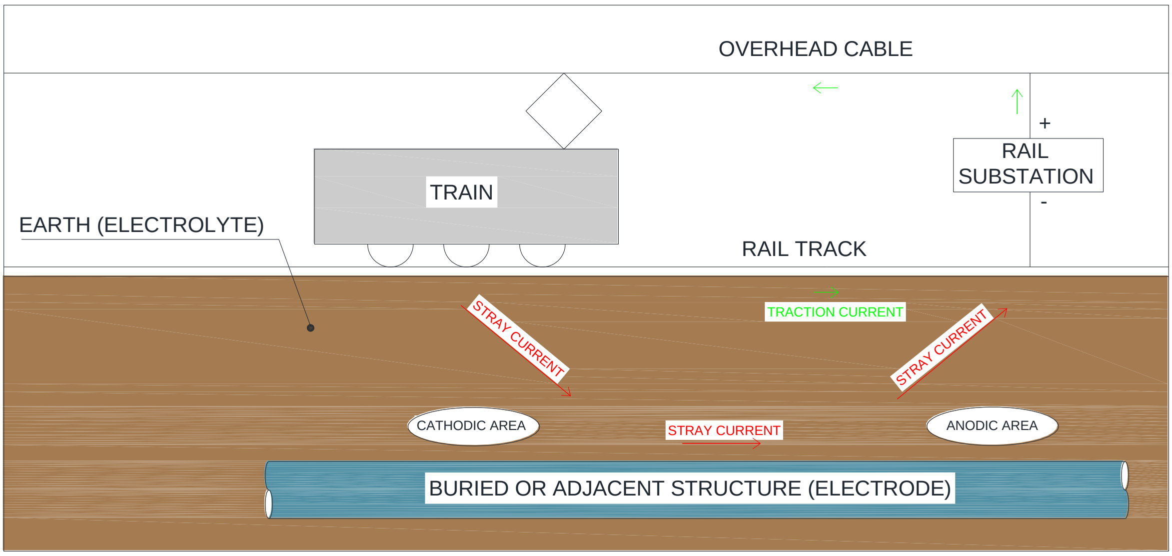


**Figure 1: Stray Current Flow Diagram**

## How Do Stray Currents Lead To Corrosion?

The current will be conducted through the structure and discharged at another location within the structure, taking the path of least resistance. The location of the current pickup becomes cathodic. At the point of discharge, the structure becomes anodic and will experience metal loss at a rate proportional to the current flow. This loss of material is known as **Electrolysis Corrosion**. (Electrolysis is the passing of direct current through an electrolyte resulting in chemical reactions at the electrodes and the separation of materials.)

There may be several anodic zones along a structure which can lead to metal loss at numerous locations. In the case of DC traction systems, adverse effects on buried structures can occur kilometres from the rail track due to interactions with buried assets, such as utility pipelines or lead sheathed telephone cables.

## Rate of Electrolysis Corrosion

Where current is discharged from a reinforced concrete structure, corrosion of the steel reinforcement will occur at a rate of approximately 9.2 kg / Amp / year. This rate is based on Faraday's Law of Electrolysis, which states that the mass of a substance produced by electrolysis is proportional to the quantity of electricity used.

$$m = \frac{Q}{F} \times \frac{M}{z}$$

| | | |
|---|---|---|
| $m$ | = | Mass of the substance liberated at an electrode in grams |
| $Q$ | = | Total electric charge passed through the substance |
| $F$ | = | Faraday constant (= 96,485 C/mol) |
| $M$ | = | Molar mass of the substance |
| $z$ | = | Valency number of ions of the substance |

For a given scenario; F, M and z are constant, therefore, the rate of corrosion loss is directly proportional to the current.

$$m \propto Q$$

Due to the large currents powering trams or trains, even currents flowing for short periods of time can cause considerable corrosion on affected structures.

## Structures Affected By Electrolysis Corrosion

Concrete is hygroscopic and will become a conductor under certain conditions, although usually at a high resistance [6]. Stray currents can conduct through the concrete and the low resistance steel reinforcement, causing electrolysis corrosion of the reinforcement at the discharge location. Typically, the risk of corrosion is greatest for the following buried elements;

- Steel or reinforced concrete piling
- Reinforced concrete foundations
- Reinforced concrete slabs or retaining walls
- Reinforced concrete tunnels

The risk of stray current interference depends on the structure’s location relative to the DC current source and the design of the structure. Structures at risk do not necessarily need to be buried, i.e. steel or reinforced concrete structures supporting electrified rail tracks, such as bridges and culverts.

- Buried columns, piles and foundations are exposed to the highest risk of adverse stray current effects. Steel piling has a higher risk of being affected than reinforced concrete piles.
- Reinforced concrete bridges or viaducts supporting rail are at very high risk if electrically connected to earth and if rail insulation is poor.

## Reinforced Concrete Degradation Mechanism

The product of the steel reinforcement corrosion at the stray current discharge location occupies a larger volume than the steel that has corroded away. The build-up of this product around the steel bars is known to cause cracking or spalling of the cover concrete surrounding the reinforcement, this behaviour affects the structural design life and durability.

The volumetric expansion rate of the steel and the resulting tensile forces applied to the concrete are difficult to accurately determine. Typically accepted industry values at which cracking of a reinforced concrete element is expected to initiate is approximately 100 to 150 micron of steel corrosion loss. Due to the inability to accurately assess the possible stray current flow paths, a lower value (<= 50 micron) should be adopted for a design basis. Utilising Faraday’s Law of Electrolysis for an assumed current, it is possible to determine the timeframe for a particular structure before cracking may be expected to occur.

## Standards and Authority Requirements Documents

AS 5100 provides only limited guidance relating to the consideration of stray currents in the design of steel and reinforced concrete elements. The relevant clauses typically indicate that reference should be made to the relevant rail authority guidelines. Appendix A of this paper summarises the relevant clauses of AS 5100, for both the 2004 and 2017 versions.

In Victoria, Metro Trans Melbourne (MTM) has provided a design standard [1] relating to the electrical protection of railways bridges. This standard indicates detailed requirements for the electrical continuity and isolation of bridges and retaining walls.

In New South Wales, the Asset Standards Authority (ASA) has produced a guidance document [2] highlighting possible mitigation measures for stray current effects.

In Queensland, the Department of Transport and Main Roads (DTMR) has recently issued the "Interim Guide to Development in a Transport Environment: Light Rail" [3]. This document provides high level guidance relating to the technical considerations relating to stray current effects.

Internationally, EN 50122-2 Part 2: "*Provisions against the effects of stray current cause by d.c. traction systems*" [4] provides comprehensive guidance and a basis for calculation to design and assess the stray current generated by a direct current system.

**Mitigation Measures**

Based on the guidance of local rail authorities, the following electrolysis corrosion mitigation measures may be considered depending on the location and application. This paper primarily discusses the first two approaches which relate to the detailing of reinforced concrete elements. The remaining approaches are related to the isolation of the structures or track elements and the use of drainage bonds.

1. **Provision of Electrical Segregation**

In general, the risk of electrolysis corrosion occurring increases with the extent of the electrically continuous section of a structure and, in particular, its continuous length along the track. Reducing the size or length of a continuous element or segregating the element into smaller elements will reduce the risk or impact of stray current corrosion.

2. **Provision of Electrical Continuity**

Electrical continuity should be provided within reinforced concrete structural elements to ensure that any stray current can be discharged over a maximum surface area of steel, thus reducing the local damage [1] [2]. This approach also protects against bar to bar corrosion occurring within an element.

3. **Isolation of Structural Elements from Stray Current**

Complete separation of the structural elements can eliminate the risk of stray currents occurring within the structure, provided no other conductive paths are present. Several methodologies are discussed below:

- Supporting the bridge deck on elastomeric bearings (resulting in a simply-supported structure) which insulate the deck from the substructure
- Installation of plastic membranes around footings and foundations
- Provision of plastic sleeves around bored piles

These methods are typically not preferred by asset owners / managers due to the difficulty in inspection or repair of the isolation elements.

### 4. Isolation of Rail Tracks from Earth

The complete electrical isolation of the rails from the earth would eliminate the flow of stray current back to the substation. This isolation is typically achieved through the use of insulating polymer pads and washers at the track to sleeper connection [7].

This solution is not practical in terms of construction or maintenance as it is likely to become damaged. Furthermore, the rail signalling system requires a minimum rail to earth leakage, i.e. the tracks cannot be fully insulated.

### 5. Use of Drainage Bonds

Electrical drainage bonds directly connect the reinforced concrete element (electrode) to the substation to eliminate material loss at the anode. It must also be considered that the “drained” structure being protected may then draw current from any adjacent structures which could experience subsequent electrolysis corrosion damage.

## Provision of Electrical Segregation

The cumulative voltage drop across a long continuous section results in the largest driving force for stray current pickup and discharge, and increases the risk of electrolysis occurring. The most commonly used design approach to mitigate against electrolysis corrosion is to reduce the length of electrically continuous sections parallel to the rail alignment by introducing electrical segregation. Dividing the structures into shorter sections will reduce the driving potential (voltage) and reduce the significance of any stray current flowing along and discharging from the structure.

Where there is high soil moisture content (low resistivity), there is the possibility of stray current jumping between electrically discontinuous sections through the soil. For this scenario, electrical bonding of the entire structure to make one single electrically continuous element may be considered. This approach must be considered in conjunction with the earthing and bonding strategy of the traction system.

- **Electrical Segregation for Retaining Wall**

Figure 2 provides a schematic detail of an isolation joint in a retaining wall structure. The structure consists of bored piles joined with reinforced shotcrete walls that are connected to the piles using chemical bonded anchors. The piles are connected using a reinforced concrete pile cap which supports a precast concrete performance level barrier and metallic safety screen.

- Electrical segregation is provided between the piles through the use of isolated dowel connections (Figure 3).
- The pile cap is also segregated by ensure the steel reinforcement is not continuous over the joint location. Only isolated dowels are provided as shear connections.

- The barriers are provided as precast elements and are inherently non-continuous. The barriers have been placed so as not to bridge the isolation joint.
- The metallic safety screen has been provided with isolating connections (in the form of acetal washers and isolation plates) to ensure it will not transmit any current from the precast barriers (Figure 4).

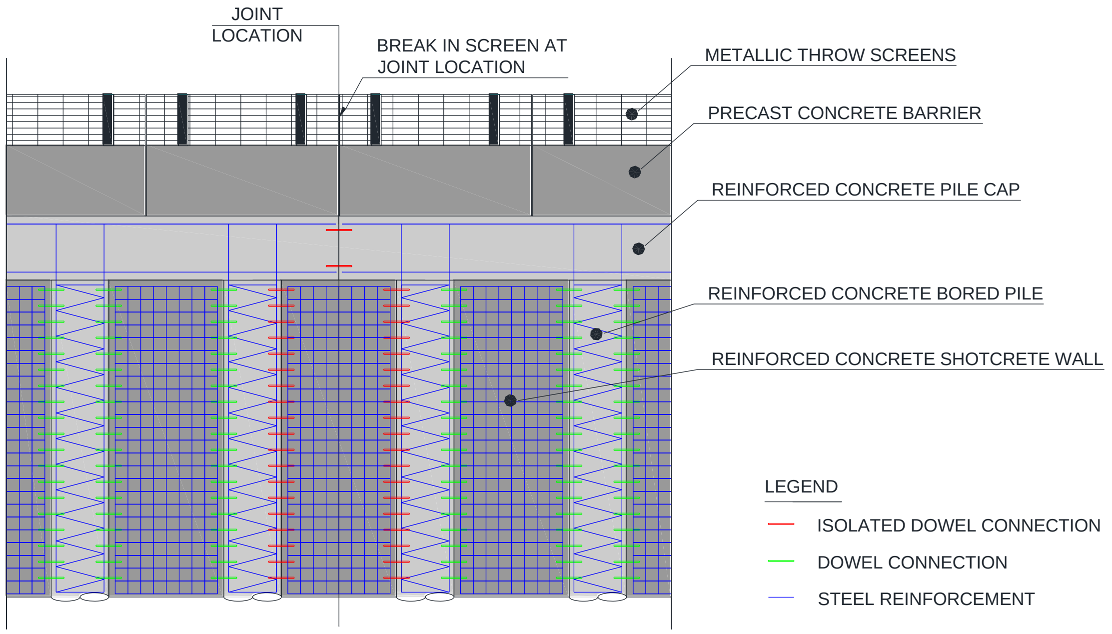


**Figure 2: Retaining Wall Isolation Joint**

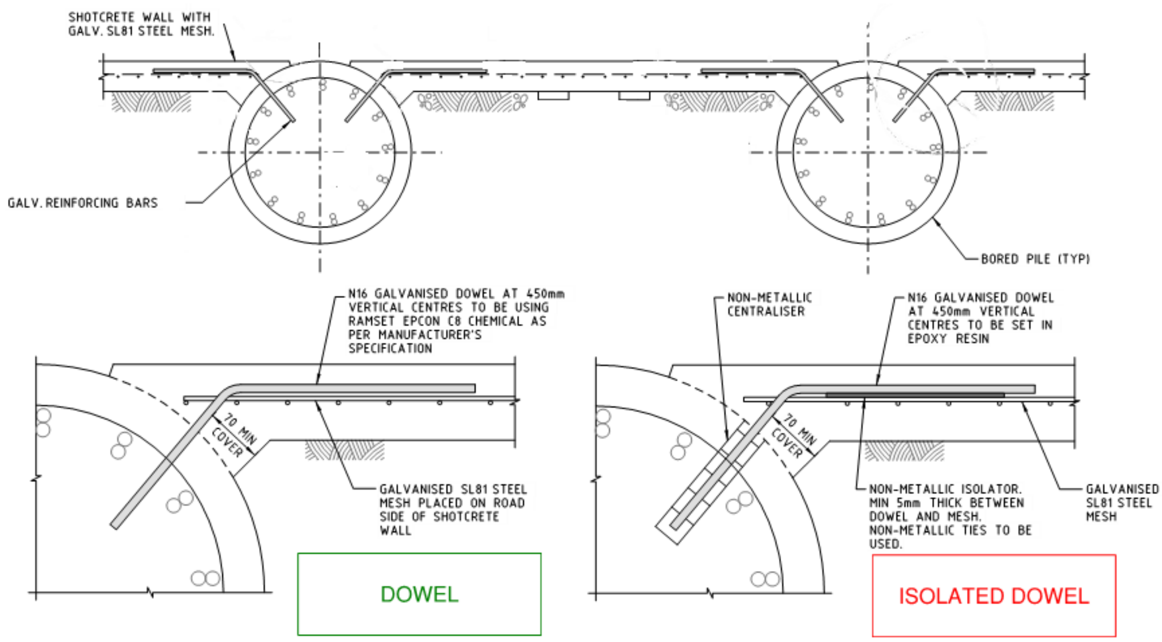


**Figure 3: Bored Pile Wall Connection Details**

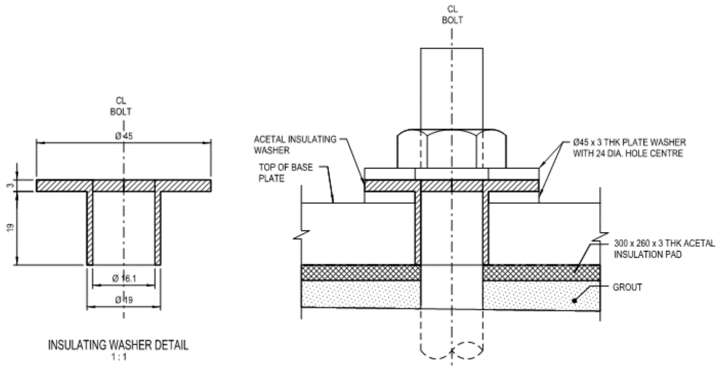


**Figure 4: Safety Screen Connection Isolation Details**

- **Electrical Segregation for Bridge Structure**

In this scenario, the bridge structure has a span of approximately 18m but with an average width of 80m. In order to reduce the current pick up along this length, the structure was electrically split in two elements, at a convenient location where a vertical step in the bridge deck was required.

- The deck slab has been completely split at the joint location with no continuity of concrete or steel (Figure 5)
- The bored pile foundations of the bridge and the pile cap are split in a manner similar to the retaining wall segregation above
- The bridge is further separated from any adjacent walls to ensure the continuous structure length is minimised (Figure 5)

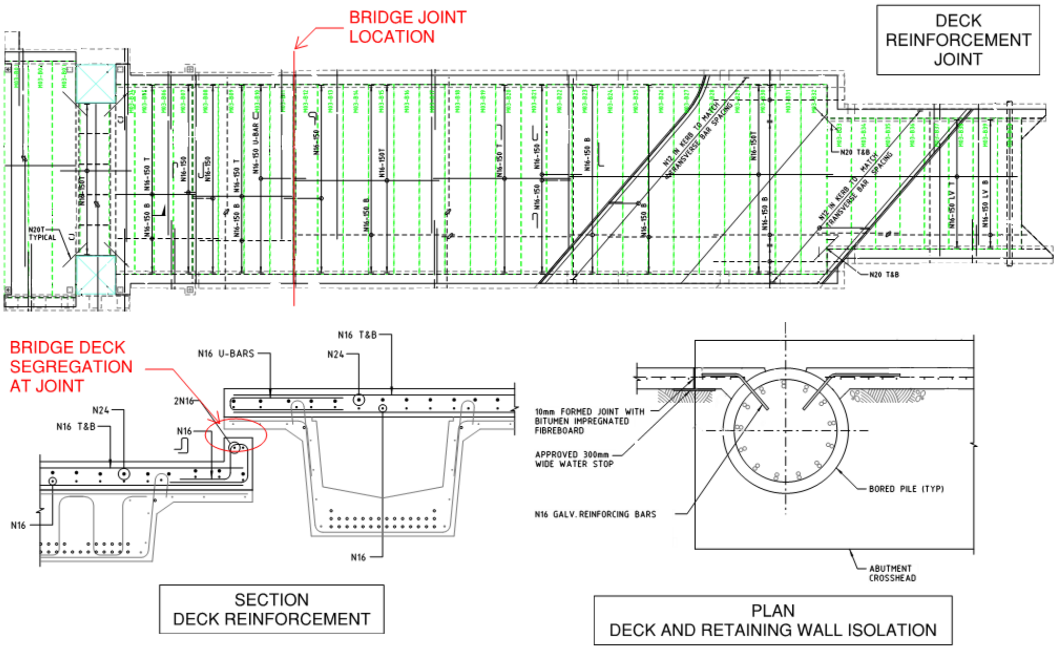


**Figure 5: Bridge Deck and Abutment Isolation Details**

## Provision of Electrical Continuity

The reinforcement within a reinforced concrete element subject to stray currents should be made continuous in order to minimise the effects of bar to bar corrosion within the concrete and to provide a larger steel mass from which the current will leave the structure, thereby reducing the likelihood of a significant loss rate occurring at a localised site.

Figure 6 below indicates the continuity requirements required for bored pile reinforcing cages, it is noted that pile cages are typically tack welded together to facilitate transport and handling. These continuity requirements are applicable for both bridge and retaining wall structures.

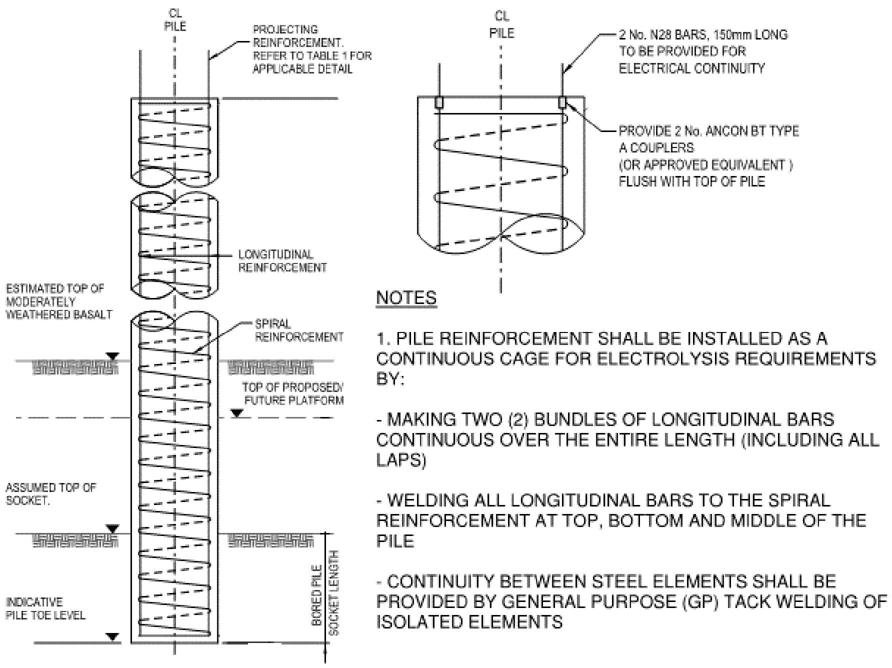


**Figure 6: Pile Continuity Details**

The continuity requirements for a complete bridge structure are more complicated and should be clearly indicated on the design drawings.

Figure 7 below indicates the continuity requirements required for a bridge superstructure.

- The longitudinal bars in the abutment are made continuous with the reinforcement projecting from the bored piles and are then also made longitudinally continuous along the length of the abutment (Figure 7: Red Lines)
- The abutments are then made continuous with each other through the longitudinal deck reinforcement (Figure 7: Green Lines)
- Finally, each portion of the deck (which are separated by lift shaft voids and precast panels in this scenario) are made continuous through transverse deck reinforcement (Figure 7: Blue Lines)

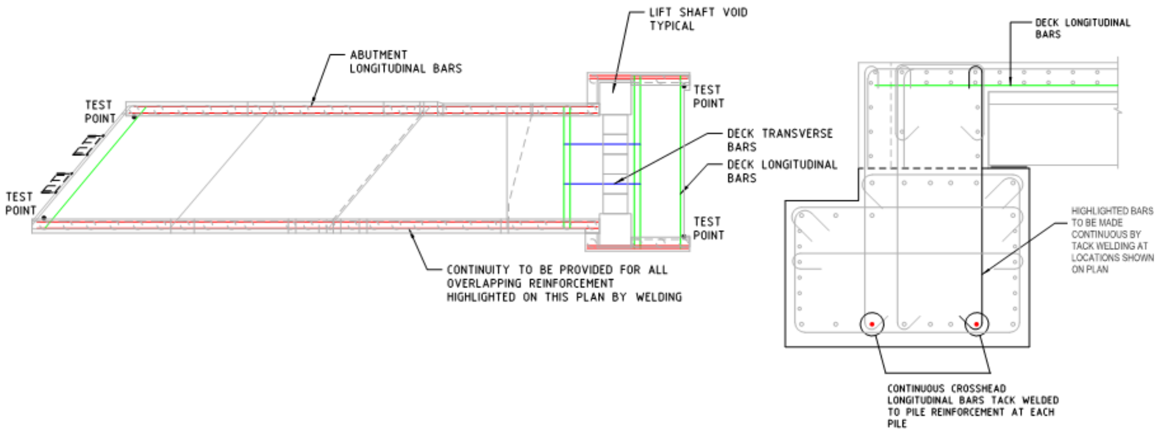


**Figure 7: Bridge Deck and Abutment Continuity Requirements**

Two methods are available in order to provide continuous reinforcement as discussed below:

- **Continuity Via Welding**

Welding between individual elements is typically the most effective method to achieve electrical continuity. Welds specifically for continuity do not need to be substantial as the expected current flows are small. The requirement for the weld is to achieve electrical continuity by penetrating both crossing / lapping bars.

These welds are not structural and the quality criteria stated in AS 1554.3 do not apply. Where continuity is required, a minimum of two welds should be provided, each weld being a minimum of one bar diameter long.

- **Continuity via tie wiring**

Historically, tie wire has been used to provide continuity in previous rail projects. However, this approach does not allow for short term fault currents the structure may be exposed to in the event of an overhead wire break. The use of tie wire (including double tying) for continuity purposes is typically no longer accepted by the relevant rail authorities.

**Mitigation Measures at Overhead Wire Supports**

- **Retaining Walls**

Overhead Wiring Support Structures (OHWS) located in cuttings are typically mounted on either:

- Capping beams where there are piled walls below, or
- Containment barrier footings where there are soil nail walls below.

In both instances, the OHWS holding down bolts are to be made electrically continuous with the capping beam (and pile) reinforcement or the barrier footing reinforcement.

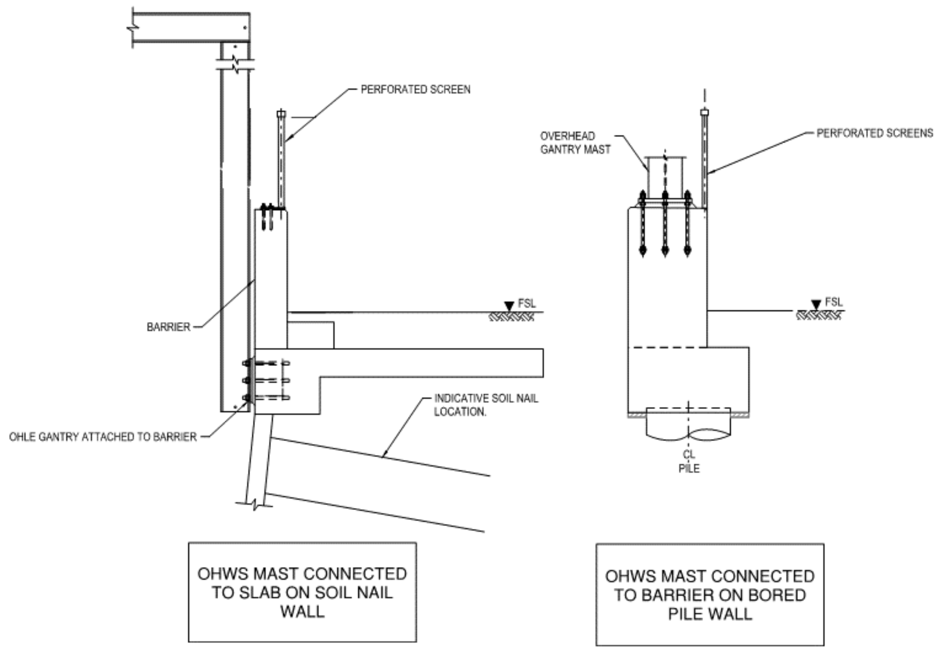


**Figure 8: Overhead Wire Retaining Wall Support Details**

Where the OHWS are mounted on independent footings, they shall be electrically isolated from retaining wall and bridge structures.

- **Bridges**

OHWS mounted on bridges, including mounts for side feeders and drop verticals, shall be insulated from the reinforcement of the bridges using insulating materials

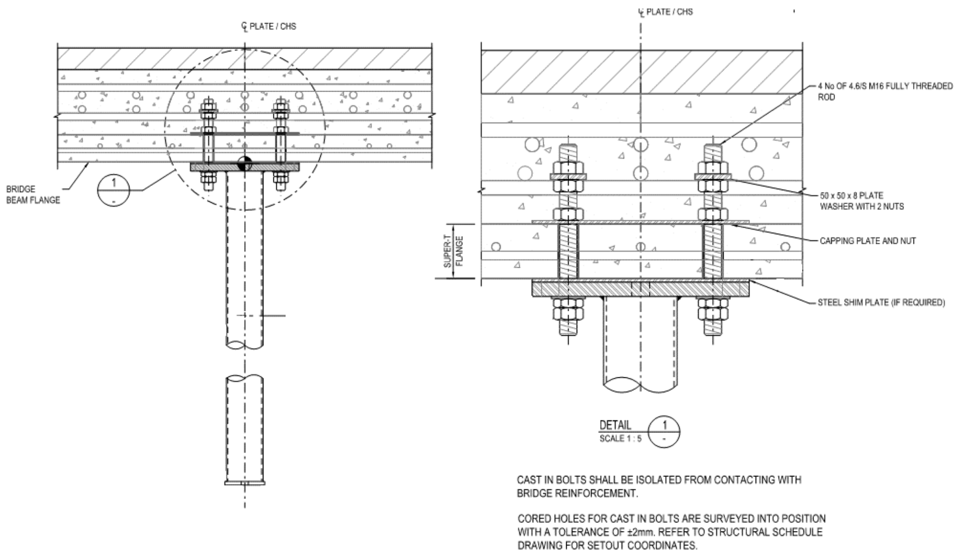


**Figure 9: Overhead Wire Bridge Support Details (Drop Verticals)**

## Electrolysis Compliance Testing

Electrical resistance testing is typically required by rail authorities to confirm that continuity works have met the required criteria [1] [2]. Test points provide an electrical connection to a metallic structure or to the reinforcement of a reinforced concrete structure in order to assess the likelihood and extent of stray current corrosion occurring.

Test points should be provided in the following locations:

- At each side of a movement joint on electrically continuous piles, capping beams or barrier footings
- At the corners of each electrically continuous bridge structure, and additionally on the adjacent capping beams to allow testing across the joint.
- Where a bridge is electrically split into two elements, at the corners of each continuous section

Test points typically consist of a threaded stainless steel ferrule cast into the concrete element as shown in Figure 10. This is attached to a grade 316 stainless steel bar welded to the capping beam reinforcement and finished flush with the surface.

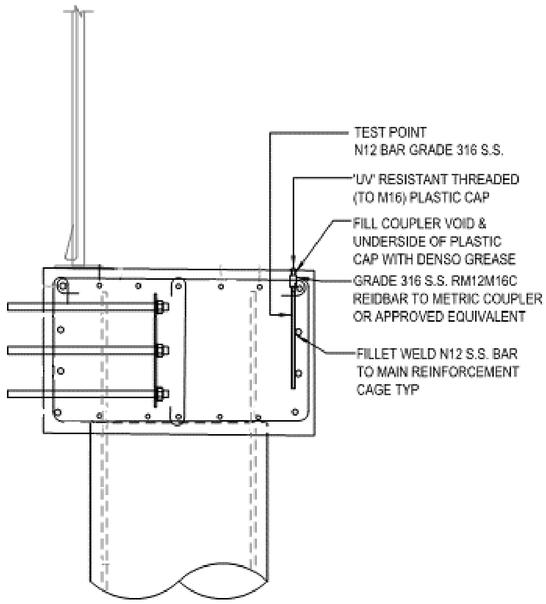


**Figure 10: Electrolysis Test Point Detail**

## Earthing and Bonding Considerations

The electrolysis and stray current mitigation strategy must be developed in conjunction with the earthing and bonding required for electrical safety, i.e., to ensure mitigation of voltage hazards for people or plant during normal operation or short circuit.

The earthing strategy may be in conflict with the electrolysis mitigation strategy and should be clarified with the asset owner from the project outset.

## CONCLUSION

The consideration of stray currents in reinforced concrete elements is vital to ensuring that the structure can achieve its design life with minimal maintenance requirements.

This paper discussed potential mitigation measures available to designers and asset owners to significantly reduce the risk of stray current electrolysis corrosion affecting reinforced concrete assets. The chosen measures must be agreed by all parties to ensure they present an acceptable maintenance regime and are aligned with the earthing and bonding strategy.

The arrangement and detailing of the structure can be modified to significantly reduce the corrosion effects. The structure should be provided as segregated (isolated) elements, with each element made (internally) electrically continuous. Isolation joints between segregated elements can be created using appropriate insulating materials. Welding of reinforcement cages between elements can provide an electrically continuous structure.

The segregation and continuity requirements should be clearly communicated in the design documentation and drawings to ensure asset owners are aware of the proposed strategy and to ensure the construction team can clearly determine the required works on site. The development of national details to provide the required continuity would benefit the industry in terms of design efficiencies and the development of robust tested details.

## REFERENCES


[1] Metro Trains Melbourne Engineering Standard – Design, MEST 000002-03 Railway Bridges, Electrical Protection and Bonding – Version 1, June 2013

[2] Asset Standards Authority, Guide - Electrolysis from Stray DC Current, T-HR-EL-12002-GU – Version 1.0, 01 May 2014

[3] Department of Transport and Main Roads, Interim Guide to Development in a Transport Environment: Light Rail, March 2017

[4] EN 50122-2, Railway Applications – Fixed Installations – Electrical safety, earthing and the return circuit – Part 2: Provisions against the effects of stray currents caused by d.c traction systems, 2010

[5] Level Crossing Removal Project Furlong Main Blackburn Heatherdale, Earthing, Bonding and Stray Current Electrolysis Mitigation Strategy, Revision 01, 27 September 2016

[6] John Lambert, Corrosion: Electrolysis, 1992, Brisbane Tramway Museum Society, COTMA Conference Perth,

[7] Dr Thomas Barlo, Dr Allan Zdunek, 1995, Stray Current Corrosion in Electrified Rail Systems – Final Report


## ACKNOWLEDGEMENTS

I wish to acknowledge Adrian Vinnell and Ulf Kreher of the Aurecon Materials Technology Team in Melbourne for their assistance in the development of the mitigation measure details discussed in this paper.

## AUTHOR BIOGRAPHY

Colin has 10 years' experience in bridge design, in leadership and design roles, on a wide range of major structures from feasibility studies to site supervision. Recently, Colin has been involved in rail grade separation projects in Melbourne and has gained experience in the design and construction of civil structures and bridges within rail corridors.

## APPENDIX A - AS 5100 Bridge Design - Stray Current Deign Provisions

| | | | |
|---|---|---|---|
| AS 5100.3:2004<br>Bridge Design Part 3:<br>Foundation and soil-supporting structures | Clause 9.3 | *Durability of Concrete* | *For buried concrete structures where stray currents are likely to be present, e.g., adjacent to electrified railway lines, action shall be taken as required by the relevant authority to prevent corrosion of the reinforcement.* |
| | Clause 9.4 | *Durability of Steel* | *For buried steel structures where stray currents are likely to be present, e.g., adjacent to electrified railway lines, action as required by the relevant authority shall be taken to minimize corrosion.* |
| AS 5100.3:2017<br>Bridge Design Part 3:<br>Foundation and soil-supporting structures | Clause 4.3 | *Durability of Concrete* | *For buried concrete structures where stray currents are likely to be present (e.g., adjacent to electrified rail lines), action shall be taken, as required by the relevant authority, to prevent corrosion of the reinforcement.* |
| | Clause 4.4 | *Durability of Steel* | *For buried steel structures where stray currents are likely to be present (e.g., adjacent to electrified rail lines), action as required by the relevant authority shall be taken to minimize corrosion.* |
| AS 5100.5:2004<br>Bridge Design Part 5:<br>Concrete | Clause 4.11 | *Provisions for Stray Current Corrosion* | *The effects of possible stray current corrosion shall be considered where necessary. Stray current corrosion is of particular concern for railway bridges carrying electrified railways and tramways, especially where they are powered by direct current.* |
| AS 5100.5:2017<br>Bridge Design Part 5:<br>Concrete | Clause 4.16 | *Provisions for Stray Current Corrosion* | *The effects of possible stray current corrosion shall be considered where necessary.*<br>*NOTE: Stray current corrosion is of particular concern for rail bridges carrying electrified rail and tramways, especially where they are powered by direct current, concrete structures located in the vicinity of high voltage power lines and where impressed current cathodic protection is installed.* |
| AS 5100.6:2004<br>Bridge Design Part 6: Steel and composite construction | Clause 3.7 | *Corrosion Resistance and Protection* | *Where necessary, the effects of possible stray current corrosion shall be considered. Stray current corrosion is of particular concern for bridges carrying electrified railways and tramways, especially where they are powered by direct current.* |
| AS 5100.6:2017<br>Bridge Design Part 6: Steel and composite construction | Clause 3.7.1 | *Resistance and Protection* | *Where necessary, the effects of possible stray current corrosion shall be considered (see Note 2).*<br>*2 A corrosion allowance is not required for structural steel in Corrosivity Categories C1 and C2 where the coatings are appropriately specified, applied, and maintained to AS/NZS 2312.1 or the structural steel is hot dip galvanized to AS/NZS 4680 with design details from AS/NZS 2312.2. For Corrosivity Categories C3, C4, C5 and CX, the selection of a coating system and the maintenance strategy should be the subject of professional advice.* |