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Government of South Australia
Department for Infrastructure and Transport

Guidelines for Low Voltage Electrical Earthing and Bonding for the Adelaide Metro Tram Network

Engineering Standard

Asset Management

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1. Introduction

The South Australian Public Transport Authority (SAPTA) is a Directorate within the Department for Infrastructure and Transport (DIT) responsible for the delivery of public transport services.

SAPTA on behalf of the department manages the Adelaide Metropolitan Public Transport Network. As part of the execution of responsibilities of this role, it must have a governance structure which includes the adoption of standards, policies and procedures.

2. Purpose

These guidelines provide design criteria, construction practices and test specifications for earthing and bonding works related to the 600V DC Adelaide Tram Network (ATN). They do not cover earthing and bonding which is required exclusively for signalling track circuits (where no return current or fault current bonding is required for traction power supply or protection purposes), signalling power supplies, signalling equipment and telecommunications equipment except as specifically noted.

They have been provided to achieve electrification network earthing and bonding related objectives as follows:

- Safety of the public and employees
- Protection of equipment, cables and buildings
- Electrical noise reduction and stray current corrosion control
- The correct, efficient and safe operation of electrical circuits.

These guidelines set out principles and specify design and installation practices for commonly encountered situations, however not every practice can be specified to solve specific Earthing and Bonding (E&B) issues. If not covered by these Guidelines, the Earthing and Bonding should be formulated to best suit the principles set out in these Guidelines following in order of precedence: Australian Standards, International Standards and Industry Guidelines. Where there is any doubt as to the conformance of such a design solution, the matter should be referred to SAPTA’s Electrical Technical Lead.

This Standard provides information and the criteria for the design of Ballasted Surface-mounted Track, Direct-Buried Uninsulated Paved Track and Surface-mounted Track on Concrete Surfaces.

3. Scope

This Standard applies to all SAPTA projects and contractor organisations designing, constructing or maintaining the Earthing and Bonding system on the Adelaide Tram Network.

The Guidelines set out in this document set out the principles of DC traction system E&B design and installation practices to manage accessible touch and step potentials and reduce to within tolerable limits or, ideally, avoid hazards altogether through isolation and separation.

This document is intended for commonly encountered Earthing and Bonding situations on the 600V DC Adelaide Metro Tram Network (ATN) only. It is not intended to be applied to other tram networks nor to the Adelaide Metropolitan ‘Heavy-Rail’ Network (AMRN).

4. Compliance with Standards

These Guidelines are based on the principles contained within EN 50122-1:2022 and EN 50122-2 and 3 *where applicable to Ballasted and Paved Uninsulated Track Types*.

Any E&B works on the ATN must be implemented in accordance with recognised national and international tramway practice.

Except where otherwise stated, the works must comply with the relevant standards, regulations, codes of practice, recommendations etc. of the following organisations:

- The Department's Technical Standards and Procedures
- SAI Global (Standards Australia)
- The International Organisation for Standardisation (ISO)
- Other European Standards (EN)
- The International Electrotechnical Commission (IEC)
- British Standards Institution (BSI)
- Institution of Electrical Engineers (IEE).

All references to Australian or International Standards, Codes of Practice or other documents referred to herein must be deemed to be the current editions and to incorporate all amendments on issue.

5. Document Roadmap

This section provides a guide for the designer and constructor of the Tram Earthing and Bonding infrastructure on how to apply this standard.

Step 1: Read and apply Sections 1 to 4 and Appendix 1. Section 6 provides an overview on the extent of the ATN and some technical background on the Traction Power System and the Overhead Wiring Infrastructure.

Step 2: Read and comply with the requirements and intent of Sections 7 and 8. Should the scope of work cause non-conformances with these sections or those in Step 1 raise them in the Design Reporting process.

Step 3: Comply with the requirements of Sections 9, 10, 11 and 12 which cover Design and Construction responsibilities including Quality, Maintainability and Reliability obligations. Prepare submissions to address these sections in a timely manner and in accordance with the specific project program.

Step 4: Apply the Common Design Criteria (CDC) in Section 13. List any non-conformances or proposed departures from these criteria for consideration by SAPTA's Electrical Technical Lead in the design report. Confirm compliance and detail how the design complies with aspects of the CDC in the design report.

Step 5: Select the track type applicable to the project scope of works and apply:

- Section 14 for Ballasted Surface Mounted Track Design Criteria;
- Section 15 for Direct Buried Uninsulated Paved Track Design Criteria; or
- Section 16 for Surface Mounted Track on Concrete Slab Design Criteria;

List any non-conformances or proposed departures from these criteria for consideration by SAPTA's Electrical Technical Lead in the design report. Confirm compliance and detail how the design complies with aspects of the Track specific design criteria in the design report.

If the use of this standard is for a maintenance purpose, Section 18 contains additional criteria that should be applied.

6. Description of the Adelaide Metropolitan Tramway DC Traction System

The ATN is dual track and comprises twenty-eight tram stops and a tram depot.

The traction electrical system for the ATN currently includes eight traction rectifier substations located at Glenelg East, Plympton, Black Forest, Wayville (not in service), South Terrace, Morphett Street (Substations MO1 and MO2 are co-located in separated buildings) and Mary Street (adjacent to the Adelaide Entertainment Centre).

The ATN Overhead Wiring System extends over two rail lines (Glenelg Line and Hindmarsh Line) between Moseley Square, Glenelg, in the South, to the Adelaide Entertainment Centre, Hindmarsh, in the North. The lines run via the City of Adelaide (King William Street, East and West along North Terrace including the extension north and east from the intersection of King William Street and North Terrace.

Both Glenelg and Hindmarsh lines are dual track with 600V DC power supplied to Tram pantographs via single overhead contact wires tensioned above each track and supported by OHW poles. The tracks contain crossovers enabling bi-directional traffic and have a Depot located at Glengowrie.

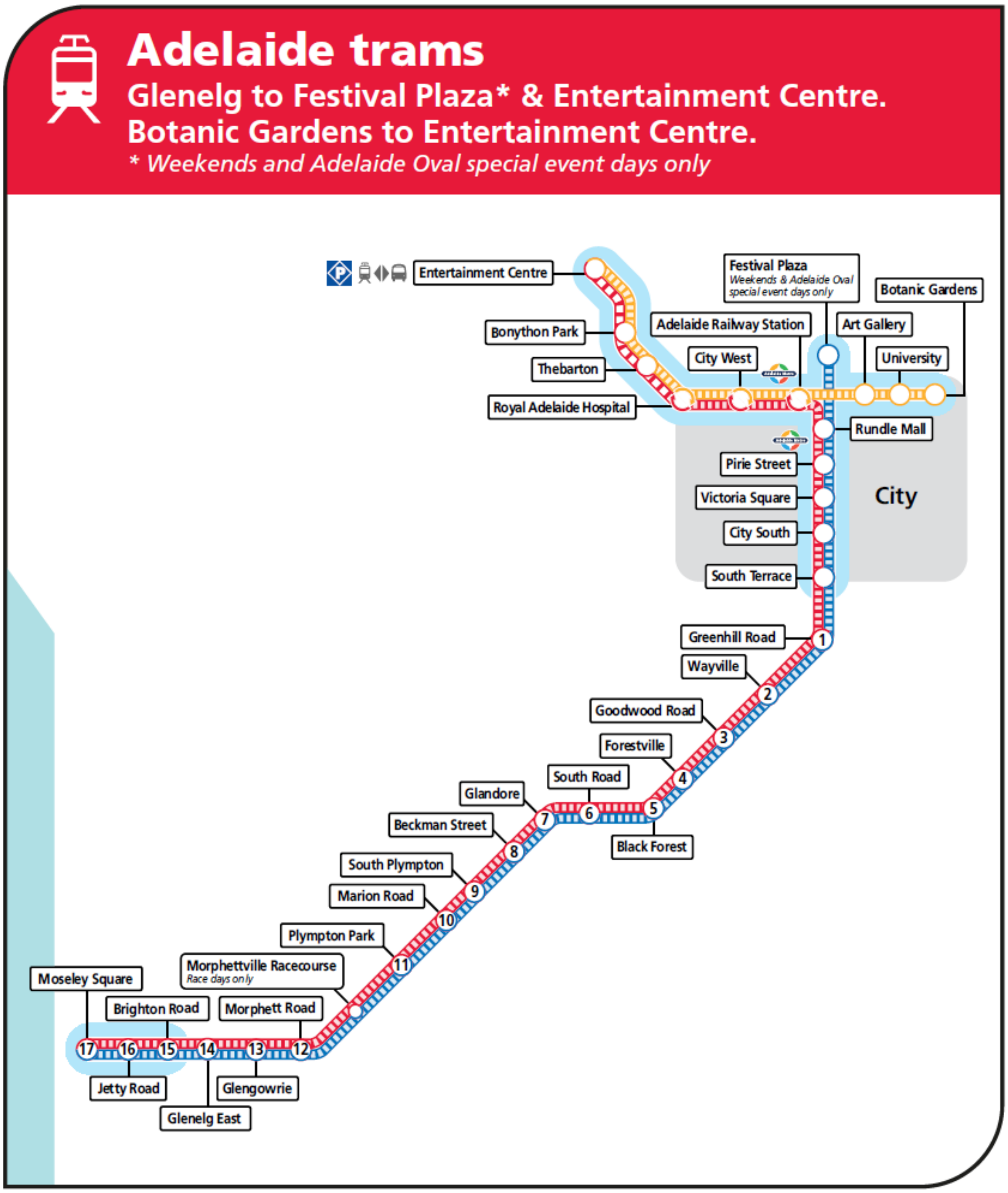


Figure 6 – Adelaide Tramway Network

6.1. The Traction Power System

Each traction substation is supplied independently via a dedicated feeder from the 11kV SA Power Networks infrastructure. The traction substations convert power from 11kV AC to 600V DC which is connected to the ATN Overhead Wiring System (OHW) and utilised by the tram rolling stock.

The Direct Current returns to the traction substation rectifiers via the negative return system which includes the rails. Although in contact with the ground via track bed, this negative return system is effectively isolated from earth (ungrounded) under normal operating conditions to prevent stray current corrosion, which can be destructive to metallic infrastructure located nearby the tracks.

Each traction substation feeds into a 400mm² feeder cable which further connects onto the overhead wire system (OHW). The feeder to OHW connections (taps) occur nominally at 450m intervals. Figure 6.1 shows how the traction substations are connected to the overhead wire system.

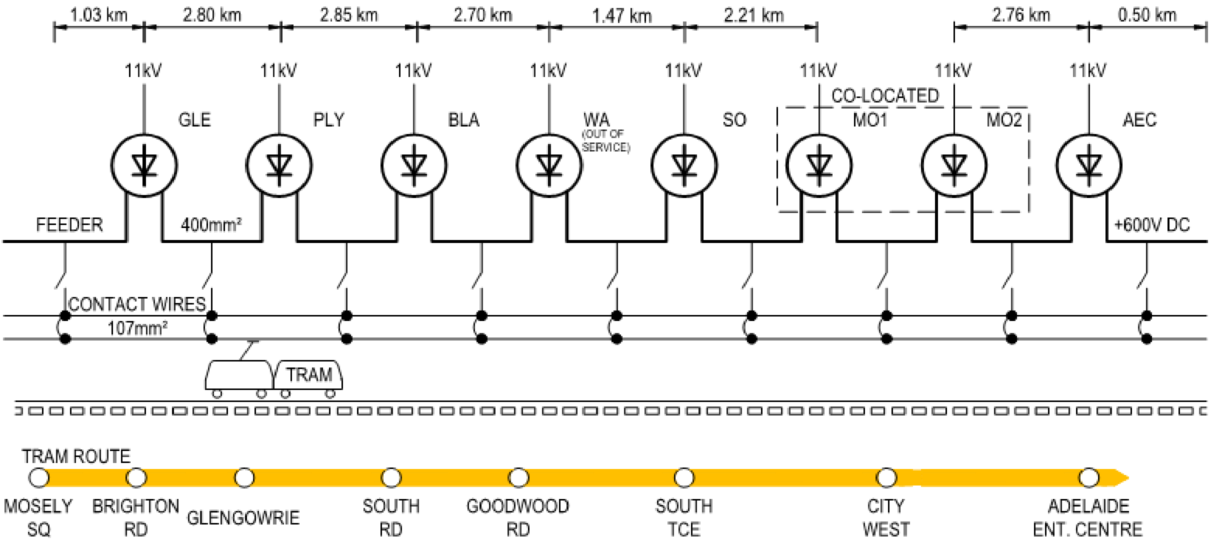


Figure 6.1 – ATN Overhead and Substation Arrangement

Each traction substation has the following general specification:

- Supply Voltage: 11kV AC
- Nominal Traction System Voltage: 600V DC
- Nominal Rectifier Transformer Rating: Varies for each Substation
- Nominal Rectifier Rating: 600kW

Typically, the 11kV system currently comprises of ABB Safeplus 11kV switchgear with revenue metering of 11kV incoming feeder supplies from SAPN at each traction substation.

Secheron DC switchgear is typically used to supply the OHW sections.

Substation auxiliary supplies typically comprise of 400/230V AC and 24V DC supplies.

An OVPD (Over-Voltage Protection Device) is installed at each traction substation to ensure rail volts (traction negative) with respect to earth remains within acceptable limits for both normal operating and fault situations. Where Spark gaps are used on OHW Poles to mitigate fault and stray current issues then SCADA monitoring of the OVPD is essential.

Common bonding of SAPN HV earth and Traction Earth is preferred from a Stray Current mitigation perspective.

6.2. OHW System

The OHW is supplied at a nominal 600V DC and the OHW poles are insulated from the DC traction wires.

The overhead wire (OHW) system consists of:
- Trolley wire that provides traction current to the tram via a pantograph;
- Rails that form a return path for the traction current;
- OHW Suspension system;
- OHW Poles.

Some of the OHW poles have additional traction electrical equipment mounted on them such as:
- Aerial switches;
- Feeder cable and tap to trolley terminations;
- Lightning arrestors.

Some of the OHW poles have non-traction electrical equipment mounted on them such as:
- Traffic signals;
- Lights.

At locations such as tram stops, there may be conductive structures in close proximity to the tram reserve.

During normal operation the trolley wire is electrically energised with a DC voltage in the range of 400V to 720V with a highest non-permanent voltage of 800V.

The majority of the overhead network suspension system is constructed of centre poles with insulated trolley wire supporting arms as shown in Figure 6.2.1.

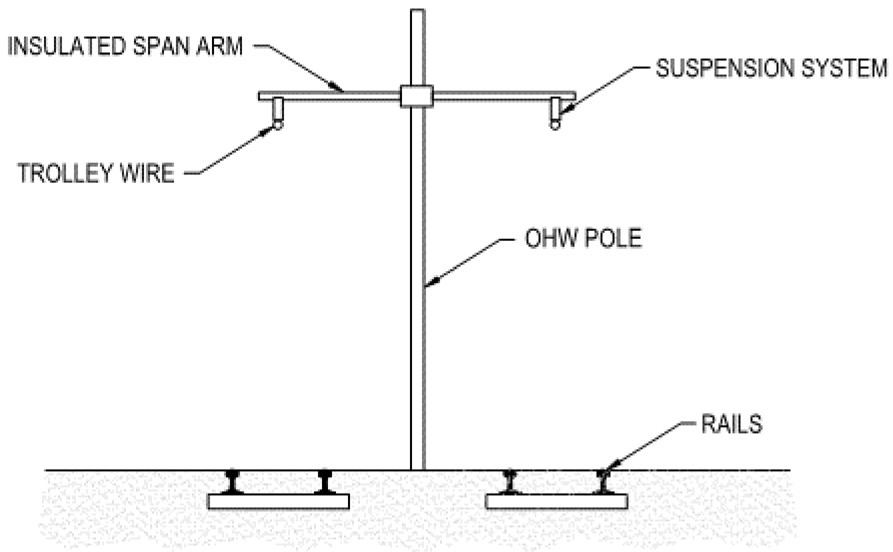


Figure 6.2.1 – Typical Centre Pole Arrangement

The remaining overhead wire suspension system is constructed of Parafil® rope, an electrical insulator, with appropriate fittings at the OHW pole and the trolley wire as shown in Figure 6.2.2.

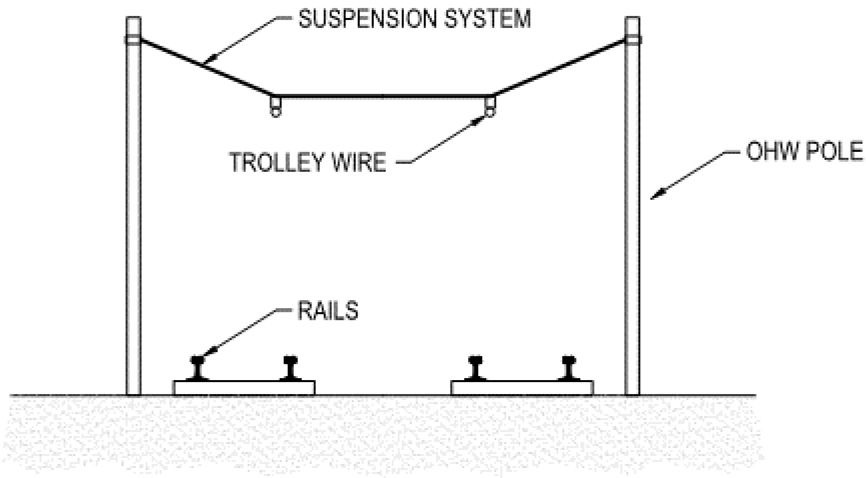


Figure 6.2.2 – Typical Cross Span Arrangement

The OHW poles are typically steel poles with concrete foundations that render the pole effectively in direct contact with the ground. The poles are electrically insulated from the 600V traction supply system by the suspension system.

6.3. Track Types and Construction

The rails are part of a track construction that is either:

- Ballast track (Brighton Road to South Terrace) — Between OHW poles G70 to G323.
- Uninsulated Paved track (City, Jetty Road and Road Crossings) — Between OHW poles H1 to H97, G1, G11 to G69, G323 to G353.
- Insulated/Booted Paved track (North Terrace Prospect and Magill Lines — Between G2 to G10, P1 to P16 and M1 to M35.
- Track on bridges — on bridge structures the rail is surface mounted bolted onto the concrete bridge slabs with a derailment prevention rail in the centre of each track.

For the section of the tram network in the CBD to Hindmarsh and Jetty Road Glenelg the track construction is paved track with the rails directly embedded in the concrete paving. Part of the city section includes 'grass track' which has grass sown between the rails, however the rails are directly embedded in concrete. The ballast track has either wood or concrete sleepers bolted between the rails on a base of ballast. The uninsulated paved track is direct buried in the concrete surround. There is reinforcement in the concrete, but this is not equipotentiality bonded or bonded to rail.

6.4. ATN Road Interfaces

There are 10 road intersections on the tram network in the city but none of these intersections include level crossings, therefore all four rails of the track form the return current path for the traction electrical system.

6.5. Rail Audio Frequency Double Track Circuits

The Glenelg Tramway uses a DC immune TI-21 style frequency track circuit equipment in some parts of the ballasted track and vehicle detection loops in parts adjacent to road intersections. Parts of the City paved areas contain the Hanning and Kahl (H&K) HSK Blocking Circuit system. Parts of the Adelaide CBD paved areas use vehicle detection loops embedded into the track concrete and linked to road traffic signalling equipment. All double rail track circuits are continuous even through crossings. There are no single rail track circuits in the ATN.

7. Bonding Design Approach

Bonding is the term used to electrically connect metallic structures within the OHW Zone and the OHW Bonding Zone, rail signalling components or cables to the negative of the traction system, typically achieved by connecting them to the rails.

As a general approach, bonding of OHW poles and other metallic structures in close proximity to the tram reserve is done to protect against:

- Insulation breakdown, flashover, or other fault condition on the traction system which may otherwise energise the pole to an unacceptable touch potential;
- Inadvertent contact between the 600V DC trolley wire and metallic structures in close proximity to the tram reserve, which may otherwise energise the metallic structures to an unacceptable touch potential.

The extent to which metallic structures are bonded is determined based on the level of acceptable risk with the following as key considerations:

- Proximity to OHW and likelihood of inadvertent contact with the 600V DC trolley wire;
- Likelihood of a person(s) coming into contact with a conductive structure that potentially has an unacceptable touch potential during a fault condition.

The objective of the E&B installation is to:

- Reduce to a level as low as reasonably practicable the risk of injury due to electric shock from accessible touch voltages;
- Reduce to a level as low as reasonably practicable the export of stray current from the DC traction system.

8. Performance Requirements

8.1. Earthing and Bonding System Design

During the course of the development of the earthing and bonding system, a continuous review must be carried out to achieve the most effective and economic earthing and bonding system design. The review must take into account the developing system designs for the traction power supply, the overhead line, the return conductors and signalling.

The correct application of earthing and bonding at all installations is essential to ensure the safe operation of traction power and overhead wiring equipment within the 600V DC electrified area. The earthing system must ensure the safety of staff and members of public from the effects of transferred voltages and high potential gradients during both traction fault and normal traction load conditions and from high potential gradients caused by lightning discharges. It is therefore essential that earthing and bonding of all traction power and overhead wiring equipment is installed in accordance with the requirements of these Guidelines.

8.2. General

The E&B system must be fit for purpose when installed into the ATN electrification system. The system must:

- Provide a very high-reliability low impedance return path for normal traction current;
- Provide a low resistance path for traction fault currents which will result in rapid tripping of controlling DC circuit breakers, whether caused by fault during normal operations of the overhead traction power system or by acts of deliberate vandalism;
- Limit readily accessible touch potentials to metalwork or semi-conductive surfaces, such as concrete, during traction fault, however caused;

- Limit structural damage which could occur as a result of falling traction supply conductors or accidental or reasonably foreseeable current paths from the traction system, whether caused accidentally or maliciously;
- Minimise the readily accessible touch potential which can occur between adjacent metalwork;
- Limit the export of potential, both under normal operation and traction fault, which may have an adverse impact upon railway services within the railway alignment and/or adjacent third-party service providers; for example, telecommunications, power, water and gas utilities;
- Prevent likelihood of arcing in the vicinity of flammable gas, liquid or oxygen when transfer is taking place.

The maximum permitted accessible touch potentials for any metalwork connected to the traction system are as required by EN 50122-1.

Table 5 — Maximum permissible body voltages $U_{b, max}$ in d.c. traction systems as a function of time duration

t s	$U_{b, max}$ V
> 300	120
300	150
1	160
0,9	165
0,8	170
0,7	175
0,6	180
0,5	190
0,4	205
0,3	220
0,2	245
0,1	285
0,05	325
0,02	370

Key

t time duration

$U_{b, max}$ permissible body voltage

Figure 8.2.1 – Excerpt from EN 50122-1 Maximum Permissible Body Voltages in DC Traction

Table 6 — Maximum permissible effective touch voltages $U_{te, max}$ in d.c. traction systems as a function of time duration

t s	$U_{te, max}$ **long-term** V	$U_{te, max}$ **short-term** V
> 300	120	-
300	150	-
1	160	-
0,9	165	-
0,8	170	-
0,7	175	-
< 0,7	-	350
0,6	-	360
0,5	-	385
0,4	-	420
0,3	-	460
0,2	-	520
0,1	-	625
0,05	-	735
0,02	-	870

Key

t time duration

$U_{te, max}$ permissible effective touch voltage

Figure 8.2.2 – Excerpt from EN 50122-1 Maximum Permissible Touch Voltages in DC Traction

EN 50122-1 requires the lower value of 60V to be applied in depots. Although this lower value is generally easier to achieve with the low tram traction currents in depots, this may not be the case where a depot is situated close to a traction substation or other HV earthing installation and EPR is exported to the depot.

9. Design Requirements

9.1. Safety Legislation and Regulations

The earthing and bonding system design must be safe. It must be safe for persons concerned in its installation, operation, maintenance, repair, and eventual disposal and must be safe in service. Examples of applicable legislation include:

- Rail Safety National Law (Act and Regulations);
- Work Health and Safety (Act and Regulations;
- Electrical (Act and Regulations).

The system must comply with all the Department's requirements and any regulations of those parties having jurisdiction over the system, including compliance with the requirements of the relevant clauses of the documents issued by authorities listed in Section 4 above.

9.2. Hold Points

Hold Points must be allowed for in the Design Program for a 2-week period to allow SAPTA to review the Design Report and ITP at each design stage.

Hold points are required in the ITP for Inspection of Bonding or Isolation quality for a representative sample for each type of bond or isolation function. By type of bond function, it is meant each functional element bonded to another — for example, column to footing reinforcement, platform bonding pole bonding. The inspection must be arranged to be completed before the bond functional element is concealed and must coincide with the witnessing of testing of that functional element. Similarly, for an isolation functional element (for example, asphaltic concrete), the inspection must be arranged to be completed while the full functional element (for example, depth of asphalt) is visible.

Hold Points are also required for testing of bonding integrity and continuity such that complying tests are received and approved by SAPTA's Electrical Technical Lead before construction proceeds to conceal or utilise the bonding for a larger bonding system.

Design programs must include time for close out of Hold Point submissions and a plan for the construction ITP in outline form including the major design elements.

9.3. Inspection Test Plan Submission

The ITP submitted for review by SAPTA's Electrical Technical Lead must have the following sections as a minimum:

1. Introduction
2. Scope of Works
3. Electrical Testing and Commissioning Overview
4. Design Compliance with Standards
5. Testing Methodology
6. Commissioning Roles and Responsibilities
7. Schedule of Hold Points
8. Programming and Witnessing
9. Test Records, Photographic Records and Certification of Compliance with Standards

9.4. Design Reports

The Earthing Design Report must consist of a written report with drawing attachments as required to explain the scope of works. The report must contain the following sections as a minimum:

1. Introduction
2. Interdisciplinary Coordination
3. Proposed Hold Points
4. Design Assumptions
5. Confirmation of Compliance with SAPTA's Tram E&B Standard (confirm compliance with each section)
6. Proposed Departures from SAPTA's Tram E&B Standard
7. Proposed Earthing Design Drawings/Cable Schedules/Bonding Locations/Bonding Types

9.5. Documentation Standards

Documentation must comply with AM4-DOC-000364 – *Drafting Standard for AutoCAD® drawings* and FR-AM-GE-806 – *Identification and Numbering of Technical Documents and Drawings*.

9.6. Documentation Process

Refer to the project specific CSTR for the documentation submission process applicable to the project and ensure that all requirements of this Standard are incorporated into the program and submission obligations under the project specific CSTR.

9.7. Certification and Verification

Refer to the project specific CSTR for the certification and verification process applicable to the project and ensure that all requirements of this Standard are incorporated into the program and submission obligations under the project specific CSTR. The contractor must provide certification that the earthing and bonding works both comply to this standard and EN 50122.

10. Construction Requirements

10.1. Inspection Test Plan Implementation

Expand on the Design ITP submission with specific test schedules for specific locations, a detailed program for testing, SAPTA representative witnessing of testing, SAPTA representative inspection of work at hold points.

10.2. Hold Points and Data Review

Hold Points must be allowed for in the Construction Program for a 2-week period to allow SAPTA to review the Design Report and ITP at each design stage.

Hold Points are required in the ITP for Inspection of Bonding or Isolation quality for a representative sample for each type of bond or isolation function. By type of bond function, it is meant each functional element bonded to another; for example, column to footing reinforcement, platform bonding pole bonding. The inspection must be arranged to be completed before the bond functional element is concealed and must coincide with the witnessing of testing of that functional element. Similarly, for an isolation functional element (for example, asphaltic concrete), the inspection must be arranged to be completed while the full functional element (for example, depth of asphalt) is visible.

Construction programs must include time for close out of Hold Point submissions and a plan for the construction ITP in outline form including the major design elements.

10.3. Testing of the Earthing and Bonding System

10.3.1. Soil Resistivity

At some selected locations, to be defined during basic design, the soil resistivity must be measured with the Wenner method (4 electrodes) as the basis for earthing calculations.

10.3.2. Resistance to Earth

The impedance to earth of completed earth electrodes must be measured at one reference terminal to ensure required values for safety of persons.

10.3.3. Test of Continuity and Completeness of Terminals

Tests must be conducted to ensure all bonding has low resistance connection to the Traction Rail.

10.3.4. Short Circuit Tests

The short circuit test takes place with a short circuit between contact wire and the outer rail or between contact wire and earth wire, as determined as the worst-case situation for each specific test. Tests will include, but are not limited to:

- **Measurement of remote rail potential and induced voltages. Memory Recorder connected to:**
  - (i) outer running rail and earth spike at least 10m at right angles from running rail
  - (ii) (at Tram Stops) voltage between Tram Stop metalwork and Tram Stop power supply MEN and incoming buried metal service earth
  - (iii) induced voltage in longest signalling cable between the converter station and short circuit site (earth reference at remote end of cable and memory recorder earth spike 10m at right angles from track)

- **Measurement of touch voltage (measurements repeated for short circuits with all bonds intact and with rail bonds, as nominated, removed). Memory recorder connected to**:
  - (i) outer running rail and earth spikes 1m (rail touch potential) and 2m (rolling-stock touch potential) at right angles from running rail
  - (ii) traction mast to earth stake 1m away
  - (iii) traction mast to closest rail
  - (iv) track to track (inner rails)
  - (v) rail to rail
  - (vi) (at tram stop) rail to tram-stop metalwork (for example, end of platform fence
  - (vii) (at converter station) touch potential to station fence
- **Measurement of short circuit currents and voltages at converter station**:
  - (i) short circuit current in feeder
  - (ii) return current from rail(s) to return current bus
  - (iii) busbar VT voltage

Both measurements take place close to short-circuit location at running rails of the track where short circuit test is done and at mid-point between rail to earth wire bonds.

10.4. Commissioning of the Earthing and Bonding System

Prior to completion of commissioning the earthing and bonding test records, witnessing records, accompanying photographic evidence must be collated into a folio and provided to SAPTA’s Electrical Technical Lead for acceptance. This must include a certification that all bonding and isolation elements required by the design is complete to the quality required by this standard.

10.5. Design Manufacture and Workmanship

All materials and workmanship must be of the best standard and must comply with the relevant Australian Standards, or if such do not exist, with the relevant IEC or International (ISO) Standards.

10.6. Photographic Submissions

Each testing submission must be accompanied by photographic evidence showing the bond or isolation element tested and a plan indicating where on site the test/photograph was taken. If multiple tests/locations are included, they must be numbered for ease of identification in the documentation submitted.

11. Maintainability and Reliability

The E&B system must be designed to minimise and facilitate maintenance.

For new installations, where bonding cables are to be buried, bonding cables must be installed within Heavy Duty UPVC Conduits to enable easy replacement. Select conduit sizes in accordance with AS/NZS 3000.

For new installations, at traction substations, the earthing system must be designed in an N-1 electrode configuration such that any one of the electrodes can be disconnected for testing without compromising the earthing system.

12. Quality Compliance and Documentation Quality

The E&B design and implementation must operate under a comprehensive quality management system in accordance with Master Specification PC-QA1 or PC-QA2, as nominated by the Department.

Bonding plans must show the entire earthing and bonding system of the design. All drawings must be of good, legible quality. A short description of each revision must be provided under consecutive revision letters or numbers together with the date. Wherever feasible, some means must be used to identify the location of the most recent revision, for instance by revision clouds.

All drawings must be brought up to date as necessary, to provide a permanent as-constructed record and must be supplied in the format specified by SAPTA's Electrical Technical Lead in the CSTR.

13. Common Design Criteria

13.1. Separation

A minimum 2m horizontal and 2.5m vertical separation must be maintained between traction bonded conductive items and non-traction bonded conductive items. A minimum 6m horizontal separation must be maintained between the traction power system/ traction power system earth return and other power systems and earth reference systems.

13.2. Overhead Wire System (OHW)

In addition to the bonding of OHW Poles for safety, covered in Sections 14 and 15, the Traction Power System operation requires regular bonding at every fifth pole to keep the system impedance below the maximum operational level. Variations to this bond spacing may be considered as part of the Traction Power System design submission.

Application Notes:

Note 1 – Avoid where possible bonding Traction Poles to rail adjacent to pedestrian crossings.

Note 2 – Avoid where possible bonding Traction Poles to rail adjacent to or on Tram Stop platforms.

Note 3 – Avoid where possible bonding Traction Poles to rail when these poles are fitted with LV equipment; for example, at Road Traffic Intersections.

13.3. Surge Arrestors

Surge arrestors are typically placed within the traction system to protect traction power equipment against system surge voltages and lightning strikes.

According to AS/NZS 1768, lightning strike flash densities in the Adelaide metropolitan region are less than 0.5 flashes / km² / year. The current ATN is located at grade amongst other urban infrastructure, which reduces the risk of lightning strike on the OHW system, however, over-voltages can also occur within the system due to other reasons.

Surge arrestors are placed at the following locations:

- Tap connection isolating switches;
- Traction substation 600V DC switchboard;
- Traction substation 11kV incoming AC circuit breaker; and
- Inside OVPD at traction substations.

Surge arrestors must be locally earthed using a 120mm² earthing conductor connected to a local earth stake in both paved uninsulated and ballast track types.

The surge arrestors currently used by the ATN at tap connection isolating switches are outdoor polymeric type and have the following characteristics:

ATN Surge Arrestor Characteristics – Tap Connection Isolating Switches	
Parameter	**Rating**
Voltage (rated)	1 kV
Nominal discharge current 8/20 µs	Minimum 50 kA

High current single impulse energy	2.3 kJ / kV
High current operating duty 4/10 µs	100 kA

Table 13.3 – Surge Arrestor Characteristics

13.4. Impedance Bonds

Impedance bonds are not installed on the Adelaide Metro Tram Network. The use of this equipment on the network would be subject to approval of SAPTA's Electrical Technical Lead.

13.5. Substation

An individual earthing & bonding study is required for any substations connected to the Adelaide Metro Tram Network or located adjacent ATN infrastructure. Quantities and sizes of bonds to the substation must be determined by the Traction Power System's design engineer.

Each study is to ensure Step, Touch and Transfer potentials are reduced to tolerable limits in accordance with this standard and the latest versions of the Australian and International standards listed below:

STANDARD	TITLE
AS 2067	Substations and high voltage installations exceeding 1 kV AC
AS/NZS 60479.1	Effects of current on human beings and livestock – General aspects
AS/NZS 4853	Electrical hazards on metallic pipelines
AS/NZS 3835	Earth potential rise, protection of telecommunications network users, personnel and plant
ENA EG1	Substation Earthing Guide
ENA C(b)1	Guidelines for design and maintenance of overhead distribution and transmission lines
EN 50122-1	Railway applications – Fixed installations – Electrical safety, earthing and the return circuit – Part 1: Protective provisions against electric shock
IEEE-80	Guide for Safety in AC Substation Grounding

Table 13.5 – Standards Regarding Step, Touch & Transfer Potentials

13.5.1. Positive Feeder Cable Screens

Positive feeder cables must comprise a centre positive conductor with an outer sheathed copper wire screen. The cable screens are to be directly bonded to earth only at traction substations.

For handling of the feeder cable screens a specific Traction Power System assessment will be required to determine the best and safest approach under fault current conditions. Generally, at each tap to trolley connection the screens are to be joined and insulated from both earth and traction negative. At pits and switch positions where the cable screen is broken, the stripped screen ends are to be joined for continuity and insulated appropriately from the pole, the rail and from earth.

The insulated screens and associated termination must be adequately insulated and appropriately IP rated to ensure bridging to earth or other conductive elements is not possible. This includes consideration for shorting due to water entry and/or flooding in cable pits. It is expected that poles supporting Traction Power equipment are double insulated from live equipment.

Due to the risk of transfer potential during an 11kV fault that may occur at one or more of the traction substations, any works on the cable screens or associated terminations or joints must be carried out with appropriate PPE including 5kV rated insulated gloves and insulation work mats. Signage must also be placed where cable screens are terminated or jointed, warning of the remote earth potential rise risk.

13.5.2. Negative Substation Connections

Negative return cables between the track and a traction substation must be unscreened type. To protect against open circuit voltage hazards, a warning sign must be placed at each terminating end with the label: “600V DC negatives – Do Not Break”.

13.5.3. Separation From Neighbouring Properties

The Substation Earthing Study must take into account properties abutting the Substation. Ideally a separation of 6m should be allowed between buildings on adjoining properties and the Substation building. The separation may be reduced to a minimum of 2m subject to EPR requirements from the Earthing Study. Within 6m of the substation an electrolysis study is also required to determine risks to external infrastructure.

13.6. Bridges / Viaducts Overpasses and Underpasses

Where an overpass exists above the ATN, the following earthing and bonding special considerations need to be made:

- Material of overpass supporting structure and proximity to rail and OHW;
- Services and equipment located on the overpass;
- Any OHW fixtures on the overpass structure; and
- Other rail systems located on, under, or adjacent the overpass.

There are four existing bridges that interact with the network:

- One where the tram passes over a road and the bridge has a Tram Stop;
- One where the tram passes under a road bridge also supporting rail overhead wires (approx. 10m away), the Morphett Substations are also beneath this bridge; and
- Two bridges exist where the tram passes over 25kV rail. One of these overpasses occurs at a railway station platform where the 600V DC traction bonded tram bridge is also bonded to the 25kV traction return bonded platform. At the other overpass the tram passes over 25kV tracks. The 25kV overhead is not supported from the bridge.

Where the tram network passes over 25kV rail, its earthing system interacts either intentionally or unintentionally with the Tram 600V DC earthing system. In each of these situations the bridge must be equipotentially (EP) bonded including all conductive elements (fences, OHW poles, handrails, tram stop infrastructure and then this bonded mass connected to the 25kV return rail via a suitably rated diode bond. The extent of equipotential bonding must be limited by a natural separation such as a movement joint that is able to be electrically insulated at the abutments on each end of the bridge structure. Movement joints between the abutments must have bonds fitted as part of the equipotential bridge bonding.

Where the tram network passes over a road all conductive elements on the bridge must be equipotentially bonded using an asset bonding cable and then bonded to rail via a diode. All SA Power Networks supplied equipment on the bridge structure must be isolated using an isolation transformer.

13.7. Depot

Ideally the Depot would have its own substation separated from the main tram line. This isn't the case at present, but it would reduce the electrolysis risk to the depot infrastructure due to the increased level of bonding required for personnel safety.

13.7.1. OHW Pole Bonding

Due to the higher risk to rail personnel in close contact with the tram's step and touch potential concerns override stray current mitigation considerations. All traction poles must be bonded to traction return.

13.7.2. Spray Painting Shed

The Spray Painting Shed is considered a Hazardous Area and precautions must be taken to isolate this building from the electrified zone. A hazardous area risk assessment is required to ensure that spark risk from traction potential differences does not compromise the safety of workers. This building should be equipotentially bonded to traction return.

13.7.3. Workshop

The LV supplies in this building must be supplied through an isolation transformer with the secondary referenced to Traction Return. The building must be equipotentially bonded to traction return. This may increase the risk of electrolysis activity that will need to be managed.

13.7.4. Other Buildings

The Storage and Tram Wash buildings at the Depot must have LV supplies through an isolation transformer with the secondary referenced to Traction Return. Each building must be equipotentially bonded to traction return. This may increase the risk of electrolysis activity that will need to be managed.

13.7.5. Track Bonding

There must be track-to-track and rail-to-rail bonding across all tracks adjacent to each building at the depot to equalise potentials and reduce track impedance.

13.7.6. Separation from Neighbouring Properties

The Depot has a neighbouring building in close proximity to the Spray Paint Booth building and the Traction Poles on the fence alignment are bonded to Traction Return.

13.8. 240V AC Electrical Equipment

Where 240V AC equipment is to be installed on metallic structures that are bonded to the traction electrical system or unbonded OHW poles, the following guidelines must be followed:

- The 240V AC supply must be isolated with an isolation transformer;
- The 240V AC supply earth electrode must be located at least 6m from the rail or bonded metallic structures;
- The 240V AC electrical fittings and electrical wiring must be double insulated to ensure separation from bonded metallic structures or unbonded OHW poles; and
- The neutral of any 240V AC supply adjacent to the Tram Network must be galvanically isolated from the traction positive or negative conductors.

13.8.1. Tram Stop

If 240V AC equipment is located outside of the OHW zone, provided that the supply switchgear and earth electrode is located at least 6m from the rail or rail bonded conductive items, no further earthing and bonding treatment will be required.

240V AC equipment should be kept outside of the OHW zone. Where the equipment is mounted onto an OHW Pole then the equipment must be installed using the method described below for sub-clause 13.8.5 – *Street Lighting*.

13.8.2. Depot

The 240VAC equipment in the Depot Workshop is operated once the Tram Traction Supply and Traction Earthing is isolated using earth switches in three locations that operate three isolation scenarios (Complete Yard, South Yard and Barn Roads) detailed in the document Overhead Isolation Procedures of Glengowrie Depot Yards and Barns.

13.8.3. Workshop

Due to the nature of the close contact with the trams all conductive items in the Workshop must be equipotentially bonded for the safety of personnel. This may cause some stray current issues however personnel safety is considered the priority in this case as the Traction System will be live during movement of the trams into the Workshop.

13.8.4. Signalling

Power for corridor signals equipment is typically reticulated spaced 3m from tram corridor danger zone. It is either 230V AC fed from SA Power Networks (stepped down using a transformer) or 110V transformed from 600V DC using a rectifier. Any Signalling supplies fed from the SA Power Networks supply must be isolated from the SA Power Networks system using an isolation transformer.

The Signalling Isolation Enclosures are each locally earthed using four earth stakes.

Cables are buried typically at 1m depth and older cables may not be in conduit. Newer cables are shielded and installed in conduit.

13.8.5. Street Lighting

Where street lighting equipment supplied from non-traction power supply is mounted onto OHW Poles they must be kept double insulated from the pole as defined in AS/NZS 3000. This includes the conductive housing of the equipment with the intention that persons touching the street lighting equipment are isolated from the touch potential of the OHW Pole during a fault or under normal operating conditions. There must also be a safe maintenance protocol established for any circumstances that could breach the insulation efficacy.

13.8.6. Traffic Lights

Where traffic light control equipment supplied from non-traction power supply are mounted onto OHW Poles they must be kept double insulated from the pole as defined in AS/NZS 3000. This includes the conductive housing of the equipment with the intention that persons touching the traffic light equipment are isolated from the touch potential of the OHW Pole during a fault or under normal operating conditions. There must also be a safe maintenance protocol established for any circumstances that could breach the insulation efficacy.

Where traffic signalling equipment creates an electrical connection between poles in an intersection then all of these poles must be bonded to rail, **or** the signalling equipment must be fed from an isolated supply/isolation transformer. This is subject to a safety in design assessment specific to the intersection under consideration and the safer choice applied.

13.8.7. Isolation Transformers

All isolation transformers must comply with the requirements of Appendix 1 of standard AR-PW-PM-SPE-00129014 (D074) and standard drawing TP4-DRG-004185.

13.9. Electrolysis and Stray Current Effects Mitigation

This section of the report presents the strategy that will be adopted in the management of electrolysis risks and the mitigation of stray DC current propagation.
It must be noted that the overall electrolysis mitigation strategy for the specific scope of works for each project is subject to the review of the South Australian Electrolysis Committee.

There are two key processes by which the flow of stray DC current associated with a traction system can lead to the electrolytic corrosion of conductive structural elements and metallic services:

- A conductive service or structural arrangement runs in parallel with electrified track in close enough proximity and over a sufficient distance to lead to the conductive service or structural element providing a low resistance parallel path for stray DC current flowing through the greater mass of earth in the vicinity of the track alignment; and
- A conductive service or structural arrangement inadvertently becomes a pick-up/drop-off point for the flow of stray DC current between the local area (near the adjacent electrified track) and other common-bonded elements (bonded through either the multiple earthed neutral system of the distribution network service provider or other conductive service interconnections) that are in turn within close proximity to the electrified track associated with the traction system.

In considering the potential impact of the flow of stray DC traction current, it is useful to keep the following two factors in mind:

- Stray DC current corrosion (electrolysis) is a function of current magnitude and duration of exposure. The generally accepted yet crude rule of thumb is that one ampere of continuous stray DC current flow will lead to the loss of 9 kg of steel over the course of a calendar year. Significant reduction of either the magnitude of current flow (insulation measures) or the duration of the exposure of the structure/service to current flow (stray current monitoring devices and processes) will directly lead to a significant reduction in corrosion; and
- Stray DC current causes damage to conductive elements only where the current leaves the conductive element and can only cause significant corrosion where the point at which the stray DC current exits is in contact with a suitable electrolyte.

13.9.1. Overarching Strategy

There are three key ways in which the propagation of stray DC current flow can be reduced:

- Minimization of the longitudinal resistance in the traction current return circuit:
    - Incorporation of all rails in the traction return circuit where possible and optimisation of the traction return bonding design;
    - Assurance of adequate bonding across track points, fishplates and other mechanical connections in the traction return rails.
- Maximization of the insulation of the traction return rails from earth:
    - Use of insulating track fixings in track-slab areas;
    - Use of insulating track fixings between rails and sleepers;

    - Maintenance of track ballast where applicable (the resistivity of the ballast decreases where there are high levels of conductive pollutants).
- Reduction in the overall distance between traction power substations:
    - The rail-earth potential that drives the leakage of stray DC current into the greater mass of earth is as much a function of the spacing of traction power substations as it is a function of the amount of traction loading on the line;
    - The rail-earth potential will usually be positive with respect to earth in the area furthest from traction substations (midway between substations) and will usually be negative with respect to earth near the traction substations; and
    - Decreasing the distance between traction substations (or introducing additional traction substations over a given length of corridor) has the effect of reducing the maximum positive and negative values of the rail-earth potential profile along the track.

The propagation of stray DC current in structures and services will be minimized in as far as possible through:

- Minimization of the longitudinal resistance of the traction current return circuit; and
- Maximization of the level of insulation between rail and earth.

It should be noted that the strategy covered in this section of the report relies heavily on the incorporation of isolation measures into the design of services and structures adjacent and parallel to the track alignment.

13.9.2. Anticipated Electrolysis Conditions

- **Traction System Loadings**
  Guidance on the traction system loadings is to be taken from the traction system design report noting that the maximum foreseeable traction system loadings over the design life of civil structures are to be considered.
- **Impact of Stray DC Current on Earthing Systems**
  An electrolysis report will be required to assess the best approach for mitigation of this risk to the 400mm^2 positive feeder cables running from substation to substation along with the treatment of the 11kV incomers from SA Power Networks for each specific substation.
- **Impact of Stray DC Current on Structures and Trackside Assets**
  Structures such as retaining walls, viaducts, under bridges and overbridges within DC traction environments are vulnerable to electrolysis (corrosion caused by the flow of stray DC current). Whereas this vulnerability cannot be completely eliminated, it can be reduced significantly by adopting the following key strategies:
    - Structural arrangements featuring exposed metalwork in direct contact with the greater mass of earth should be avoided where possible as the options to protect such structures from electrolysis are extremely limited (for example steel sheet piles);
    - For steel rebar reinforced concrete structures:
      (i) A minimum compressive strength of 40MPa is recommended for structural elements that will be embedded in the earth (higher compressive strength ratings typically result in higher resistivity values due to the hydrophobic nature of the finished surface);
      (ii) Steel reinforcement must be made electrically continuous within each structural element (where practical) using welded

connections at maximum intervals of 2m in each axis with bonding terminals incorporated into the design of the reinforced concrete structural element for use as either electrolysis monitoring terminals or as points of connection into a broader circuit;

(iii) Depending on the calculated value of the anticipated stray DC current induced potential on or across each structural element, it may be appropriate to maintain isolation between structural elements at constructions joints, expansion joints and other interfaces where there is no default metallic conductive path;

(iv) In some case it may be more appropriate to interconnect adjacent structural elements to form a larger electrically continuous structure (where it is more feasible to protect the structural elements as a whole or the structures are within an equipotential zone); and

(v) Where applicable it can be advantageous to utilise insulating membranes to provide an additional layer of mitigation (for example, vapour barriers used under cast in-situ slab foundations). All non-conductive membranes will provide some additional resistance however proprietary options specifically designed to provide a degree of electrical insulation are available and should be considered as an alternative to generic options where practical.

- For steel fibre reinforced concrete:

(i) Steel fibre reinforced concrete presents an unusual challenge in terms of electrolysis mitigation as the conductivity of the concrete mixture can vary dramatically depending on the amount of steel in the mixture and the shaping of the fibres (can range from highly resistive through to conductive enough to be deliberately used as the current return path for electric forklifts in factory floors);

(ii) There is a knee-point, typically at the point where volumetric content of steel reaches approximately 2%, beyond which the resistivity of the concrete mixture drops dramatically;

(iii) Where steel fibre reinforced concrete is to be used in the installation the volumetric content of steel in the mixture is to be kept as low as possible in order to minimize the flow of stray DC current as it is generally not practical to implement conventional approaches to monitoring electrolysis in volumes of steel fibre reinforced concrete (nothing to bond the electrolysis monitoring terminals to); and

(iv) In most cases where the volumetric content of steel in the mixture is kept well below 2%, stray DC current flow in the body of concrete is limited in the long-term as the paths for the propagation of stray DC current (the individual steel fibres) near the surface of the concrete corrode away leading only to minor surface discolouration where exposed to the eye.

- For line side fencing and conductive service conduits:

(i) All fencing and conductive service conduits (GST, metallic pipes) must be isolated at interfaces with tram-stop equipotential zones, under bridges and overbridges;

(ii) Isolation measures may also be required to mitigate touch potential hazards relating to OHWS and HV earthing arrangements;

(iii) Continuous lengths of fencing and conductive service conduits will be limited to less than or equal to 500m where not already broken up due to isolation measures associated with tram stops, bridges and touch potential hazards;

(iv) Care will be taken to ensure that isolation measures in fencing and conductive service conduits running parallel with one another and within 2000mm of each other have aligned isolation measures such that the absence of isolation measures in one does not undermine the isolation measures implemented in the other; and

(v) The design decision on whether to implement a single isolation gap or a pair of isolation gaps (nominally spaced at 2m apart) should be based on a site-specific risk assessment taking into account whether one or both sides of the service or feature is accessible to the public.

13.9.3. Equipotential Bonding Zones and interfaces with Third Party Assets

There are a number of key considerations that will need to be taken into account with regard to managing electrolysis risks imposed on third party assets and systems and ensuring the integrity of equipotential bonding zones:

- At structural interfaces with assets outside of the rail corridor and/or local equipotential bonding zones (including but not limited to the interfaces with the tunnel linings):
    - No conductive reinforcement is to be permitted to transition across the boundary of the equipotential bonding zone such that a minimum clearance of 100mm will be maintained between conductive reinforcement associated with structural elements within the equipotential bonding zone and conductive reinforcement associated with structural elements outside of the equipotential bonding zone; and
    - Structural steel elements (and other conductive materials) will not be permitted to traverse the boundaries of the equipotential bonding zone for the tram-stop precinct.
- All services and conductive service conduits (GST, metallic pipes) must be isolated at interfaces with the tram stop’s equipotential zone:
    - Where the services or conductive service conduits enter the tram-stop precinct from outside of the traction system environment; and
    - Where the services or conductive service conduits enter the tram stop.

13.10. Stray Current Measurement and Electrolysis Assessment

As direct measurement of stray currents in the rail is not possible, a measurement of the conductance per unit length of the running rails is representative of stray currents leaving this rail section. If the rail potential in a section changes compared to the baseline measurements taken during commissioning, the cause could be a low resistance circuit between the return circuit and the structure earth. This would need to be located through further investigation. This may only be practical for replaced or new rail sections but should be considered.

The use of a Stray Current Monitoring System at the substation would assist with identification of the significance of the issue in the rail corridor. Voltage Limiting Devices (VLDs) may be used with an integral current measurement device it is possible to measure stray current through the VLD when closed to confirm the health of the track section.

13.10.1. Identify At-Risk Areas

Potential risk areas include concrete footings of elevated structures, the bottom flanges of rails embedded in the ground, rail tie plates, and rail spikes, footings of bonded tram-stop structures, fence footings. The earthing electrodes and any infrastructure relied upon for isolation must be routinely inspected to check for deterioration.

13.10.2. Monitor At-Risk Elements

Once a suspected significant source of DC stray current is identified, detailed monitoring must be planned to identify the magnitude of electrolysis risk to the element and determine mitigation requirements:

- Element-to-Soil Voltage change along metallic elements in proximity to the rail with two or more buried parts, caused by stray current;
- Localised corrosion near the stray current source.

13.10.3. DC Stray Current Identification for Buried Metal Elements

Consult with third party infrastructure operators and use Dial-Before-You-Dig to identify buried infrastructure adjacent to or crossing the tram corridor.

A practical method for identification of stray current risk is the use of close interval potential survey (CIPS) to determine the stray current pickup and discharge region.

The structure-to-electrolyte potential measurements can be used as a tool for locating probable electrolysis risk conditions on an unprotected buried metal element. The structure-to-electrolyte potential measurements utilise a close interval potential survey (CIPS) technique.

The structure-to-electrolyte potential survey is conducted by making individual readings at 3m intervals along the route directly above of the element under test. Probable electrolysis risk conditions are indicated at survey points where the most negative voltage readings are determined.

13.10.4. Test Methods for Rail Infrastructure

Refer to the EN50122 Part 2 Annexures A and B for rail infrastructure testing methods for Stray Current

13.10.5. Test Methods for Buried Metal Objects:

Direct Current Voltage Gradient method for current flow

The Direct Current Voltage Gradient (DCVG) method; that is, a two-reference-electrode potential survey measures the direction of the potential gradient along the earth’s surface. Measurements must be made at 3m intervals directly over the centreline of the buried metal element. Suspected electrolysis risk condition and their magnitudes can be confirmed by making two-reference-electrode tests laterally to the pipeline. One reference electrode is placed over the line and the other spaced laterally the same distance as for the transverse measurements over the line. These tests should be made on both sides of the pipe to verify that current is leaving the line.

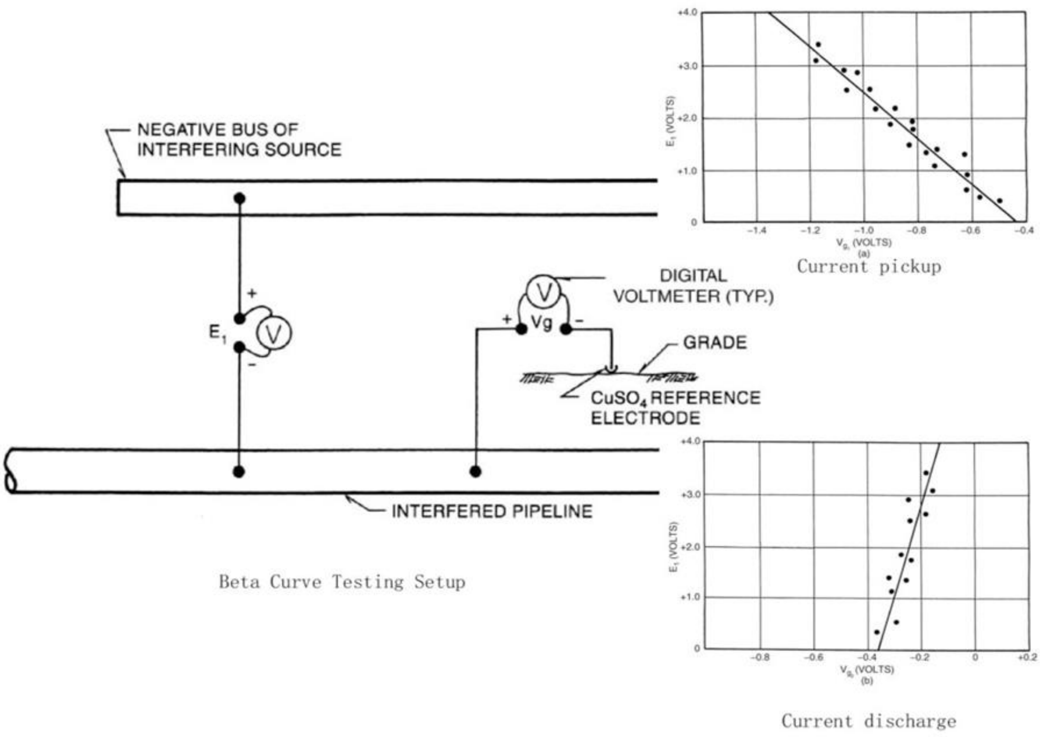


Figure 13.10.5 – Direct Current Gradient Method

Refer also to the EN50122 Part 2 Annexure C for rail infrastructure testing methods for Stray Current

13.11. Stray Current Monitoring and Mitigation

13.11.1. Ongoing Monitoring of Electrolysis Risk Items

Maintain the monitoring station over a period of dry and wet seasons in a calendar year.

If it is noted that the stray current levels increase over the test period then a specific cathodic analysis study may be warranted for that area to identify treatments such as sacrificial electrodes, spark gaps.

Keeping a separation between AS/NZS 3000 MEN infrastructure and Traction Earthed infrastructure is required to prevent transfer of Traction Power fault currents onto the MEN (>2m) and also to prevent damage to the MEN earthing electrodes (>4m). Where unavoidably in close proximity (<4m) to Traction Rail and at a distance from Substations, these earthing electrodes are considered at risk and must be checked regularly.

13.11.2. Apply Prevention Measures

Where practical apply separation rules to minimise the potential impact of stray current. Minimise equipotential bonding and bonding to traction rail where not required for the safety of people.

Ensure that the Tram Infrastructure bonding and isolation is maintained including rectification of defective bonds/connections, insulating elements and OHW insulation failures.

13.11.3. Treat any Severe Issues

Impressed potential cathodic protection systems or unidirectional diode “drainage” circuits may protect the intended asset but generally then pose a risk to all other assets/systems in the same environment. Usually used as an absolute last resort and only under the scrutiny of a body like an electrolysis committee or working group. Consult the SA Electrolysis Committee for advice prior to proposing this method.

13.12. Soil Resistivity Testing

For regions of soil where there is a higher risk to conductive elements of electrolysis, the soil resistivity must be measured with the Wenner method (4 electrodes) as the basis for earthing calculations. The measurements must be made at the correct electrode spacing and soil depths to minimise error and take into account Annex A of IEEE Std 81. The testing as well as the test reporting must be carried out in accordance with Clause 5.3.3 of ENA EG1.

Low soil resistivity regions adjacent to DC Traction can be an indicator of a higher risk of electrolysis for buried metallic elements and should be monitored.

13.13. Line Signalling and Telecommunications Equipment

13.13.1. Interference with Audio Track Circuit Signals

All bonding designs proposed must be submitted for review by SAPTA's Earthing and Bonding Technical Lead and Electrical Technical Lead.

Rail-to-Rail and Track-to-Track bonding must be kept a minimum of 2m from track circuiting equipment such as H&K Blocking Circuits, vehicle induction loops (used in the city paved areas) and TI-21 Track Circuit Blocks to ensure that their operation is not adversely affected. The spacing of this bonding prior to construction will be subject to final confirmation by SAPTA's Signalling Technical Lead and Electrical Technical Lead.

13.14. Earthing & Bonding Conductors

Table 13.14 shows the common cable types/sizes used for E&B within the ATN. Where available, electrically equivalent sizes of non-copper conductors may be used to reduce the attractiveness of the conductor and to reduce the risk of theft. Alternatively, anti-theft installation methods must be used.

Cable Code / Size	Material	Type	Lug and Lug Bolt Size	Usage
EC16/ 16mm²	Copper	Olex BAAP15AA001 or Equivalent	With Lug to suit M8 Lug Bolt	Surge arrestor positive connection where length is less than 1m
EC120A/ 120mm² * * Size subject to earthing design	Copper	Green/Yellow 0.6/1kV XLPE/PVC or Green/Yellow 0.6/1kV PVC/PVC insulated	With Lug to suit M12 Lug Bolt	Traction Substation Earthing & Equipotential Conductors Substation Rail to Earth Contactor (OVPD, NPMPD) Earthing Connections
EC120B/ 120mm²	Generally insulated copper but insulated steel	Olex BDBP23AA001 or 0.6/1kV Ethylene Propylene Rubber EPR or PVC/HDPE	With Lug to suit M12 Lug Bolt	Pole to rail bonds, bonding of metal structures at platforms

Cable Code / Size	Material	Type	Lug and Lug Bolt Size	Usage
	providing equivalent performance may be used to reduce theft risk			
EC185/ 185mm²	Flexible copper	Triangle Cables 1cx185	With Lug to suit M12 Lug Bolt	Rail to rail bonds, Tap to trolley Connections
EC400/ 400mm²	Copper conductor and screen	Olex 0.6/1kV 1Cx400m2 Cu/XLPE/CWS/PVC Cable, Triangle Cables 1c400 Shielded (Used when Olex cable is not flexible enough)	With Lug to suit M12 Lug Bolt	Positive feeder cable, Substation Negative Return Cables, Every third rail to rail bond, long bonds

Table 13.14 – Bonding Cables Used Within the Tram Network

13.14.1. Screened and Unscreened Cables

Where screening or armour sheaths are provided for rail-to-rail or long-bond cables they are for mechanical protection only from the installation situation or vandalism risk prevention. In this situation the screen must be kept unbonded. Where screens are not bonded, they must be adequately insulated. Unbonded screens must be peeled back a set distance from the termination and treated with a Raychem boot or equivalent. Substation cabling screens must be bonded at the substation end only. All other cables will be an unscreened type.

13.14.2. Colour Marking on Cables for Type Identification

Signalling bonds must be identified using yellow heatshrink tubing over the cable termination onto the rail. In addition, the sleeper end adjacent to the bond must be painted yellow.

Earthing and Bonding bonds must be identified using red heatshrink tubing over the cable termination onto the rail. In addition, the sleeper end adjacent to the bond must be painted red.

Where bonds have a shared use by both Signalling and Earthing and Bonding, they must have both colours of heatshrink tubing clearly visible at the cable termination and the sleeper end painted half yellow and half red.

13.15. Bond Location Labelling

Locations of all bond connections to embedded rail must be marked. Prior to pouring the concrete, the location of each bond connection to rail must be marked with a single punch mark in the head of the guardrail. After the concrete has been poured the location of the connection must be marked utilising brass cable markers as per Figure 13.15 below. The brass markers must be labelled CBM, meaning Concealed Bond Marking, to differentiate them from buried cables with other purposes.

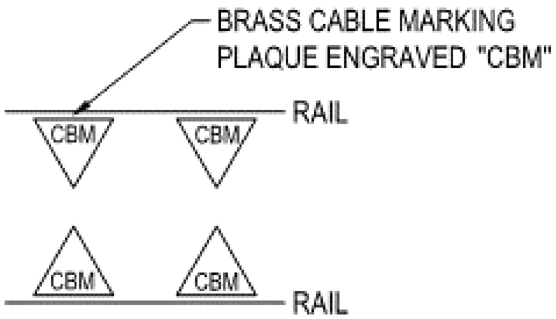


Figure 13.15 – Paved Track Bond Marking

14. Ballasted Surface Mounted Track Design Criteria

14.1. OHW Pole Bonding

The following sub-clauses are based on the assumption that the OHW installation has an effective two layers of insulation in accordance with EN50122-1.

The network contains three types of poles, categorised based on the equipment they do or do not contain:

- Type A:
  - Traction Pole ***not*** fitted with a switch arrangement or feeder cabling;
  - Outside of the OHW fall zone; and
  - Two layers of effective insulation between the live conductors and the Traction Pole

Note: Type A poles may be fitted with non-isolated LV SAPN connected equipment.

- Type B:
  - Traction Pole fitted with switch arrangement or feeder cabling;
- Type C:
  - Traction Pole fitted with switch arrangement or feeder cabling; and
  - Traffic Signals and/or LV lighting on the Traction Pole.

SITUATIONAL ATTRIBUTE	BONDING TREATMENT
Is the Traction Pole used as a feeder point?	Type C – A site specific Traction Power study is required to be included in the design report to determine the bonding approach.
Is there a switching arrangement at the Traction Pole?	Type C – Bond the pole via a Spark Gap Device
Is there two layers of effective insulation between the live conductors and the Traction Pole?	Type A unless within the OHW fall zone. If within the OHW fall zone a separate risk assessment is required.
Is the Traction Pole inside/outside the OHW fall zone?	Type A unless fitted with Traction equipment. If fitted with Traction equipment, then Type C requirements apply.
Is the Traction Pole accessible to the general public?	Avoid installing Traction equipment on this pole at tram stops or other areas where public are in regular contact with the pole. An Earthing Study/Risk Assessment must be submitted with the design report in locations where the designer deems this unavoidable.
Are there traffic signals mounted on the Traction Pole?	Avoid installing Traction equipment on this pole. An Earthing Study/Risk Assessment must be submitted with the design report in locations where the designer deems this unavoidable.

SITUATIONAL ATTRIBUTE	BONDING TREATMENT
Is there any LV equipment (incl lighting) mounted on the Traction Pole?	Avoid installing Traction equipment on this pole. An Earthing Study/Risk Assessment must be submitted with the design report in locations where the designer deems this unavoidable.
Are there conductive interconnections between the Traction Pole and other Traction Poles (via conductive services or structural interfaces)? What is the categorisation of the Traction Poles it is interconnected with?	Typically, this occurs where switches and feeders are installed. In these locations LV Equipment must not be installed on the pole. An Earthing Study/Risk Assessment must be submitted with the design report in locations where the designer deems this unavoidable.
What is the Traction Pole mounted on? (Standalone footing, extended reinforced concrete slab etc);	In Ballasted track areas this is typically ballast rocks.
Is the Traction Pole in a location frequented by staff?	In Depots the requirement for bonding to ensure safety overrides the requirement to mitigate stray currents and all poles are bonded. If there are other areas on the network such as at substations where rail personnel are more frequently in proximity to the Traction Pole then and Earthing Study must be provided in the design reporting to assess and mitigate this specific risk situation.
Is the Traction Pole in a location adjacent to where LRVs commonly stop (Potential touch-voltage hazards between pole and stationary LRV at stop lights, etc.)?	Poles at traffic intersections and tram stops must typically be arranged to be Type A. An Earthing Study/Risk Assessment must be submitted with the design report in locations where the designer deems a Type A pole is not possible.

Table 14.1 – Bonding Approaches in Specific Situations

14.1.1. The Use of Pole Mounted Spark Gap Equipment

Where previously an OHW pole was required to be bonded to rail it must now have this bond removed and be fitted with a Spark Gap device as per Figure 14.1.1 below.

Spark Gap equipment is installed onto OHW poles to provide a safe path back to the OHW circuit for traction current in the event that an OHW contacts the pole.

Distance of spark gap connection to rail requires review from SAPTA's Electrical Technical Lead to prevent interference with signalling equipment's operation.

Spark Gap cable connection to traction return rail must be no longer than 5m.

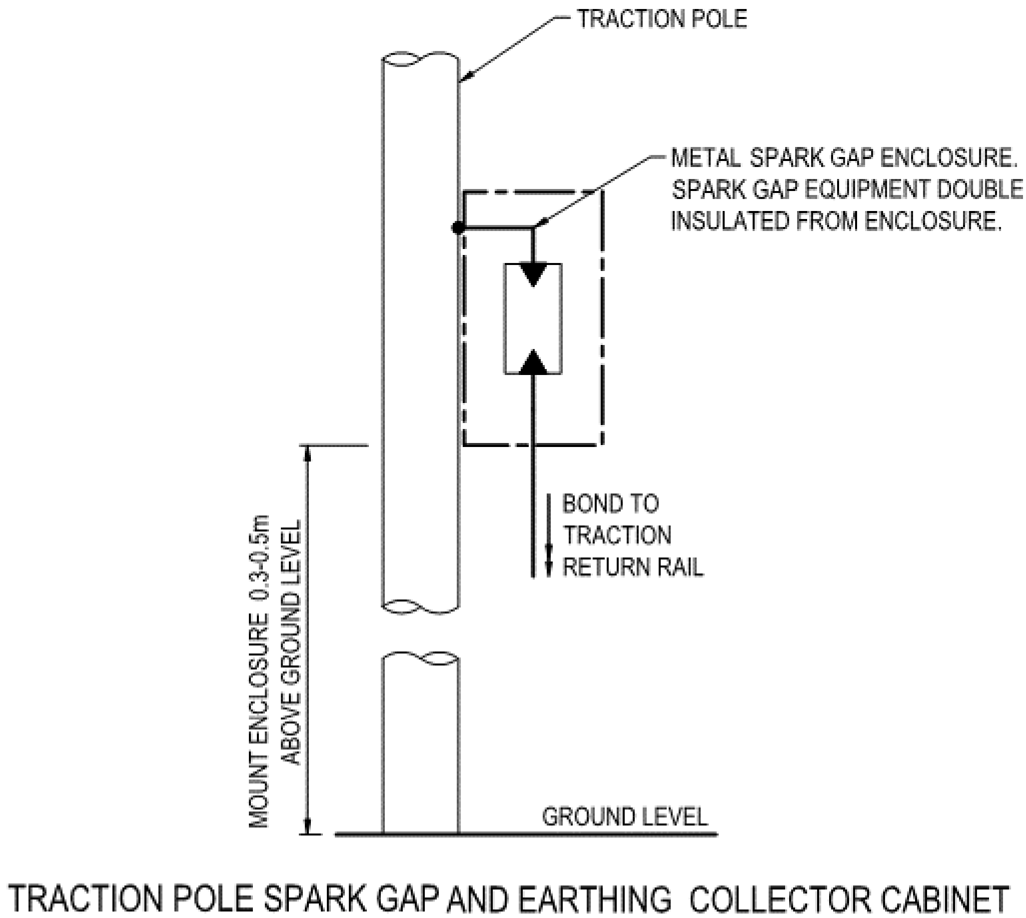


Figure 14.1.1 – Traction Pole Spark Gap Installation

14.1.2. Situations Where OHW Pole Bonding is Not Required

OHW poles not easily accessible to the general public or poles with no additional traction electrical equipment mounted on them do not need to be bonded to the tram rails, and do not need to be deliberately bonded to earth unless the measured pole to remote earth resistance is greater than 10 Ohms. The OHW pole installation examples shown in Figures 14.8.1 and 15.8.1 do not require bonding to the tram rails as the OHW poles are insulated from the 600V DC trolley wire ***unless*** they are supporting additional equipment as described in the following sub-clause.

OHW cross-span structures that are:

- supporting Parafil rope; and
- separated from the OHW live parts with a minimum of two layers of effective insulation to EN50122-1,
- with or without LV AC lighting or other SA Power Networks AC supplied equipment mounted onto the OHW pole

must not be bonded to traction return.

14.1.3. Situations Where OHW Pole Bonding is Required

OHW poles that have additional traction electrical equipment mounted on them (such as aerial switches, cable terminations, etc.) are required to be bonded to the tram rails using Spark Gap Devices as shown in Figure 14.1.1 above. This is because the additional electrical equipment causes 600V DC conductors to be in close proximity to the pole.

OHW poles with surge arrestors and other lightning arresting devices (and no other equipment) must be deliberately earthed. This will likely result in most of the lighting strike being dissipated locally, rather than potentially damaging other equipment if it were connected to the traction negative. The surge arrestor must be connected between the trolley wire or the tap connection and directly earthed using a separate 120mm^2 earthing conductor to a suitable separate earth rod;

OHW structures serving as feeding points require special consideration. For these poles a specific Traction Power System assessment will be required to determine the best and safest approach under fault current conditions.

14.2. Bonding Shared with Track Circuiting

Where possible, two termination points must be used so that a single disconnection will not cause the track circuit to show occupied.

Where necessary, subject to advice from the Signalling Engineer (either the installation contractor's engineer for new work or SAPTA's Signalling Technical Lead for existing work), to ensure continuity across rail joints within a track circuit, the rails on each side of the joint must be bonded together. Two bonds are fitted across each joint and secured to the rail. Bonds must be run close to the base of the rail and not threaded through fishplates, rail fastenings or under the rail.

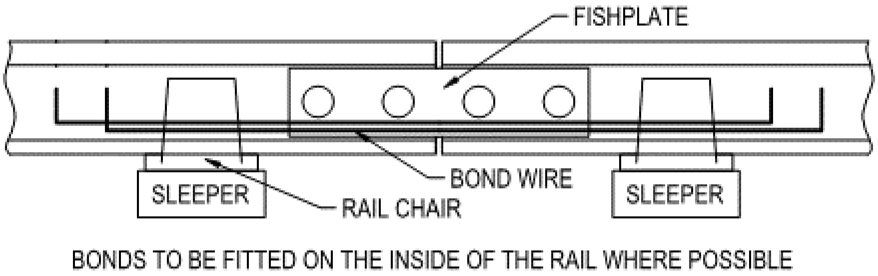


Figure 14.2 – Rail Joint Bond Detail

14.3. Rail-to-Rail Bonding

Rail-to-Rail Bonds must be provided at 150m spacing along Double Rail Track Circuited sections of the tram corridor to assist with keeping rail impedance within acceptable tolerances. Each Rail-to-Rail Bond must be positioned outside of Track Circuit Transmitter/ Receiver Blocks. The positioning of these bonds may adversely affect the operation of the Track Circuits if not designed appropriately and will require the approval of Signalling Engineer (either the installation contractor's engineer for new work or SAPTA's Signalling Technical Lead for existing work) prior to construction. Where Rail-to-Rail bonds are required, they must be duplicated.

14.4. Track-to-Track Bonding

14.4.1. Tie-In Bonding (Cross Bonding of Double Rail Track Circuited Areas)

Tie-In Bonding is the cross bonding of negative rail on adjacent tracks, typically at intervals of 0.8km and 1.6km. Where this bonding is required, it must be duplicated.

Cross bonds must be as short as possible on parallel tracks.

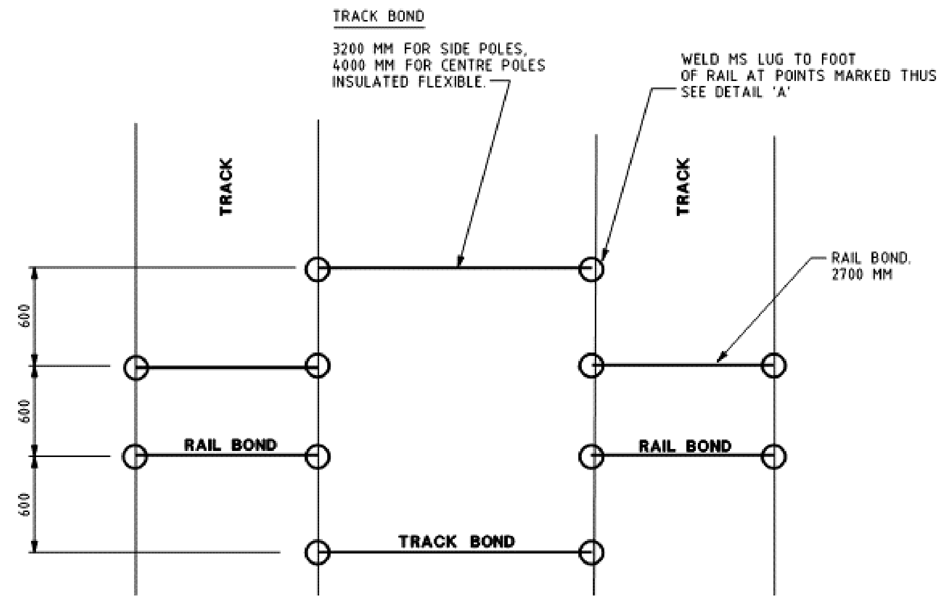


Figure 14.4.1 – Pre-Signalling Coordination Indicative Set-out of Rail-to-Rail and Track-to-Track Bonds

14.5. Tram Stops

Figures 14.5.1 and 14.5.2 below are the typical bonding arrangement for Tram-stop Infrastructure in Ballasted Track areas. There are two scenarios presented; the first where the Tram-stop's Platform and Equipment is within 2m of the OHW Zone and the second for the situation where the Tram-stop's Platform and Equipment is outside the areas where bonding to rail will be required. Figure 14.5.3 illustrates a typical tram-stop layout for one platform. Apply this arrangement to either the up or down platforms. Figure 14.5.4 provides the bonding schematic for each platform including the connection of all bonded elements on a platform to the diode via the Earthing Collector Cabinet (ECC).

Scenario 1: Conductive Items or 240V AC Supplied Equipment Within 2m of the OHW Zone

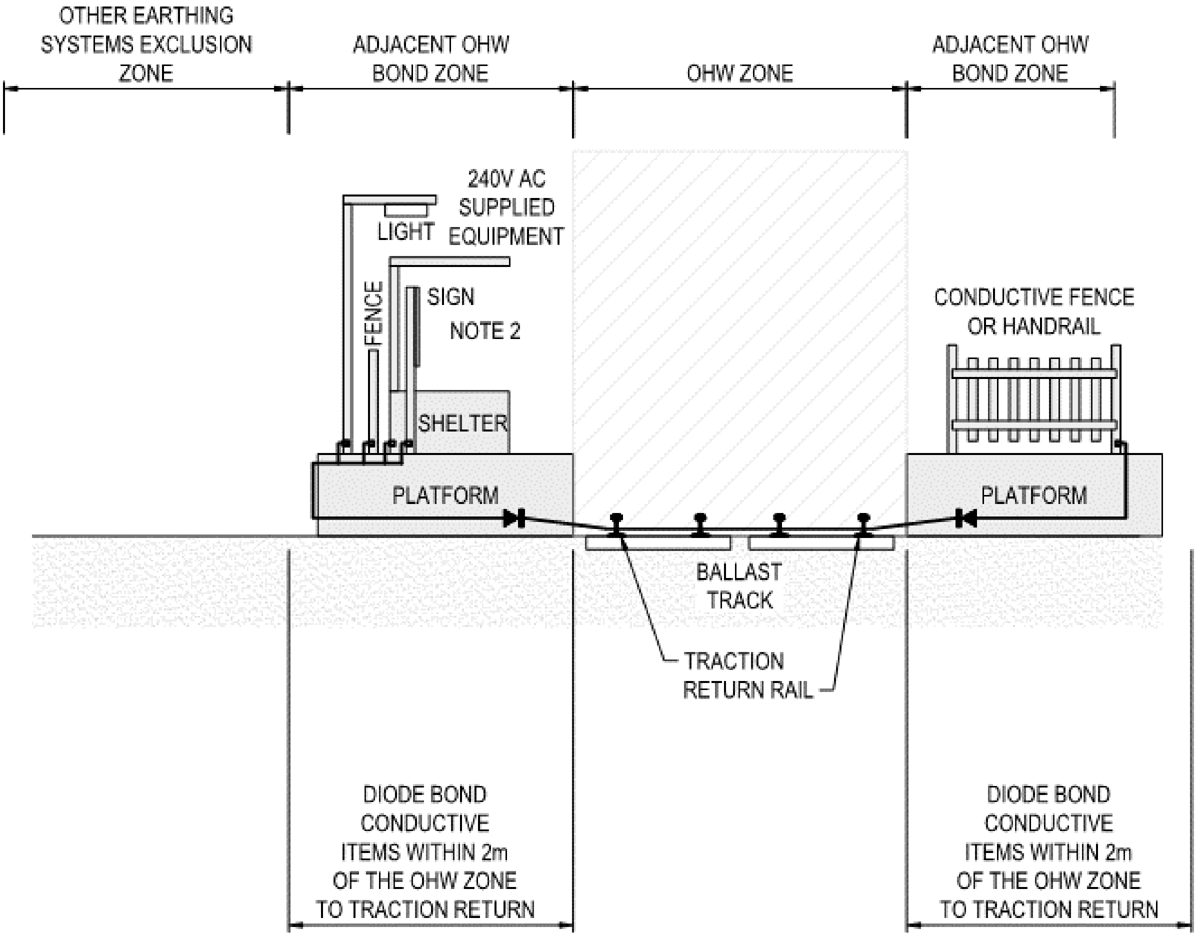


Figure 14.5.1 - Ballast Track Tram-Stop Typical Bonding, Scenario 1

Figure 14.5.1 Notes:

1. Refer to 14.5.3 for when Tram-stop Platform lighting and other LV equipment is required to be isolated from the SA Power Networks MEN system via an isolating transformer.
2. Where tram-stop structures or other infrastructure (handrails, fences etc.) pass into the OHW Zone they must be non-conductive material.
3. Diagrammatic representation in this figure is not to scale.

Scenario 2: Conductive Items or 240V AC Supplied Equipment Beyond 2m of the OHW Zone

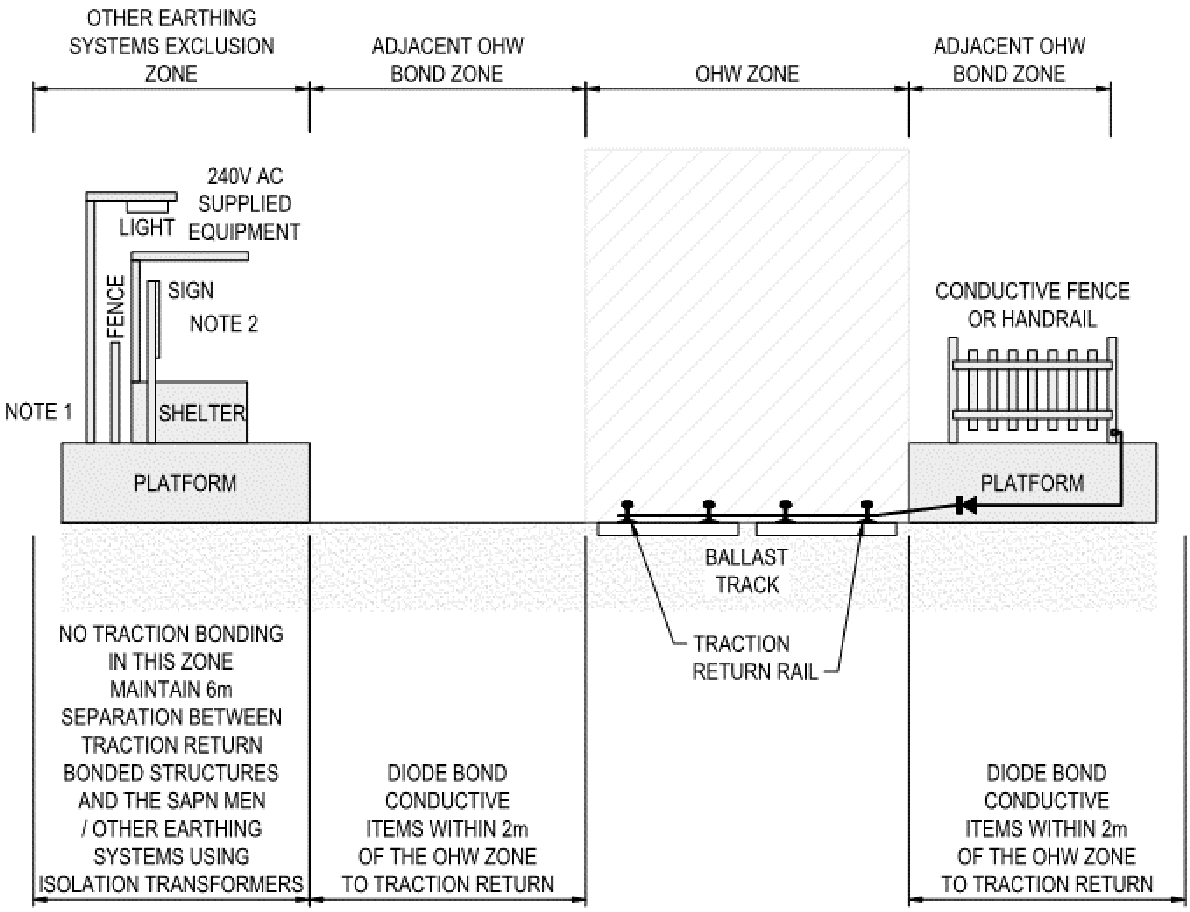
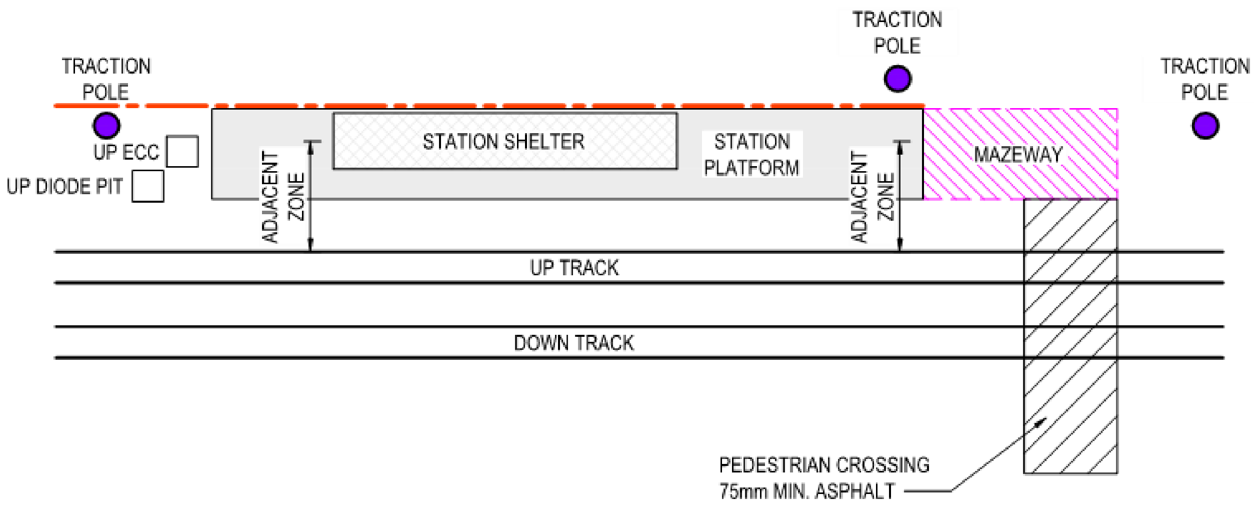


Figure 14.5.2 - Ballast Track Tram-Stop Bonding, Scenario 2

Figure 14.5.2 Notes:

1. Refer to 14.5.3 for when Tram-stop Platform lighting and other LV equipment is required to be isolated from the SA Power Networks MEN system via an isolating transformer.
2. Where tram stop or other infrastructure (handrails, fences etc.) pass into the OHW Zone they must be non-conductive material.
3. Diagrammatic representation in this figure is not to scale.



NOTE:
SEPARATE BONDING/DIODE/ECC OF UPTRACK FROM DOWN TRACK.
ALL BONDING SHALL BE A STAR CONNECTION TO THE ECC. THE ECC TO THE DIODE SHALL BE A SINGLE CONNECTION AND THEN CONNECT TO THE TRACK.
ISOLATE CONDUCTIVE ELEMENTS (EG FENCE GAPS/ISOLATION PANELS) BEYOND ADJACENT ZONE.
SHELTER IS TYPICALLY BONDED TO THE ECC. THE FENCE BEHIND THE SHELTER SHOULD BE BONDED TO THE ECC BUT SEPARATED FROM THE REMAINDER OF THE STATION FENCING.
FENCES WITHIN THE ADJACENT ZONE ARE TO BE BONDED BUT ALSO SEPARATED FROM ADJOINING FENCES USING NON-CONDUCTIVE FENCE SECTIONS.
TRACTION POLES CONTAINING SURGE DIVERTERS, SWITCHES OR FEEDERS SHALL BE KEPT >40m FROM STATIONS/LEVEL CROSSINGS/BRIDGES.
DO NOT MOUNT LIGHTING OR OTHER NON-TRACTION INFRASTRUCTURE ONTO TRACTION POLES.
KEEP SAPN SWITCHBOARDS AND EARTH SYSTEMS > 6m FROM TRACTION BONDED ELEMENTS. THIS INCLUDES ISOLATION TRANSFORMERS.
KEEP PLATFORM LV SUPPLIED LIGHT POLES OUTSIDE OF THE ADJACENT ZONE AND 2m FROM PLATFORM BONDED ELEMENTS INCL FENCE SECTIONS AND THE SHELTER.

DIODE PIT - A ROBUST FULLY RECESSED CONCRETE PIT WITH A LOCKABLE LID
ECC - EARTH COLLECTOR CABINET.

SEPARATE ECC AND DIODE FOR UP TRACK AND DOWN TRACK STATION SIDES.

Figure 14.5.3 – Typical Ballast Track Tram-Stop Bonding Arrangement

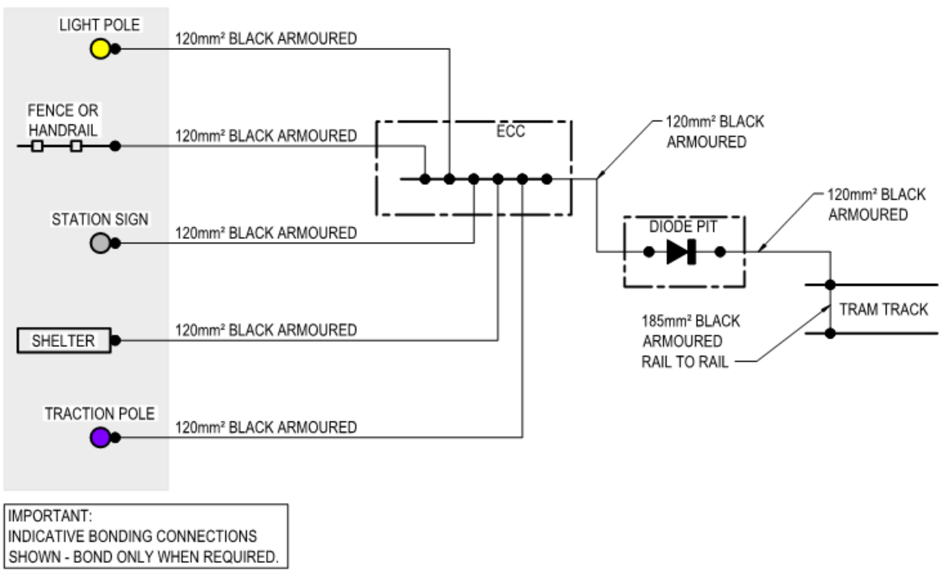


Figure 14.5.4 – Typical Ballast Track Tram-Stop Bonding Schematic

14.5.1. Tram Stop Structures

Keep tram-stop structures outside of the OHW Zone. Equipotentially bond all conductive parts of structures within the Adjacent OHW Bond Zone. Where located beyond these zones equipotential bonding of the structures is not required.

If the tram stop's shelter is fitted with 240V AC supplied equipment (lighting, vending machines etc.) located outside the OHW zone and not equi-potentially connected to the OHW poles then equipotentially bond the structure but do not bond the structure or furniture (bins, handrails, signage etc.) to traction return. In this situation the SA Power Networks connected LV MEN cabling will supply the shelter mounted equipment. This cabling must be kept electrically isolated from any infrastructure in the rail corridor that is Traction Return bonded. This includes maintaining an electrical separation for the under-track crossing from the SA Power Networks supply switchboard to the platform.

It is preferred that the tram stop's shelter and structures are not conductively connected to the traction poles or OHW structure.

If the tram stop's shelter is fitted with LV MEN supplied equipment (lighting, vending machines etc.), outside the OHW zone and conductively connected to the OHW poles (for example the portal frame at the Entertainment Centre Tram Stop) then equipotentially bond the structure to traction return via the tram-stop's diode bond and supply the LV MEN equipment from the SA Power Networks source via an isolation transformer with the secondary bonded to Traction Return.

Additionally, in this situation a safe work practice will need to be established to de-energise the Traction Power to work on the LV MEN equipment.

14.5.2. Tram Stop Fencing and Handrails

Keep conductive tram-stop fencing and handrails outside of the OHW Zone. If possible, keep conductive fencing outside of the Adjacent OHW Bond Zone. Equipotentially bond all conductive parts of fencing within the Adjacent OHW Bond Zone to allow bonding to traction rail. Where located beyond these zones do not bond fencing or handrails.

On the platform conductive handrails can be installed at the edge of the platform within the Adjacent OHW Bonding Zone but outside of the OHW zone. These must be bonded using a single asset bond as close to the base of the vertical handrail support as practical in a neat (cable and lug perpendicular and as flush as practical to the vertical rail) short (maximum 50mm exposed bond cable) discrete bond lug bolted to the handrail with good conductive contact made by removing any treatment or paint from the bonded area. This bond must be connected into the diode bond terminal. Where parts of the platform or connected access ramps/pathways are situated beneath the OHW zone any handrail sections within this zone must be non-conductive.

14.5.3. Platform Bonding

The reinforcement in the platform must be equipotentially bonded but ***not*** bonded to Traction Return.

14.6. Road Interface with ATN

There are several road traffic intersections on the ATN where the Tram OHW Infrastructure passes through shared road vehicle and pedestrian areas. At these intersections where the trolley wire drop zone passes above handrails or fences the section of these fences or handrails within the OHW Zone must be isolated from the adjacent parts using a non-conductive insulating panel section for the extent of the OHW Zone and the Adjacent OHW Bond Zone.

14.7. Adjacent Infrastructure

14.7.1. Asset Protection Bonding

Assets are defined as non-Tram infrastructure that is within the Tram corridor OHW Zone or within the Adjacent Bonded OHW Zone.
Bond all assets including road signage that are within the OHW Zone.

14.7.2. Interfaces with AC Electrification

The ATN is adjacent the AC Electrification at the Morphett Street bridge where the OHW is supported via isolators from the underside of the bridge. The Morphett Street Substations 1 and 2 are located beneath the bridge in an elevated structure separated from the bridge columns by a distance of 2m and approximately 6m from the AMRN.

The ATN passes over the AMRN at the Goodwood Bridge and on Port Road. The bridge at Port Road has movement gaps.

14.7.3. Interfaces with Other Administrations' Railways

The ATN passes over the ARTC non-electrified rail at the Goodwood Bridge and on Port Road. The bridge at Port Road has movement gaps.

14.7.4. Corridor Fencing

Corridor fencing must only be treated if within the Adjacent OHW Bonding Zone. Corridor fencing must be non-conductive if within the OHW zone. Fencing within 3m of tram stops, 3m of substations or within 1m of Traction Poles must be fitted with 2m wide non-conductive fence sections. This fence treatment will only be required on the side of the corridor that the tram stop, substation or pole is located. For tram stops, these fence sections must be fitted just beyond each tram-stop platform or tram-stop access path extent to mitigate the risk of spread of stray current from the tram-stop bonding or bringing corridor fault current to the tram stop. For substations, these fence sections must be fitted 4m from each end of the substation. For poles, they must be fitted adjacent to each side of the pole.

Non-conductive insulating panels or fence sections must be provided every 100m for stray current mitigation.

14.8. Bond Types

Bonds must be made using steel or other material rather than copper to reduce the likelihood of conductor theft.

All bond cables must have a black outer sheath as an anti-theft measure so that they are less visible.

In publicly accessible parts of the corridor the cable must be an armoured type as an anti-theft measure.

Ballast Track tram stops are currently bonded to earth via 130A rectifier diodes. All tram-stop bonding cables are joined at a star point on the tram-stop side terminal of the diode. The diode installed direction directs current flow towards the traction return. This diode offers both fault current and cathodic protection for the tram stop's bonded elements.

Connecting a diode in series between the tram-stop elements that require bonding and the Traction Return will increase the resistance of the leakage current path to earth. Fault Current treatment alternatives to this, not presently in use on the network, that may be considered by SAPTA's Electrical Technical Lead are the use of a Voltage Limiting Device incorporating Stray Current Monitoring; for example, Secheron.

Identification of stray currents and the protection of other assets or infrastructure element in sections of the corridor away from tram stops will require a detailed study of the specific scenario.

14.8.1. Ballast Track Diode Bond

Where a metallic structure is in an area of ballast track and is to be bonded to the tram rails, an earthing diode must be used in series with the bond. This bond type is illustrated in Figure 14.8.1.

On ballast track the track construction provides an improved rail to earth resistance. In this situation a direct bond may cause an increased risk of unintentional stray current corrosion by allowing traction return current to leave the rails and enter the earth via the 'direct bond' and the pole base. Because of this an 'earthing' diode must be used for all bonds in ballast track. The bond connection to rail in ballast track must be able to be disconnected for testing.

The installation details for the diode bond, which is used to control stray current flow back to traction return as well as fault current. This bond forms the junction/star point to consolidate asset bonds at a tram stop.

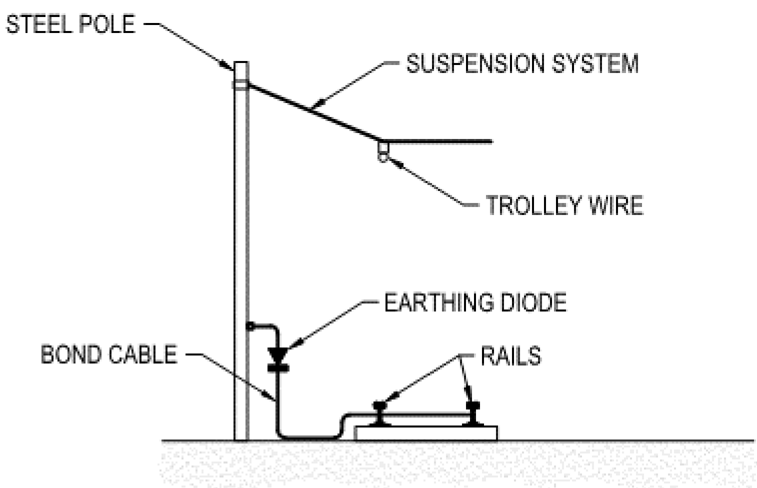


Figure 14.8.1 – Diode Pole Bonding Arrangement

14.8.2. Spider Connections, Long Bonds, Negative Feeders & Asset Bonds

Spider Connections

Wrap the cable junction or spider connection with electrical Denso® tape or equivalent. Install this junction at a depth of at least 500mm below finished ground level below the rail sub-base.

Long Bonding

Long Bonding is required to bridge the tracks around special track areas.

Install the cables in orange HD PVC conduit between the connections and under the rail to the asset for mechanical and theft prevention. Conceal the cabling as far as practical. Bond to the asset using the lug and cable specified in Clause 13.14 – *Earthing & Bonding Conductors*.

Wrap the cable junction with electrical Denso® tape or approved equivalent. Conceal inside sealed conduit at least 500mm beneath the finished ground level. Sweep bend the conduit up to the asset. Cut and seal off the conduit at ground level and surface mount the bond to the asset.

Where duplicate bonds are required, the centre of two rail bonds is attached by the 'Wheeze' process at each end of the 400mm² conductor to form four legs at each end.

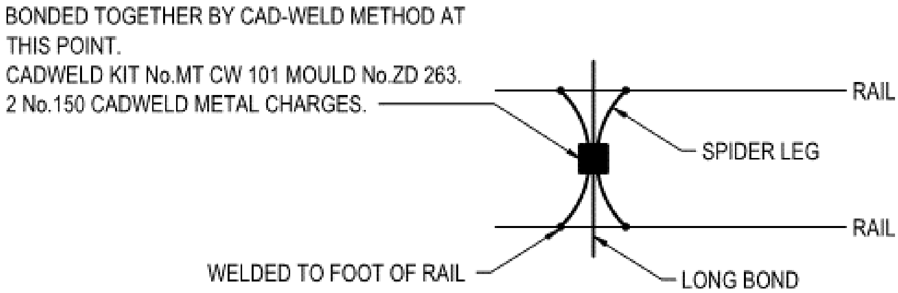


Figure 14.8.2.1 – Duplicate Long Bonds Installation Detail.

Negative Feeder Bonds
Provide multiples of the Negative feeder connections from each track with rail-to-rail connections as shown in Figure 14.8.3 with quantities as specified by the Traction Power Engineer specific to each network Substation.

Wrap the cable junction with electrical Denso® tape or approved equivalent and located it at least 500mm beneath the finished ground level.

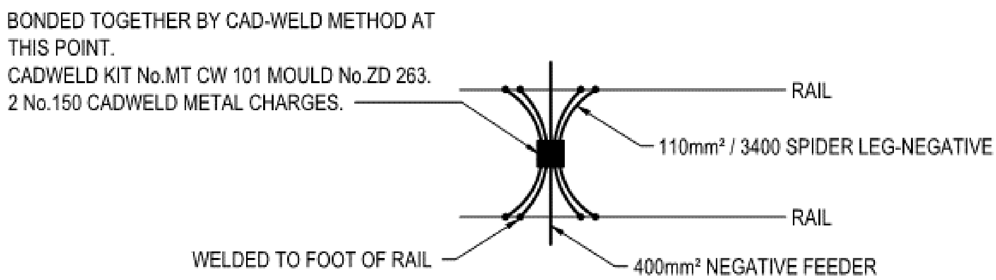


Figure 14.8.2.2 – Typical Negative Feeder Connection Detail

Asset Bonds
Install bonds to assets where specified as required by other parts of this standard (tram-stop shelter structures, fences, handrails) to each rail of the track using the method shown in Figure 14.8.4 with Cembre® connections to the track. Provide a single bond to each asset.

Install the cables in orange HD PVC conduit between the connections and under the rail to the asset for mechanical and theft prevention. Conceal the cabling as far as practical. Bond to the asset using the lug and cable specified in Clause 13.14 – *Earthing & Bonding Conductors*.

Wrap the cable junction with electrical Denso® tape or approved equivalent. Conceal inside sealed conduit at least 500mm beneath the finished ground level. Sweep bend the conduit up to the asset. Cut and seal off the conduit at ground level and surface mount the bond to the asset.

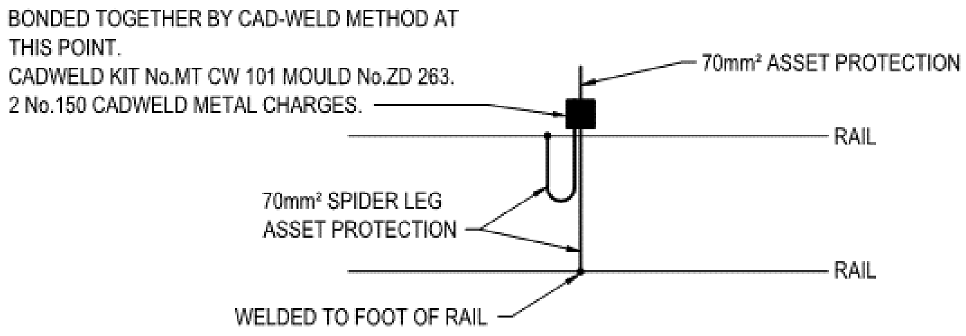


Figure 14.8.2.3 – Typical Asset Bond Connection Detail

Pole Bonds

Install bonds to poles where specified, as required by other parts of this standard (for example, Clause 14.1 – *OHW Pole Bonding*), to each rail of the track using the method shown in Figure 14.8.5 with Cembre® connections to the track. Provide one bond to the pole cross-bonded to each track by creating a rail-to-rail bond on each track and bonding track-to-track adjacent the pole.

Install the cables in orange HD PVC conduit between the connections and under the rail to the pole for mechanical and theft prevention. Conceal the cabling as far as practical. Bond to the asset using the lug and cable specified in the Clause 13.14 – *Earthing & Bonding Conductors*.

Sweep bend the conduit up to the asset. Cut and seal off the conduit at ground level and surface mount the bond to the asset.

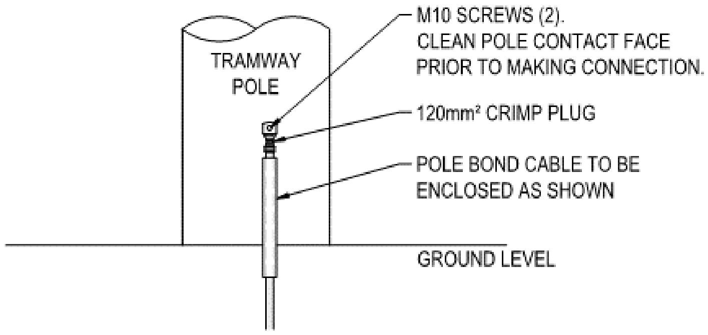


Figure 14.8.2.4 – Typical Ballast Track Pole Bond Installation

14.8.3. Physical Protection of Bonds and Theft Prevention Techniques

Where bonds are liable to physical damage (for example, across roadways or platforms), they must be adequately mechanically protected.
Where bonds are liable to be damaged or removed without authorisation, then theft prevention methods must be applied. This issue is especially prevalent on ballast track sections and on the overbridges.

Some theft prevention methods acceptable for use on the ATN are:

- To conceal the bond cable in conduit buried beneath the track;
- Use of tamper proof nuts on the rail and bonded item connection point;
- Metal cover plates over surface mounted bonds between the rails on the ballasted track — these must not be used where a spark gap device is fitted to a nearby OHW pole;
- Metal cover plates over the pole mounted bond;
- Keeping the bonds as short and discrete as possible;
- Steel armouring in the bond cable;
- Using asphalt to conceal the bonds (this has is used at pedestrian crossings to provide step potential protection.

Wherever possible, the traction bonds must be routed and arranged as shown on the appropriate design drawings included in the traction overhead system design. The traction bonds must be buried inside sealed conduits below the surface run of the ballast, formation or ground level unless otherwise approved by SAPTA's Electrical Technical Lead. Traction bonds must be supported where necessary to avoid damage or movement.

In areas with jointless track circuits, bonds which pass beneath a running or conductor rail must be encased in orange coloured plastic conduit such that inadvertent contact between the bond and the rail is prevented even if the bond insulation becomes damaged.

14.8.4. Buried Bonding Cables

The minimum depth of buried bonding or negative return cables is 500mm and the cables must have protective slabs and marking.

14.9. Rail Connections / Terminations, Termination Details / Geometry of Bonds, Including Cable Sizes and Lug Bolt Size Details

All cables must be securely terminated to the rails.

Cables placed under the rails must be secured and run through an orange rigid HD UPVC conduit so that they cannot move or be damaged by work on the rail. Bonding must be arranged to minimise as far as practical the length of all bonds. All bonds to rail in ballast track construction must be installed after tamping of track because tamping will damage any previously installed bonds. Each bond must be installed as per the detail below. All bonds, other than rail-joint bonds, must be protected by a minimum of 300mm ballast.

14.9.1. Crimped Lug Termination

This termination type is used for attachment of bonds to poles and cabinets.

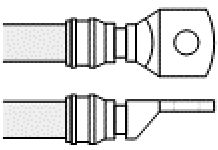


Figure 14.9.1 – Crimped Lug Termination

14.9.2. Cembre Rail Connection

All rail connections in ballast track construction must be achieved using the 'Cembre® AR' series of connectors with the specific connector appropriate for the rail geometry installed as per Figure 14.9.2. Any holes drilled through the web of the rail must be a minimum of 150mm from any other hole or weld in the rail.

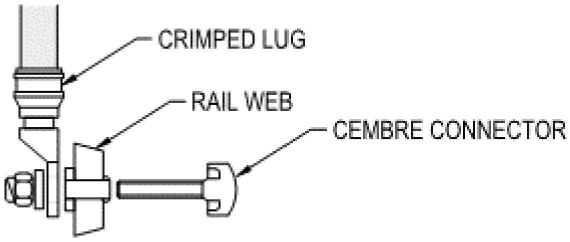


Figure 14.9.2 – Cembre Rail Connection

14.9.3. Drainage Bonding

This standard covers the electrolysis mitigation drainage bonds for the tram corridor only. Electrolysis protection measures specific to the substations must be considered in the Traction Power System standard.

In uninsulated tram rails on ballast the use of polarised diode drainage circuits is currently the best practice for mitigation of stray current. Other alternative methods such as a stray current collecting net, where reinforcement rods are bonded to form a mesh beneath the concrete layer under the running rails, should be considered in paved track areas with surface mounted rail; that is, the concrete tram bridge decks.

Traction electrolysis cables (also known as drainage bonds) are erected on distribution poles to enable underground metal structures such as water mains to be bonded to the rails of the tram traction system. They provide a return circuit for stray DC leakage currents produced by the traction systems, thereby reducing electrolytic corrosion of the underground structures.
The bond or connection is made on a pole mounted control box or in a dedicated in-ground pit using a diode which allows DC current to flow in only one direction from the asset to the rails.

Other technology exists, such as an electrical contactor that closes automatically when the DC voltage polarity between the rails and the underground asset is such that current would flow from the underground asset to the rails. However, these installations require an unmetered LV supply to the electrolysis equipment box and are not currently in use on the ATN.

14.9.4. Tram Stop Diode Bond Installation

At each tram stop provide the 130A SemiKron diode assembly (Assembly Part Number Stack 2947, Diode Part Number Westcode W3697VC160-280) shown in Figures 14.9.4.1 and 14.9.4.2 inside a dedicated secure pit. Use an M12 lug suitable for the 120mm^2 with a reducer to fit to the M6 terminals on the diode assembly.

Figure 14.9.4.1 – Earthing Diode Assembly External View

Figure 14.9.4.2 – Earthing Diode Assembly Internal View

Cable pits must be made of precast concrete, glass reinforced polyester (GRP) or high density polyethylene (HDPE), unsupported and structurally tested and subject to meeting structural requirements that will depend on soil conditions and preparation associated with installation, certified and badged for the required loading. They must be fitted with heavy duty, well fitting, metal or Composite Resin Fill (CRF), lockable (by padlocks) lids, AS 3996 certified and badged Class B 80kN.

The locking mechanism may reside in the lid, in a separate lid section, or can be incorporated in the pit structure. The securing mechanism for the lid (to the pit) must directly engage the outside edges of the lid with the side of the pit, or with the side of a separately secured lid section. A securing mechanism that does not directly lock down or latch at least two opposing sides of the lid must not be deemed to meet these requirements.

Pit gaskets are to be installed for sealing and prevention of sharps and other hazardous material from being inserted into the pit. Gaskets must be secured to the lids in such a way that they remain with the lid upon removal of the lid from the pit.

The pit must be installed upon a bed of minimum 75mm thick crushed rock for drainage.

Conduits for the drainage bond cables must be sealed to the pit wall with a sealant approved by the Department.

The diode must be encapsulated in an IP68 junction box filled with Raychem KGEL-FLEX flexible setting insulating compound, or equivalent.

14.10. Pedestrian Crossings

At pedestrian crossings, bonds to rail must be connected via an ECC and then a diode, as per Figure 14.5.4.

Provide an asphaltic platform of a minimum 200mm depth and a minimum 2.5m wide at each pedestrian crossing of the tram corridor.

14.11. Special Track Areas

Bonding for Level Crossings, Junctions, Crossovers and Turnout are special track areas which have a high level of interaction with the signalling installation due to the use of the bonding cabling for signalling functionality. Any bonding design for these areas cannot be finalized without specific review and confirmation of compatibility with the Signalling System by SAPTA's Signalling Technical Lead.

The bonding requirements for crossovers are provided in general terms for guidance without specific reference to the signalling and IRJ equipment position which interacts with and impacts on the specific design positions of bonding.

14.12. Level Crossings

The bond to rail must avoid the rail used for level crossing approach track circuits (where appropriate).

14.13. Crossovers

All connections must be past any manganese rail sections. All cables must be installed in HD PVC rigid conduit in the substrate beneath the rail sub-base. Each long bond must be a continuous cable or may be joined with approval using exothermic welding. Figure 14.13 provides a diagrammatic bonding layout without the Track Circuit continuity bonds required for the ATN.

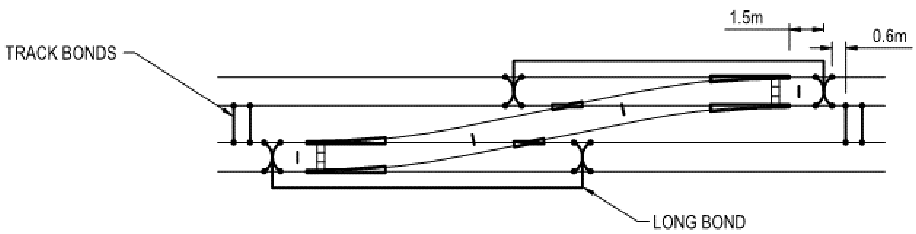


Figure 14.13 – Typical Bonding at Crossovers

14.14. Turnouts

All connections must be past any manganese rail sections. All cables must be installed in HD PVC rigid conduit in the substrate beneath the rail sub-base. Each long bond must be a continuous cable or may be joined with approval using exothermic welding.

Figure 14.14 provides a diagrammatic bonding layout without the Track Circuit continuity bonds required for the ATN.

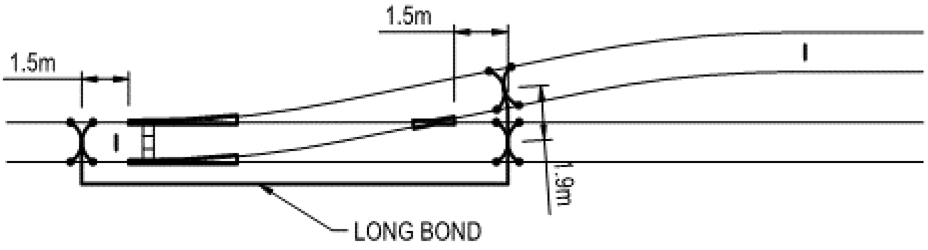


Figure 14.14 – Typical Bonding at Crossovers

15. Direct Buried Uninsulated Paved Track Design Criteria

15.1. OHW Pole Bonding

The following sub-clauses are based on the assumption that the OHW installation has an effective two layers of insulation in accordance with EN50122-1.

The network contains three types of poles, categorised based on the equipment they do or do not contain:

- Type A:
  - Traction Pole ***not*** fitted with a switch arrangement or feeder cabling;
  - Outside of the OHW fall zone; and
  - Two layers of effective insulation between the live conductors and the Traction Pole.

Note: Type A poles may be fitted with non-isolated LV SAPN connected equipment.

- Type B:
  - Traction Pole fitted with switch arrangement or feeder cabling.

- Type C:
  - Traction Pole fitted with switch arrangement or feeder cabling; and
  - Traffic Signals and/or LV lighting on the Traction Pole.

SITUATIONAL ATTRIBUTE	BONDING TREATMENT
Is the Traction Pole used as a feeder point?	Type C – A site specific Traction Power study is required to be included in the design report to determine the bonding approach.
Is there a switching arrangement at the Traction Pole?	Type C – Bond the pole via a Spark Gap Device
Is there two layers of effective insulation between the live conductors and the Traction Pole?	Type A unless within the OHW fall zone. If within the OHW fall zone a separate risk assessment is required.
Is the Traction Pole inside/outside the OHW fall zone?	Type A unless fitted with Traction equipment. If fitted with Traction equipment, then Type C requirements apply.
Is the Traction Pole accessible to the general public?	Avoid installing Traction equipment on this pole at tram stops or other areas where public are in regular contact with the pole. An Earthing Study/Risk Assessment must be submitted with the design report in locations where the designer deems this unavoidable.

SITUATIONAL ATTRIBUTE	BONDING TREATMENT
Are there traffic signals mounted on the Traction Pole?	Avoid installing Traction equipment on this pole. An Earthing Study/Risk Assessment must be submitted with the design report in locations where the designer deems this unavoidable.
Is there any LV equipment (incl lighting) mounted on the Traction Pole?	Avoid installing Traction equipment on this pole. An Earthing Study/Risk Assessment must be submitted with the design report in locations where the designer deems this unavoidable.
Are there conductive interconnections between the Traction Pole and other Traction Poles (via conductive services or structural interfaces)? What is the categorisation of the Traction Poles it is interconnected with?	Typically, this occurs where switches and feeders are installed. In these locations LV Equipment must not be installed on the pole. An Earthing Study/Risk Assessment must be submitted with the design report in locations where the designer deems this unavoidable.
What is the Traction Pole mounted on? (Standalone footing, extended reinforced concrete slab etc.);	In Paved track areas this is typically concrete with reinforcement.
Is the Traction Pole in a location frequented by staff?	In Depots, the requirement for bonding to ensure safety overrides the requirement to mitigate stray currents and all poles are bonded. If there are other areas on the network such as at substations where rail personnel are more frequently in proximity to the Traction Pole, then and Earthing Study must be provided in the design reporting to assess and mitigate this specific risk situation.
Is the Traction Pole in a location adjacent to where LRVs commonly stop (Potential touch-voltage hazards between pole and stationary LRV at stop lights, etc.)?	Poles at traffic intersections and tram stops must typically be arranged to be Type A. An Earthing Study/Risk Assessment must be submitted with the design report in locations where the designer deems a Type A pole is not possible.

Table 15.1 – Bonding Approaches in Specific Situations

15.1.1. The Use of Pole Mounted Spark Gap Equipment

Where previously an OHW pole was required to be bonded directly to rail it must now have this bond removed and be fitted with a Spark Gap device as per Figure 15.1.1.

Spark Gap equipment is installed onto OHW poles to provide a safe path back to the OHW circuit for traction current in the event that an OHW contacts the pole.

Distance of spark gap connection to rail requires review from SAPTA's Electrical Technical Lead to prevent interference with signalling equipment operation.

Spark Gap cable connection to traction return rail must be no longer than 5m.

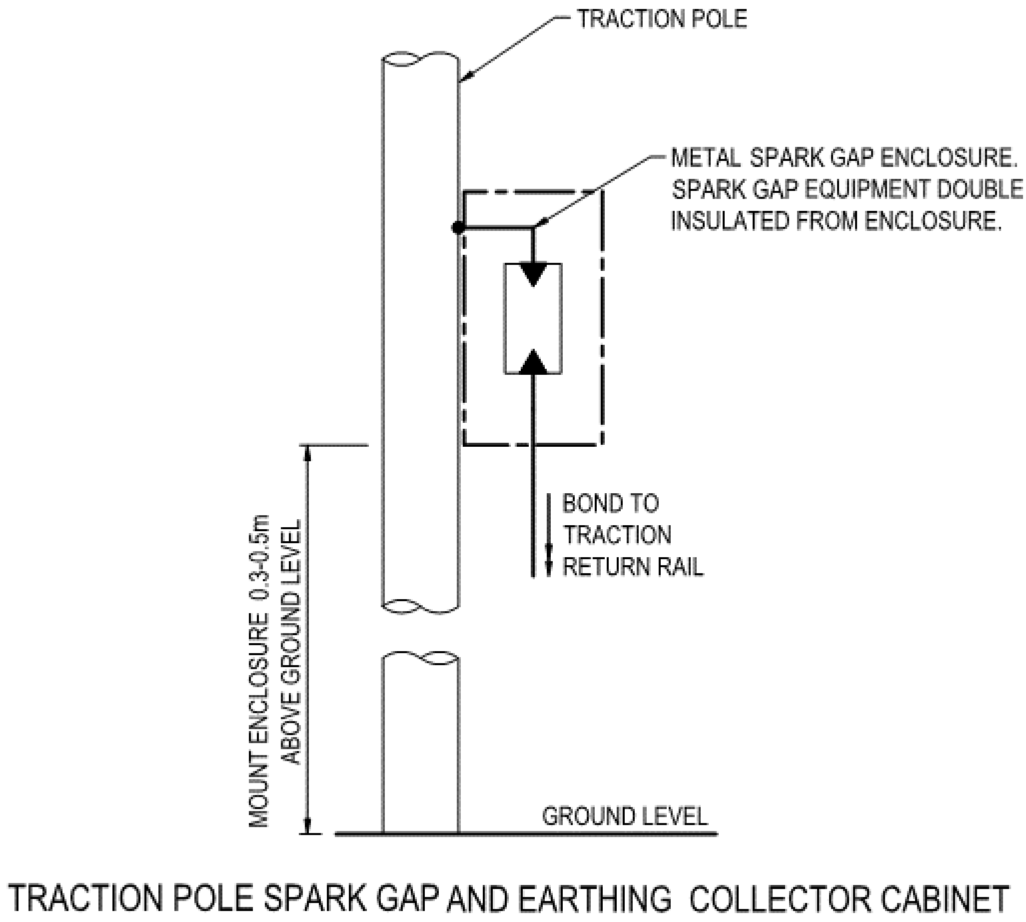


Figure 15.1.1 – Traction Pole Spark Gap Installation

15.1.2. Situations Where OHW Pole Bonding is Not Required

OHW poles not easily accessible to the general public or poles with no additional traction electrical equipment mounted on them do not need to be bonded to the tram rails, and do not need to be deliberately bonded to earth ***unless*** the measured pole to remote earth resistance is greater than 10 Ohms.

OHW cross-span structures that are:

- supporting Parafil rope, and
- separated from the OHW live parts with a minimum of two layers of effective insulation to EN50122-1,
- with or without LV AC lighting or other SA Power Networks AC supplied equipment mounted onto the OHW pole must ***not*** be bonded to traction return.

15.1.3. Situations Where OHW Pole Bonding is Required

OHW poles with surge arrestors and other lightning arresting devices (and no other equipment) must be earthed. This will result in most of the lighting strike being dissipated locally, rather than potentially damaging the rectifier if it were connected to the traction negative. The surge arrestor must be connected between the trolley wire or the tap connection and directly earthed using a separate 120mm^2 earthing conductor to a suitable separate earth rod.

OHW poles that have additional traction electrical equipment mounted on them (such as aerial switches, cable terminations, etc.) are required to be bonded to the tram rails. This is because the additional electrical equipment causes 600V DC conductors to be in close proximity to the pole.

15.2. Bonding Shared with Track Circuiting

Where possible, dual termination points must be used so that a single disconnection will not cause the track circuit to show occupied.

Where necessary, subject to advice from the Signalling Engineer (either the installation contractor's engineer for new work or SAPTA's Signalling Technical Lead for existing work), to ensure continuity across rail joints within a track circuit, the rails on each side of the joint must be bonded together. Two bonds are fitted across each joint and secured to the rail. Bonds must be run close to the base of the rail and not threaded through fishplates, rail fastenings or under the rail.

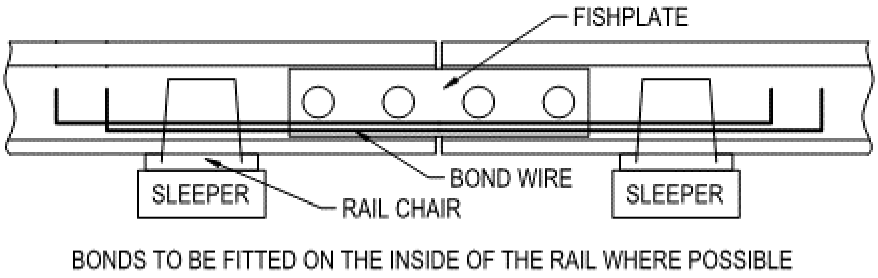


Figure 15.2 – Rail Joint Bond Detail

15.3. Rail-to-Rail Bonding

Rail-to-Rail Bonds must be provided at 150m spacing along Double Rail Track Circuited sections of the tram corridor to assist with keeping rail impedance within acceptable tolerances. Each Rail-to-Rail Bond must be positioned outside of Track Circuit Transmitter/ Receiver Blocks. The positioning of these bonds may adversely affect the operation of the Track Circuits if not designed appropriately and will require the approval of the Signalling Engineer (either the installation contractor's engineer for new work or SAPTA's Signalling Technical Lead for existing work) prior to construction. Where Rail-to-Rail Bonds are required, they must be duplicated.

15.4. Track-to-Track Bonding

15.4.1. Tie-In Bonding (Cross Bonding of Double Rail Track Circuited Areas)

Tie-In Bonding is the cross bonding of negative rail on adjacent tracks, typically at intervals of 0.8km and 1.6km.

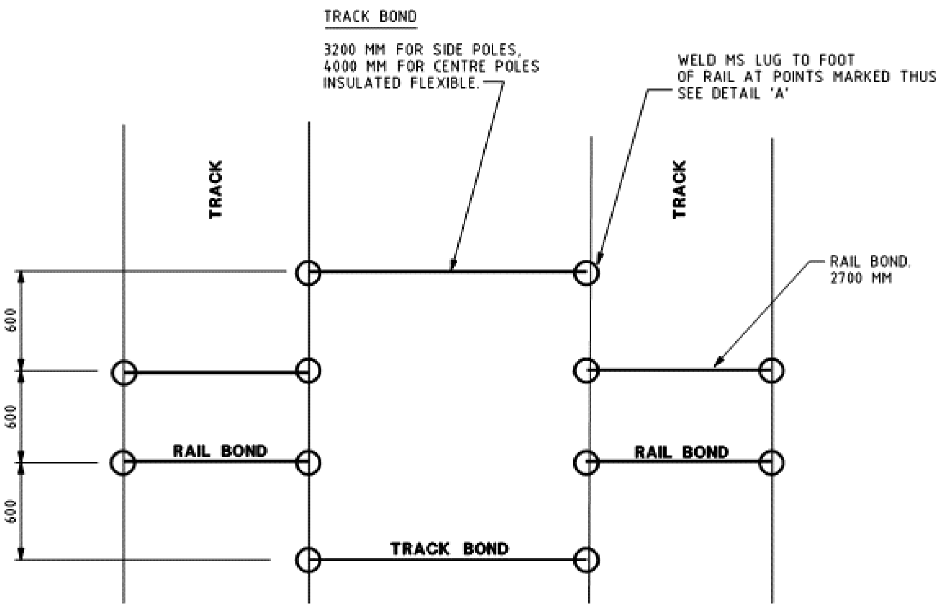


Figure 15.4.1.1 – Typical Set-out for Rail-to-Rail and Track-to-Track Bonds

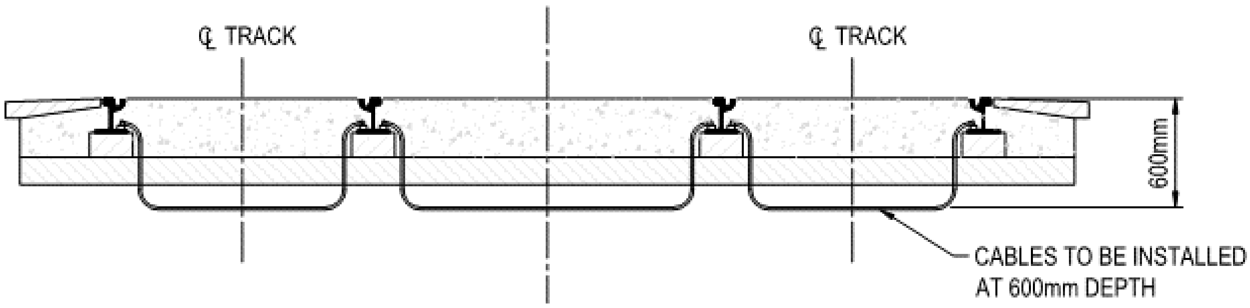
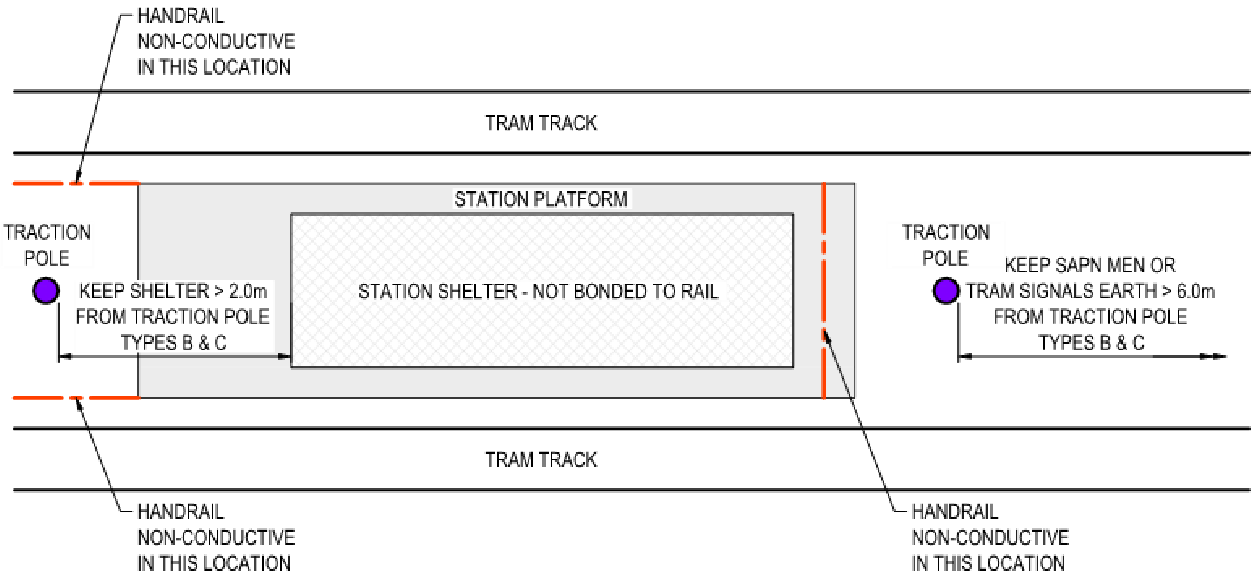


Figure 15.4.1.2 – Section for Track-to-Track and Rail-to-Rail Bonding in Paved Track

15.5. Tram Stops

Figures 15.5.1 to 15.5.3 show example bonding arrangements for three types of tram stops in Paved Track areas: Centre Mounted Tram-stop and Traction Poles, Centre Island Type Tram Stop with Side Mounted Traction Poles and Tram Stop with Traction Portals.

Example 1: Centre Tram Stop and Traction Poles

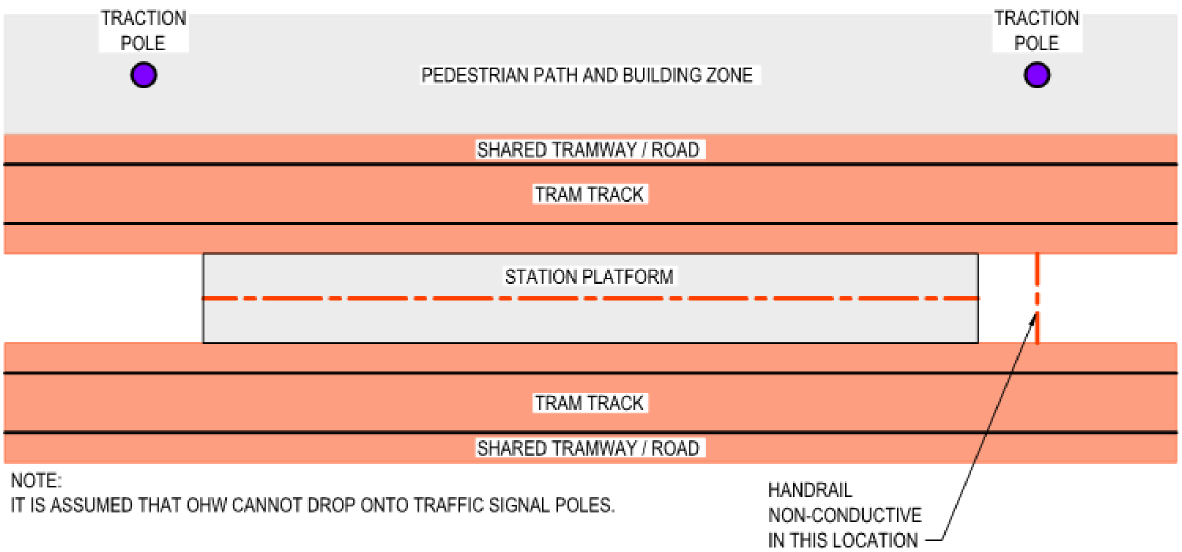


TRACTION POLE TYPE EARTHING AND BONDING TREATMENTS		
TP TYPE A:	TRACTION POLE **NOT** FITTED WITH SWITCH/FEEDER CABLING. OHW CANNOT DROP ONTO POLE. TWO POINTS OF EFFECTIVE INSULATION BETWEEN OHW AND POLE.	NO E&B SPECIFIC SPACING RESTRICTIONS BETWEEN TRACTION POLE & OTHER CONDUCTIVE ELEMENTS.
TP TYPE B:	TRACTION POLE FITTED WITH SWITCH/FEEDER CABLING.	FIT SPARK GAP TO BOND FROM TRACTION POLE TO TRACTION RETURN RAIL. SEPARATE >2m FROM CONDUCTIVE ELEMENTS EG HANDRAILS, SHELTER ETC.
TP TYPE C:	TRACTION POLE FITTED WITH SWITCH/FEEDER CABLING AND TRAFFIC SIGNALS EQUIPMENT OR LV LIGHTING.	FIT SPARK GAP TO BOND FROM POLE TO TRACTION RETURN RAIL. SEPARATE >2m FROM CONDUCTIVE ELEMENTS EG HANDRAILS, SHELTER ETC. SUPPLY TRAFFIC SIGNALS/ LV LIGHTING FROM AN ISOLATION TRANSFORMER WITH SAPN (PRIMARY SIDE) EARTH >6m FROM POLE. IF THE TRAFFIC SIGNALS EQUIPMENT IS CABLED TO OTHER TRAFFIC POLES EG AN INTERSECTION THESE WOULD ALSO REQUIRE AN ISOLATED SUPPLY BUT THE SAFER SOLUTION IS TO RELOCATE THE SWITCH/FEEDER CONNECTION TO ANOTHER TRACTION POLE.

NOTE:
IF THE ABOVE TREATMENTS ARE NOT POSSIBLE THEN RELOCATE EITHER THE SWITCH/FEEDER OR TRAFFIC SIGNALS EQUIPMENT TO ANOTHER POLE.

Figure 15.5.1 – Centre Tram Stop on Paved Track

Example 2: Centre Island Type Tram Stop with Side Mounted Traction Poles

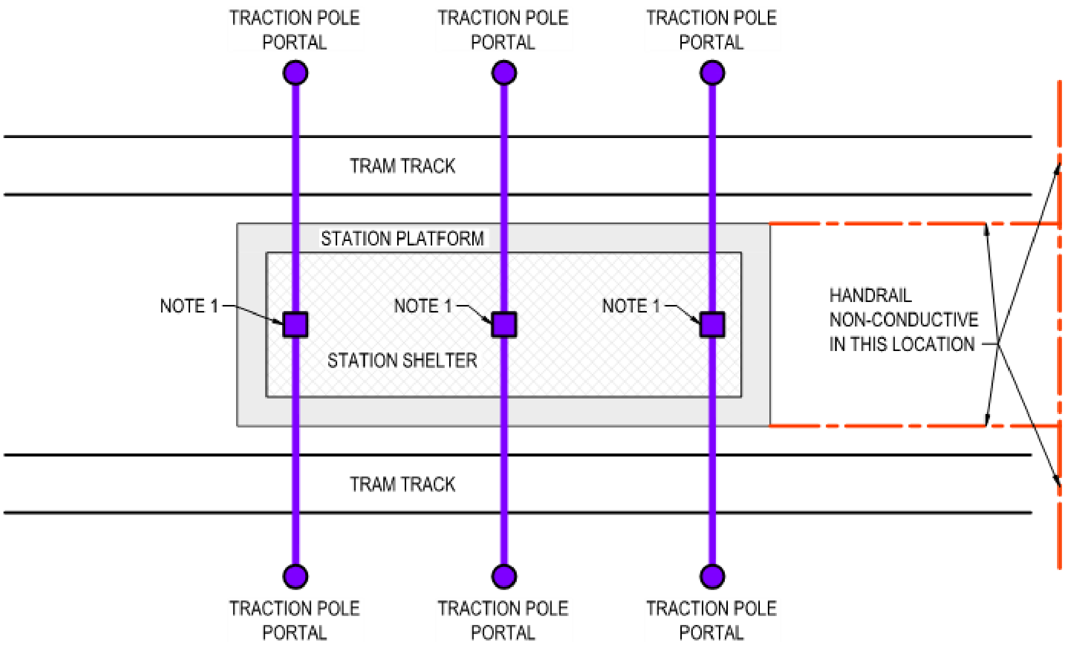


TRACTION POLE TYPE EARTHING AND BONDING TREATMENTS		
TP TYPE A:	TRACTION POLE **NOT** FITTED WITH SWITCH/FEEDER CABLING. OHW CANNOT DROP ONTO POLE. TWO POINTS OF EFFECTIVE INSULATION BETWEEN OHW AND POLE.	NO E&B SPECIFIC SPACING RESTRICTIONS BETWEEN TRACTION POLE & OTHER CONDUCTIVE ELEMENTS.
TP TYPE B:	TRACTION POLE FITTED WITH SWITCH/FEEDER CABLING.	FIT SPARK GAP TO BOND FROM TRACTION POLE TO TRACTION RETURN RAIL. SEPARATE >2m FROM CONDUCTIVE ELEMENTS EG HANDRAILS, AWNINGS ETC.
TP TYPE C:	TRACTION POLE FITTED WITH SWITCH/FEEDER CABLING AND TRAFFIC SIGNALS EQUIPMENT OR LV LIGHTING.	FIT SPARK GAP TO BOND FROM POLE TO TRACTION RETURN RAIL. SEPARATE >2m FROM CONDUCTIVE ELEMENTS EG HANDRAILS, SHELTER ETC. SUPPLY TRAFFIC SIGNALS/ LV LIGHTING FROM AN ISOLATION TRANSFORMER WITH SAPN (PRIMARY SIDE) EARTH >6m FROM POLE. IF THE TRAFFIC SIGNALS EQUIPMENT IS CABLED TO OTHER TRAFFIC POLES EG AN INTERSECTION THESE WOULD ALSO REQUIRE AN ISOLATED SUPPLY BUT THE SAFER SOLUTION IS TO RELOCATE THE SWITCH/FEEDER CONNECTION TO ANOTHER TRACTION POLE.

NOTE:
IF THE ABOVE TREATMENTS ARE NOT POSSIBLE THEN RELOCATE EITHER THE SWITCH/FEEDER OR TRAFFIC SIGNALS EQUIPMENT TO ANOTHER POLE.

Figure 15.5.2 – Centre Island Paved Track Tram Stop with Side Mounted Traction Poles

Example 3: Tram Stop with Traction Portals



TRACTION POLE TYPE EARTHING AND BONDING TREATMENTS		
TP PORTAL TYPE A:	TRACTION POLE **NOT** FITTED WITH SWITCH/FEEDER CABLING. OHW CANNOT DROP ONTO POLE. TWO POINTS OF EFFECTIVE INSULATION BETWEEN OHW AND POLE.	NO E&B SPECIFIC SPACING RESTRICTIONS BETWEEN TRACTION POLE PORTAL & OTHER CONDUCTIVE ELEMENTS.
TP PORTAL TYPE B:	TRACTION POLE FITTED WITH SWITCH/FEEDER CABLING.	**AVOID THIS SITUATION.** IF REQUIRED A DETAILED EARTHING STUDY WILL BE REQUIRED TO ACHIEVE COMPLIANCE WITH EN50122 PARTS 1, 2 AND 3.
TP PORTAL TYPE C:	TRACTION POLE FITTED WITH SWITCH/FEEDER CABLING AND TRAFFIC SIGNALS EQUIPMENT OR LV LIGHTING.	**AVOID THIS SITUATION.** IF REQUIRED A DETAILED EARTHING STUDY WILL BE REQUIRED TO ACHIEVE COMPLIANCE WITH EN50122 PARTS 1, 2 AND 3.

NOTE 1: SHELTER STRUCTURE EQUIPOTENTIALLY BONDED TO THE TRACTION PORTAL IN THREE LOCATIONS
NOTE 2: THE HAND RAIL IS REQUIRED TO BE NON-CONDUCTIVE AS INDICATED.
NOTE 3: THE DECORATIVE AND FUNCTIONAL LIGHTING MOUNTED ONTO THE TRACTION PORTALS SHALL BE FED VIA AN ISOLATION TRANSFORMER AND MAINTAINED ONLY WHEN THE TRACTION POWER SYSTEM IS DE-ENERGISED.

Figure 15.5.3 – Centre Paved Track Tram Stop with Traction Portals

15.5.1. Tram Stop Structures

Keep tram stop Structures outside of the OHW Zone. Equipotentially bond all conductive parts of structures within the Adjacent OHW Bond Zone. Where located beyond these zones equipotential bonding of the structures is not required.

If the tram stop's shelter is fitted with 240V AC supplied equipment (lighting, vending machines etc.), located outside the OHW zone and not equi-potentially connected to the OHW poles then equipotentially bond the structure but do not bond the structure or furniture (bins, handrails, signage etc.) to traction return. In this situation the SA Power Networks connected LV MEN cabling will supply the shelter mounted equipment. This cabling must be kept electrically isolated from any infrastructure in the rail corridor that is Traction Return bonded. This includes maintaining an electrical separation for the under-track crossing from the SA Power Networks supply switchboard to the platform.

It is preferred that the tram stop's shelter and structures are not conductively connected to the traction poles or OHW structure.

If the tram stop's shelter is fitted with LV MEN supplied equipment (lighting, vending machines etc.), outside the OHW zone but conductively connected to the OHW poles (for example the portal frame at the Entertainment Centre Tram Stop) then equipotentially bond the structure to traction return and supply the LV MEN equipment from the SA Power Networks source via an isolation transformer with the secondary bonded to Traction Return. Additionally, in this situation a safe work practice will need to be established to de-energise the Traction Power to work on the LV MEN equipment.

15.5.2. Tram Stop Fencing and Handrails

Keep conductive tram stop fencing and handrails outside of the OHW Zone. If possible, keep conductive fencing outside of the Adjacent OHW Bond Zone. Equipotentially bond all conductive parts of fencing within the Adjacent OHW Bond Zone to allow bonding to traction rail. Where located beyond these zones do not bond fencing or handrails.

On the platform conductive handrails can be installed at the edge of the platform within the Adjacent OHW Bonding Zone but outside of the OHW Zone. These must be bonded using a single asset bond as close to the base of the vertical handrail support as practical in a neat (cable and lug perpendicular and as flush as practical to the vertical rail) short (maximum 50mm exposed bond cable) discrete bond lug bolted to the handrail with good conductive contact made by removing any treatment or paint from the bonded area.

Where parts of the platform or connected access ramps/pathways are situated beneath the OHW zone any handrail sections within this zone must be non-conductive.

15.5.3. Tram Stop Platform

The reinforcement in the platform must not be equipotentially bonded or bonded to Traction Return. Where paths cross the tram corridor use asphaltic concrete without continuous reinforcement.

15.6. Road Interface with the ATN

There are several road traffic intersections on the ATN where the tram OHW Infrastructure passes through shared road vehicle and pedestrian areas.
At these intersections where the trolley wire drop zone passes above handrails or fences the section of these fences or handrails within the OHW Zone must be isolated from the adjacent parts using a non-conductive insulating panel section for the extent of the OHW Zone and the Adjacent OHW Bond Zone.

15.7. Adjacent Infrastructure

15.7.1. Asset Protection Bonding

Assets are defined as non-Tram infrastructure that is within the tram corridor OHW Zone or within the Adjacent Bonded OHW Zone.
Bond all assets including road signage that are within the OHW Zone.

15.7.2. Interfaces with AC Electrification

The ATN is adjacent the AC Electrification at the Morphett Street bridge where the OHW is supported via isolators from the underside of the bridge. The Morphett Street Substations 1 and 2 are located beneath the bridge in an elevated structure separated from the bridge columns by a distance of 2m and approximately 6m from the AMRN.

The ATN passes over the AMRN at the Goodwood Bridge and on Port Road. The bridge at Port Road has movement gaps.

15.7.3. Interfaces with Other Administrations' Railways

The ATN passes over the ARTC non-electrified rail at the Goodwood Bridge and on Port Road. The bridge at Port Road has movement gaps.

15.7.4. Corridor Fencing

Corridor fencing must only be treated if within the Adjacent OHW Bonding Zone. Corridor fencing must be non-conductive if within the OHW zone. Fencing within 3m of tram stops, 3m of substations or within 1m of Traction Poles must be fitted with 2m wide non-conductive fence sections. This fence treatment will only be required on the side of the corridor that the tram stop, substation or pole is located. For tram stops, these fence sections must be fitted just beyond each tram stop platform or tram stop access path extent to mitigate the risk of spread of stray current from the tram stop's bonding or bringing corridor fault current to the tram stop. For substations, these fence sections must be fitted 4m from each end of the substation. For poles, they must be fitted adjacent to each side of the pole.

Non-conductive insulating panels or fence sections must be provided every 100m for stray current mitigation.

15.8. Bond Types

Bonds must be made using steel or other material rather than copper to reduce the likelihood of conductor theft.

All bond cables must have a black outer sheath as an anti-theft measure so that they are less visible.

In publicly accessible parts of the corridor the cable must be an armoured type as an anti-theft measure.

15.8.1. Direct Bond

Where a metallic structure is in an area of paved track and is to be bonded to the tram rails using direct bonds. This provides electrical protection against an unacceptable touch potential on an OHW pole or metallic structure. The 'bond' cable is connected between the pole/structure and the rail. This arrangement is referred to as a 'direct bond' and is illustrated in Figure 15.8.1.

Since the OHW pole is effectively earthed as a result of its construction, the installation of a direct bond has the potential to create stray current electrolysis issues. However, since the rails are also effectively earthed (compared to a ballast track construction) any additional stray current electrolysis issues as a result of direct bonding are considered negligible.

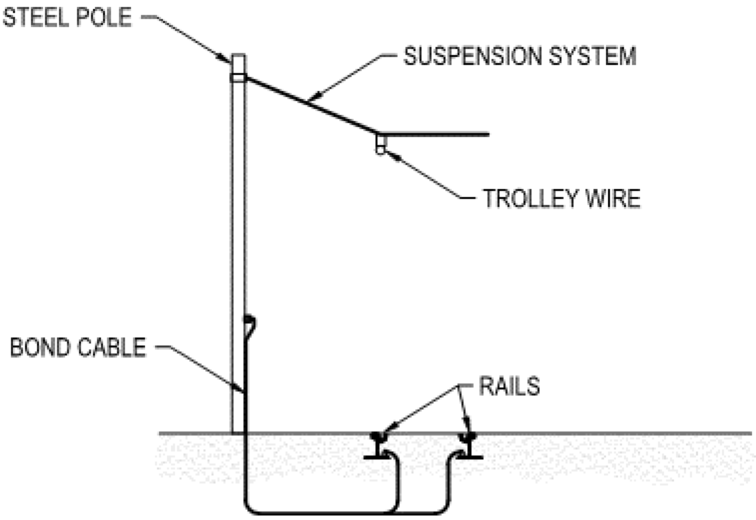


Figure 15.8.1 – Direct Bonding Arrangement

15.8.2. Paved Track Bonds

Where bond cables are installed in paved track, more than one connection to each rail must be made to provide redundancy in case of joint failure since the connections to rail cannot be inspected or tested.

All rail connections in concrete track construction must be bolted to the rail side wall with Cembre® connections.

15.8.3. Spider Connections, Long Bonds, Negative Feeders & Asset Bonds

Spider Connections Typical Installation Detail

In Paved areas the spider connection must be installed in the arrangement shown in Figure 15.8.3.1.

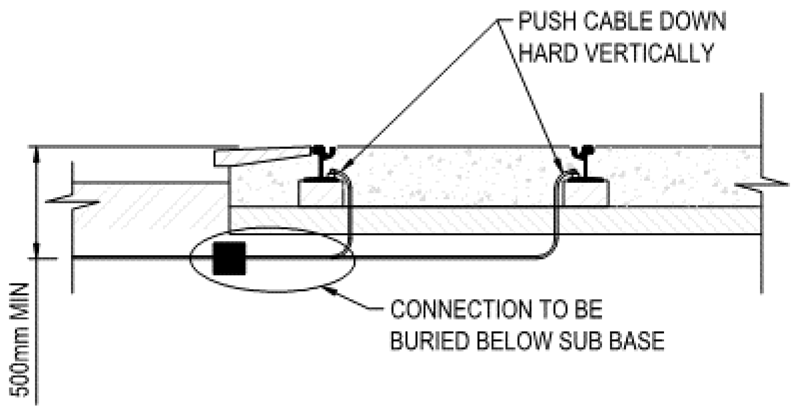


Figure 15.8.3.1 - Typical Spider Connection Section in Paved Track

Long Bonding

Long Bonding is required to bridge the tracks around special track areas.

A bare copper conductor of 400mm² must be used to form each long bond. Install the cables in orange HD PVC conduit between the connections and under the rail to the asset for mechanical and theft prevention. Conceal the cabling as far as practical. Bond to the asset using the lug and cable specified in Clause 13.14 – *Earthing & Bonding Conductors*.

Wrap the cable junction with electrical Denso® tape or approved equivalent. Conceal inside sealed conduit at least 500mm beneath the finished ground level. Sweep bend the conduit up to the asset. Cut and seal off the conduit at ground level and surface mount the bond to the asset.

Long bonding must not be placed in the region of Signalling Track Circuits.

Duplicate bonds are required in paved track. In this situation, the centre of two rail bonds is attached by the 'Wheeze' process at each end of the 400mm² conductor to form four legs at each end.

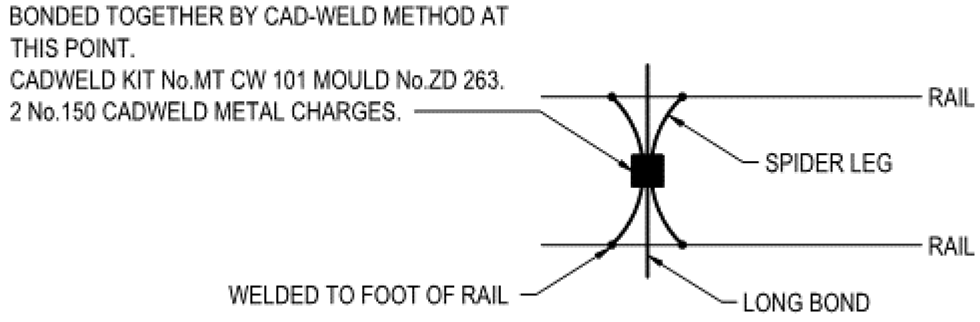


Figure 15.8.3.2 – Duplicate Long Bonds Installation Detail.

Negative Feeder Bonds

Provide multiples of the Negative feeder connections from each track with rail-to-rail connections as shown in Figure 15.8.3.3 with quantities as specified by the Traction Power Engineer specific to each network Substation.

Wrap the cable junction with electrical Denso® tape or approved equivalent and located at least 500mm beneath the finished ground level.

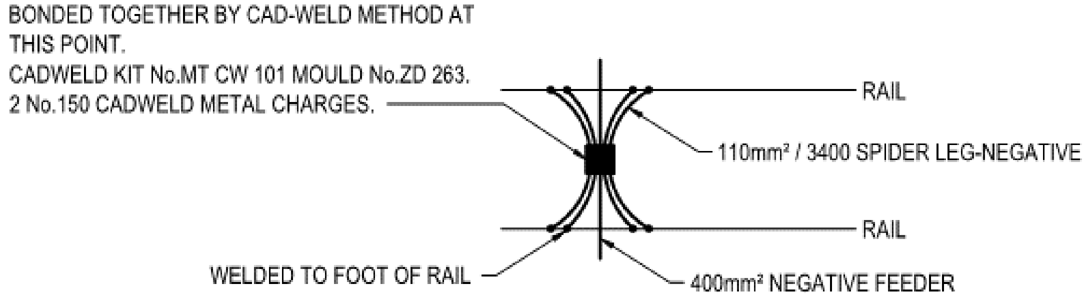


Figure 15.8.3.3 - Typical Negative Feeder Connection Detail

Asset Bonds

Install bonds to assets where specified as required by other parts of this standard (Tram Stop Shelter Structures, Fences, Handrails) to each rail of the track using the method shown in Figure 15.8.3.4 with Cembre connections to the track. Provide two bonds to each asset.

Install the cables in orange HD PVC conduit between the connections and under the rail to the asset for mechanical and theft prevention. Conceal the cabling as far as practical. Bond to the asset using the lug and cable specified in 13.14 – *Earthing & Bonding Conductors*.

Wrap the cable junction with electrical Denso® tape or approved equivalent. Conceal inside sealed conduit at least 500mm beneath the finished ground level. Sweep-bend the conduit up to the asset. Cut and seal off the conduit at ground level and surface mount the bond to the asset.

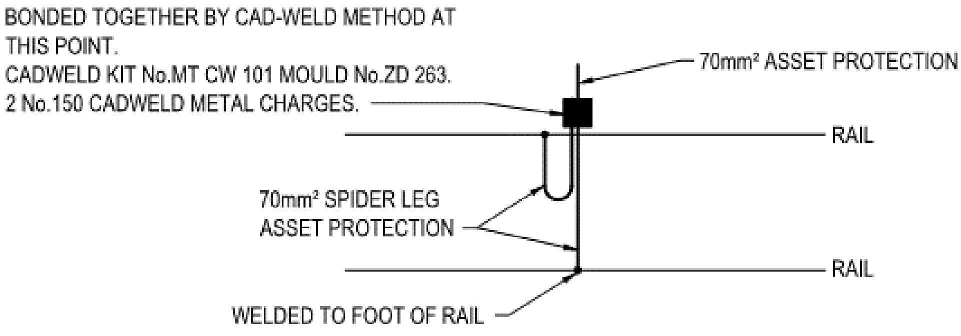


Figure 15.8.3.4 - Typical Asset Bond Detail

Pole Bonds

Install bonds to poles where specified as required by other parts of this standard (for example, Clause 15.1 – *OHW Pole Bonding*) to each rail of the track using the method shown in Figure 15.8.3.5 with Cembre® connections to the track. Provide two bonds to each pole, one from each track by creating a rail-to-rail bond on each track and bonding track to track adjacent the pole.

Install the cables in orange HD PVC conduit between the connections and under the rail to the pole for mechanical and theft prevention. Conceal the cabling as far as practical. Bond to the asset using the lug and cable specified in Clause 13.14 – *Earthing & Bonding Conductors*.

Sweep-bend the conduit up to the asset. Cut and seal off the conduit at ground level and surface mount the bond to the asset.

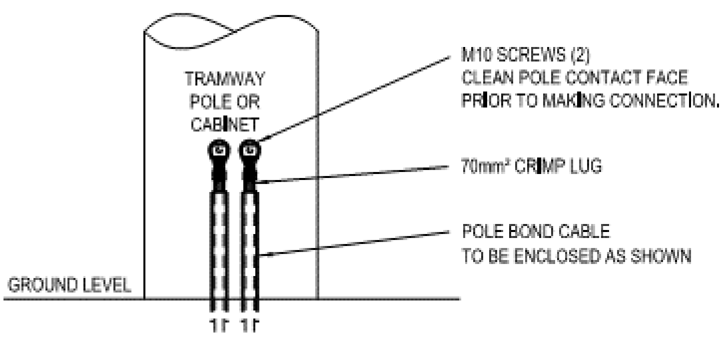


Figure 15.8.3.5 – Typical Paved Track Pole Bond Installation

15.8.4. Physical Protection of Bonds and Theft Prevention Techniques

Where bonds are liable to physical damage; for example, across roadways or platforms they must be adequately mechanically protected.

Where bonds are liable to be damaged or removed without authorisation, then theft prevention methods must be applied. This issue is especially prevalent on ballast track sections and on the overbridges.

Some theft prevention methods acceptable for use on the ATN are:

- To conceal the bond cable in conduit buried beneath the track;
- Use of tamper proof nuts on the rail and bonded item connection point;
- Metal cover plates over surface mounted bonds between the rails on the ballasted track — these must not be used where a spark gap device is fitted to a nearby OHW pole;
- Metal cover plates over the pole mounted bond;
- Keeping the bonds as short and discrete as possible;
- Steel armouring in the bond cable;
- Using asphalt to conceal the bonds (this has is used at pedestrian crossings to provide step potential protection.

Wherever possible, the traction bonds must be routed and arranged as shown on the appropriate design drawings included in the traction overhead wiring system design. The traction bonds must be buried inside sealed HD UPVC conduits below the surface run of the ballast, formation or ground level unless otherwise approved by the Technical Manager Electrification. Traction bonds must be supported where necessary to avoid damage or movement.

In areas with jointless track circuits, bonds which pass beneath a running or conductor rail must be encased in orange coloured plastic conduit such that inadvertent contact between the bond and the rail is prevented even if the bond insulation becomes damaged.

15.8.5. Buried Bonding Cables

The minimum depth of buried bonding or negative return cables is 500mm and the cables must have protective slabs and warning marking within 200mm of the cables. In public streets the cabling running between the tram corridor and the substation must be laid in the centre of a dedicated minimum 1m wide easement to a depth of 1m.

15.9. Rail Connections/Terminations, Termination Details/Geometry of Bonds Including Cable Sizes and Lug Bolt Size Details

All cables must be securely terminated to the rails.

Cables placed under the rails must be secured and run through an orange rigid HD PVC conduit so that they cannot move or be damaged by work on the rail.
Bonding must be arranged to minimise as far as practical the length of all bonds.
All bonds to rail in ballast track construction must be installed after tamping of track because tamping will damage any previously installed bonds. Each bond must be installed as per the detail below. All bonds, other than rail joint bonds, must be protected by a minimum of 300mm ballast.

15.9.1. Crimped Lug Termination

This termination type is used for attachment of bonds to poles and cabinets.

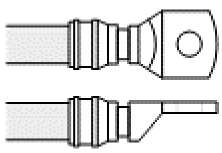


Figure 15.9.1 – Crimped Lug Termination

15.9.2. Cembre Rail Connection

All rail connections in paved track construction must be achieved using the 'Cembre® AR' series of connectors with the specific connector appropriate for the rail geometry installed as per Figure 15.9.2 below. Any holes drilled through the web of the rail must be a minimum of 150mm from any other hole or weld in the rail.

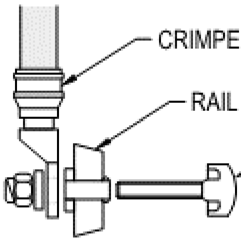


Figure 15.9.2 – Cembre Rail Connection

15.9.3. Drainage Bonds

Drainage bonds are used to protect third‑party assets by controlling the exit of stray DC current from them rather than the return of stray DC current into the traction return rails. The positioning of these bonds in the uninsulated embedded paved track will be subject to an electrolysis study of the location and conditions at the point in the corridor considered a risk to third party infrastructure.

Fast-switching Schottky diodes may be used to bond third party assets where stray current risk has been identified. This diode will be connected to rail to control current exit path back to rail with the aim of minimising damage to the third-party asset victim structure.

15.9.4. Spark Gap Devices

Spark gap devices (SG) must be DEHN SDS spark gap capsules configured for 60V let through mounted into a proprietary lockable electrical enclosure at 2.5m from the ground surface. They must be circuited via a 70mm^2 bond cable that joins the bare pole metal to the SG and another that joins the SG to the live OHW.

15.10. Pedestrian Crossings

Provide an asphaltic platform of a minimum 200mm depth and a minimum 2.5m wide at each pedestrian crossing of the tram corridor.

15.11. Special Track Areas

Bonding for Level Crossings, Junctions, Crossovers and Turnout are special track areas which have a high level of interaction with the Signalling installation due to the use of the bonding cabling for signalling functionality. Any bonding design for these areas cannot be finalised without specific review and confirmation of compatibility with the Signalling System by SAPTA's Signalling Technical Lead.

The bonding requirements for Crossovers are provided in general terms for guidance without specific reference to the signalling and IRJ equipment position which interacts with and impacts on the specific design positions of bonding.

15.12. Level Crossings

The bond to rail must avoid the rail used for level crossing approach track circuits (where appropriate).

15.13. Crossovers

All connections must be past any manganese rail sections. All cables must be installed in HD PVC rigid conduit in the substrate beneath the rail sub-base. Each long bond must be a continuous cable or may be joined with approval using exothermic welding. Figure 15.13 provides a diagrammatic bonding layout without the Track Circuit continuity bonds required for the ATN.

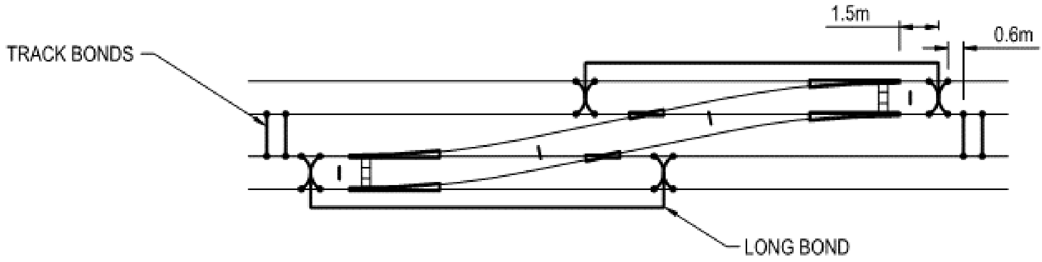


Figure 15.13 – Typical Bonding at Crossovers

15.14. Turnouts

All connections must be past any manganese rail sections. All cables must be installed in HD PVC rigid conduit in the substrate beneath the rail sub-base. Each long bond must be a continuous cable or may be joined with approval using exothermic welding.

Figure 15.14 provides a diagrammatic bonding layout without the Track Circuit continuity bonds required for the ATN.

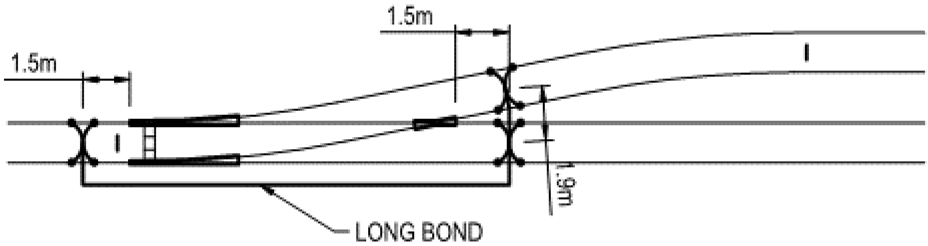


Figure 15.14 – Typical Bonding at Turnouts

16. Surface Mounted Track on Concrete Surface (Bridges) Design Criteria

As this track type only occurs on bridges, refer to the Bridge Section of this guideline for details of bonding in this situation.

17. Future Direct Buried Insulated ('Booted') Paved Track Design Criteria

This section is to be completed in a future edition of this standard and has been included here as a placeholder.

18. Maintenance and Testing

18.1. Bonding Diodes

Each diode condition is to be included in maintenance inspections. Periodic inspection and testing must be undertaken to confirm operation. Specific inspection and test is to be undertaken if a system power fault or a lightning strike is suspected.

18.2. Spark Gap Devices

Each spark gap module condition is to be included in maintenance inspections. Periodic inspection and testing must be undertaken to confirm operation. Specific inspection and test to be undertaken if a system power fault or a lightning strike is suspected.

18.3. Overvoltage Protection Device

The operation of the OVPD at each DC substation is to be tested as part of a regular maintenance program.

18.4. Ballasted Track Surface

The track ballast must be kept clean of debris; for example, leaves, dirt etc. that may breakdown the insulating properties of the ballast for earthing purposes.

APPENDIX 1 – DEFINITIONS

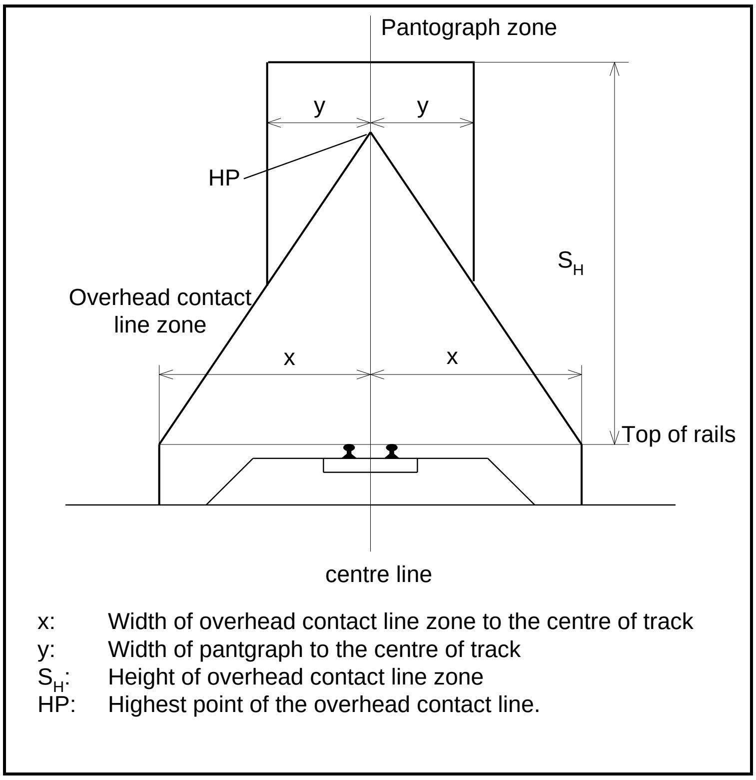
<table>
<tr><th>TERM</th><th>DEFINITION</th></tr>
<tr><td>OHW zone</td><td>
The Overhead Wiring Zone for the Tram Network is the zone within which structures and track side equipment could accidentally become live due to contact with broken Overhead Wire.
Figure A1.1 defines the zone inside which such contact is considered to be probable. It is also frequently referred to as the “Drop Zone”.


Figure A1.1 – Overhead Wiring Zone Definition
The point HP is the position of the highest conductor of the overhead contact line under all operational conditions considered in the centre of the track. The limits of the overhead contact line zone below the top of the rail are extended vertically downwards until the surface is reached. These limits, however, need not be extended beyond the upper surface of any barrier (deck, platform or wall).
Special exemptions to defined dimensions x, y, S_H, and HP may be made, on a site-specific basis, by SAPTA’s Electrical Technical Lead.
The parameters x and y are x = 4.0m (extended to 5.0m for track with curves less than 1000m) and y = 2.0m. The total height S_H is defined to be 8.0m above top of the rails.
It may be investigated if dimension X = 5m for curves with radius less than 1000m can be reduced (but not less than 4m), on a site-specific basis, with approval of SAPTA’s Electrical Technical Lead.
</td></tr>
<tr><td>Two Effective Layers of Insulation</td><td>This means the provision of two separate layers of insulation, each suitable to withstand the maximum 600V DC possible on the ATN. Each layer of insulation must be compliant with EN 50122-1, must be proprietary equipment and type approved.</td></tr>
<tr><td>Note:</td><td>For all other applicable definitions please refer to EN50122-1:2022</td></tr>
</table>