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Railway Overhead Wiring Structures in Australia: Review and Structural Assessment

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Abstract: Overhead wiring structures (OWS) provide physical support to overhead electrical wires that power trains. They are typically spaced at 50 to 70 m. In a rail network, tens of thousands of these structures are required. Although they are simple structures, due to their numbers; design, construction and maintenance often involve large capital investments. Their reliability is also crucial to a safe operating rail network. This paper presents a review of OWS in Australia. Electrification of train services began in the 1910s, making some of the OWS over 100 years old. Descriptions in this article include their structural forms, design, construction, assessment and maintenance. It follows with a structural assessment carried out on a century-old riveted OWS built in the 1910s. This OWS was decommissioned in a recent railway renewal project which allowed the assessments to carry out. The assessment provides insights into hundreds of similar aged OWS still being used today. Assessments carried out consisted of tensile tests, corrosion depth measurements, radiographic imaging, scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDX). Crevice corrosion is common in locations where moisture accumulated. Material properties were similar to modern-day Grade 250 steel with satisfactory ductility. Corrosion depths were less than those predicted. Samples of riveted connection showed no sign of deterioration within connected plates. This study may provide insights into structural design, construction and maintenance of similar structures in Australia and abroad.

Keywords: overhead wiring structures; historical steel structures; structural assessment

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1. Introduction

Overhead wiring structures (OWS) play a vital role in the operation of electrified rail networks. They support overhead electrical wires that provide the necessary power to the operation of trains. Typical spacing between OWS in a straight track is between 50 to 70 m. In sharper turns, their spacing may reduce to 30 m [1]. Trains draw electric power through their pantographs, which require leveled power wires. To achieve this, the wire which supplies electricity, called the contact wire, are suspended from sagged catenary wires using droppers. Their relationship is illustrated in Figure 1. The wires are tensioned to a specific value, e.g., at 20 kN. Weight stacks and pulleys are commonly used to provide a constant tension regardless of temperature, as shown in Figure 2. In some instances, modern overhead line tensioners with self-regulated compensation mechanisms are used.

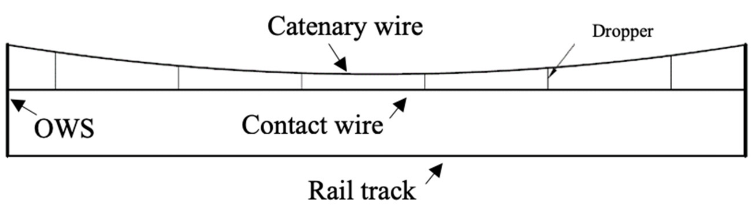


Figure 1. Schematic diagram of rail overhead wiring.

Figure 2. Weight stack and pulley system.

Today, there are approximately 13,000 OWS in the Melbourne metropolitan network. Their age varied from a century old to newly built constructions. OWS are typically constructed in several structural forms: single masts, inverted-L cantilevers and portals. The choice of structural types depends on the geometric configuration of the tracks, local soil conditions and line of sight for OWS that carries light signals. They are typically lightweight simple steel structures that are exposed to the environment. Deterioration due to corrosion, wind and train-induced vibrations and thermal effects constantly affect these structures. Inspection and maintenance are expensive when thousands of kilometers of these transmission lines are in operation. OWS lack structural redundancies and failure in a single location may cause large deflection or even complete collapse. When a single overhead structure fails, operation of trains will be suspended and causes economic loss to the rail company and commuters. Two major incidents which happened in February and March 2012 in the Queensland south-east rail network were caused by failures in the OWS [2]. The incidents caused interruption to tens of thousands of commuters and cost over $2 million for the "fare free day". Later investigations revealed that the incidents were due to incorrect installation of a wedge clamp (i.e., human error) and failure to identify vegetation in contact with overhead wires.

This article begins with a review of related works on OWS. Then the article reviews the structural aspects of OWS in Australia, both historical and modern designs are included. An assessment of a century old OWS in the metropolitan Melbourne rail network is then described. Samples are studied via tensile tests, ultrasonic thickness measurements, radiographic imaging, scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDX) analysis.

2. Related Works on OWS

2.1. Inspection of Contact Wires

Geometric deviation and wear of overhead contact wire jeopardize reliability of the power supply to trains and thus require frequent inspection. In Australia, the geometric standards and tolerance of OWS and contact wires are specified in local standards [3]. Inspections are often carried out by specialist contractors who are equipped with state-of-the-art inspection equipment. Reference [4] discussed automated wear inspection of overhead contact line by laser technology developed in Japan. Inspection systems are fitted on inspection cars and operated at the speed of Shinkansen (270 km/h). Reference [5] described several optical instruments that are used to inspect overhead contact wires in Europe. More recently, LiDAR [6,7], radar [8], ultrasonic ranging [9], linear array cameras [10] and computer vision [11,12] have been studied for such inspections. References [13,14] described installation of accelerometers on OWS wires and monitored their vibrations using vibration-based diagnostics. Reference [15] discussed the application of fiber optics on pantograph to detect static and dynamic strain in high-speed railways. Reference [16] describes fatigue failures of contact wires.

2.2. Pantograph-Catenary Dynamics

The electrical contact of pantograph system of trains and contact wire has been a classical engineering problem–contact resistance, thermal effects, wear, effects of arc on pantographs and onboard electrical systems have been widely studied [17–23]. As high-speed trains are becoming more popular in some countries, the pantograph-catenary dynamics become a more significant problem–it is more difficult to establish a permanent contact between pantograph and contact wire without increasing wear and noise. Many numerical models have been developed to capture realistic characteristics [24]. Reference [25] presented a benchmark problem such that different numerical methodologies can be compared. Reference [26] studied the effects of contact wire irregularities and [27] provided a review of recent advances in this topic.

2.3. Wind and Earthquake Effects on OWS

Crosswind causes deflection onto the overhead wires and such deflection needs to be estimated. Traditionally empirical methods are used and formulas are presented in [23]. The empirical method provides equivalent static forces for the design of OWS. However, dynamic effects on the overhead lines caused by fluctuating winds cannot be fully described. Recent studies on dynamic effects include galloping [28,29], vortex shedding [30] and buffeting [31]. Reference [32] used a response spectrum method to assess dynamic deflections in overhead contact lines, while reference [33] uses computational fluid dynamics method. Reference [34] compares empirical methods and FE approach and concluded that empirical methods give similar results when turbulence intensity is less than 10%.

A group of researchers in Birmingham Centre for Railway Research and Education have conducted a series of research on wind and earthquake effects on OWS. Reference [35] studied wind effects on single masts OWS due to hurricanes and reference [36] studied dynamic properties of OWS with consideration of soil-structure interaction. In reference [37], they studied the far-field earthquake response of OWS and observed a beating phenomenon—A period coupling effect between translational and torsional mode of vibration.

2.4. Maintenace of OWS

Like other rail infrastructures and equipment, mechanical and electrical wear causes the hardware to degrade and a robust maintenance regime is required to safeguard the reliability of the rail network. While most train operators adopted planned and scheduled inspection and maintenance works, predictive maintenance has gained momentum in academia. References [38,39] discussed scheduling of maintenance activities based on anticipated risks, Reference [40] presented mathematical formulations to schedule maintenance according to resource constraints. In attempts to achieve more cost-effective maintenance, recent advances in predictive maintenance include the use of Bayesian Network [41], Markov Decision [42], reliability analysis [43], heuristic algorithm [44], big data [45,46] and machine learning [47].

3. OWS in Australia

In Melbourne, Victoria, electrification of the railways began in the 1910s using English 1.5 kV DC technology. Electric train service began in 1919. Electrification of train service in Sydney, New South Wales began in 1926 using the same system. In other major Australian cities such as Brisbane and Perth, an international standard of 25 kV AC electrification systems is used.

Currently in the metropolitan area of Melbourne, there are approximately 13,000 overhead structures. Predominantly there are three structural types: (1) Single masts (10%), (2) Cantilever (46%) and (3) Portal structures (30%). The remaining types consist of other structural forms such as anchored structures and walkway structures where access is required for signaling systems or feeder cables.

3.1. Common Structural Forms of OWS in Australia

The structural forms of OWS have evolved over a hundred years. Original OWS when electrification began typically involved rivetted steel sections. Examples include the riveted truss supported in battened columns described in Section 3 of this article. Hot riveting involved the insertion of rivets through pre-drilled holes. Historically it was a common practice to join steel sections permanently, but it is now replaced by welding and structural bolting. However, many riveted OWS remain in use today. Modern OWS are designed, fabricated and constructed according to limit state design philosophy, with consideration of track geometries, design loads, durability and facilitate rapid installation on site. Even within the same train lines, the structural details of OWS vary significantly, as the design changes over time and are often carried out by different structural specialists. Typical structural forms are described below.

3.1.1. Single Mast OWS

Single mast OWS are usually constructed from steel H-sections (called universal columns in Australia) with a fixed base. An example is shown in Figure 3. The base fixity is provided either by a base plate and holding down bolts embedded in a reinforced concrete footing, or a long length of steel section potted in an augured hole with reinforced concrete surround. The catenary wire is supported by a cantilever jib via a suspension insulator. The jib is commonly clamped onto the H-section instead of permanent welding or bolting to facilitate adjustment of its elevation. Single mast OWS are typically used for a single-track arrangement. Common durability issues of single masts include corrosion, loss of grout/crack at base plate, and deviation from plumb.

Figure 3. Single mast OWS.

3.1.2. Cantilever OWS

Historical cantilever OWS are riveted laced truss with a braced knee to enhance their bending strengths, as shown in Figure 4a. In these riveted structures open sections such as angles, channels and flat plates are often used. The crevices between joined members accumulate moisture and are frequently susceptible to corrosion. Modern cantilever OWS (Figure 4b,c) are typically made up of rectangular hollow sections. They are comprised of a vertical cantilever column and a horizontal beam with a vertical drop at its end. An end-plate connection between beam and column is commonly adopted to facilitate in-situ installation. The vertical drop is clamped onto the beam to allow in-situ adjustment of its position. Two dressing arms (one for the contact wire and one for the catenary wire) extend across one or two tracks in order to provide support to the overhead wirings over two tracks. Durability issues in addition to those in single masts include crevice corrosion between connecting plates (especially in riveted OWS), deflections on cantilever arms, etc.

(**a**) (**b**) (**c**)

Figure 4. (**a**) historical riveted cantilever OWS, (**b**) a newly built cantilever OWS and (**c**) its foundation.

3.1.3. Portal OWS

Portal OWS are simple portal frames which are often used to support overhead wirings in twin-track arrangements. Structural I-sections are typically selected as frame members. Wirings are supported by clamped vertical drops. Therefore, portal OWS provide better geometrical flexibility such as in curved tracks, track junctions, and at train stations. Sometimes "knees" at beam-to-column connections are provided to enhance structural strength. Out-of-plane stability is provided by fixity at their bases, similar to those in cantilever OWS. Figure 5a shows a portal OWS is used in conjunction with cantilever OWS in a newly built rail line. Corrosion in locations where moisture accumulates, such as bottom flanges of I-sections and at base connection (Figure 5b).

(**a**) (**b**)

Figure 5. (**a**) Newly built cantilever and portal OWS; (**b**) Base plate of an old portal OWS.

3.1.4. Walkway OWS

Walkway OWS are larger structures that provide easy access to signal hardware and/or feeder wirings, as maintenance may be frequent. Walkway OWS could be portal structures, cantilever structures but more commonly a truss type portal as shown in Figure 6. Handrails and access ladder are installed to provide a safe work environment.

Figure 6. A signal gantry.

3.2. Design and Construction of OWS

In Australia, the modern design of OWS involves the loading specifications in AS1170 [48], design of steel structures AS4100 [49], design of concrete structures AS3600 [50], design of platforms and walkway AS1657 [51], design of piled foundation AS2159 [52] and hot-dip galvanized coatings in AS/NZS4680 [53]. In addition to these national standards, each state has its own governing body in rail and state-specific guidelines or manuals are followed. Generally, design loads on OWS include seven load cases and seven load combinations, as listed in Tables 1 and 2. Load combinations LC1 to LC5 are strength limit states, LC6 and 7 are serviceability limit states and LC8 is a stability limit state [54]. In a serviceability limit state, in-plane and out-of-plane deflection limits are imposed but the magnitudes may differ slightly across different jurisdictions. The stability limit state considers overturning of structure using a factor if 1.2 for forces causing overturn effect and 0.9 for forces causing stabilizing effect.

Table 1. Load cases of OWS design.

Load Case	Comments
Dead loads	Self-weight of structure, electrical fittings and insulators, static weight of wires, stack weights, etc.
Live loads	OWS are non-trafficable and thus not subjected to any live loads. However, an allowance for construction load which represent the weight of a person on the contact wire is required.
Radial loads	Radial loads are produced by geometrical and tension effects caused by wiring. i.e., when wiring changes directions. At termination points, OWS is anchored, and the reaction forces produced by guy-wire is also considered.
Wind loads on wire	Overhead wiring may span up to 70 m and wind forces accumulated on the wiring are transferred to the OWS. Wind forces based on 100-year return period is required for new OWS designs.
Wind loads on structure (x-direction)	OWS are exposed structures and thus need to be designed against wind actions. Values of wind force depend on local topography, importance level and design return-period. Modern OWS are commonly designed with a 100-year design life.
Wind loads on structure (y-direction)	
Wind loads on structure (45°)	

Table 2. Load combinations of OWS design.

Load Combinations	Comments
LC1	1.35 × (Dead load + radial load)
LC2	1.2 × (Dead load + radial load) + 1.5 × Live load
LC3	1.2 × (Dead load + radial load) + Wind load on wire and structure (x-direction)
LC4	1.2 × (Dead load + radial load) + 0.5 × Wind load on wire + Wind load on structure (45°)
LC5	1.2 × (Dead load + radial load) + Wind load on structure (y-direction)
LC6	Dead load + radial load
LC7	0.65 (wind load on wire + wind load on structure x-direction)
LC8	Out of plane restoring moment/overturning moment > 1.2

Construction of OWS is carried out by specialist contractors who are experienced in steel work fabrications and installations. Segments of OWS are fabricated off-site in shop environment and delivered to site for installation. Construction is facilitated by specialized trucks which have modified wheels to travel on tracks and are equipped with elevated platforms and cranes. Structural joints are fabricated to facilitate rapid bolting. In-situ bolting is preferred over welding for better construction efficiency and workmanship control. Structural members are galvanized in order to provide good durability under exposed condition. In case of replacement of old OWS, temporary suspension of train services is required. It is common to install new OWS in close proximity to a decommissioned one to facilitate relocation of existing wiring, as shown in Figure 7.

Figure 7. Construction of a new OWS next to a decommissioned one.

3.3. Inspections and Assessments of Existing OWS

OWS are exposed structures and environmental effects accelerate their deterioration over time. A reliable train network requires proper inspections and assessment of these structures. The AS4292 Railway safety management [55] provides the overarching requirements and Part 2 of the standard [56] covers requirements on civil infrastructures. However, a standardized method of inspections or assessment criteria is unavailable, and the procedures are commonly an “in-house” practice, i.e., train companies have their own internal procedures to safeguard reliability of their assets. Detail procedures of inspection and assessment differ from company to company, but they can be divided into planned maintenance which is carried out on a regular time interval, and condition-based maintenance which is carried out only when necessary. Regardless of jurisdictions, maintenance work often follows similar considerations:

1. A historical archive is maintained, and information includes structural drawings, design loads, year of construction, failure histories, previous inspection reports and maintenance records, etc.
2. A planned inspection schedule, e.g., every two years.
3. Several “levels of inspections” are prescribed. An example is shown in Table 3. A low-level inspection involves visual inspections without disruption to train service. Inspectors typically look for signs of deterioration such as corrosion, plumb deviation or deflection, loosening of bolts, cracks, erosion of soil around foundation, conditions of electrical fittings, nearby vegetations, etc. A score will be assigned to different components and recorded. If remedies are deemed required, the defects are further categorized into different priorities for scheduled maintenance. A significant defect will flag an urgent repair which may require suspension of train service. A poor result from a low-level inspection will trigger a high level of inspection.
4. A higher level of inspection requires engineering assessments by experienced engineers. The use of destructive or non-destructive testing to gather quantitative data

is required. Assessment may include estimation of thickness loss due to corrosion, measurement of paint thickness, etc.

5. Once determined necessary, remedial works on existing OWS are determined by engineers. Remedial works such as application of surface coatings, replacements of foundations, partial replacement of structural members, or complete replacement of OWS structure.

Table 3. Inspection levels.

Inspection Level	Purpose
General observation	To identify safety hazards
Level 1 Visual inspection	To confirm if the structure is safe for operational purposes
Level 2 Detailed visual inspection	To identify and prioritise maintenance needs
Level 3 Engineering assessment	To provide a comprehensive load-carrying capacity rating
Special inspection	To monitor specific defects/Reassess defects

Figure 8a shows an example of retrofitting of an OWS by replacement of foundation. Extensive spalling of concrete was observed in the original foundation and new reinforced concrete is cast around an existing laced column of a signal gantry. Figure 8b shows partial replacement of corroded steel members in a signal gantry with new galvanized sections. The heavily corroded portion is patched up with a steel plate.

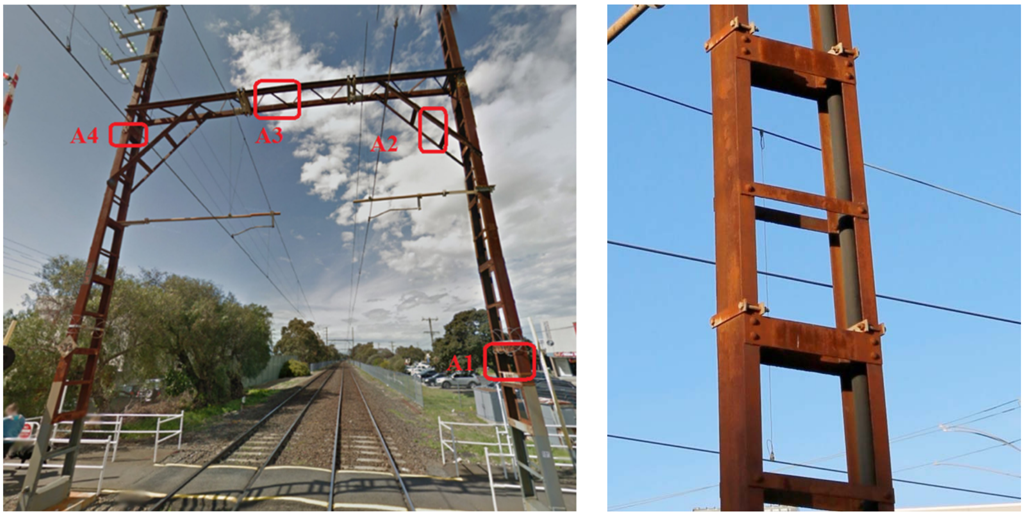
Although steel OWS are simple structures and their assessments are less complex than the assessment of steel bridges, due to the amount in a rail network a more scientific approach to assessment may deem more cost-effective. The authors have proposed a time-dependent structural reliability approach to assess OWS. Readers who are interested in this approach may refer to [57].

(**a**) (**b**)

Figure 8. Retrofits of an existing OWS. (**a**) New concrete foundation, (**b**) Partial replacement of steel truss members.

4. Structural Assessment of a Century-Old OWS

The OWS described in this section is a twin-track riveted portal structure that belonged to a railway line approximately 250 m away from the seashore. Figure 9a shows the OWS prior to its demolition. A 9.14 m (30′) long laced steel beam was elevated at 8.7 m (28′8″) above ground by two battened columns and carried centenary wires for two tracks. It also carried electricity transmission lines for power distribution. The OWS appeared to be unpainted except the bottom 2 m near the foundation. The age of the structure precedes the invention of weathering steel in the 1930s, however. The annotation represents the sampling locations, and Figure 9b shows the construction of battened column. Vertical members of the battened columns were equal flange channels connected by horizontal steel plates. The structure was connected with rivets. The original structure was built in the 1910s during the electrification of the railway, making it approximately a century old at the time of this writing. The manufacturer was uncertain but given its age the steel members were probably imported from Britain. The material specifications and maintenance records could not be identified. The structure was decommissioned in an upgrade project in which most of the OWS in the same train line were replaced. The bottom 2 m segments of the battened columns were covered by paint. Figure 10 shows the original drawing dated in the 1910s.



(**a**) (**b**)

Figure 9. (**a**) Assessed OWS prior to demolition, (**b**) battened column.

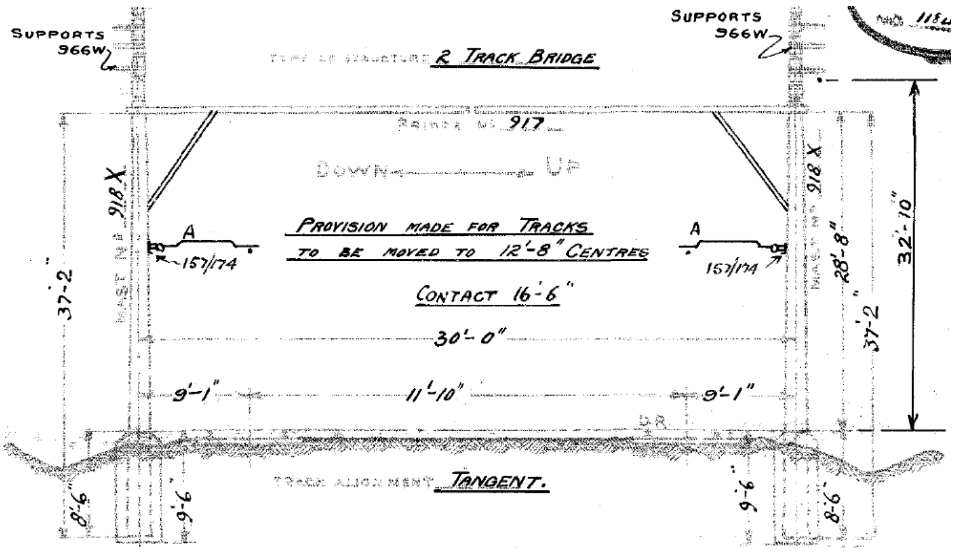


Figure 10. Original drawing in the 1910s.

4.1. Visual Inspections

The decommissioned OWS were cut into segments and stockpiled in a scrap metal yard, which allowed the authors to carry out a close examination. An identification number on the structure allowed the authors to identify this structure to its original drawing. The bottom 2 m of the battened column were painted, and this portion was in good condition as indicated in Figure 11a. Immediately above the paint, however, significant deterioration on batten plates is observed. The severity varied significantly: one particular batten plate was corroded through, while the next plate at the same elevation appeared intact, as shown in Figure 11b. The rivets observed were intact and tight. Crevice corrosion frequently occurred at junctions between riveted parts where moisture accumulated. Samples of the structures were taken to further laboratory testing.

(**a**) (**b**)

Figure 11. Demolished battened column. (**a**) bottom section, (**b**) Mid-section.

4.2. Tensile Tests

Test coupons were taken from a battened column, and bridge and knee brace of the examined structure, as indicated in Figure 9a. Dimensions according to AS1391 [58] were followed. The true stress versus strain diagram is shown in Figure 12 and Table 4 summarized the results. Yield stresses of specimens were very close to modern-day Grade 250, with ultimate stress in excess of 540 MPa (current standard requirement is 410 MPa) [59]. All samples exhibited good ductility.

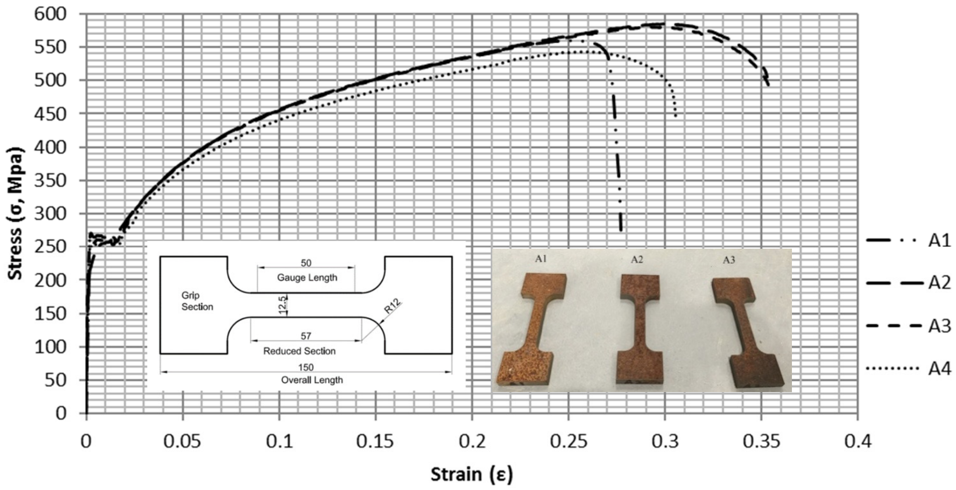


Figure 12. True stress-strain behavior from tensile tests.

Table 4. Experimental result of the tensile tests.

Sample	A1	A2	A3	A4	Mean
Yield stress [MPa]	271.1	258.72	264.81	260.37	263.75
Ultimate stress [MPa]	559.93	584.38	580.28	543.42	567.00
Max strain	0.277	0.353	0.355	0.306	0.323

Corrosion depths were estimated by comparing original thickness and measured thickness of samples collected when rust was removed (there was no paint on the samples). An ultrasonic thickness gauge was used for this purpose. To obtain meaningful measurements, surface rust must be removed [60] and it was carried out manually and the specimens were cleaned and degreased. Care was taken to ensure only the rust was removed. Figure 13 shows the sample before and after rust removal. Twelve measurements were made on each sample and corrosion depths were estimated by comparing to historical nominal values. Results are summarized in Table 5. Percentage loss showed a great variation. The largest material loss was found in steel angles sourced from the knee brace, apparently attributed to moisture accumulation. It was impossible to calibrate any corrosion model with measurement at a single point in time, and a general rate of corrosion is inconclusive given the variability in observed results. However, corrosion depths were less than those predicted by AS4312, for which it predicted 2.5–8.0 mm at category C3/C4 medium to high corrosivity [61].

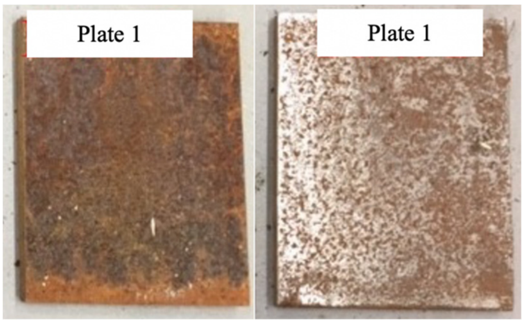


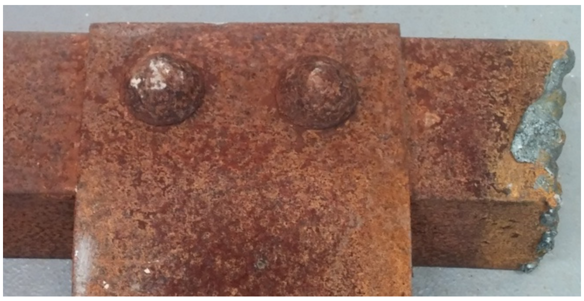
Figure 13. Sample before and after rust removal.

Table 5. Corrosion depth measurements.

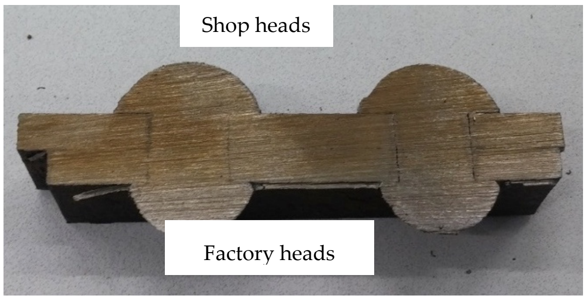
Sample	Original Thickness [mm]	Measured Thickness [mm]	Corrosion Depth [mm]	% Loss
A1	10.92	9.41	1.51	13.8
A2	10.92	9.53	1.39	12.7
P1	7.94	7.79	0.15	1.9
P2	7.94	7.51	0.43	5.4
C1	9.14	8.43	0.71	7.8

4.3. Riveted Joints

A rivet joint from a knee brace was cut through for examination, as shown in Figure 14a. The surface of the rivets was heavily rusted, but the connection was tight. The connection was cut through, exposing its cross-section as shown in Figure 14b. The 1/8″ (3.175 mm) hole clearance had been completely closed by forging. The rivets clamped two connecting plates tightly and corrosion was not evident. The shop heads could be readily identified by its imperfect shape, and they were larger than the factory heads. Radiographic images were taken, and a sample image is shown in Figure 14c. No internal crack was identified in any sample collected. It indicates that the rivets performed satisfactorily and eliminated air and moisture even after 100 years of usage.



(**a**)



(**b**)

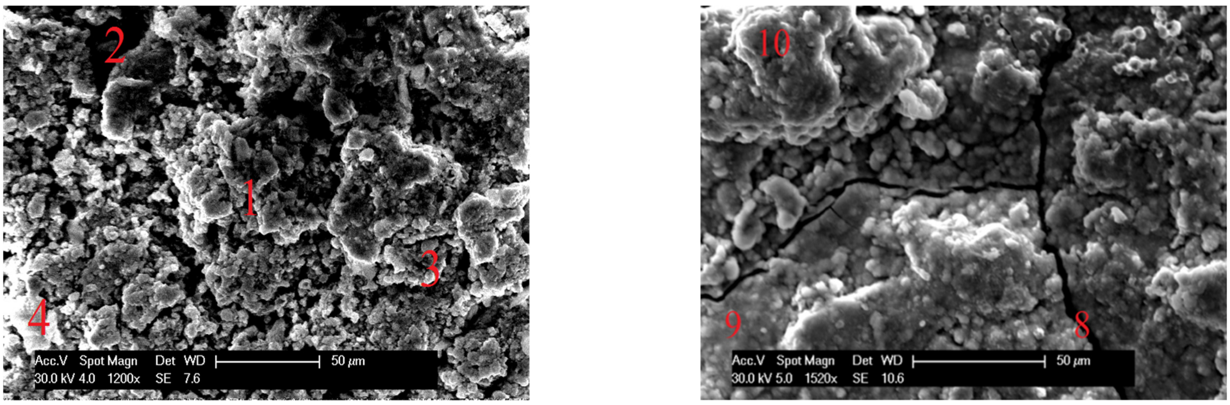
Figure 14. *Cont.*

(**c**)

Figure 14. Riveted joint (**a**) sample as collected, (**b**) cut-through section and (**c**) radiographic image.

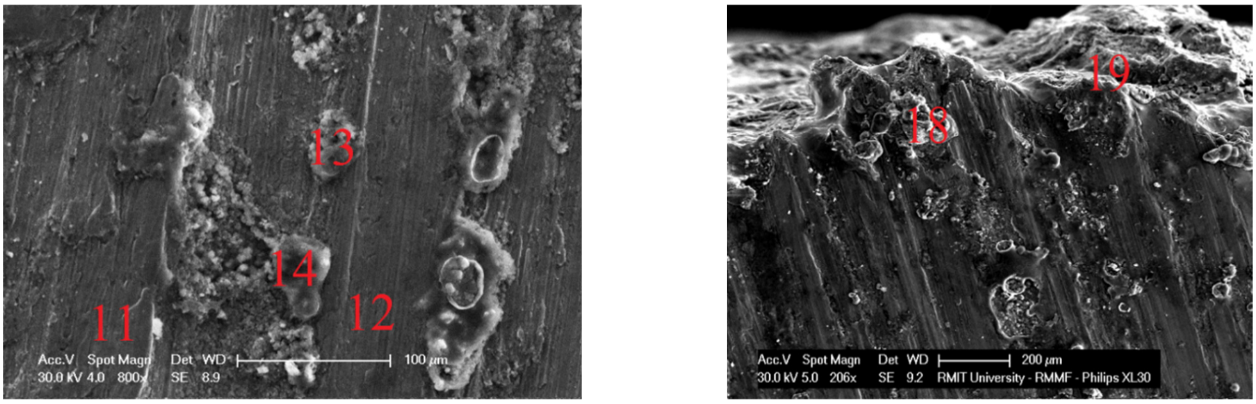
4.4. Scanning Electronic Microscopy and Energy Dispersive X-ray

Scanning Electronic Microscopy (SEM) was carried out on steel specimens taken from the battened column using a Philips XL30 SEM. The microscope had a specimen stage of 50 mm × 50 mm, which was limited by the size of its vacuum chamber. The microscope is also equipped with an energy dispersive X-ray (EDX) detector. The samples were cut into approximately 20 mm × 20 mm. Figure 15a,b show typical images taken on the rust surface. The numbers indicate on the image were the sites where EDX was carried out. Rust products of rough and loose structure were visible. Results of EDX taken on rust surface revealed that, in addition to iron and oxygen, traces of lead and arsenic were found. It indicated that certain kinds of lead-based and arsenic-based corrosion inhibitors were applied. Figure 15c,d show images taken on a cut surface. In Figure 15c, deposits of corrosion products have grown, and straight grain boundaries are visible. Figure 15d shows an image taken on the edge of the cross-section. EDX results measured on the cross-section surface revealed impurities including silicon (max. 0.3%), manganese (max 0.5%) and silicon (max. 0.3%) were detected. However, their concentrations were low and within requirements of Grade 250 at modern-day standard (AS3678 [59]). However, the concentration of sulphur (max. 0.5%) exceeded the limits in two measurement locations.



(**a**) (**b**)

Figure 15. *Cont.*



(c) (d)

Figure 15. SEM images. (**a**) and (**b**) surface and (**c**) and (**d**) cross section.

5. Conclusions

Rail overhead wiring structures (OWS) are an essential part of an electric rail network. They provide support to overhead power wires to power train services. Although they are simple steel structures, a rail network may consist of tens of thousands of these OWS and they represent a large capital expenditure. This article presents a review of structural aspects of OWS in Australia, which has evolved over the 100-year period since electrification began. Discussion includes their typical structural forms, design, construction, assessment and maintenance. This article then describes an assessment carried out on a century-old, riveted OWS. The structure was located approximately 250 m from the seashore and severe corrosion occurred in the structure. The structure was decommissioned in a railway upgrade project which allowed detailed assessments to be carried out. Due to its age, the original material grade and record of maintenance was unknown. Tensile tests on samples indicated yield strengths were very close to modern-day Grade 250 steel, and ultimate stress exceeded 540 MPa. All samples showed good ductility. Depending on the location of samples were taken from, corrosion depths showed great variations and conclusive value of corrosion rate cannot be made. The measurement of corrosion depth ranged from 0.15 mm (1.9% depth) to completely rust-through. Rivet joint samples were examined and revealed that they remained structurally robust and tightly clamp connecting parts together after 100 years of service. Corrosion inside the joints was not identified and internal cracks were not detected via radiographic imaging. SEM and EDX analyses were conducted, and results indicated that lead and arsenic-based corrosion inhibitors had been applied on the metal surface, and impurities in the material were low and generally met modern-day standards. The study gives an insight into the steel material and construction during the era of electrification of rail a century began. Other than severe corrosion in certain locations, the assessed OWS remained structurally sound. It gives confidence to the community as many similar overhead wiring structures are still being used today.

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