Live line OPGW refurbishment in an urban environment

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ABSTRACT

SP AusNet, an energy company that operates the high-voltage energy network in Victoria, Australia plans to reinforce their communication link between the Malvern and Richmond Terminal Stations in Melbourne, Australia by refurbishing the existing communications routes that connect the two termination stations with a new overhead Optical Fibre Ground Wire (OPGW). The OPGW will be installed as a refurbishment for one of the two existing ground wires on the existing quad circuit 220 kV and 66 kV transmission line that connects between the two terminal stations – approximately 10 km apart.

Working closely with SP AusNet, Beca worked through the contractor's proposed construction methodology and modelled the transmission line to assess relevant construction loads and weather cases to provide a constructible and safe design for the refurbishment of the existing ground wire with the new OPGW.

In this paper we report on the engineering leading to the design solution to overcome the construction issues posed by: dense urban environment that the transmission line traverses; re-conductoring over buildings, electrified rail, motorways and rivers; the high rigging loads applied by the catenary support system for the installation of the new OPGW; the limited outage availability on the line; and modification and strengthening of the 1960's towers' groundwire crossarms for attachments, construction loads, safety requirements and compliance with modern design standards.

Introduction and Background

SP AusNet (SPA), an energy company that operates the high voltage power network in Victoria, Australia identified the need to invest in reinforcing their communications link between Malvern and Richmond terminal stations in central Melbourne. The existing communications route between these two terminal stations, an All Dielectric Self Supporting (ADSS) system running on their distribution network, is to be reinforced by refurbishing one of the two existing groundwires on the connecting transmission line with an Optical Fibre Ground Wire (OPGW).

The transmission line used for installation of the new OPGW is a quad circuit line carrying two 220 kV circuits and two 66 kV circuits.

The route of the short 10 km section of the line between the two stations, comprising 33 strain towers, traverses a dense urban area in central Melbourne. Not only does the line traverse over a substantial amount of residential and industrial buildings, it also crosses a number of roads, major freeways and intersections, electrified rail corridors and the Yarra River. These issues together with the limited outage availability on any of its four circuits posed significant challenges to the engineering design for construction and safety.

Working closely with SPA, Beca's role was to investigate and appraise the various solution options and provide the engineering design to achieve the refurbishment of the OPGW.

The following sections of this paper report on the engineering design process leading to the proposed solution for the installation of the OPGW using a Catenary Support System (CSS).

Site constraints leading to construction requirements

The first stage of the design for the reconductoring was to complete a line familiarisation walkover. The aim of this walkover was to: confirm and classify the tower types on the line; assess their condition; identify potential stringing sites and identify potential hazards for the stringing works. The site visit also allowed confirmation of line details that would impact on the design solution for specific spans such as those crossing major freeways, electrified rail crossings and multiple residential and industrial buildings.

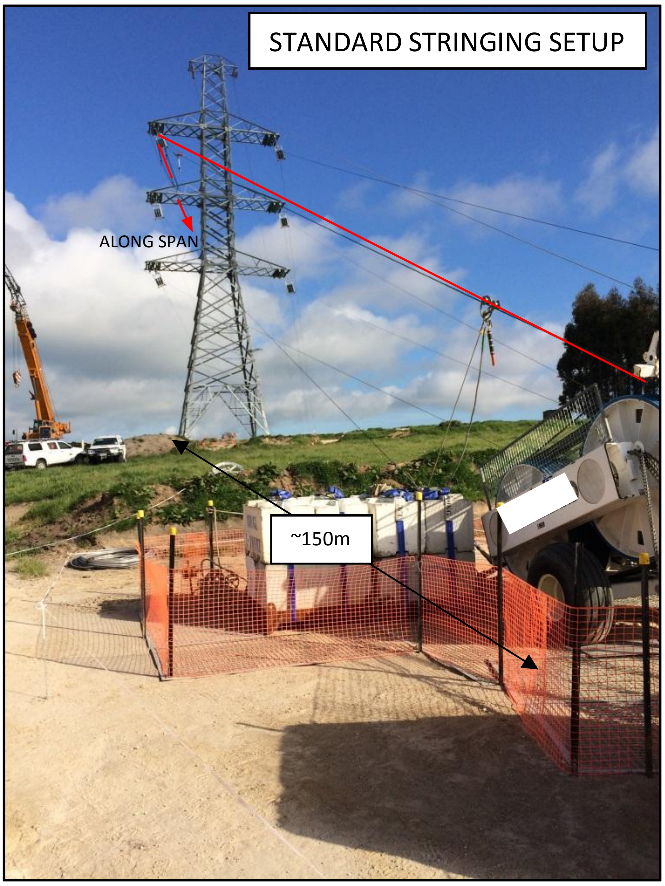
The average tower deviation angles on this section of the line is 22° (ranging between 3° and 50°), therefore, short pulling sections were required to keep the accumulated deviation angle of each run within acceptable levels (as the accumulated deviation angle increases it becomes harder to manage the constant pulling tensions across the section). These short stringing runs created the need for stringing sites in both the ahead and back spans of all stringing towers (with exception of those at each end of the line).

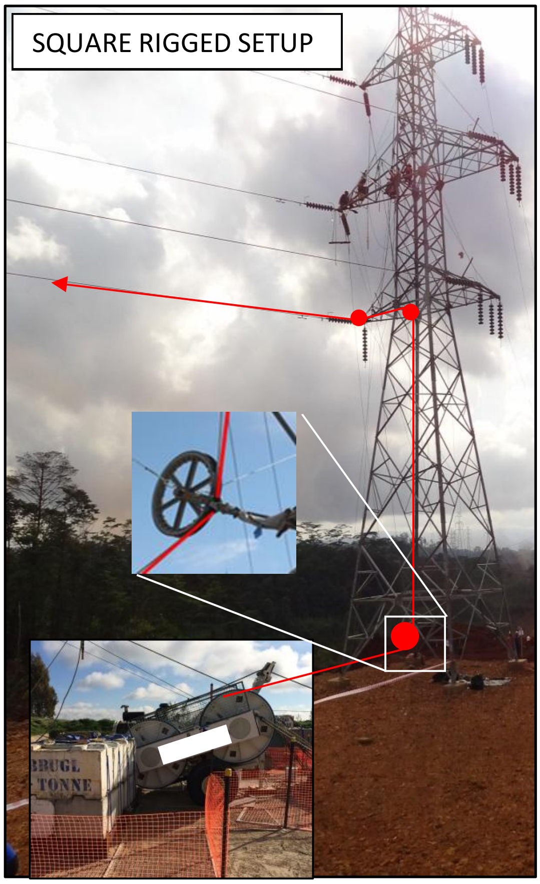
Normal stringing practices would aim to have a stringing site located at a distance from the first tower of at least double or triple that towers height. Setting up at this distance allows the new conductor to be pulled directly through the stringing blocks at a shallow angle which minimises longitudinal and vertical loads applied to the rigging attachment points.

With typical tower heights on this line being in the range of 40 m to 50 m, this would necessitate a clear area in the ahead and back spans of each stringing tower of approximately 100 m to 150 m; however, due to the significant underbuild below the line and its close proximity to most towers, this amount of free space is not available at any of the tower locations, therefore, whichever construction method is finally adopted for installing the OPGW it would be necessary to allow for square rigging on the towers.

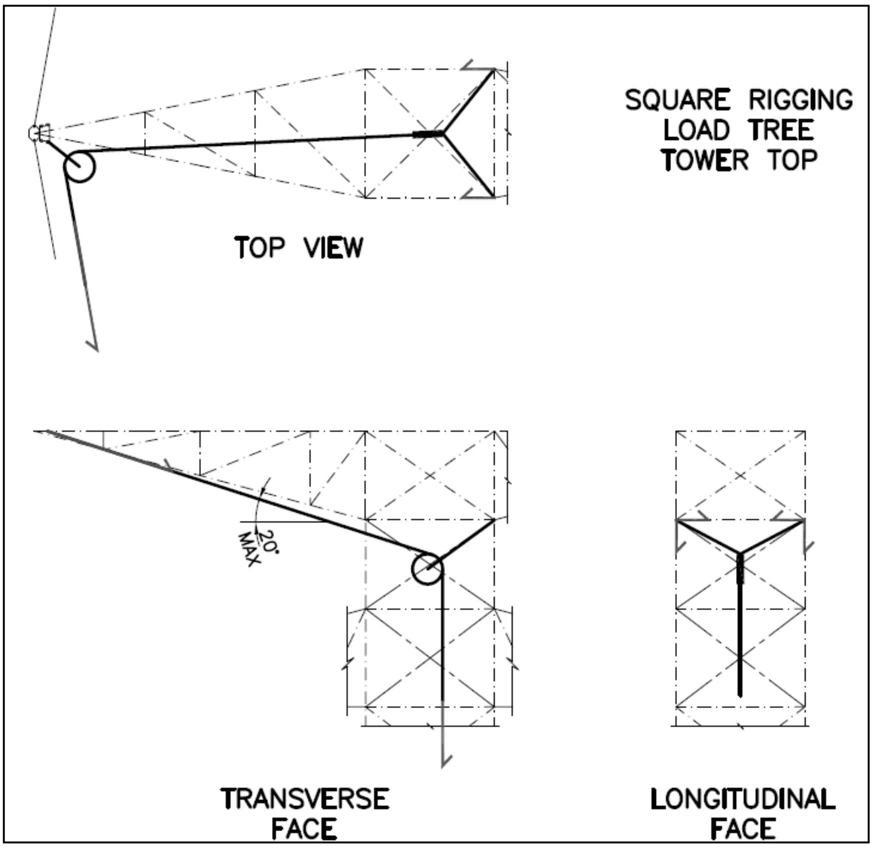
The main advantage of square rigging is that the area required for the stringing site for pulling and tensioning equipment can be located close to or within the footprint of the tower, the conductor can also be strung in both directions without having to relocate equipment. A disadvantage of square rigging is that it imposes loads greater than those from standard stringing to the support structure. These loads, especially to rigging points on crossarms, would not necessarily have been considered at the time of the original tower design. A typical square rigging set-up will have the puller or tensioner located close to the tower and use a system of stringing blocks (pulleys) to guide the conductor up the tower.

Schematics of a standard stringing set up and a square rigging set up can be seen in the photographs below.





The investigation into the possible conductor paths and block locations for square rigging of the towers, taking into account the limiting issues of the towers supporting four circuits, for which there is limited outage availability and therefore a need to work live, concluded it would be best to run the OPGW up inside the tower body, as opposed to up the face of the tower. This methodology maximises electrical clearances and mitigates the potential for flashover from the live circuits. Removing cables from the face of the tower also reduces impact on the climbing corridor for the towers. A schematic of the proposed conductor path through the tower to the end of the groundwire crossarm is given below.

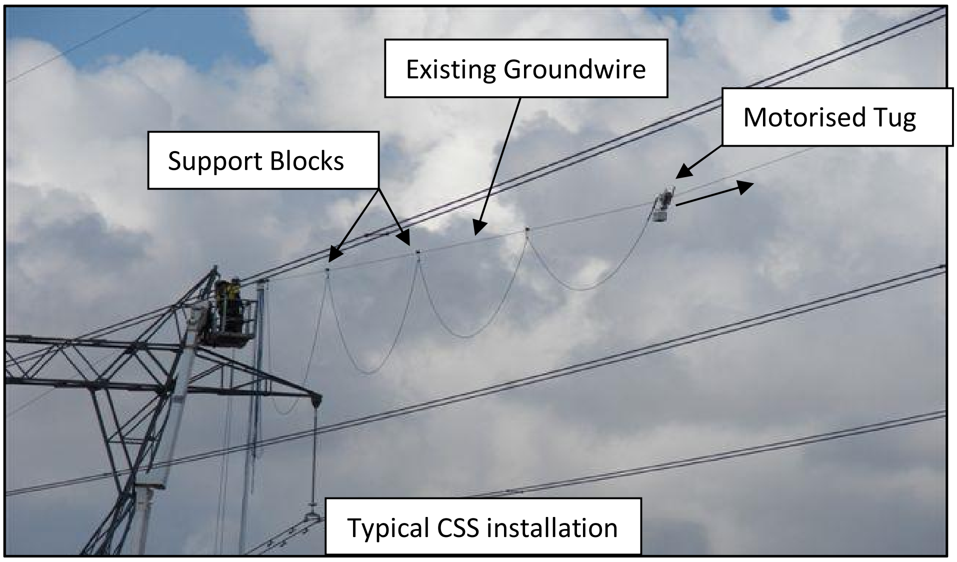


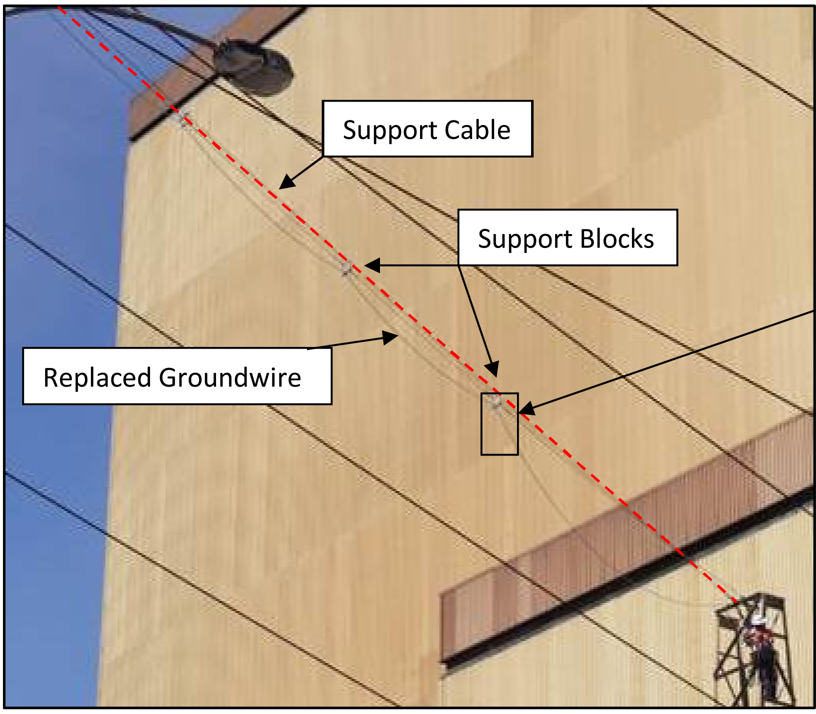
Construction Methodology, Load Application and 'Safety in Design'

To determine the loads that would be applied to the towers under the construction load combinations and which towers would be called upon to carry these loads, it was important to accurately understand the construction methodology to be used. This was achieved through structured meetings held between Beca, SPA and the Contractor. At these meetings working methods and methodology were discussed and agreed, and hazards and risk assessments with acceptable levels of mitigation identified.

The major impact of underbuild, crossing of major freeways, working over live circuits and limited space led to the decision to utilise a CSS for carrying out the restringing of the OPGW. This system would be installed in critical spans along the line.

A CSS is a stringing system that can allow a conductor, or groundwire, to be supported during stringing without the need for netting/scaffolding, road closures or de-energising circuits. The support system is installed, in this case along the existing groundwire, using a motorised tug to pull out a support wire with blocks spaced at specified intervals. Once the support system is pulled out and secured to the towers, the new groundwire is connected to the existing groundwire and pulled through using the existing groundwire. If a failure occurs on the groundwire while it is being pulled out, it will be supported by the CSS to prevent it contacting any obstructions below.





The stringing methodology was worked through in detail to confirm procedures and parameters for pull-out of the CSS, reconductoring with the OPGW and removal of the CSS. The general methodology agreed for installation of the OPGW using the CSS is:

- connect a motorised tug to the existing groundwire to pull out the CSS;
- tension the CSS to meet a specified sag and secure it to the towers;
- square rig the OPGW through the stringing tower and connect it to the existing groundwire;
- reduce the tension in the groundwire and use it to pull through the new OPGW;
- once the OPGW is pulled through, secure it to the tower and retract the CSS along the OPGW;
- sag the OPGW to design tensions

An investigation was carried out to assess the loading that would be applied to the towers and clearances for each of the stages of construction, using the CSS.

The construction methodology and investigation were subjected to a Safety in Design (SiD) review attended by Beca, SPA and a contractor. The purpose of the review was to challenge the solution, identify hazards and key risks, and potential mitigation measures that could be taken to further reduce risks.

Some of the key outcomes from the SiD review included confirmation that sags of the groundwire created by the addition of the CSS would come close to infringing on minimum electrical clearances to the 220 kV circuit directly below the groundwire. This was mitigated by obtaining short duration outages on the 220 kV circuit below the groundwire being replaced and using an alternative, lightweight CSS to reduce the load on the towers.

The SiD review identified risks that could not be mitigated sufficiently by design and needed to be passed onto the Contractor for management before and during construction, these included: allowance for rigging and lifting loads, identifying members on the towers that may not support man-standing loads, identifying preferred locations for block connections/hook ladder attachment and outage constraints. A scope of works document was produced summarising the assumed methodology and collating all of the risks identified. This document could then be provided to the Contractor allowing construction risks to be highlighted at an early stage of the project so the Contractor has sufficient time to produce detailed work procedures to carry out the works safely.

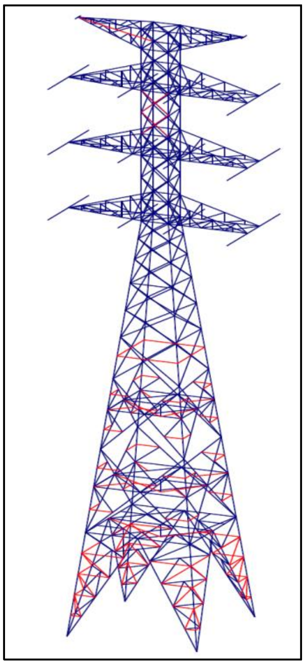
Tower Appraisal

The connecting transmission line comprises four different tower types: Light Strain (LS) and Heavy Strain (HS) from a 1963 contract; and Light Strain (FC5) and Heavy Strain (FC6) from a 1985 contract. Archive records made available by SPA contained drawing information for all four tower types. Although the quality of the 'old' drawings was variable, a problem that is often encountered with legacy assets, it was possible to determine geometry, member sizes and connections, and fabrication details with sufficient confidence for detail design. The four towers were modelled and appraised using a 3D finite element program.

Having established the methodology of how the refurbishment of the OPGW was to be achieved the load cases and combinations were determined.

Design Standards and Codes

Transmission line and tower loads for different weather and load cases were calculated in accordance with AS/NZS 7000:2010 - Overhead line design. This was completed for both standard duties of 'existing'[1] and 'proposed new'[2], to allow a comparison to be made between the two configurations, and 'construction' load combinations.



Standard duty loading

Under 'existing' and 'proposed new' standard duty loading issues were identified in elements of the older 1963 contract towers, for both the LS & HS towers. The elements affected indicated/highlighted in red in the adjacent schematic, were redundant members in the lower

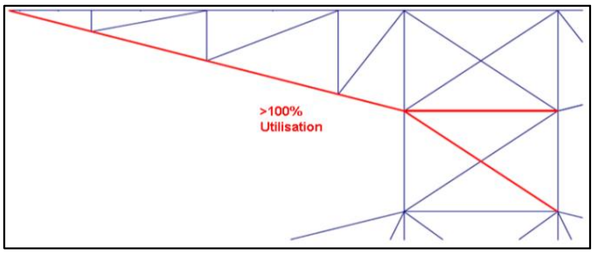
[1] Existing conductors and groundwires

[2] Existing conductors and new OPGW for one existing groundwire

parts of the tower body and crossing diagonals in the upper regions of the tower, the causation of which could be attributed solely to the difference in standards and analysis methods employed in 2014 to those in 1963, when the original design was carried out.

The FC5 & FC6 towers from the 1985 contract were found to be operating within their capacity for both ‘existing’ and ‘proposed new’ standard duty loading.

Construction duty loading



Analysis of the groundwire peak and crossarm showed that all the LS & HS towers from the 1963 contract exhibited over-utilised elements under construction duty loading. The over-utilisations, some as high as 150% were restricted to connections at the groundwire crossarm ends and strut buckling of all segments of the bottom chord member, and crossing diagonals in the groundwire peak.

The over-utilised elements in the LS & HS towers’ groundwire peaks are as a direct result of the new construction duty loading cases only. This is not necessarily surprising as the specific construction method to be employed, of a catenary support system combined with the loads from square rigging, would not have been part of the original design for the towers. The LS & HS towers’ groundwire peak and crossarms are satisfactory for normal maintenance and access loading.

The FC5 & FC6 towers from the 1985 contract were found to be operating within their capacity for construction duty loading.

Strengthening Requirements

Before arriving at engineering solutions, consideration was given to employ temporary measures over permanent strengthening of the groundwire peak connections and members.

Alternative temporary options considered included:

- bracing the groundwire peak from the bottom crossarm to share any additional loads at the groundwire crossarm with the conductor crossarms below;
- installing a cantilever beam out from the body of the tower along the top of the groundwire peak to add another load path for construction loads back to the tower body; and
- supporting the groundwire peak by installing a gin pole above the tower top and tying this to the crossarm end

Following discussions with SPA and the Contractor, it was decided these alternative temporary methods could introduce additional issues that require significant modifications to connections and members not already identified as needing upgrading, not mitigate overall safety, and impact on short time recall; therefore, it was concluded to proceed with strengthening of the crossarm connections and members. This would also produce a permanent solution that could realise benefits for construction and safety for future work on the tower.

Construction loads can be difficult to predict and control. This point, together with there being no load path redundancy were the bottom strut to fail, and that additional elements were to be added on site to an existing already loaded structure, led to including an additional margin for strengthening (permanent or temporary) to further minimise the possibility of the groundwire peak becoming overloaded. A target calculated maximum utilisation of 80% was used for the strengthening design.

Structure Utilisation

In accordance with the SPA's policy, where analysis shows members are already over-utilised for the 'existing' standard duty loading and the increase in utilisation for the 'proposed new' standard duty loading is marginal, then risks from this would be assessed to determine if they can be managed rather than performing strengthening, something that introduces its own risks.

The approach was different for construction duty loading where loads, although temporary, are 'real' loads to be supported by the structure. Therefore, all over-utilisation due to construction duty loading was identified and strengthening solutions designed to be completed prior to the installation of the OPGW.

Crossing diagonals and struts

Crossing diagonal[3] failures were identified in the superstructure of the LS & HS towers with the governing failure for these members being buckling.

The permanent solution selected was to clamp a hollow section to the inside of the angle to reinforce the element, thereby increasing its compression capacity to an adequate level.

Redundant (secondary) Members - Leg restraints

A principal function of redundant members is to limit the effective length of and provide restraint to principal members in axial compression.

The LS & HS towers share a common outline, and brace, redundant member and connection sizes. The main structural difference between the two towers is the leg configuration, which on the HS tower is a cruciform section to account for the greater magnitude of head load and resultant leg forces. The redundant members are within their capacity for the LS tower and provide satisfactory restraint to the legs for maximum axial forces that occur for standard duty loading, and in most of cases also comply with the requirements[4] of AS3995:1994. The redundant members supporting the HS tower cruciform legs, which have a higher compression capacity and actual force, were identified as not meeting with the requirements of AS3995:1994. This situation is a pre-existing condition for both 'existing' and 'proposed new' standard duty loading but not an issue for the construction duty loading, therefore, in accordance with SPA's policy it remains and any issues arising are managed.

Redundant (secondary) Members - Climbing Loads

A climbing load[5] check confirmed some redundant members in the LS & HS towers would not comply with current requirement to support a man standing,

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[3] In accordance with AS 3995 -1994 the magnitude of the tension force in the supporting crossing tension member must be at least 60% of the supported crossing compression member force for support to be assumed.

[4] To support 2.5% of the leg compression capacity.

[5] In accordance with AS 3995 -1994 all members that form an angle of less than 30° to the horizontal shall be designed to support a concentrated vertical load of 1.7 kN at midspan.

This result is not too surprising as the design requirements for man-climbing and redundant member design has changed over the years since these towers were originally designed, and although appropriately sized for the original design, requirements are more onerous today to what would have been in place in 1963. This issue featured at the SiD where it was concluded that upgrading of redundant members for the tower structure would be impractical and any issue arising could reasonably and practically be managed on site by the Contractor to mitigate this risk.

Members in tower types FC5 & FC6 were found to be satisfactory for climbing loads.

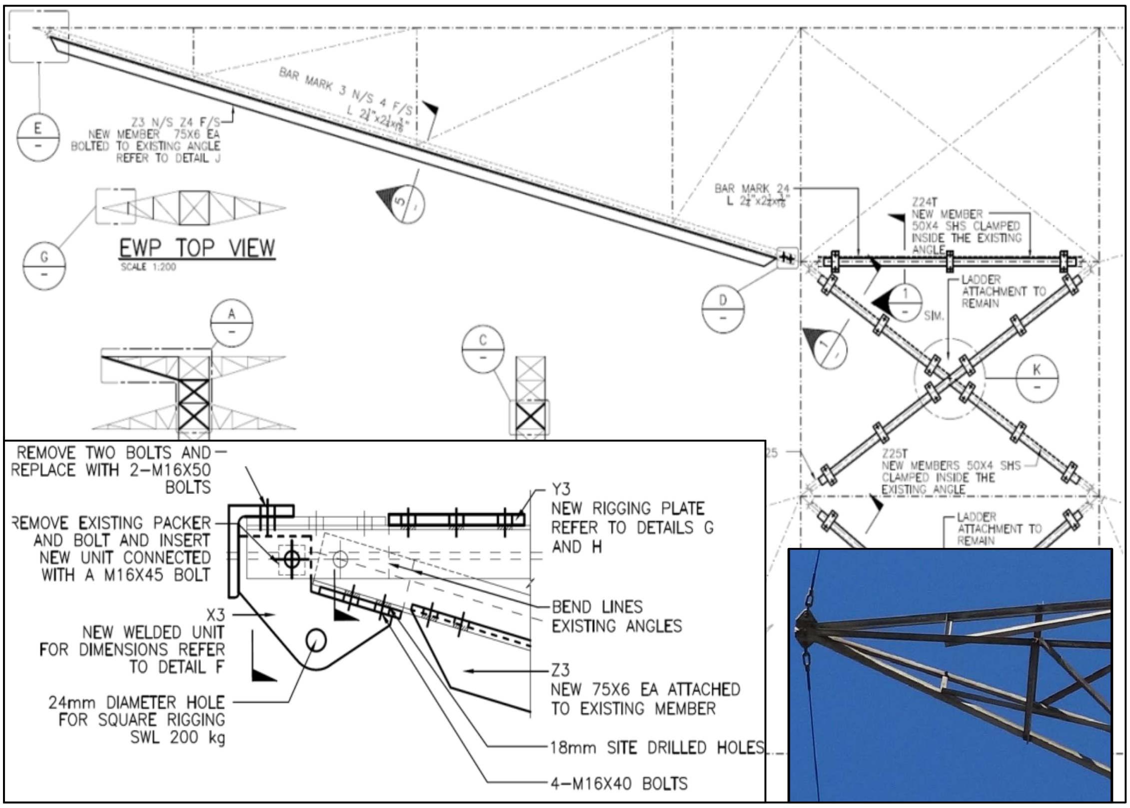
Footings

A review of the foundation load, comparing it between 'existing' and 'proposed new' standard duty loading, showed an increase in the axial compression load of approximately 2% due to increased overturning moment. This was within the capacity of the stub and footing for combined action under compression and bending due to brace shear.

Strengthening

Strengthening necessary to enable the refurbishment of the new OPGW was limited to the groundwire peak and crossarm. The solution was arrived at to improve connection strength, reinforce the bottom chord member and crossing diagonal braces by:

- installing a welded unit at the crossarm end to engage with additional bolts, replacing existing bolts with larger diameter bolts;
- affixing a reinforcing member to the length of the bottom chord;
- adding additional members to reduce the slenderness of the strut segments;
- adding specific rigging point to be used during the construction works; and
- clamping a reinforcing member to the inside of the crossing brace



Conclusion

Even though the structural demand of the ‘proposed new’ duty on an existing (old) asset can be demonstrated to be little or no different to its ‘existing’ duty, conditions may have changed since the original design and its build that pose new or different problems in achieving the construction, such as changes to:

- the physical environment in which it is to be build;
- the construction practices; and
- codes and regulation.

This has been the case for the transmission line between Malvern and Richmond Terminal Stations, where the present environment has driven the selection of a specific construction solution. This has proved to be problematic for the groundwire peak and crossarms whose original design would be to previous standards and not have considered construction duty loading from a method not employed at that time.