

Nepean River Green Bridge (Yandhai Nepean Crossing)

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ABSTRACT

The Nepean River Green Bridge (now known as Yandhai Nepean Crossing) is a new pedestrian and cyclist bridge spanning the Nepean River between Penrith and Emu Plains. The bridge is a steel truss with a 200 m span and is the longest pedestrian bridge in the southern hemisphere. The geometry of the bridge is very complex and is approximately 800 tonnes in weight. It was built and erected in a workshop in Newcastle where checks were performed on the structure to ensure design specifications and tight tolerances were satisfied. The bridge set-out points on the two bottom and single upper chords are inaccessible which required innovative ideas, methodology and equipment. The bridge was initially tack-welded into position and due to the width, height and length of the structure with respect to the workshop was assembled at 90 degrees to its true position. After the bridge had been surveyed for conformity, it was then dismantled into large sections, transported to Penrith and for a second time re-assembled in a workshop, this time in an upright position. The bridge has a series of punch marks (survey reference marks) strategically placed in order to make the re-assembly quick and easy. The bridge was tack-welded, surveyed for conformance, final weld performed and then incrementally launched in sections using temporary supports placed in the Nepean River. This paper focusses on the required survey work, which was high-precision, involved rotating survey control and bridge design values about different x, y & z coordinates due to the bridge initially being constructed at 90 degrees, and necessitated surveying, thinking and analysing in three dimensions. The bridge was officially opened on 28 October 2018.

KEYWORDS: *Bridge, precision, tolerance, assembly, conformance.*

1 INTRODUCTION

The Nepean River Green Bridge (now known as Yandhai Nepean Crossing) was built by Roads and Maritime Services (RMS) to provide a safe pedestrian and cyclist connection between Penrith and Emu Plains, as well as a landmark structure with regional significance. RMS partnered with KI Studio, BG&E and Seymour Whyte Constructions to meet these objectives and deliver an iconic architectural bridge crossing over the Nepean River.

The main feature of the project is the 200-metre long Warren truss, which has the longest unsupported span for a shared-path bridge in Australia. This truss was built by assembling pre-fabricated sections on one side of the river and then progressively launching them over temporary piers in the Nepean River by the ‘node-by-node’ incremental launching technique. This construction methodology was extremely innovative as it was the first time this form of incremental launching had been used in Australia.

This paper outlines the design, construction and surveying challenges that presented themselves at various stages and were resolved through collaboration and expertise of the project team. The

Nepean River Green Bridge was successfully opened to the community on 28 October 2018, with this world-class piece of infrastructure welcomed and now under constant use from the people of Western Sydney (Figure 1).

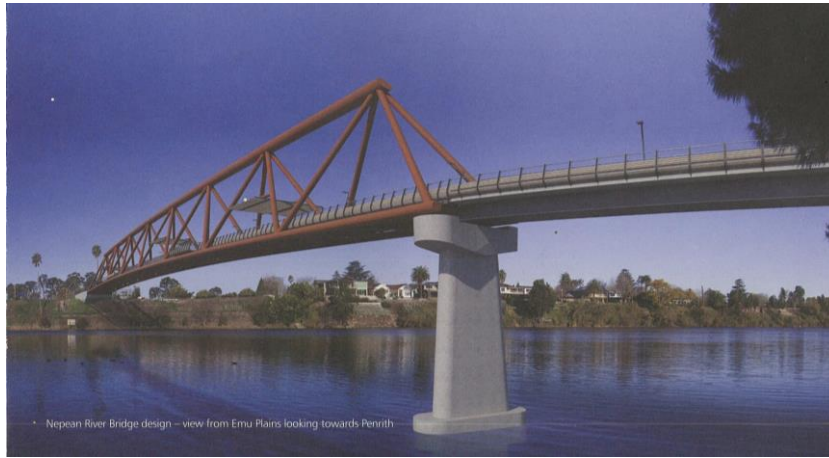


Figure 1: Nepean River Green Bridge design.

2 FABRICATION AND CONSTRUCTION OF THE BRIDGE

The actual manufacture and construction of the steel truss was a 2-staged process, which is outlined in this section.

2.1 Stage 1: Tomago

The fabrication of the structural steel components was undertaken by Civmec at their Tomago (Newcastle) Engineering Facility for a ‘trial fit’. This trial fit was basically manufacturing and then constructing the steel truss bridge (tack or pre welding) to ensure the strict spatial tolerances were achievable. After conformity, the structural steel of the bridge would be dismantled and delivered in 8 bays – 25 m long by 8 m wide. Each bay was split by the bottom floor and top truss due to height restrictions, supplying the complete bridge in components (Figures 2-4).



Figure 2: Manufacturing of top and bottom chords/bays. These we surveyed to ensure correct lengths and grades.



Figure 3: Bottom and top chords/bays lifted into their correct horizontal and vertical alignments. These alignments were positioned by survey. Inter-connecting bays at this stage were only tack/pre welded together as a part of the trial fit.

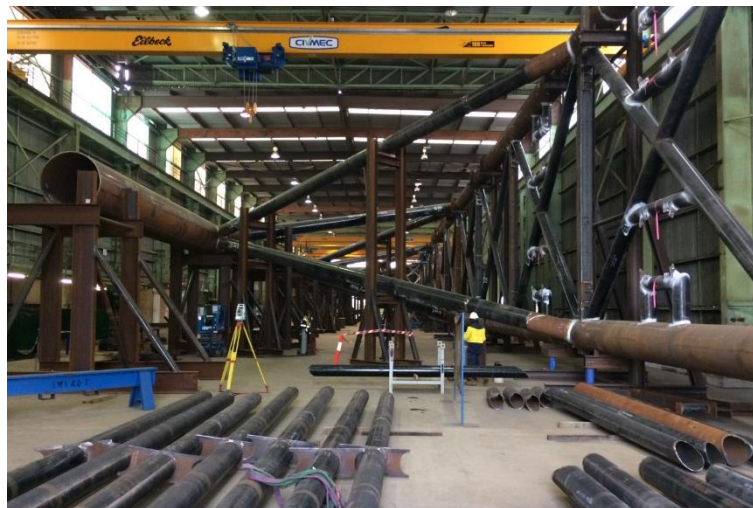


Figure 4: Diagonals being craned into position with the aid of survey and then being tack/pre welded together ready for conformance surveys.

Stage 1 was really aimed at determining whether the bridge could be fabricated to design specifications. The spatial tolerance for each bay in accordance to the bridge designer was “think of the size of a pea”. This was even more difficult to achieve when taking into account that the trial assembly was performed during the winter months when temperatures dipped as low as 2°C and welding of the structural steel components resulted in shrinkage and pipe distortions. In addition, critical points of interest were inaccessible, the physical work environment was very restrictive, working at heights of approximately 9 m above the ground, and dealing with a communication barrier between workers.

2.2 Stage 2: Penrith

Once in Penrith, the final bridge section re-assembly took place in a 65-metre long and 15-metre high purpose-built workshop, which included two brand new 20-tonne gantry cranes and engineered collapsible access platforms 12 m high. After the re-assembly and conformance of each bay, which was a very meticulous process for the bridge fabricator and surveyors, the bridge was painted and progressively launched across to the western side. Temporary piers were

installed while the bridge was being moved to its final position (Figure 5).

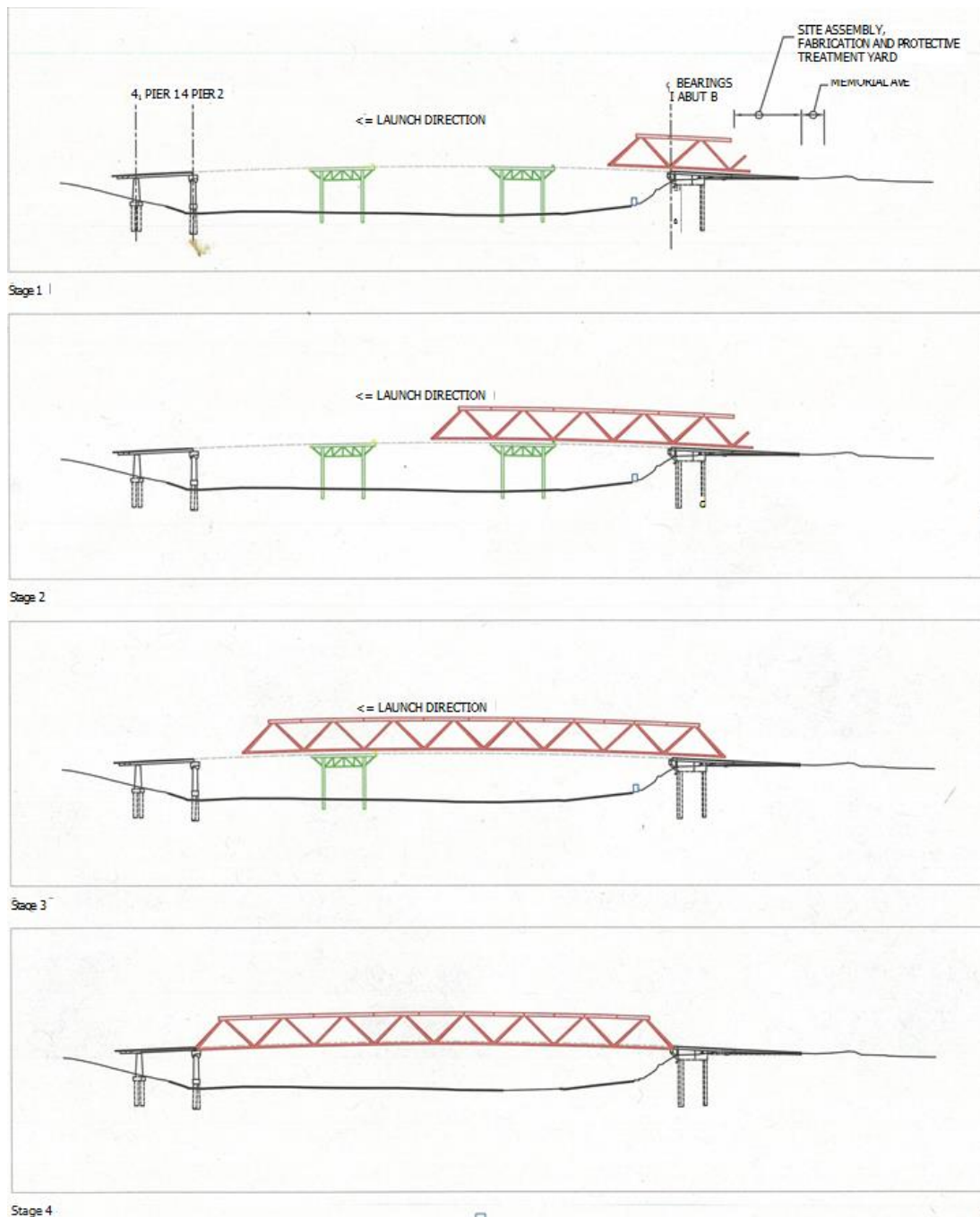


Figure 5: Using temporary piers to progressively launch the bridge across the river.

During the entire build, surveyors had the task of ensuring the unique and complex geometrical design was constructed to strict 3-dimensional spatial tolerances. In addition to the obvious environmental constraints, such as large temperature variations and strong winds, the physical barrier of the Nepean River and working at heights also made the process that much more difficult to manage. A successful outcome was achieved by working in collaboration with all stakeholders, having the ability to solve complex problems in a relatively short period of time, consultation, utilising latest surveying equipment, employing basic surveying principals, improvising and always taking into consideration atmospheric corrections to correctly apply the thermal coefficient linear expansion of steel.

3 SIZE, CONSTRAINTS AND COMPLEXITY OF THE PROJECT

The Nepean River Green Bridge main span has a length of 200 m, truss width of 8 m and height of 13.5 m. With the Engineering Workshop Facility in Tomago only being 120 m long and 10 m high (i.e. the bridge is longer and higher than the workshop), an innovative approach to the assembly of the bridge was required. Because the horizontal and vertical bridge alignments were symmetrical, it was decided to construct the bridge in two sections longitudinally.

Bays 1-5 along the bottom two chords and bays 1-4 along the top chord was section 1. After truss fabrication and 3-dimensional conformity the bridge was dismantled, sent for painting and transported to Penrith for re-assembly. Section 2 consisted of bays 5-9 along the bottom two chords and bays 4-8 along the top chord. To make this 2-staged process a little more difficult, the truss had to be constructed on a rotation of 90 degrees so that it would fit into the workshop. The re-assembly in Penrith was performed with the truss in the upright position.



Figure 6: Assembly sequence of nodes/braces into the final jig.

The main bridge facts are (RMS, 2019):

- Main span length – 200 m.
- Overall bridge deck length – 257 m.
- Overall length of shared path – 455 m.
- Truss width – 8 m.
- Truss height – 13.5 m.
- Steel tonnage of truss – 485 t.
- Steel tonnage of deck – 240 t.
- Bridge total tonnage – 800 t.

The enormity of the project becomes clear when a scaled cross section of the bridge is produced (Figure 7). The top chord diameter is 1450 mm with the bottom two chords being 750 mm. The thickness of the steel varied from 25 to 40 mm.

Due to the width of the bottom truss/bays, heavy haulage permits from Tomago to Penrith had to be organised well in advance of the scheduled delivery dates. These dates formed part of the critical path for delivery of the structural steel components to Penrith. The estimated cost of the bridge was \$49 million.

From a surveying perspective in terms of just the steel truss, the points of interest referencing all of the individual components together were the ‘nodes’. There were nine nodes along each bottom chord and eight on the top chord. In total, there were 26 nodes requiring positioning to a very high precision (Figure 8).

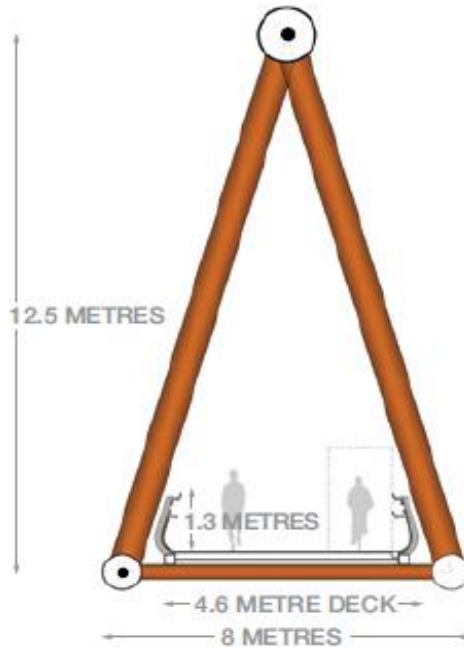


Figure 7: Scaled cross section of the bridge (indicative only).

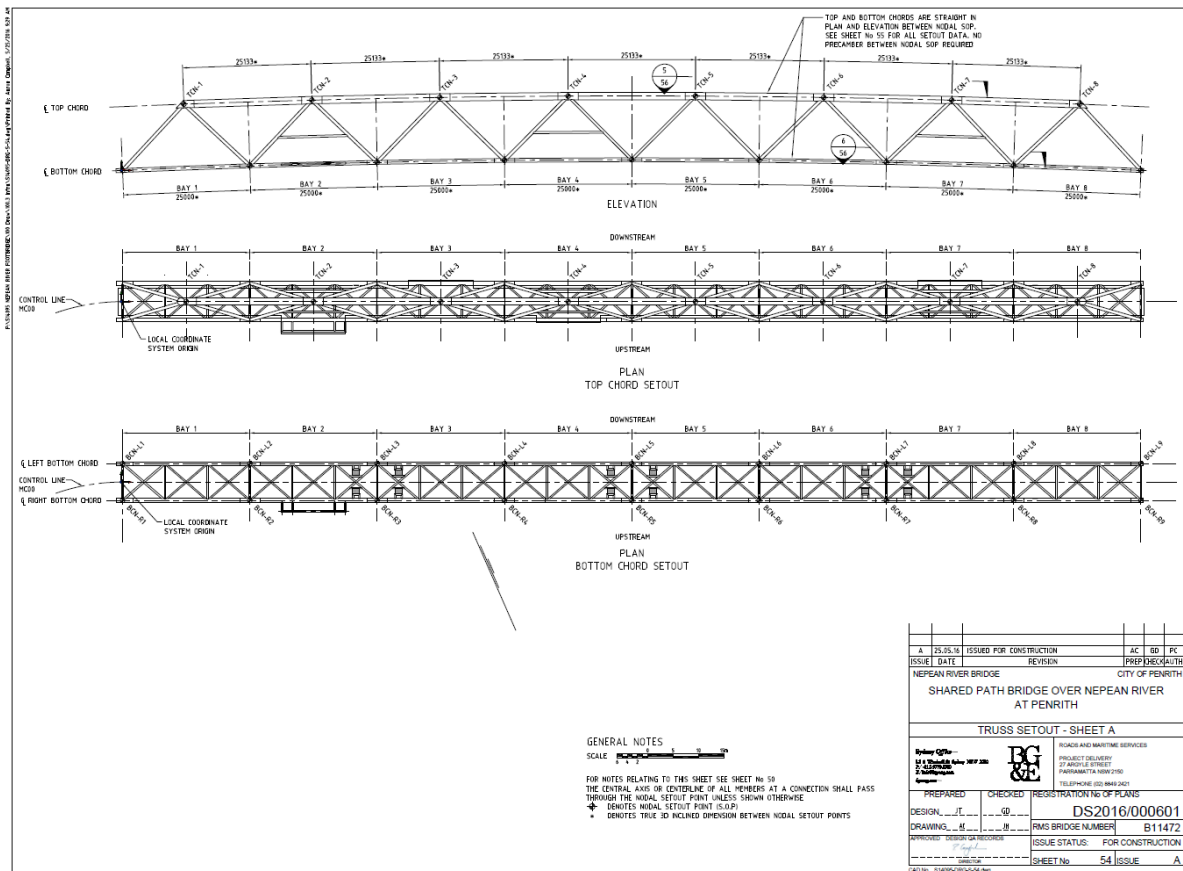


Figure 8: Diagram illustrating The Nepean River Bridge.

The complexity associated with surveying, calculating, coordinating and positioning the nodes was that they were a point in space that could *not* be accessed. They were actually the centre point on the inside of intersecting tubular steel (Figure 9a). In addition to positioning these node 'reference points', it was critical that the butt joints connecting each node exhibited little to no deflections. The butt joints were located mid span between each node (Figure 9b). For the truss to maintain its structural integrity, it was paramount to have these joints within millimetres of the horizontal and vertical alignments.

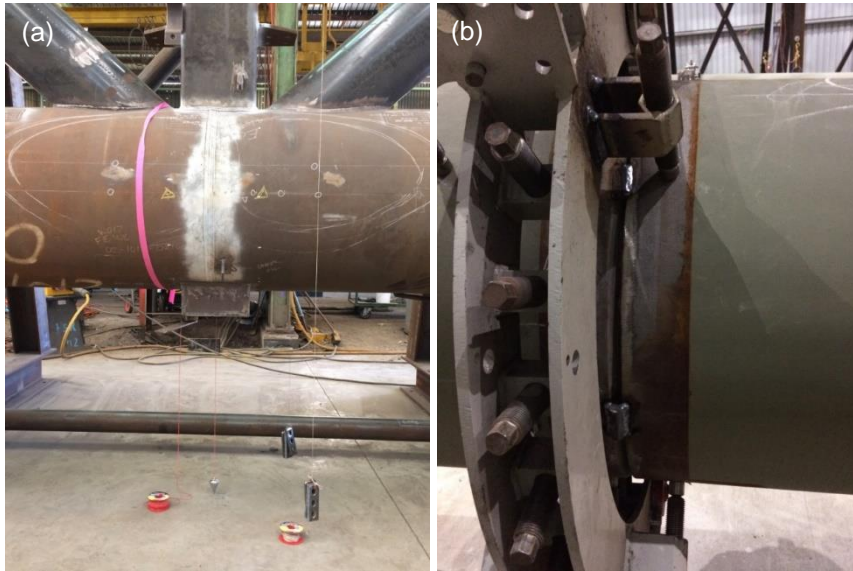


Figure 9: (a) Node positions are the centre point of the intersecting chords, and (b) butt joint alignments were critical and difficult to survey due to accessibility (here the joint is being tack welded together).

4 METHODOLOGY

Node positions were calculated and verified by surveying the outside of pipes (measuring the circumference, dividing the pipe into equal quadrants and locating accurately by EDM), creating pipe centrelines and extrapolating lengths until a common chainage was reached (Figure 10). Through trial and error, it was concluded that intersecting lines on flat grades produced large error ellipses which rendered the technique not viable for this project.

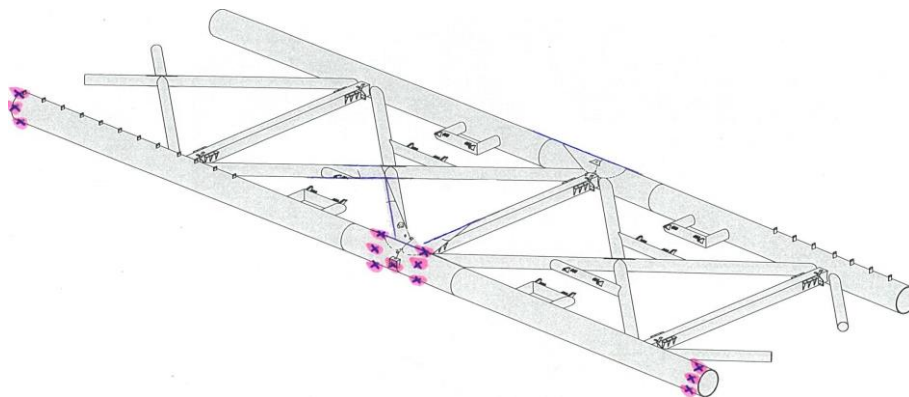


Figure 10: Diagram illustrating indicative field observations on the bottom truss bay.

Calculating the position of a single node to the highest possible accuracy was difficult and time consuming, taking a minimum of 13 EDM recordings. A chord that was elevated to between 4

m and 9 m above the ground (which was two thirds of the time) often required measuring with a hidden point tool. When measuring to a hidden point tool, three measurements at a time would be required. Therefore any recorded measurements to the hidden point tool would increase the number of observations, measurements and time required.

Figure 11 illustrates that taking a measurement on top of a pipe suspended 4 m or higher above the ground required problem solving skills. It was impossible to see directly onto the top of the pipe, and due to obstacles and safety, accessibility was very difficult. Holding a ranging pole vertically and record accurate measurements safely was next to impossible. The hidden point tool (Figure 12) became invaluable in this situation.



Figure 11: Taking a measurement on top of a pipe suspended 4 m or higher above the ground.



Figure 12: Hidden point tool in action.

Once a node position was calculated and verified, punch marks were strategically placed on the steel truss as close to the node as possible, which. These punch marks acted like ‘survey reference marks’ and became critical to the project. Whether located in Tomago or Penrith, once all nodes had been surveyed and referenced, a single measurement to a punch mark could provide a report on the 3-dimensional node position after applying the referencing details.

However, as more and more pipes were being added to the truss, punch marks started to be destroyed (Figure 13) – just like traditional survey marks! It was therefore necessary to continuously monitor, upgrade and replace marks.



Figure 13: Adding pipes to the truss caused punch marks to be destroyed.

Other interesting complexities were encountered during the trial fit at the Tomago Engineering Facility Workshop. One of the first was that the 90° rotation of the bridge required us to transpose the y & z coordinate values. With regards to the bridge centreline, offsets now became heights and the bridge vertical alignment became offsets. Fortunately, the bridge rotation had no impact on chainage values.

During the fabrication and assembly of the steel truss in Tomago, even though the bridge was on a 90° rotation, the geometrical properties were still correct as the truss was being supported at multiple points throughout. However, after the bridge was launched and mid-supports were removed in Penrith, the design truss geometry was under ‘self-weight’ supported permanently at bearings. The difference in node position between the ‘two’ bridge design positions was in the order of 120 mm in length and 500 mm vertically.

Figure 14 illustrates the visual difference between the ‘weightless’ and ‘under self-weight’ bridge geometry. In order to determine the weightless fabricated node geometry that was used to perform the set-out work in Tomago, pre-camber offsets had to be applied to the under self-weight design truss node values. Extreme care was required in performing these calculations because pre-camber values were sometimes positive and sometimes negative.

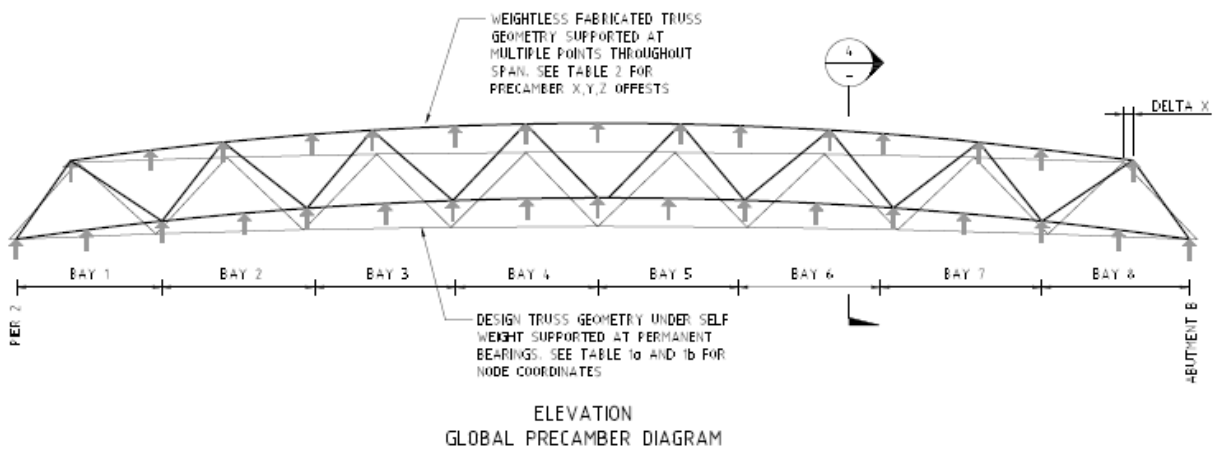


Figure 14: Visual difference between the ‘weightless’ and ‘under self-weight’ bridge geometry.

After the trial fit in Tomago, the complexities of the project grew exponentially during the Penrith re-assembly phase. There was a period when the trial-fit on the second half of the bridge was performed in Tomago, while also assisting with the set-out and conformance surveys of the re-assembly process in Penrith. Travelling between the two site locations on a good day takes about 3 hours. Each location had to be treated vastly different. With respect to the Engineering Facility at Tomago, the bridge was rotated at 90° and on an assumed datum. In Penrith for the re-assembly, the bridge was upright and on Map Grid of Australia (MGA) orientation with Australian Height Datum (AHD) elevations. Successfully managing this process required excellent communication, storage of spatial data capture and concentration.

5 TRUSS RE-ASSEMBLY IN PENRITH

It was clear that the first re-assembly would be the largest, most difficult and completely different to the ensuing six launches. With the assistance of survey, nodes 1, 2 & 3 on both bottom chords and top chord nodes 1 & 2 were configured in accordance to reference nodes and data logs recorded in Tomago from the trial fit. In order to hold the truss in a temporary fully supported position with 'weightless' geometry, the bridge required tack welding in strategic positions. This stage was referred to as a 'pre-weld' survey.

In order to re-position the nodes, our reference/punch mark values derived in Tomago were utilised, now *rotated* upright (Figure 15 & 16). To take advantage of optimum temperature conditions, RMS performed critical survey measurements of nodes and butt joins in the very early hours of the morning. It took around 2 hours to record approximately 15 precise measurements because accessibility in the purpose-built workshop was slow and difficult. Extreme care was taken for all surveying activities to ensure accurately recorded measurements were taken on every occasion.

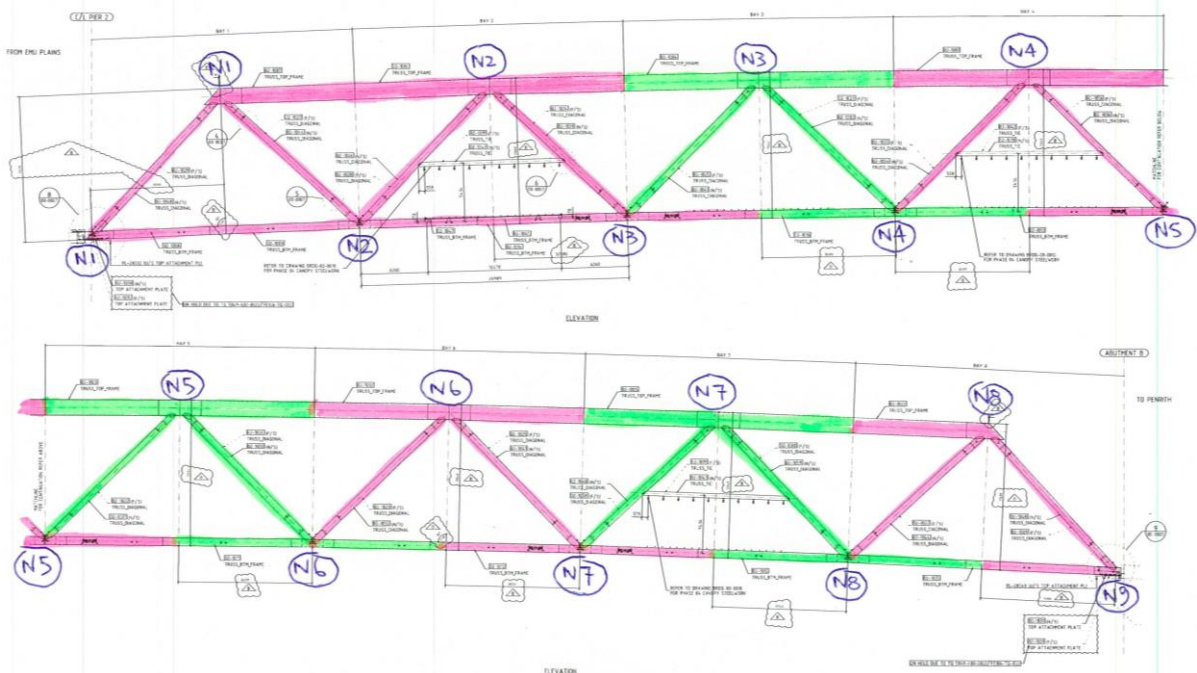


Figure 15: Diagram highlighting the seven different staged launching sequences.

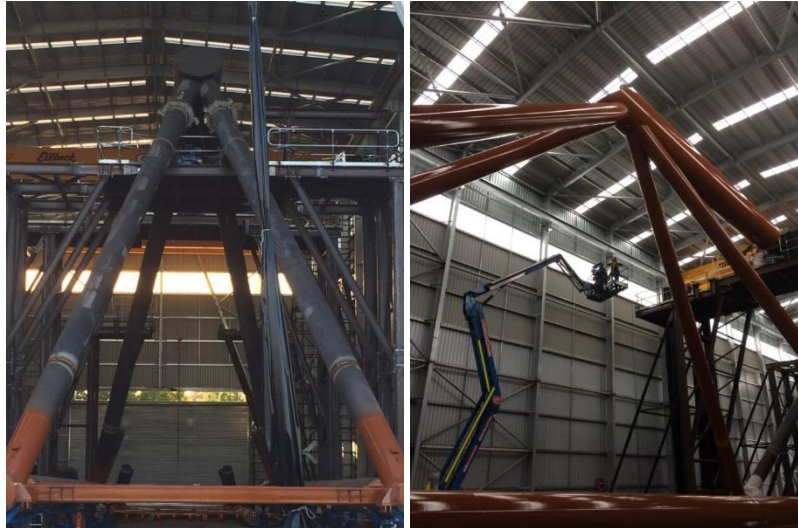


Figure 16: Re-assembly process.

Once the vital points of interest were located and recorded in the workshop, the computations commenced. This was another 2-hour process, made all the more difficult due to the pressure of not being able to perform pre-calculations. During this first re-assembly extreme difficulties were experienced in performing the office-based calculations. This was largely due to the purpose-built workshop floor being constructed on a 3% grade to assist with the launching process. Therefore the truss and floor were on a skew to one another, which significantly impacted chainage lengths and Reduced Levels (RLs). This constraint also impacted the design node values, which had to be re-calculated.

After discovering that computer-aided design and drafting (CADD) software 3-dimensional transformation packages did not always yield correct results, a plan was devised to use a combination of vertical angles calculated long-hand along with 3-dimensional CADD package transformations. This process had to be performed after *each* set of observations. After every node survey, these calculations had to be performed.

If the nodes and butt joints were not within tolerance, we would advise and assist with the truss re-alignment. This process could take as little as 2 hours or up to a day. If the truss geometry was within a 5 mm tolerance, a report would be sent to the bridge designer for his concurrence and release of the hold point. Upon hold point release, all of the truss *tack* welds would be progressed into final welds. The process of moving from a 'pre' to 'post' weld stage took about 3 days. Truss movement was continuously monitored until conformance was achieved. It was absolutely critical that a 'post' weld survey be performed in the early morning prior to the bridge being launched. After each successive launch, the bridge running chainages, offset position and heights would be lost. We could only then deal with absolute positions, which were calculated from the 'post' weld survey results. The staged process of moving from pre to post weld including the release of hold points and launch was an intense 2-week period.

Re-assembly of stages 2 through to 7 was a comparable process. Stage 2 involved positioning bottom nodes 4 and top node 3 into the back of the workshop and re-assembly from data logs recorded in Tomago. Positioning these three new nodes could only be done by using the immediate three preceding nodes. That is, determining the position of new bottom nodes 4 and top node 3 could only be done from existing bottom nodes 3 and top node 2. Each node in section view would form a triangular shape (Figure 17a). Therefore, to position a new 'triangle', one could only use the immediate adjoining one that had already been completely welded.

Figure 17b illustrates that as the bridge was being progressively launched, the nodes being supported would vary due to the vertical alignment.



Figure 17: (a) View of triangular shaped truss being re-assembled in sections, and (b) nodes being supported during launch vary due to the vertical alignment.

During the truss re-assembly, very minor corrections had to be applied to achieve conformance. For example, when setting out bottom node 5 right-hand-side, we took into consideration the ‘post’ weld position of bottom node 4 right-hand-side. The chainage on node 4 was 3 mm short, height was -3 mm and alignment good. These values theoretically could *not* change irrespective where the bridge was positioned after launching. Therefore, the position node 5 was set out after taking into consideration corrections for temperature and weld shrinkage was a few millimetres longer and a few millimetres higher with no adjustment to alignment. The ‘post’ weld results for node 5 were 1 mm long, height -1 mm and alignment good. Continuing to apply this method of corrections throughout the re-assembly process proved to be very successful.

By utilising the latest surveying theodolites and traditional surveying techniques, real-time results were provided on a very complicated project. Being able to assist, guide and provide information in real time on a construction site in a pressurised environment is paramount, hence the reason for using traditional equipment. As an independent sanity check, nodes were often scanned to verify the conformance reports (Figure 18). The scanned results provided excellent comparisons often to within millimetres to the values determined by conventional means.



Figure 18: Scanned image of a node.

6 OTHER CHALLENGES THAT HAD TO BE OVERCOME

The unexpected difficulties associated with the seven re-assemblies and their subsequent launches in Penrith caught everyone by surprise. Although the purpose-built workshop provided a controlled working environment to a certain degree, during summer indoor temperatures frequently exceeded 40°C. Even the temperature variation in the workshop between working at ground level and at an elevation of about 13 m was quite profound. As the bridge propagated into direct sunlight, the temperature effects on the expansion of the steel truss were extraordinary. There were times when the steel truss reached temperatures of 55°C.

With these extremely high summer temperatures, the expansion of the steel truss was so significant that it actually started to distort out of its true geometrical shape, even after being completely welded. The uncertainty in these circumstances was how consistent can the linear thermal expansion of steel be applied? A 20°C temperature variation over the length of a 25 m bay is equivalent to approximately 6 mm in length. Taking this into consideration and remembering that the thermal expansion of the truss will occur 3-dimensionally (Figure 19), trying to achieve this spherical (pea size) accuracy of 5 mm was becoming more and more difficult to achieve. Another factor that required consideration was the further away from the standardised 20°C temperature critical surveying measurements were performed, the least confident or accurate the corrections for the linear thermal expansion of steel became.

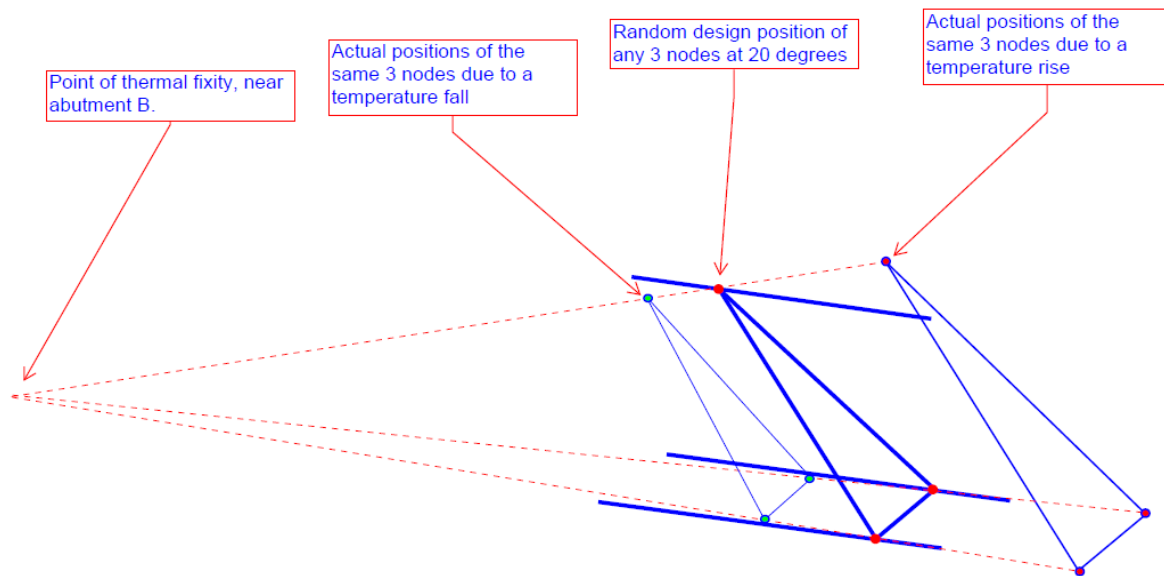


Figure 19: Diagram illustrating that thermal expansion is 3-dimensional.

In order to compensate for temperature variations, derived scale factors had to be applied. The ideal strategy we devised to counter-act the effects of temperature was to perform critical surveying set-out and conformances in the early hours of the morning. The RMS Hunter Survey Team would travel to Penrith during the evenings in order to commence surveying activities the next morning at 2 am. Having these early starts provided the best opportunity to have (1) little to no temperature variations during surveying, and (2) the optimum ambient temperature of 20°C, therefore eliminating the need to apply scale factors.

In conjunction with temperature, another significant environmental factor to consider was wind. The bridge orientation is in an east-west direction spanning over the Nepean River. During the summer season, numerous strong southerly changes were encountered which would funnel up

the river at high velocity. These strong winds would deflect the bottom chords to the north by as much as 40 mm. This value is significant, considering that any deflection values greater than 5 mm were considered non-conforming. As a result of these large deflections, the truss geometry would distort and twist, providing false chainage values in particular. To counter-act these significant distorted values, effective communication, forward planning, an eye on the weather forecast and very early morning starts were required at all times. Early mornings not only enhanced optimum environmental conditions, but also provided minimal worker on foot movements on and across the bridge. Despite the truss rigidity, a worker walking across the bridge would hinder our ability to record precise measurements due to vibration and movement.

7 CONCLUDING REMARKS

This paper has outlined the numerous surveying challenges encountered during the fabrication, construction and launch of the Nepean River Green Bridge (Figure 20), which was officially opened on 28 October 2018 and is now called Yandhai Nepean Crossing. In undertaking this project, many difficulties were encountered, which required an elevated level of problem solving skills and technical excellence to overcome.



Figure 20: Construction of the Nepean River Green Bridge.

A summary of these challenges is provided here:

- Working at two locations approximately 200 km apart on different coordinate systems and performing completely different tasks.
- Positioning a reference point (node) 3-dimensionally that could not be physically accessed.
- Rotating coordinate values, mainly the y & z components for the trial fit at Tomago where the truss was rotated at 90 degrees.
- Collaboration with the large number of diverse stakeholders.
- Working in confined and restrictive areas, at heights and above a river.
- Dealing with temperature variations exceeding 40°C and applying scale factors.
- Weld shrinkage and distortions.
- Surveying the truss, girder, decks, bearings and structures to millimetre precision on *every* occasion at all hours of the day/night.

REFERENCES

RMS (2019) Yandhai Nepean Crossing, <https://www.rms.nsw.gov.au/projects/sydney-west/nepean-river-bridge/index.html> (accessed March 2019).