REHABILITATION AND UPGRADING OF A HERITAGE LISTED TIMBER TRUSS BRIDGE

Keith Crews
Professor of Structural Engineering & Assoc Dean
University of Technology Sydney,
Australia
keith.crews@uts.edu.au

Keith is an internationally recognised expert in the area of Sustainable Infrastructure – such as timber bridges, buildings & infrastructure. Keith has published extensively, and is an Editor for the Construction and Building Materials Journal.

Summary

The Tharwa Bridge over the Murrumbidgee River was originally constructed in 1895, and is the oldest and largest surviving four span, timber Allan truss bridge in Australia. A key objective of the rehabilitation of the old bridge was to maintain the integrity of it's national heritage value, by keeping as close as possible to the original design, rather than providing an alternative bridge using modern materials such as prestressed concrete or steel.

In order to accomplish this, and upgrade the load carrying capacity to modern standards, the analysis and design methods utilised were based upon research that was undertaken previously at the University of Technology, Sydney – particularly in regard to use of a 110m long stress laminated timber deck and advanced techniques for modelling the buckling characteristics of timber truss members.

This paper presents an overview of the design and construction innovations in timber truss bridge design that were undertaken for successful completion of the project in 2011. It also highlights the fact that successful application of new techniques and innovative design can be directly attributed to the collaborative efforts between owners, designers, advisors and construction teams that made this happen.

Keywords: Heritage Bridges, stress laminated timber, timber trusses, buckling.

1. Introduction

1.1 Background

The original Tharwa Bridge was 180m long and for over 100 years it has been the main crossing over the Murrumbidgee River for the local community and visitors to Tharwa, which is located some 30 kilometres south of Canberra. The bridge was initially constructed entirely of timber; with timber piles supporting timber piers up to 12m high for the four main 90ft (27.4m) truss spans and simply supported span approaches (each approx 9m) on either side. Subsequent rehabilitation works during the 1960s replaced the timber substructure with concrete piers, as well as replacing most of the approach spans with reinforced concrete decks.

Degradation as a result of inadequate maintenance and construction details that trap moisture, has meant that the principal timber truss elements have been periodically replaced throughout the life of the bridge. However, by the turn of the 20th century significant deterioration of the structure eventually caused a loss in capacity of the main truss elements, resulting in installation of Bailey support trusses in 2005 and then finally closure of the bridge in 2006. Subsequently, in response to community support for the original bridge design and recognition of its significance, Roads ACT proposed a $25m rehabilitation in 2007, involving upgrading of the Allan truss structures rather than the replacement of the bridge.

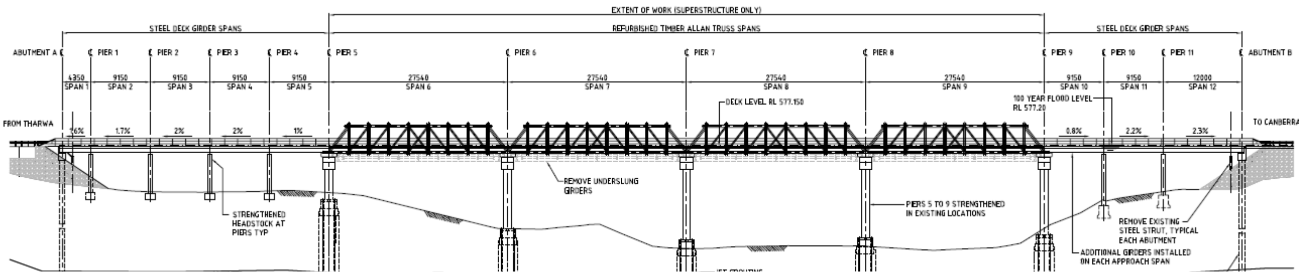

Figure 1 – Elevation of Tharwa Bridge

Figure 2 – Bailey Trusses in 2005

Figure 3 – Temporary support structure 2008

2. Overview of the Project

The project was split into four stages to enable traffic to use the facility throughout the upgrade works:

2.1 Stage 1

The first stage involved temporarily supporting the deck using steel under-slung girders so as to remove the Bailey and timber trusses, and allow traffic access after nearly two years of closure. The bridge was re-opened with a 5 tonne load limit in August 2008.

2.2 Stage 2

Due to the degradation that had occurred, refurbishment and strengthening of the existing concrete approach spans and piers for an increased T44 live load capacity (44 tonne vehicle) was required. Strengthening of the main span piers was undertaken using jet grouting around the perimeter of each pier to provide scour protection of the foundation and stability of the piers during a flood event was increased through micro-piles tied back to the pier face and anchored into bedrock.

Strengthening of the approach span piers was required for the increased traffic loading. This was achieved by the addition of two longitudinal I-beam girders under the deck in each span and installing carbon fibre containment strips wrapped around each concrete pier headstock to provide additional shear strength.

2.3 Stage 3

This stage of the works involved the replacement of the timber trusses, deck, and traffic barriers by the Roads and Traffic Authority of NSW (RTA), who have replicated as near as possible the original methods of construction for the trusses. This work forms the main focus of the restoration and is discussed below in further detail.

2.4 Stage 4

The final stage involved removal of the under-slung girders and temporary steelwork, including rehabilitation of the surrounding public area. The entire reconstruction was undertaken while still providing traffic access during the refurbishment operation. With the exception of several short term bridge closures, access interruption for Tharwa residents and visitors to the area was kept to a minimum.

Figure 4 – Strengthening of the approach spans

Figure 5 – FRP strengthening of the headstocks

3. Design Innovations

3.1 Challenges

One of the significant challenges in undertaking restoration of historic timber truss bridges is the fact that structural behaviour and interaction of elements is not accurately modelled using conventional analysis techniques and the prediction of truss capacities tends to be quite conservative when applying procedures in design codes that were essentially developed for residential buildings. The combination of these two factors has meant that designers have usually produced designs that require truss elements that are significantly larger than the original members, which in turn has resulted in changes to the structural form and loss of heritage value – even though the trusses had been safely carrying the required vehicles prior to rehabilitation.

The solution to this problem has been to develop more refined analysis methods, particularly in regard to prediction of buckling capacity and modelling of connections within a truss, which is the outcome of several research projects undertaken at the University of Technology Sydney since 2008 [1], [2], [3].

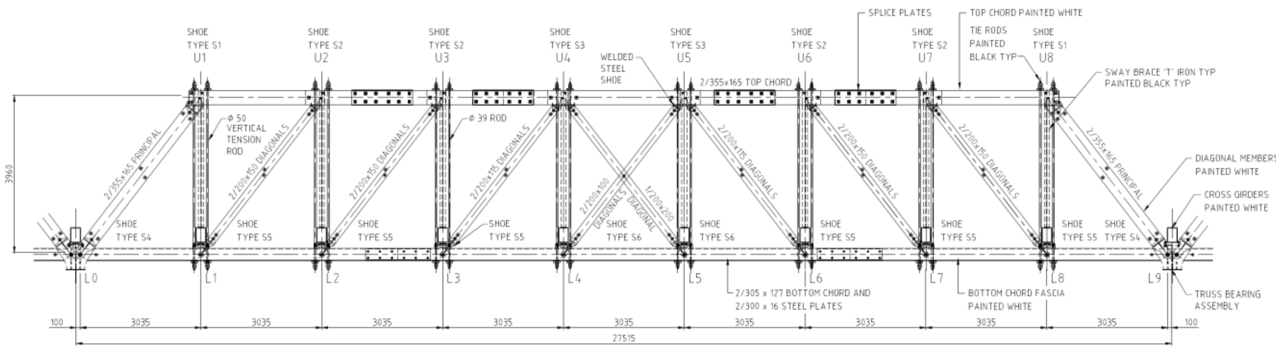

Figure 6 – Side Elevation of the Allen Truss

3.2 Improving Truss Performance

Design of the Tharwa trusses was based on this research which led to a number of innovations that utilise the timber very effectively. Additionally since timber is generally more suited to compression than tension, the bottom chords were replaced by two steel plates which carry the full tensile load. The diagonals are then connected at the plates through a simple pinned steel connector (shoes). Timber members were connected to the outside of the steel plates to maintain the visual appearance of the original bridge without acting as primary structural elements. All critical steel elements were replaced with low temperature, high strength grade steel suited to the temperatures experienced in Tharwa, limiting the possibility of failure as a consequence of brittle fracture. This material replaces the original cast iron shoes historically used in construction.

3.3 Designing for Durability

Durability of exposed timber in bridge trusses is always a major consideration since timber deterioration is influenced by many factors, particularly exposure to weather and water. The interface between steel and timber tends to be an area of degradation due to the propensity to act as moisture traps. To address these issues, specific details were developed that reflect "best practice" for creating inherent durability in the construction.

Timber/steel interfaces were fully painted to reduce the probability of decay resulting from fungal infestation. Steel flashing covering the top of the truss top chords, end diagonals and bottom chords limited the deleterious effects of moisture by providing a protective cover and appropriate air movement. All timber elements are painted white, a simple yet effective method of sustaining the life of the timber elements through reflection of light energy, and a detailed maintenance regime has been established to ensure that the paint and fungal decay protection systems remain effective.

3.4 Other Design Issues

New requirements in bridge design to current standards have been merged with maintaining the aesthetics of the original design. Traffic barriers are shaped to match the original design but are constructed of stronger steel sections. The four truss spans are fixed to the piers to promote load sharing between the piers and to prevent the vertical movement of the deck during flood events.

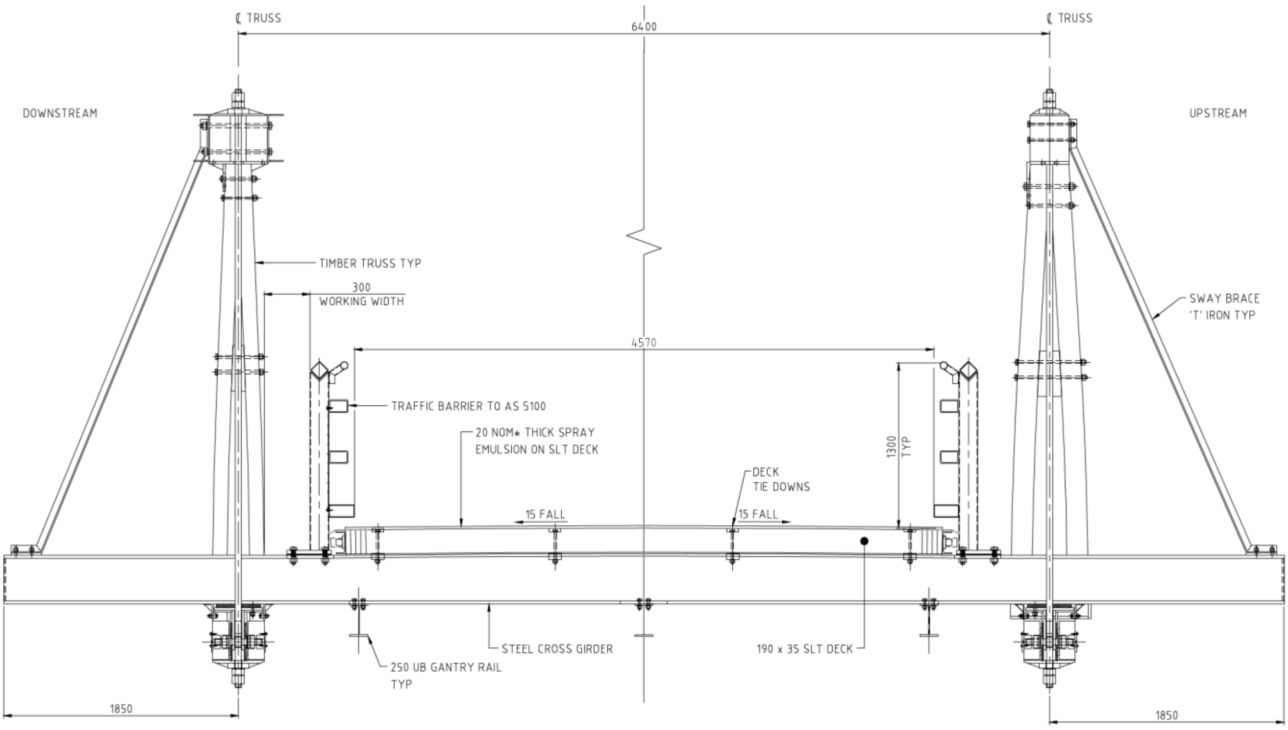

Figure 7 – Typical Cross Section of the new trusses, showing traffic barrier & SLT deck

3.5 Deck Design

The traditional construction method for decking timber bridges involves using a multitude of timber elements fastened to beams using bolts or spikes. This technique requires frequent maintenance (retightening of the connections) and contains provides numerous areas where degradation can occur at each connection and the interfaces between members, since the gaps tend to become inherent moisture traps.

The modern high performance alternative to traditional decking is the stressed laminated timber plate deck, which consists of kiln dried (in this case native hardwood) timber laminates compressed together using high strength strands or bars. In the case of the Tharwa bridge, the stress laminated timber (SLT) deck is laid directly on and fixed to the cross girders, which have been constructed of steel to ensure durability. Timber cross girders, used in the past, are one of the most frequently replaced elements due to the rate of degradation in this location, and they are known to be one of the first modes of failure in a timber Allan truss. Differential movement between the deck and the trusses is taken up at elastomeric bearings under each cross girder, with appropriate tie downs that prevent deck vibration movements and permit horizontal shear transfer into the main structure.

Figure 8 – Truss Assembly on site

Figure 9 – Assembling the SLT deck on site

The SLT deck was constructed as a monolithic orthotropic plate, 110 metres long, which eliminated the need for joints between the truss - a reduction in joints from a possible five to just one at each end. Deck joints in timber decks tend to be prone to high rates of degradation under traffic loading and this consideration justified the adoption of a full length deck. However, this length of SLT deck is double that of any previously launched in Australia and as such, posed new challenges in the ensuring uniform stressing and correct positioning of the deck. The deck was constructed on site, aligned with the bridge centreline for eventual launching using swivel castor rollers. Careful planning and monitoring of both stress levels and alignment of the deck ensured that it was launched and installed in place successfully.

4. Procurement of Timber and Fabrication of the Trusses

4.1 Material Sourcing and Preparation

Quality management of timber sourcing and the seasoning process were critical processes in ensuring that the timber was suitable in terms of strength, stiffness and durability. The trusses required procurement of 86 m^3 of high grade native hardwood timber (Eucalyptus) in December 2008 which was subsequently seasoned for 12 months in storage. This process involved surveillance of all activities in the supply chain - including identification of the logs in the forest, felling of trees, sawmilling, inspection and confirmation of grade of the sawn members, and seasoning.

4.2 Truss Fabrication and Installation

A camber of 31mm was designed and built into each truss, since the truss shoes would have been overstressed if the truss was built square and level prior to inducing the camber. A truss assembly pad was designed and built on site to allow assembly of the eight trusses in a narrow line which also enabled the crane to reach all of them from a single set up. Progressive installation of temporary props allowed progressive truss assembly to occur. Temporary truss supports were also installed to prevent the trusses pulling apart during lifting. Planning for truss lift commenced some over 12 months prior to the lift date.

The fully assembled trusses (each 22 tonnes) were installed in three days using a 400 tonne mobile crane with a reach of 45m, allowing installation from a single site set-up adjacent to the Murrumbidgee River. The weight of each timber member was confirmed during truss fabrication to accurately verify the assumed timber density and calculated truss weight. Joint site inspections were undertaken with the crane operator and a specific truss lifting Safe Work Method Statement was developed. Whilst six days were programmed for the installation of the trusses, all eight lifts were completed within three days.

Figure 10 – Truss being lifted into place using a 400t mobile crane

5. Construction of the Stress Laminated Timber (SLT) Deck:

5.1 Design Constraints

The SLT deck was fully fabricated on site (on the eastern end of the bridge approaches) between May and July 2010. The design required a variety of timber lengths for the SLT deck laminates, to address the following constraints:

1. the stressing elements had to “fit” within the truss geometry to ensure appropriate access for stressing hardware in order for re-stressing to occur
2. the deck needed to utilise readily available standard sized timber
3. The butt joint pattern was not to exceed one joint in every four laminates across the deck width (1 in 4 pattern).

The deck was designed as a continuous plate in conformity with the new RTA standard [4] using kiln dried F27 blackbutt, with design properties of $f'_b = 80$ MPa and MOE = 18500 MPa. Construction consisted of 3,500 individual laminates which were fabricated (docking and drilling of holes) off site, then sorted with each bundle delivered to site in a planned sequence to optimise construction. Once on site the workmen laid out the laminates in the order they were to be nailed, saving sorting time on site and reducing exposure of laminates to wet weather. A specifically designed SLT support bed and work area was constructed, including key blocks along the centreline of the deck to provide lateral stability during stressing. The SLT deck was built 200mm longer than specified to allow it to be cut to the final "actual" length.

Figure 12 – Construction of the SLT deck showing laminate lay-up

5.2 Stressing

Initial stressing was completed using 36 x 30 tonne hydraulic jacks with associated hoses and fittings, and a single hydraulic pump. The 144 strands were numbered from 1 to 4 to represent 4 jacking stations. The process of stressing entailed the repeated force application of 25%, 50% and 100% of the maximum permissible design jacking force. Final restressing was completed in April 2011 and achieved the modified target force of 191kN. The width of the deck reduced 65-75mm from its initial value after completion of the final stressing.

5.3 Launching

Launching of the SLT deck was carried out in 3 days in early May 2011 using a 24 tonne truck with an 8 tonne winch pulling from the front end, with another 24 tonne truck and winch restraining the deck from the rear end. The winch steel wire rope was attached to a specially designed and fabricated launching nose and pulling frame. The actual maximum pulling force exerted on the 100 tonne deck was 2 tonnes. The deck was then winched along on swivel castors which were guided by a channel fixed to the underside of the deck to keep it in line.

Figure 13 – SLT deck Launching Nose

Figure 14 – Launching of the SLT deck

6. Conclusions

This project presented a unique opportunity to rehabilitate a 100 year old timber bridge which has highly significant heritage value for Australia. The challenges of maintaining the inherent structural integrity and form of the trusses, whilst incorporating new design and construction technologies to re-instate the bridge to carry modern vehicle loadings, were successfully addressed and the bridge was opened in June 2011.

The two major project milestones were the truss lifting in November 2010 and SLT deck launching in May 2011, and both were achieved successfully through detailed planning and preparation, with a superb safety record for the duration of this stage of the project. The safe, correctly fitting truss and deck installation process was testament to the great efforts of the RTA construction team. Working with a 116 year old structure and with a natural material like timber will always create challenges. Despite this, the required truss tolerances of 1mm to 5mm and the SLT deck width tolerance of 30mm over 110m were both achieved, as a consequence of meticulous attention to detail by the AURECON designers, ACT Heritage and the RTA construction team.

The new timber trusses and deck are rated to safely carry an enhanced traffic loading up to 42.5 tonnes (T44) legal load. The visual appearance is now almost identical to the original Allan trusses and has preserved the historical significance of the four span Allan truss in Tharwa. Success of this project can be measured not only by the restoration of this valued structure, but by the initiative taken to meet the challenges of working with new solutions, and the cooperation and dedication of all parties working in an Alliance relationship, to achieve a best for project outcome.

7. Acknowledgements

The author wishes to acknowledge Ms Marcia Prelog and Mr John Hilton, AURECON Consulting Engineers, Sydney and Mr Sam Millie, Roads and Traffic Authority, NSW for their assistance in preparation of this paper.

8. References

[1] Crews (2008) - *Rehabilitation Designs on Some Timber Heritage Bridges in Australia*; Structural Faults & Repairs, Edinburgh, 2008.

[2] Nicholas (2011) - *Capacity of Compression Members in RTA Timber Truss Bridges*; Master of Engineering (Structural) Thesis, University of Technology, Sydney

[3] Nicholas & Crews (2012) - *Capacity of Compression Members in Heritage Timber Truss Bridges*; IABMAS 2012 – 6th International Conference on Bridge Maintenance, Safety & Management, Stresa Italy, 2012.

[4] Crews (2012) - *Guide for the Design of Stress Laminated Timber Bridge Decks*; Roads and Traffic Authority, NSW, Australia – ISBN: ISBN: 1 86365 146 2