Redbournberry Bridge – Dual Composite Design

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SYNOPSIS

The new $9.5M Redbournberry Bridge spans the Hunter River near Singleton in NSW, alongside an existing 19th century historically significant iron truss bridge. The main spans consist of continuous steel composite trough girders. A limitation of conventional composite structures is the inefficiency of hogging sections. One solution to this problem is to provide a second composite slab at the bottom flange level, thus providing several advantages over more traditional methods. This paper will outline this and other innovative features of the design and construction of the main river spans and describe the preservation of the existing iron spans as a working part of the new bridge scheme. The bridge is currently under construction by John Holland.

1 BACKGROUND AND HERITAGE CONSIDERATIONS

The existing bridge, shown in Figure 1, has three iron lattice truss continuous spans of 27.7m, 36.3m & 27.7m over the Hunter River near Singleton. The approach to these spans on the Singleton side consists of a long timber pile trestle and beam type bridge.

Figure 1: Existing Bridge

Various modifications have been made to the bridge since its construction following damage from flooding, including the addition of timber spans. However the three metal spans have not been significantly modified.

The bridge was designed by the noted J.A. McDonald and was constructed in 1892. It is one of seven similar NSW wrought iron lattice bridges designed by J.A. McDonald in the period 1887-95.

These bridges are:

1887 Paterson River near Paterson in Hunter Valley
1888 Taemas Bridge over Murrumbidgee south of Yass (washed away)
1888 Snowy River at Dalgety
1891 Hunter River at Elderslie
1892 Redbournberry Bridge over Hunter River near Singleton
1893 Hunter River at Aberdeen
1895 Murray River at Corowa

The metal spans are of a distinctive design and records indicate that the use of continuity to obtain a slender design was a conscious feature of the design. The top chord is curved down at the ends. This distinctive design was only used in NSW.

Although iron lattice trusses are an example of British technology this bridge was manufactured in Belgium.

The J.A.McDonald designed bridges ended a 35 year period of iron lattice bridge design (eg iron lattice bridge over Hunter River at Muswellbrook 1861 is one of the oldest metal truss bridges in Australia). Shortly after the design and construction of the Redbournberry Bridge iron lattice bridges lost favour and designers moved towards the use of American bridge technology and began to use Pratt trusses for major bridges.

Although there are a number of similar bridges in NSW (including in the Hunter Region) the Redbournberry Bridge is a fine example of an early metal continuous bridge. Whilst the bridge is not protected by any heritage order, the RTA has been keen to preserve the metal spans of this bridge and this has been an important factor in the bridge that was developed and is now being constructed.

A disadvantage with the metal spans is the narrow width of approximately 5.9m between the timber kerbs, which will not safely allow two trucks to pass and is considered as substandard for two lanes of traffic. Also, strengthening would be required to provide an adequate safety factor for the current SM1600 loading.

The RTA made the decision that if possible the existing metal spans should be retained as part of the new bridge crossing.

The timber spans are in a very poor condition and have reached the end of their life with a very high maintenance cost. An unusual feature of the timber approach spans is a kink or bend part of the way along the timber bridge to join the skew approach road with the metal spans which cross the river square. Although this kink is unusual and has some heritage significance it has also been a traffic hazard and the scene of a number of accidents. After a heritage study the RTA determined that all the timber spans were to be demolished.

1.1 Options Considered

Option 1 was to retain the metal spans and to replace only the timber approach spans. This option was by far the cheapest option and the only option initially considered when funds for the project were limited. This option had the disadvantage of the metal span bridge width being substandard for two way traffic and the option was later abandoned.

Option 2 was to construct a new bridge and to abandon/demolish the existing bridge including the metal spans. Although there was not strong opposition to this from the local community the RTA was opposed to the removal of the metal spans because of their heritage value.

Option 3 was to construct twin bridges with the existing metal spans forming part of one of the bridges. One disadvantage with this option was that the life of one of the bridges would be governed by the life of the existing metal spans and that this life is considered to be significantly less than 100 years under SM1600 loading. Another disadvantage was that the carriageway width of each bridge had to be made sufficiently wide to allow the passing of a stationary broken down truck (ie about 70% of width of a new two way bridge).

These three options were than evaluated and subjected to a Value Management Study which included the local council, community representatives, other relevant government organisations as well as the RTA. From this meeting Option 4 emerged as the preferred option.

Option 4 was to construct a new bridge for traffic and to use the existing metal spans for a combined footway/cycleway. The new bridge would carry the footway cycleway over the flood plain with a link span to connect the existing bridge to carry the footway cycleway over the river. This option had the advantage of retaining the existing metal spans, which would have an indefinite life under the relatively light footway/cycleway loading. There was not a big difference in the estimated bridge cost of all the options except Option 1, which was significantly cheaper but also was considered sub-standard. Option 4 was the solution adopted and described in this paper.

1.2 Heritage Considerations – New Bridge

The RTA, in conjunction with Connell Wagner, decided at the concept stage that where possible and economical the main spans of the new bridge should be in sympathy aesthetically with the existing bridge.

It was decided that:

- The river spans would match the existing bridge spans, with the new piers in line with the existing piers.
- Steel girders were preferred over concrete girders; other considerations such as flood clearance and vertical alignment limited the available superstructure depth, favouring steel over concrete in any case.

- The river span piers would consist of twin steel cylinders with steel web bracing plates between them and curved cut-outs to match reasonably closely the existing bridge piers.
- The Link Span (that connects the river footway cycleway on the existing bridge to the floodplain footway cycleway on the new bridge) would comprise a steel truss with "X" orientation of diagonal members and turned down top chord, in sympathy with the cross lattice web and curved down top chord of the existing bridge.

1.3 Construction

At the time of writing, the construction of the bridge is nearing completion, with Stage 1, which is the opening of the new bridge to traffic, being programmed for completion on the 17 March 2004. Stage 2, which involves the completion of the Link Span and work on the existing iron lattice bridge deck to allow it to be used for pedestrian access across the river, is programmed to be completed by early May 2004.

2 THE RIVER SPANS – DUAL COMPOSITE DESIGN

2.1 Introduction

The key challenge of the project was to bridge the Hunter River using a form of construction that was both economic and sympathetic to the retained original bridge spans. For the medium length spans considered, a number of options were available, however the tight constraints of the project meant that an innovative solution was required.

2.2 The Constraints

- The bridge was required to accommodate one 4.5m wide traffic lane in each direction. Pedestrians and cycles were to be accommodated by the retained metal truss spans.
- The span arrangement of 19m/28m/36m/28m/22m was dictated by the positions of the retained original bridge piers. The RTA brief required that spans be continuous.
- Finished road levels also needed to match those of the existing road.
- Flood levels – specifically the need to maintain clearance from the Q100 flood.
- Loading: SM1600.

In summary, an extremely shallow structure was required. The original truss utilised the luxury of depth to span the required distance. The challenge to the design team was to span the same distance as the original trusses, using an economic girder form of construction, considering modern loading, with the available structural depth being little more than the original truss bottom chord thickness. The bridge elevation is shown in Figure 2.

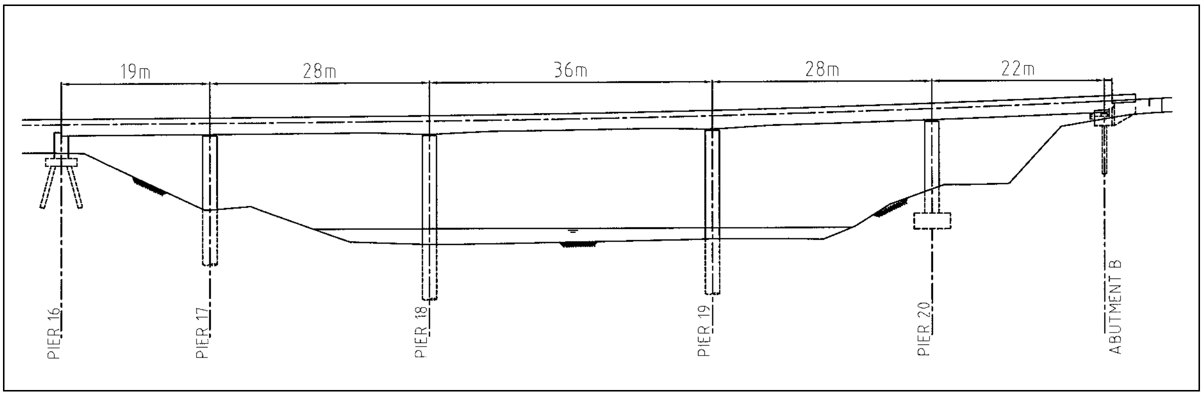

Figure 2: River spans elevation

2.3 The Solution – Dual Composite Action

A steel composite box girder was considered to be an appropriate form of construction for the spans considered. For this continuous structure, haunching was clearly advantageous at piers, however the extremely tight geometric constraints meant that no significant haunching could be allowed at the lower (western) end of the bridge. The final arrangement incorporated a localised haunch at the central piers only. The bridge cross-section is shown in Figure 3 and girder details at negative moment regions (ie with dual composite slabs) in Figure 4.

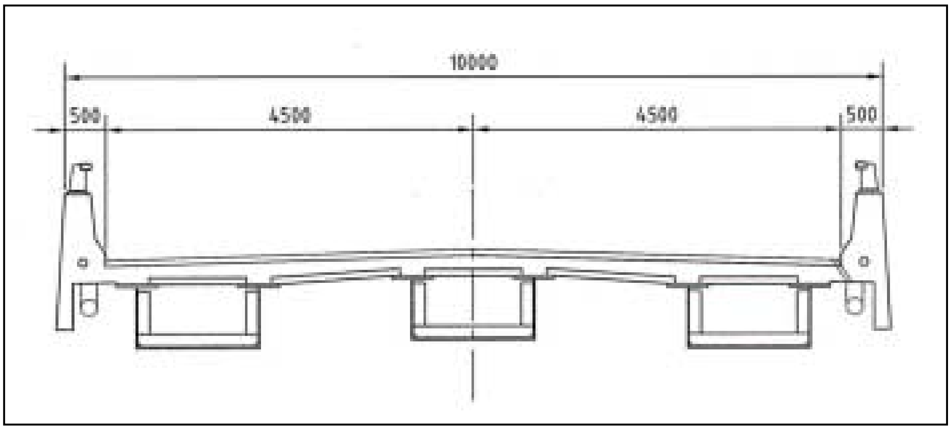

Figure 3: Deck Cross-section

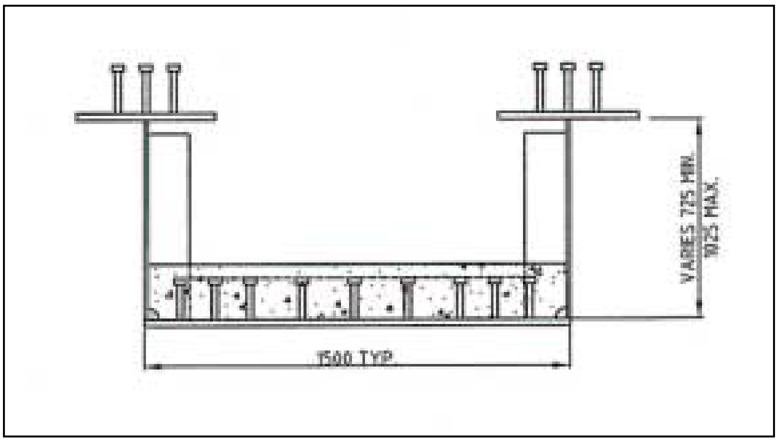

Figure 4: Girder Details at internal piers

2.3.1 The experience overseas

Dual composite bridges – both plate and box girder varieties – have been successfully used in Europe (particularly Germany) and recently in the USA as an economic alternative to traditional forms of construction. To the authors' knowledge, Redbournberry is the first example of this form in Australia.

Saul (1) of Leonhardt Andra Germany, has described three dual composite bridges, all completed in the 1990s. The railway bridge over the Main River, which is shown in Figure 4, employed the technique to reduce deformations. For the Caroni River Bridge in Venezuela, dual composite action helped reduce the amount of expensive imported steel. The Elbe River bridge in Germany was required, like Redbournberry, to be very slender for aesthetic reasons. This latter example achieves an amazing span to depth ratio (L/D) at one pier of 41.

Figure 5: Dual composite Railway Bridge across the Main River, Germany

In the USA, the University of South Florida has undertaken research on behalf of the Florida Department of Transportation on the subject of economic medium span bridges. The research team's conclusion was that double composite design offered the best alternative to conventional solutions for the span range considered. Stroh (2) has summarised this work and proposed a number of alternative dual composite systems. These include standardised multiple "tub" girders, larger box girders and plate girders. The latter system requires a suspended concrete bottom flange to be constructed between adjacent steel I beam bottom flanges. It is not clear whether any such bridges have been constructed. It was concluded that superstructure savings of up to 10% could be achieved using dual composite design.

2.4 Costs

At preliminary design stage, a conventional composite design was prepared in order to compare costs with the dual composite alternative. In order to satisfy the constraints on girder depth outlined above, a conventional composite girder required very heavy flanges in order to compensate for the inefficiency inherent in the high L/D ratio. Longitudinal stiffeners within the bottom flange were proposed for the hogging regions. Table 1 below summarises the cost comparison exercise, adjusted for tendered rates.

Construction form:	**Conventional composite**	**Dual composite**
Total steel weight (Tonnes)	315	280
Steel costs ($k)	1,806	1,605
Total concrete volume (m^3)	482	527
Concrete costs ($k)	606	644
Total costs ($k)	2,412	2,249
Superstructure cost /m^2 ($)	2,002	1,866

Table 1: Cost comparison: Conventional vs Dual composite construction

The above table demonstrates that a saving of 7% in superstructure costs is achieved using dual composite design. The comparison did not account for any savings arising from simpler fabrication or lighter girder erection. Potential savings are therefore considered to be even greater than this.

2.5 Advantages of Dual Composite Action

- Material savings– specifically savings in steel weight.
- Erection cost savings. The steep Hunter River Valley made it necessary to construct significant platforms for the heavy cranes required for the lifts. By minimising steel weight, direct savings were achieved.
- Labour Savings: simplification of the fabricated box, especially via the elimination of longitudinal stiffeners and the need to weld heavier plates.
- Reduction in girder depth: the total construction depth of the deck varies between 1.0m to 1.3m. Thus the L/D varies between 27.5 at central piers to 36 at midspan.
- Increase in overall stiffness. This leads to, amongst other advantages, a decrease in deflection under live load.

2.6 Other features of the design

- Grade 450 MPa steel was employed to help optimise the steel design. This enabled, for instance, 12mm plate to be used for all webs, without longitudinal web stiffeners.
- The top slab is itself a composite member, being made up of 85mm thick precast panels dropped into place between flanges and topped with in-situ concrete to form the total 225mm nominal thickness. Thus there is no “lost” formwork. The precast is placed quickly and the full concrete section is used.

A photograph showing the girders shortly after erection of the first span is included as Figure 6.

Figure 6: Under Construction: Trough Girders erected

3 THE RIVER PIERS – INNOVATIVE AESTHETIC SOLUTIONS

3.1 General Description

The piers for the main spans across the river have been constructed with a pair of cast insitu concrete columns with steel casing braced together with steel plate. The piers were positioned in the river to match the positions of the existing bridge piers for aesthetic reasons and to limit the constriction to the flood flows of the river. The steel plate bracing between the pier columns was detailed to match the detailing of the plate bracing on the existing bridge. The span arrangement is shown on Figure 2.

3.2 Articulation

The main spans are continuous for 133 metres over the river and are 20 metres above the founding rock level at midlength. The height above water is typically about 12m, with water depth under normal conditions being 2 to 3m. Despite the height above the river at midlength it was decided to restrain the superstructure against longitudinal movement by fixing the bearings at Piers 18 and 19. These restraints near at midlength were chosen because of the potential for problems with maintaining the bearings and the expansion joint at Pier 16 due to the large thermal movements if the superstructure was fixed against longitudinal movement at Abutment B. The decision to fix the bearings at Piers 18 and 19 against longitudinal movement was also motivated by the fact that these piers also had to be designed for very large flood loadings which necessitated uplift restraint being provided on the upstream columns of Piers 17, 18, 19 and 20.

3.3 Foundations

Pier 17 is located on the western bank of the river and has a soil profile consisting of approximately 10 metres stiff alluvial clay overlying gravels and rock. Piers 18 and 19 are located in the river and have a soil profile consisting of several metres of sands and gravels overlying sandstone. Pier 20 and the Abutment B are located on the eastern bank of the river where rock was found at or just below the existing ground level.

The close proximity of rock to the ground surface level allowed Pier 20 to be constructed with pad footings founded directly on the rock. The footings were detailed with anchor bolts and starter reinforcing bars projecting out of the top of the footing to bolt the steel tube to and make a splice connection with the reinforcement cage for the concrete infill. The pad footings were held down against overturning from the flood and friction loadings with N36 galvanised passive anchors embedded 4.5 metres into the rock.

For Piers 17, 18 and 19, the steel tubes were vibrated down to the rock level, the soil within the tubes removed and a 1 metre deep socket was cut into the rock to provide a shear key for the columns. The shallow weathering profile of the rock and the confined work area within the piles was such that it was not feasible to socket the piles further into the rock to provide sufficient uplift capacity under the flood loading and fixity for overturning moments under the braking loads. This uplift restraint and fixity had to be provided with a pair of 27 x 15.2mm strand rock anchors placed at 425mm from the centreline of the pile in the direction of the bridge span in each of the columns for the Piers 18 and 19 and a single 27 x 15.2mm strand rock anchor placed centrally within the Pier 17 columns. The columns were constructed to ground level then the rock anchors were installed and stressed at this level prior to the continuation of the pier construction.

3.4 Substructure

Piers 17, 18, 19 and 20 were designed using 1800mm diameter steel tube columns with steel plate bracing between the columns to replicate the existing bridge piers. The steel tubes have been filled with reinforced concrete to provide the majority of the strength and stiffness of the columns. The headstocks were designed using a similar system with permanent steel formwork and reinforced concrete infill.

The piers act as a pair of cantilever members under the longitudinal forces and will act as a braced frames under the transverse flood loadings. The pier bracing plates are an integral part of the bracing system for the piers under these transverse loadings. The plates were designed with elliptical voids within them to match the existing bridge. In keeping with the original design the circumference of the voids and the area between the voids were stiffened with plate stiffeners. Piers were modelled using the Finite Element Analysis Programme STRAND 7 to determine the stress distribution and buckling capacity of the bracing plates and to optimise the sizes for the plate and the stiffeners. A 3D-element stress plot from the analysis is shown in Figure 7. The bracing plates were fabricated out of 20mm Grade 250 plate with 250mm wide, 20mm and 24mm thick stiffener plates.

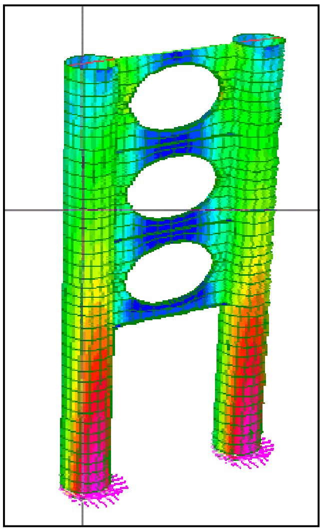

Figure 7: STRAND7 Model of Pier

One of the main design detailing issues for the piers was to provide sufficient construction tolerance on the steelwork. The connections between the columns and the bracing and the columns and headstock were designed using field welds and allowed for the base of the columns to be installed out of position by the +/-75mm tolerance specified in the Piling Code and the RTA Specification B58. It was envisaged that the contractor would site weld the column extensions onto the piles then weld the bracing plates and headstocks onto the columns. The contractor instead chose to assemble the columns, bracing and headstocks on site adjacent to the bridge using the as built survey from the piles then lift the completed steelwork into position and then weld the columns to the piles. A photograph showing the placement of one of the pier shells is shown as Figure 8.

Figure 8: Under Construction: Erection of Pier 18

4 CONCLUSIONS

Innovative solutions to design challenges, including readily constructible modifications to standard medium span bridge design forms, can result in significant cost savings and deliver aesthetically superior solutions. Dual composite action, whereby the concept of steel composite design is extended to allow efficient continuous bridge design, has helped to achieve this objective for the replacement bridge at Redbournberry. Sensitivity to heritage considerations in the design, notably by retaining the existing iron trusses and linking them to the new bridge and by matching the appearance of the existing piers, has added to the value of this significant project.

REFERENCES

1 Saul R., "Bridges with Double Composite Action". *Structural Engineering International* Volume 1, 1996, pp 32-36

2 Stroh L., "Innovative Design Concepts for Steel Bridges". *"A Review of the Current State-of-the-Art for Producing Cost Effective Steel Bridges" presentations made on* Friday, January 18, 2002 at the University of South Florida.