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Replacement of cast iron piers on an 1886 wrought iron truss bridge in New South Wales, Australia – the challenge of preserving heritage significance during major rehabilitation work

Substituição de pilares de ferro fundido numa ponte de treliça de ferro forjado de 1886 em New South Wales, Austrália – o desafio de preservar o significado do património em grandes obras de reabilitação

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Abstract

The Namoi River Road Bridge is a colonial era high level wrought iron lattice truss bridge crossing the Namoi River (Manilla) built in 1886 to replace a dangerous river crossing. The bridge was part of the main road between Sydney (New South Wales – NSW), and Brisbane (Queensland), with the opening of the bridge allowing wool trade from the northern extents of the colony of NSW to be exported via the Port of Sydney. The six approach spans crossing the southern flood plain have history of differential settlement due to ground conditions which has resulted in damage to five bridge piers and variations to the vertical alignment of the bridge. This paper describes the method employed to restore the vertical alignment of the bridge and replace the damaged piers whilst ensuring retention of the structure's cultural heritage significance, enabling the bridge to continue to operate as part of the NSW State Road network.

KEYWORDS
Bridge
Cast iron
Wrought iron
Pier replacement
Manilla NSW

Resumo

A ponte rodoviária do rio Namoi em Manilla, New South Wales (NSW), é uma ponte em treliça de ferro forjado da era colonial, construída em 1886 para substituir uma perigosa travessia do rio Namoi. A ponte fazia parte da estrada principal entre Sidney, (NSW) e Brisbane (Queensland) e a sua abertura permitiu que o comércio de lã da zona norte da colónia de NGS fosse exportado através do porto de Sidney. Os seis vãos de aproximação que atravessam a planície de inundação a sul têm um assentamento diferencial devido às condições do solo, resultando em danos em cinco pilares e em variações no alinhamento vertical da ponte. Este artigo descreve o método utilizado para restaurar o alinhamento vertical da ponte e substituir os pilares danificados, assegurando simultaneamente a preservação da importância cultural da estrutura, e o funcionamento da ponte como parte da rede rodoviária estatal de NSW.

PALAVRAS-CHAVE
Ponte
Ferro fundido
Ferro forjado
Substituição de pilares
Manilla New South Wales

Introduction

The Namoi River Road Bridge at Manilla in New South Wales (NSW) is a rare and State significant heritage wrought iron lattice truss road bridge designed by the eminent colonial bridge engineer John A McDonald. The bridge represented a significant engineering achievement and financial investment for the Colony of NSW at a time when the vast majority of road and rail bridges were constructed from timber. The bridge has previously been assessed as being of State heritage significance, the highest level of significance afforded under NSW heritage legislation.

The bridge is a large, high-level crossing over a wide river with a severe flood regime. It is an 11-span lattice truss structure with five main spans and six approach spans supported on cast iron piers. The five approach span piers have a history of settlement, with routine bridge inspections recording general differential settlement and pier rotation and cracking at the cross-braced connections between the pier cylinders since 1949. A bridge load performance test undertaken in 2017 found that the pier foundations were insufficiently firm, that there was settlement-related cracking in the pier columns and the diagonal braces on all the approach span piers and that some structural steel members were unduly loaded because of differential settlement. The differential vertical settlement also resulted in variations to the alignment of the approach span undertrusses and an uneven ride on the bridge deck. It was recommended that Piers 1 to 5 be underpinned to prevent further settlement, that the original vertical alignment of the piers be restored and that all damaged pier elements be repaired or replaced. The construction of new pier foundations was successful, however given the extent of cracking observed in the pier columns whilst attempting to restore the vertical alignment, a decision was made to fully replace the damaged piers.

This paper explores how the need to repair the bridge in order to maintain a vital piece of road infrastructure was balanced against the need to respect the heritage significance of the structure and to undertake the work in such a way that the bridge could continue to operate without load restrictions, halt the ongoing settlement of the piers and return the approach spans to their original alignment, and incorporate new elements into the structure without compromising its heritage significance

History of Namoi River Road Bridge

The Namoi River Road Bridge is located at Manilla, a small town with a population of 2,500 people located in northern NSW, 460 km north-west of Sydney. In 1886 when the bridge was constructed Manilla was on the main inland road route from northern NSW to Queensland. At the time, Queensland was a separate British colony and wool was a valuable export commodity. The lack of a bridge over the often deep and fast flowing river at Manilla meant wool grown in northern NSW was sent to Queensland for export, resulting in loss of revenue for NSW.

Most colonial-era road and rail bridges in NSW were constructed from native hardwood timber - abundant and well suited to the construction of large and small bridges. Timber bridges could be built quicker and cheaper than those of iron as the NSW iron industry was in its infancy and unable to produce the quality and quantity of material needed for metal bridge construction, with structural iron needing to be imported from Britain or Belgium. The early metal bridges cost up to six times more per sq/m than an equivalent timber truss bridge and were only constructed on major roads. Of the 27 wrought iron lattice truss road bridges built in NSW between 1871 and 1893, 18 are still in use today [1].

During its construction a major newspaper reported that:

> *a contract has been taken by the firm of G. H. Royce and Co., of Sydney, for the erection of an iron lattice bridge over the Namoi River at the above-named township. Such bridge consists of some five main spans, each about 120 feet long, resting upon cylinders sunk*

> *into the rock to the number of ten, thus forming five piers for the main girders to be connected with and bolted down to. It is also composed of six spans of approach, each 60 feet long, also having large … cylinders for the formation of those piers, thus making a thorough and strongly constructed bridge for the requirements of the main Government road right through to the borders of Queensland.* [2]

The Manilla Bridge is unique amongst all the wrought iron truss road bridges built in NSW in having all its spans, not just the main spans, of lattice construction, with all other bridges of this type having simpler and lighter approach spans of timber or iron beam construction. It is not documented why lattice spans were chosen for the approaches on this bridge however the use of trusses meant that each approach could achieve a longer span than if timber or iron beam options had been used. In February 1864 the township was destroyed by a large flood with loss of life due to both the sudden rise of the river and the fact it occurred at night [3]. It is thought that the designers of the bridge opted for longer spans, and therefore fewer piers, to reduce potential flood effects on the bridge, particularly the piers which are vulnerable to damage from flood debris (Figure 1 and Figure 2).

The bridge was still considered a significant achievement 50 years after its completion, in 1936 with an article in the local newspaper dedicated to it:

> *It is fifty years since the building was started of that huge work of steel that spans the Namoi at Manilla, known far and wide as the Manilla bridge. Work was commenced on the bridge in 1885 and it was completed and opened for traffic in 1886. During that fifty years the structure has withstood the floods that have swept down the Namoi and between its huge steel cylinders billions of tons of water has passed on its way to the ocean at Adelaide, via the network of the Western inland streams of this State. Despite this strain and the ravages of time not a bolt or a rivet has given way and the bridge stands today a monument to the engineering skill of its designers and to the contractor, whose faithful workmanship has been largely responsible for its success. As appearances go at the present time, there seems every likelihood that another 50 years hence will find this steel structure as stout and serviceable as it is to-day.* [6]

Figure 1. The bridge at time of opening. Note that the approach spans are to the left side of this image after the main truss spans (Photo: NSW Department of Public Works).

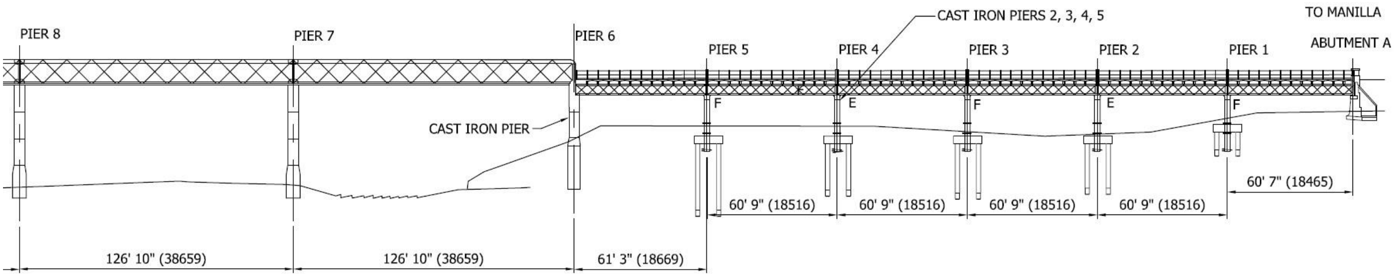

Figure 2. Original bridge configuration [5].

Figure 3. Buckled metal brace, Pier 1 (photo: C. Everett, 2017).

Maintenance records for the bridge only date back to 1949. A routine inspection of the bridge at that time reported settlement in Piers 1 to 4 and cracking at Piers 1 and 3. Repairs were suggested in the report but were never undertaken. Over the following decades inspection records reported distortion of the metal bracing (Figure 3) as well as additional cracks forming in the pier columns (Figure 4).

Figure 4. Crack in Pier 3 column (photo: C. Everett, 2017).

A bridge load performance test undertaken in July 2017 found the foundations of piers 1 and 2 were not sufficiently firm, which had resulted in differential settlement of those piers. The report concluded that if the differential settlement of the approach spans was not halted the settlement would continue and result in further damage to the piers and eventually damage the approach spans above. It was recommended that:

- Piers 1-5 be underpinned;
- Damaged braces and connections be repaired or replaced;
- All bearings on the approach span piers (1-5) be reset to level.

In 2020 new reinforced concrete foundations were installed under all the five approach span piers, with Piers 2-5 jacked and retained with a grouted shear key to restore the original approach span design levels. Additional cracks were identified in the columns of those piers during the jacking process.

It became apparent that these additional cracks as well as the cracks identified previously meant the piers were no longer strong enough to support the load of the spans above and that additional cracks were likely to form. An immediate load limit was applied on the bridge and temporary supports installed at each pier.

The challenge to restore a significant bridge

The bridge is a highly significant heritage structure as well as a major piece of road infrastructure. The approach span piers add to this significance due to their design, the substantial diameter of cast iron columns (760 mm) to support the wrought iron lattice trusses spanning 18.5 metres between piers. The piers and trusses are highly visible in the landscape, with the riverbank and floodplain adjacent the bridge used as a recreational campground. Further, this is a popular location for walking and picnics and recreational fishing.

Any option selected to remedy the cracks in the piers had to balance the operational requirements of the bridge with the need to retain its heritage significance. In developing these options and in selecting the preferred option, Transport for NSW (TfNSW), the owner of the bridge, needed to apply the principles of the Australia ICOMOS *Burra Charter*, which provides guidance to heritage practitioners and owners of heritage items when making decisions on the management of places of cultural heritage significance [4]. The principles considered when developing options included: 1) having respect for original fabric through changing as much as is necessary but as little as possible; 2) continued use of a heritage item where its function contributes toward its heritage significance.

The bridge had previously been assessed as being of State heritage significance. As part of the significance assessment the contribution of each component of the bridge to that significance had also been determined in accordance with the *NSW Heritage Manual* [7]. The approach span piers were determined to be of high heritage significance, while the wrought iron trusses, the defining feature of the bridge, were determined to be of exceptional significance. The determination of high heritage significance for the approach span piers was based on their aesthetic properties and unusual design, unique to this bridge. The understanding of what gave the piers their heritage significance as well as the contribution the piers made to the overall significance of the bridge was the starting point for developing a solution to either repair or replace the piers.

Non-destructive testing of the cast iron in the damaged piers was undertaken to see if the damage could be repaired. The testing found the cast iron was not weldable and thus repair of the damaged fabric was not possible.

As the damaged piers could not be repaired, four options were considered to address the cracking and allow the bridge to function free of the temporary support system. The options included iterations of individual element replacement through to full replacement of all pier columns and bracing. It was determined that full pier replacement would produce the best project outcome, noting that all other options, whilst retaining greater quantities of original fabric, would result in higher and avoidable permanent structural risk and would also not permit restoration of the bridge's original vertical alignment. Pier 1 was undamaged and did not require replacement.

As the damaged fabric could neither be retained nor replicated, one of the design criteria was for the form of the replacement piers to resemble the original piers to a large extent whilst also meeting current bridge design requirements. The high visibility of the piers in the landscape and the one remaining original pier adjacent meant that any major changes in form or detail would be visually jarring and negatively affect the overall aesthetics of the bridge. The replacement piers also needed to be designed in a manner that would enable them to be installed without damaging the temporary support system supporting the approach spans. TfNSW considered constructing the replacement piers from spheroidal graphite cast iron to provide consistency with the original pier fabric, however this material could not meet the structural requirements of the current Australian standard for bridge design hence the new piers were fabricated from steel [8].

Design

Temporary support system

Temporary supports were required to carry the bridge and traffic loads and allow the bridge to remain open to traffic until the pier replacement works could be completed. The temporary supports used a combination of proprietary modular components designed and verified by the supplier and custom fabricated sections.

Original piers vs new piers

The damaged piers comprised two vertical concrete filled cast iron columns connected by horizontal and vertical bracing. Each column comprised an upper segment and a lower segment connected with a bolted flange joint. Horizontal and diagonal bracing was secured to the columns via an oversized lug cast integral with the columns. The top of the upper segment connected to the approach span bearings, and the bottom of the lower segment connected to a cast iron screw pile approximately 150 mm above the buried concrete pile cap. The cast iron screw piles were the original bridge foundations; however, the new columns were to be attached to a reinforced concrete pile and pile cap arrangement to halt the differential settlement of the piers that had plagued the bridge since opening.

The permanent design needed to be completed in such a way that it met both structural and heritage criteria. This differed from a typical design process where the most efficient form is determined by engineering theory, whereas for this project the form was set by the original design and the designer needed to reverse-engineer the piers to ensure compliance with Australian Standards and TfNSW technical requirements.

The new piers were designed entirely out of new steel using a combination of off-the-shelf sections and custom milled sections. Many hours were spent analysing the minutia of the original details and resolving variations between the work as executed drawings and the piers as constructed to ensure that the replacement piers were faithful to the original design detailing. However, it was also important that the new piers could be identified as new and not just a replica of the original piers. Vertical weld seams on the columns and changes to the bearing guide plates are visible to the astute observer, and in the case of the guide plates, enabled changes to be made to facilitate maintenance of the bearings between the piers and the spans above.

The new columns were constructed from steel tubes with the same external diameter as the existing elements. The spacing between columns was retained and the new elements were custom colour matched to the existing bridge. The length of the upper column segment and the bolted flange joint arrangement between segments was also retained. However, the length of the lower segment was extended to allow the new columns to be connected directly to the reinforced concrete pile cap, thereby leaving the original cast iron screw piles structurally redundant.

The top of the original upper column section featured a top plate which was cast integral with the column. The plate included a large hole to permit installation of mass concrete into the column after erection. Above the top plate was a fixed plate with shoulders that acted as guides for movement of the trussed superstructure. This arrangement affixed directly to the undertruss bottom chord plate through bearing bolts. These plates were the same material and size at both the fixed bearing piers and the expansion bearing piers. The expansion bearing plates were slotted to facilitate movement. There were variations between the work as executed (WAE) drawings and site measurement of the extant piers in most of these elements, in which case the site measurements were considered original as there was no evidence of prior modification to the bridge.

The original top plates were cast with the pier columns with a casting radius of 45 mm between the top plate and the column wall. The new top plates were machined from a single piece of 100 mm thick steel plate to allow this detail to be retained, with the arrangement then welded atop the new steel tube sections. The hole in the top plate was removed to allow the new column segments to be hermetically sealed to prevent internal corrosion.

The guide plate was replaced with a new steel plate with 40 mm thick shoulders to guide the articulation of the bottom chord. The expansion bearings require periodic maintenance to remove dirt, debris and install additional grease, so the shoulder section of each plate was made removable to allow better access (Figure 5).

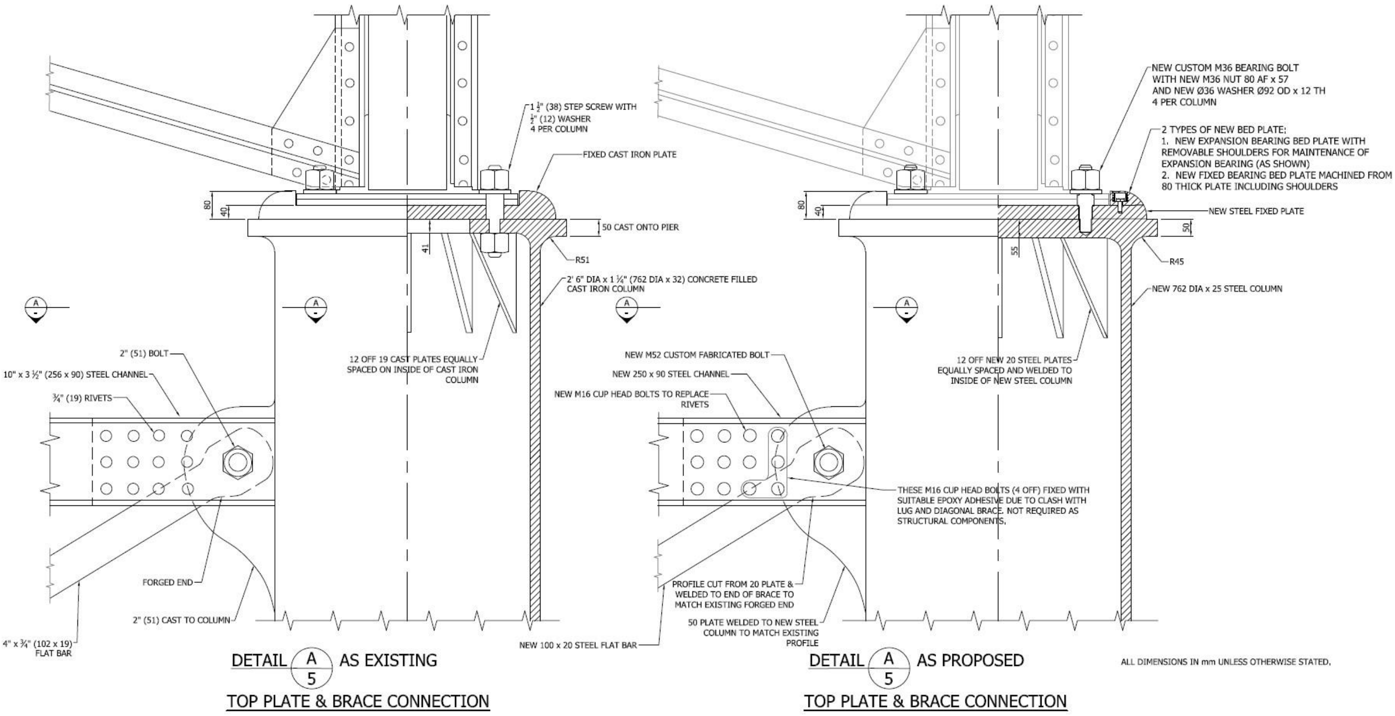

Figure 5. Comparison between original and new pier column top detailing [5].

No changes to overall bridge articulation were required. The existing bearing bolts, which secured the fixed or sliding plates at piers, were replaced with custom fabricated threaded stud bolts installed into threaded holes in the top plate of the column. The original wrought iron and gunmetal bearing plates affixed to the bottom chords of the under truss were in fair condition and were retained.

The original columns were braced with a combination of horizontal channel iron sections and diagonal steel plate bracing. All bracing elements were doubled and placed back-to-back and connected to the columns via a bolted cast iron lug affixed to the column section.

The horizontal braces ran directly between the lugs at the top and bottom of each upper column section and were held together by hex head bolts and an internal spacer tube. The diagonal braces ran diagonally between opposing lugs on each column. They consisted of steel plate for most of their length, however the final 8” (103 mm) was enlarged to connect to the column lug. These braces were significantly warped due to settlement of the bridge.

The horizontal bracing was replaced with the equivalent metric steel section (250 Parallel Flange Channel) and the diagonal bracing was machined from new steel plate to retain the geometrical features of the original elements. All bracing was connected to the new steel columns via new fabricated steel lugs and custom bolts used for connections to replicate original detailing. The new lugs were constructed from 50 mm steel plate and connected to the steel column via a large radius weld to provide visual similarity to the original casting process. The new pier columns replicated the above features to the greatest possible extent but on close inspection can be differentiated from the original design visible in the remaining original Pier 1 (Figure 6).

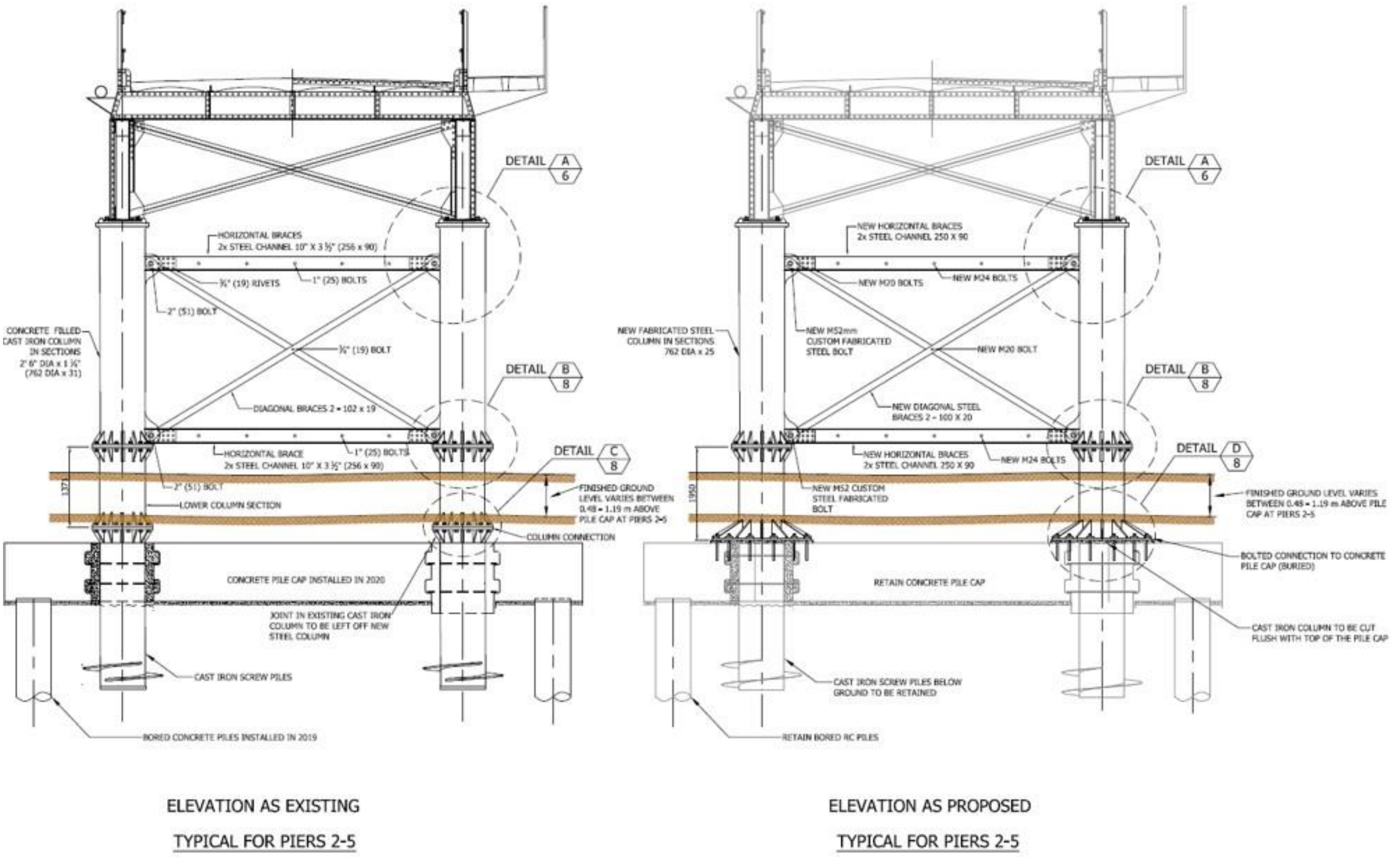

Figure 6. Design of original piers vs new [5].

Construction

Construction sequencing was generally well defined with a single critical path with mostly finish-start relationships. The high-level methodology was logically sequential, however the detailing and precision required within each construction step introduced an interesting level of complexity into the project.

The construction methodology was itemised into four main work fronts: 1) installation of temporary supports; 2) removal of the damaged piers; 3) jacking the bridge to the original vertical levels; 4) installation of the new steel piers.

Temporary supports

Temporary supports were installed to carry the bridge and traffic loads and allow the bridge to remain open to traffic until the pier replacement works could be completed. The temporary supports utilised a combination of proprietary modular components and custom fabricated sections which were delivered to site and assembled. The bridge was originally designed so the upper bearing plates attached to the undertruss bottom chord bore evenly on the lower bearing plates atop the pier columns. Synchronously linked jacks were used to create a 15 mm air gap between these two plates (the gap then being retained with inserted steel plates), thereby relieving the pier columns of their duty in supporting the bridge and associated live loads. The temporary support frames supported the truss at the first node in from the piers, with the introduced air gap then becoming a constructability constraint for the pier removal activities. This constraint required the columns to be separated into sections and for each section to be removed smoothly on a near horizontal plane.

Heavy vehicles were detoured around the bridge until the temporary supports were installed. Installation of the temporary support system was completed within two weeks of the cracking being discovered.

Removal of damaged piers

The columns in the piers were surrounded by the temporary support frames which provided horizontal working constraints, magnified by the concern the damage to the support frames during removal of the column sections may induce collapse of the bridge. The constraint required the pier sections to be removed in a consistent horizontal trajectory with minimal ability to make side-to-side adjustments during extraction.

These physical constraints resulted in diamond wire sawing being selected to separate the piers into three sections for removal. Steel bars were installed to provide fixity between the cast iron column wall and the mass concrete infill, after which each column was cut into three sections and extracted by either a 24 t excavator with a hydraulic grab or mobile crane (Figure 7), with the place selection based on the mass of each section and available working room.

Figure 7. Pier removal using mobile crane (photo: A. Rosnell, 2021).

Jacking the bridge to the original vertical levels

The temporary support frames incorporated two horizontally parallel steel beams to permit vertical jacking of the bridge superstructure to transfer bridge loading from the original piers to the temporary supports. With the damaged piers now removed, the same system was employed to incrementally jack and restore the bridge to its original design level to allow the new columns to be placed. Eight synchronously linked hydraulic jacks were installed to concurrently raise the bridge at each pier. Each lift was limited to 35 mm at a time, and sequenced across piers, to limit the translation or rotation of the superstructure at each end of the span. The bridge span was then resecured to the temporary support frame upon completion of each jacking operation. Traffic was detoured around the bridge during the jacking.

Installation of new steel piers

The new piers were installed under strict dimensional tolerances to ensure that they would perfectly mate with the existing bridge at its restored vertical alignment. The piers were fabricated off-site and installed using a mobile crane (Figure 8a). New chemical anchors were match-drilled into the reinforced concrete pile cap, with the finishing touches including grouting under the new column base plates and patch painting of all field connections. The bridge was then lowered onto the new column top plates using a reversal of the jacking operation, thereby rendering the new piers functional and allowing the temporary support system to be removed (Figure 8b).

Figure 8. Bridge: *a)* completed column; *b)* new piers in place (photos: A. Rosnell, 2021).

Conclusion

The bridge realignment and pier replacement was completed successfully, with the vertical alignment restored, temporary supports and load limits were removed. The authors consider this project to be the first documented example of replacement of colonial era cast iron piers on a road bridge with new steel piers without compromising the heritage value of the structure. The integration between physical engineering standards and non-tangible values is a fine example of multi-disciplinary coordination producing a superior community outcome.

The project has enabled a highly significant heritage bridge to remain in use on the NSW State road network for many years to come.

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