Examples of Bridge Assessment and Strengthening in Victoria

Huy Binh Pham, Technical Principal, SMEC Australia

ABSTRACT

Due to aging infrastructure and high demand to move heavier vehicles, there has been an increasing number of road bridges that are required to be strengthened in Victoria. Finding a suitable bridge strengthening solution is not a straightforward exercise for most cases. The selection of a solution depends on many factors including contractor’s preferences, bridge types, bridge conditions, type and level of deficiency, traffic restrictions, site condition...

This paper presents several recent examples of bridge assessment and strengthening in Victoria, Australia. In these examples, various strengthening techniques were employed including traditional bridge strengthening approaches as well as more recent innovative approaches. The paper is based on the work by the author and his colleagues over the last few years assessing and strengthening Victorian bridges.

1 INTRODUCTION

Aging infrastructure and ever-increasing demand to move heavier vehicles are the primary reasons for bridge assessment and strengthening. The requirement for the speed of the assessment, and strengthening design and construction is also ever-increasing due to the fact that large number of bridges are often involved and minimum traffic disruption is often required.

Each bridge is unique on its own and most bridge strengthening projects are different. However, many road and highway bridges are of small to medium spans and have some similarities. Therefore, many lessons learnt from one project are also applicable for others.

This paper describes some of the bridge strengthening works carried out by the author and his colleagues at SMEC Australia in Victoria over the last few years and outlines findings from these works. Most these bridges are small to medium span bridges.

2 ST GEORGES STREET BRIDGE

2.1 Background

The St Georges Road Bridge carries St Georges Road over the Merri Creek in Melbourne. It was originally built in 1886 and subsequently widened in 1916 and 1961. The bridge is comprised of steel girders and rolled steel joints simply supported over three spans of 10.2 m, 16.9 m and 10.5 m. Supporting the bridge’s superstructure are two concrete piers and two concrete retaining abutments.

Two traffic lanes run in each direction over the bridge, with the inner central two lanes being shared by road vehicles and tram. Two footpaths of 2.1 m width also run over the bridge. The sections of the deck supporting the central two lanes are separated from the sections of the deck carrying the outer lanes and footpaths by longitudinal joints. Various services are suspended under the superstructure and buried underground near the abutments.
For the outer bridge segments, original shear connectors were provided to connect the girders and in-situ slab to ensure composite actions. For the girders in between the longitudinal expansion joints, the concrete deck slabs are made from precast units that are connected to the girders via embedded steel angles. As the transverse joints between precast slab units do not allow transferring of loads longitudinally through the concrete deck, composite actions are not achieved. Therefore, these girders were treated as non-composite beams.

2.2 Assessment findings and strengthening works

The non-composite girders between the longitudinal expansion joints were found to be insufficient to carry road and tram loads. The fatigue strength of the girders was found to be adequate.
To achieve the required bending moment capacity for the girders under the tram tracks, an additional cover plate shall be welded to the bottom flange of the girders, and two additional cover plates welded to the top half of the web of the girders (both sides of web). This would be required for all girders in between the longitudinal expansion joints (12No. total). The cover plates are not required for the whole length of the girders. The extents of the plates have been optimised based on the bending moment distribution across the total length of the girders.

![Figure 3: Girder strengthening details for St Georges Street Bridge](image1)

The existing bearings and bearing pins were found to have inadequate capacity to resist both longitudinal braking forces and the minimum lateral restraint requirements. To overcome this issue, lateral bearing restraints were provided through additional steel plates and M24 anchor bolts. This design relies on the existing girder steel diaphragm channels connecting each girder at the girder supports to transfer load laterally across the bridge.

![Figure 4: Bearing strengthening details for St Georges Street Bridge](image2)

The piers and abutments were found to have sufficient structural capacity to carry current and expected future vehicle and tram loads. However, the north abutment needed to be strengthened due to poor ground condition.

To improve the stability of the abutment, soil nails were introduced. To improve the bearing capacity, bored piles socketed into basalt were proposed. The details for these works are illustrated below.
3 SHEPHERD BRIDGE

3.1 Background

The existing Shepherd’s Bridge connects Footscray Road over the Maribyrnong River. Designed and built in the 1950’s, the design vehicle of that era was the HS20-S16-44. Due to its proximity to the Port of Melbourne freight handling facilities the bridge is currently, and has been historically, subject to a high volume of heavy vehicles. Shepherd’s Bridge is a combination of bridge forms with the main centre three spans comprising steel I-girders with a concrete deck. The approaches comprise reinforced concrete (RC) beams and concrete slab deck, and reinforced concrete rigid frames. All spans are supported on reinforced concrete piers and abutments, with a mixture of pile and pad footings.

To cater for the additional traffic lanes, the existing deck required widening by approximately 600mm on both the north and south sides of the bridge. To account for this, the existing railing, elevated footpaths and kerbs were removed and the deck was widened for RC beam and steel girder spans. For the portal frames, a similar extent of widening was implemented. In addition, a section of the existing deck was hydro-blasted to remove the top 80mm (approx.) in order to install new reinforcement to tie the new widened section of deck into the existing.
3.2 Assessment findings and strengthening works

The primary works developed for the composite spans include removal of the middle joints making the bridge fully continuous.
Strengthening measures to cater for deficiencies determined in the RC beams due to the prescribed loading utilised carbon fibre (CF) fabrics and laminates. The design of the CFRP strengthening was performed in accordance with ACI440, including recommended detailing practices, utilising Sika CarboDur S and SikaWrap 230 C.

Other strengthening works include pier top strengthening using stressbars, FRP strengthening of pier/abutment crossheads, additional top reinforcement for the twin span culvert and adding edge beams for the single span culverts.
4 E.J WHITTEN BRIDGE

4.1 Background

The M80 Ring Road Upgrade from Sunshine Avenue to Calder Freeway is a 3 km long freeway widening project. The existing Maribyrnong River Bridge consists of two main bridges: The E.J Whitten Bridge and the Southern Approach Structure. E.J Whitten Bridge is composed of two separate ten span concrete box girder viaducts of 520m total length and up to 50 m above the ground. The current air gap between the structures was to be in-filled with a new deck structure and made integral with the existing viaducts. The new deck is supported off crosshead beams spanning between the existing viaduct pier tops. The only new ground bearing structures for the main bridge are new abutments supporting the new deck at each end of the bridge.
The South Approach Structures consist of two post-tensioned concrete slabs each 14.3 m wide. They are different in length with the western and eastern carriageway 126 and 104 metres long respectively. The slab has a constant depth of 650 mm, whereas the footpath varies in depth from 250 to 200 mm. Both slabs have a total of 14 tendons with vertical varying profile to maximize prestressing actions at mid-span and over the piers. The slabs are articulated at centre of the structure (Pier D) resulting in essential two separate structures per carriageway. The structures are on top of a disused landfill which overlays basalt rock. The bridges are supported on rows of driven piles that transfer the loads directly to the basalt layer.

The project was designed by a joint venture between SMEC, ARUP and COWI.

4.2 Assessment findings and strengthening works

It was identified that due to the increase in loading, two outer abutment bearings experienced significant uplifting. To overcome this issue, the new bearings were placed offset from the original location providing more lever arm and eliminating the uplift issue.

The existing Southern Approach Structure was also found to be deficient for the new loads with existing pile overloaded and existing deck overstressed. The strengthening solution consists installing stiff edge beams that would take some loads from the original structures.
5 PRINCES HIGHWAY WEST BRIDGES

5.1 Background

This project comprises strengthening of five bridges along Princes Highway in Melbourne. The first two bridges are called Bridges over Werribee River. The bridges were originally constructed circa 1959. Both bridges consist of three spans of 25, 33.5 and 25m, with an original width of 10.11m per bridge. The superstructures consist of steel welded I girders with a concrete deck slab. Each girder consists of two anchor spans and a drop-in span of 18.3m. Each bridge was widened in 2004 to an overall width 16m. The widened superstructures consist of welded steel I girders with a concrete deck. At the interface between the original and new bridges, the decks were stitched together.

The original and widened piers each consist of a crosshead with columns supported on a combination of pad footings and piles. Each original abutment consists of a sill beam supported by columns on piles. The widened abutment consists of a sill beam supported directly onto piles.
Another bridge which required strengthening is the Bridge over Railway Avenue in Laverton. The structure was originally constructed circa 1959 and comprises two separate bridges with the western bridge catering to Melbourne bound traffic and the eastern side bridge catering to Geelong bound traffic. Both bridges consist of three spans with approximately 8.1m and 13.1m span lengths for the approach spans and main span respectively. The superstructure of both bridges comprises rolled steel joists (RSJs) with a cast in-situ composite reinforced concrete deck slab. All steel girders are simply supported on steel bearing plates.

In circa 1972, the existing bridges were joined at the centre through the addition of a widening and widened on both external sides. The widened superstructures consist of universal beams with composite reinforced concrete deck.

The original and widened superstructures are separated by longitudinal expansion joints placed at the edges of the decks. A concrete barrier is placed on the concrete deck directly over the central girder of the central widening to separate the Melbourne and Geelong bound traffic.

The original and widened piers consist of rectangular crossheads on circular concrete columns supported on pad footings. The original abutments are supported on columns with pad footing while the widened abutments are supported on driven steel H piles.

Figure 14: Bridges over Werribee River
5.2 Assessment findings and strengthening works

5.2.1 Bridges over Werribee River

The original steel girders have been found to be deficient. The main deficiency is due to hogging moments over the pier. To strengthen the girders, longitudinal stiffeners were added. Additional lateral bracings were also introduced. Cover plates were not used due to the difficulties to connect them at the bearings. Additional vertical stiffeners welded to the original girders were also installed to take the load from the pier bearings.

Figure 16: Girder Strengthening on Bridges over Werribee River

The pot bearings under the outer edge widening girders were found to be deficient. They were replaced with pot bearings of the same articulation but with higher compression capacities. To facilitate removal and installation of these bearings, significant temporary works were designed and implemented. The figure below shows the configuration proposed for the bearing replacement works. At the abutments, a lifting jack was be placed directly in front of the existing bearing plinth on the crosshead. At the halving joint, a fabricated steel girder bolted to the soffit of the support girder was utilised to partially lift the drop-in span girder. At the piers, fabricated steel brackets bolted to both
sides of the pier crosshead were utilised. At all locations, additional stiffeners were welded to the existing girders to provide stiffness during lifting works.

![Figure 17: Girder Strengthening on Bridges over Werribee River](image)

The original pier crossheads were also strengthened using externally bonded carbon fibre reinforced polymers wraps and laminates.

![Figure 18: CFRP strengthening work over the pier crossheads](image)

### 5.2.2 Bridges over Railway Avenue

Strengthening was required for a number of components on this bridge. A number of girders were strengthened in flexure by welding cover plates to the girder bottom flanges and installing additional shear connectors. Four crossheads were strengthened using externally bonded CFRP. Four other crossheads were strengthened by installing concrete brackets around the columns. The crossheads were also joined to share longitudinal loads better using steel shear brackets. The abutment sill beams were also strengthened using concrete section enlargement.
A number of bearings and their pedestals were also strengthened and rehabilitated.

Figure 19: Some strengthening works at Bridge over Railway Avenue

6 HODDLE STREET BRIDGE

6.1 Background

The bridge superstructure comprises three 1.22m deep concrete box girders spanning continuously over three spans of 38.1m, 9.8m and 38.1m. The box girders are connected by a 203mm thick deck slab. The superstructure is supported on elastomeric bearings on the south abutment and on pot bearings on the north abutment and two central piers. The abutments are supported on piles connected by a crosshead. The central piers each comprise of 3 blade columns, each supporting a girder by a pair of pot bearings.

Currently the bridge accommodates eight traffic lanes with four in each direction, separated by a central median. Two out of four northern traffic lanes transition into the Eastern freeway on-ramp. The remaining two northern traffic lanes, separated by a median from the Eastern freeway on-ramp, continue towards north. The bridge also accommodates two footpaths.
6.2 Assessment findings and strengthening works

The bridge was required to be strengthened in flexure and shear. The extent of flexural and shear strengthening was designed in accordance with AS5100.8-2017. Strengthening for sagging involved FRP laminates bonded on the box girder sofit under the outer web. Strengthening for hogging involved FRP laminates bonded in grooves on the top deck. Shear strengthening was achieved by bonding vertical FRP strips on the inner webs.
Figure 22: Strengthening works on Hoddle Street Bridge

Currently there is no detailing provision for near-surface mounted horizontal FRP laminates width in AS5100.8-2017. Hence, a limiting strain equivalent to surface bonded FRP was imposed on embedded laminates as per AS5100.8-2017 and groove dimensions are based on TR55-2012, ACI 440.2R-2017 and HB305-2008 guidelines. A width of 10 mm was provided either side of bonded of near-surface mounted laminates to ensure full encapsulation of the FRP laminate by the bonding agent. Within the same groove, a 6 mm layer of cementations grout was provided to resist heat transfer during asphalt curing, followed by a waterproofing layer below the asphalt layer.

Figure 23: A photo of CFRP bonded to deck

Demand for shear strengthening varies between girders. The FRP laminate spacing varies from 230 to 300mm.
7 OTHER BRIDGES

CityLink Tulla Widening Project

SMEC proof engineered the strengthening works for five bridges for this project. The strengthening techniques involved including CFRP bonding, installation of new external members, adding cover plates, new deck propping…

West Gate Tunnel Bridges

SMEC/AECOM proof engineered the strengthening works for numerous bridges for West Gate Tunnel Project. The strengthening techniques involved including CFRP bonding, pier column widening, adding stress bars, installation of new shear connectors…

Melbourne train and tram bridges

SMEC designed strengthening works on various train and tram bridges in Melbourne including Hawthorn Road Bridge over Elster Creek, North Melbourne Flyover… Strengthening techniques involve include new deck overlay, new steel brackets…

Monash Widening Project

SMEC/ARUP designed bridge strengthening for several bridges along Monash Freeway in Melbourne. Minimum strengthening work was required including pier wall strengthening for collision loads, additional steel brackets for lateral restraints…

Highway bridge assessment in Victoria

SMEC have assessed over 40 highway bridges and developed strengthening concepts for some of those bridges in the last two and a half years. The techniques include deck overlay, CFRP, concrete thickening, external post tensioning, new props…

8 COMMENTS ON BRIDGE STRENGTHENING TECHNIQUES

Strengthening of bridges is emerging as an important part of bridge design. This is due to aging infrastructures and increasing needs for bridges to accommodate heavier vehicles/trains/trams. A successful strengthening design would require deep understanding of bridge loads, bridge behaviors, available construction techniques and site constraints. Some traditional approaches include deck overlay with concrete slab, concrete thickening, adding cover plates, external post-tensioning and adding new structural members.

Placing a deck overlay would improve the bridge superstructure capacities by increasing structural depth and improving load distribution between the girders. It also provides an opportunity to upgrade the barriers. However, a deck overlay would introduce significant weight on the existing girders and
the substructure. Connection between the new deck to the existing deck/girders can also be difficult due to the required large number of dowels. Significant works would also require at the approaches and expansion joints.

Thickening the concrete girder sections can be effective solution. However, this often requires significant amount of formworks and falseworks. This technique also results in much additional weight on the substructure.

Welding or bolting cover plates to a steel section can increase the section capacity significantly. Welding can be an economical solution but the weld details and methodology should be carefully designed and planned to avoid fatigue issues and distortion of steel elements. Welding would not be appropriate near gas pipes. Bolting would require drilling into existing plates and often involves a significant number of bolts.

External post-tensioning is a very effective solution. This can be achieved by stressing strands or tendons or stressbars. Anchorage for large tension forces is often an issue. As large additional forces are introduced to the structure, the design is often more complex.

Adding new structural member is not popular due to a significant amount of work involved. This is to be used as the last resort only.

Some more innovative approaches include FRP bonding, deck overlay with UHPC, improvement of load distribution and modifying bridge articulation. Each approach has its pros and cons. It is important that those pros and cons are understood and assessed before a suitable solution is selected.

In the last few years, there has been an increase in the use of FRP bonding in Australia. This technique is popular due to the use of light weight material with minimum falsework required. FRP strengthening is however a complex topic and often requires specialists’ advice. FRP strengthening is generally not suitable for severely deficient structures.

While deck overlay with UHPC has been used in Europe and other parts of the world, to the author’s knowledge, it has not been used in Australia. This technique is useful in reinstating a corroded deck. Due to its limited thickness, the improvement in strength would not be significant.

To improve load distribution amount girders, transverse members can be installed. This can be implemented for cases where access to the underside of the deck and connecting to the existing girders are feasible.

Modifying bridge articulation can be a very effective solution. An example is to introduce continuity into the spans. This in most cases would improve the design actions on the girders and bearings. However, the design and detailing are often complex. This also often requires bearing replacement.

9 SUMMARY

Several recent examples of bridge assessment and strengthening in Victoria Australia have been presented. These examples have highlighted various strengthening techniques that were designed and constructed. The advantages and disadvantages for several techniques have been discussed. Inputs from various stake holders, and experiences of the design engineer and the contractor would be essential. In the design phase, a right solution would require a rigorous bridge assessment, and a deep understanding of bridge loads, bridge behaviors, available construction techniques and site constraints.

10 REFERENCES

- AS5100:2017: Bridge Design
11 ACKNOWLEDGEMENTS

The authors wish to thank his colleagues at SMEC for helping deliver these successful projects. The views expressed in this paper are those of the authors.

12 AUTHOR BIOGRAPHIES

Dr Binh Pham, Technical Principal (Structures), SMEC Australia.

Dr Binh Pham has over 19 year experience in structural design for various projects in Australia, Middle East and Southeast Asia. He has worked on numerous projects from large multidiscipline construction projects to smaller bridge assessment and strengthening projects.

Binh is a specialist in strengthening structures using fibre reinforced polymers and advanced modelling of bridges. He has authored/co-authored over 25 publications. He is the reviewer for Elsevier’s journals and ICE Bridge Engineering Proceedings.