AUSTROADS BRIDGE CONFERENCE 2022

Hosted by the Department for Infrastructure and Transport, South Australia

Peer reviewed paper

Managing the suspension bridge in Kangaroo Valley (Hampden Bridge)

Henry Fok, Bridge Inspection Engineer, Transport for NSW

Syed Nowmani, Bridge Planner, Transport for NSW

Shah Parvez, Senior Bridge Engineer, Transport for NSW

Abstract

The aim of this paper is to share the experience in managing the risks facing a 125 years old Hampden Bridge which is a unique road suspension bridge in Kangaroo Valley, New South Wales. It was built in 1897 and this is a load-deficient bridge which is required to carry one lane of current legal loads. This paper covers all aspects of the original design, the strengthening and rehabilitation designs following the failure of a few of the critical members, findings from numerous consultant investigations since 1990, inspections with non-destructive tests, load tests and structural health monitoring. This paper also discusses some long-term, sustainable and cost-effective solutions to manage the risk of this bridge by the asset owner.

This bridge underwent a major rehabilitation in 2010 and a significant amount of additional dead load has been added to the original bridge in stages. After this rehabilitation, however, a few critical members were not performing as intended and were failing. This highlighted the need for follow-up investigations to resolve the root cause of these failures for this highly complex long span bridge. Observation of the bridge under usual traffic conditions was required to determine the bridge behaviour and to examine the failure of critical elements.

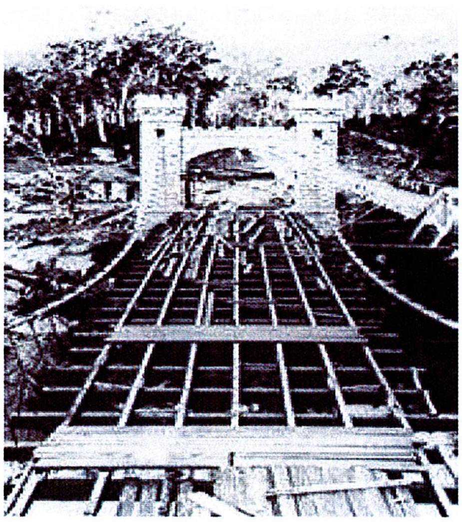
The Technical Services team in Transport for New South Wales carried out these investigations including structural health monitoring. Based on these findings a short-term and long-term strategy for this bridge is in progress which will assist asset owner to keep this complex bridge in safe operation for the current approved load.

Keywords: suspension bridge, load deficient, structural health monitoring, non-destructive tests, complex bridge.

1. Introduction

Elevation of bridge

An above view of bridge

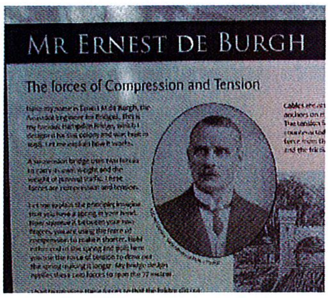
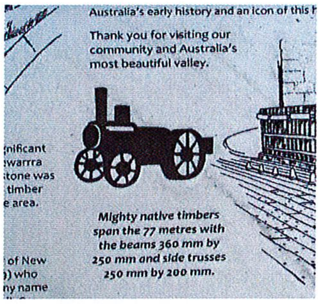


During construction

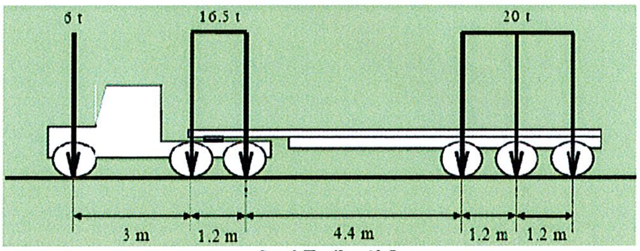
The subject bridge is a load-deficient bridge for current traffic loads. It is a wonder that the structural engineers and the project managers have kept it in safe operation. This bridge has rarity value as the only surviving timber decked vehicular suspension bridge from the nineteenth century in NSW.

The bridge is a timber suspension bridge. It is in Kangaroo Valley, NSW and is a heritage attraction. It was built before 1900. The span is 77m (253ft) and is carried by two main cables via 78 iron hangers. The main cables are supported by two masonry towers about 12.8m (42ft) high at both ends. The cables are anchored to the sandstone using iron/steel connections below ground. The original deck consisted of timber cross girders, timber stringers and sheeting. On both sides of the span are two timber stiffening trusses. Total width of deck between kerbs is only 5.5m (18ft) and one lane of traffic is restricted to travel along the centre-line.

2. Comparison of Current traffic loads vs Original design loads

 Bridge designer	 14 tonne steam roller	Uniformed Distributed Loads was 60lb per sq ft, with 84lb per sq ft as concentrations. 60lb per sq ft = 2.9kPA

VEHICLE CONFIGURATIONS



Semi-Trailer 42.5t

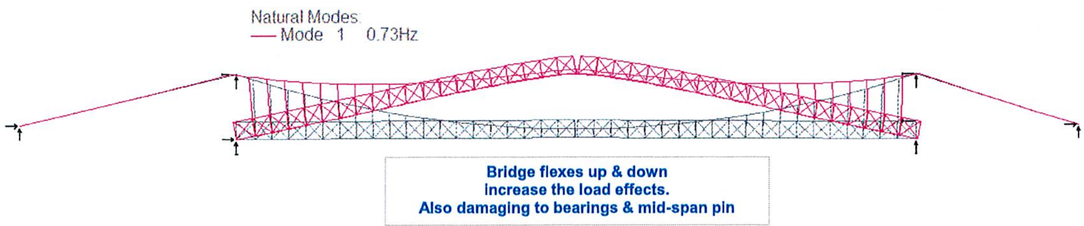
ST42.5t is a 1,2,3 axle configured six axle articulated* vehicle with GVM 42.5 tons.

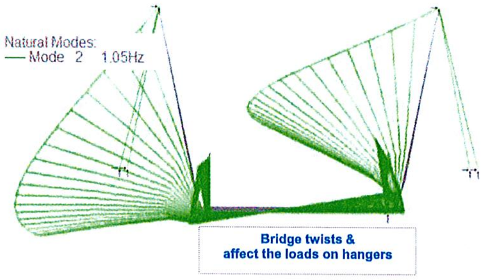
Current traffic – 42.5t Semi-Trailer

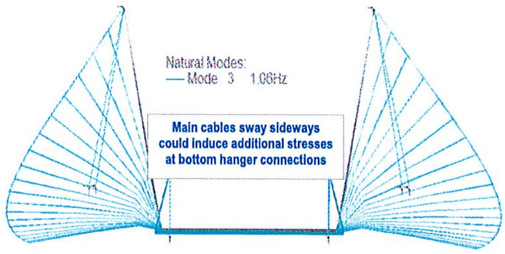
The original design loads were only one 14t steam roller and an UDL of only 60lb per sq ft (i.e. 2.9 kPA). Design loads were significantly less than current traffic 42.5t. In 1968, a load limit of 20t was considered but this was not feasible due to traffic demands. Hence, the bridge had been carrying loads exceeding its design loads.

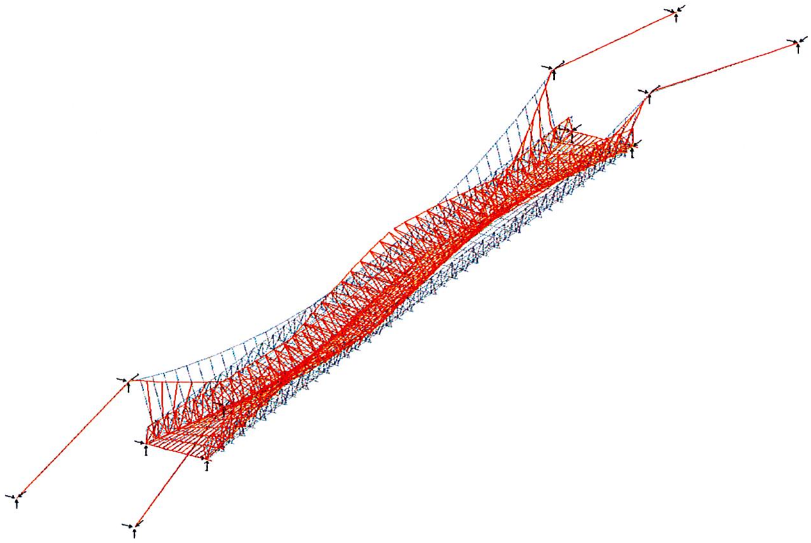
Some complex behaviours due to overloading

Overloading this bridge had caused some complex behaviours. The bridge bounces up and down, sways and twists.





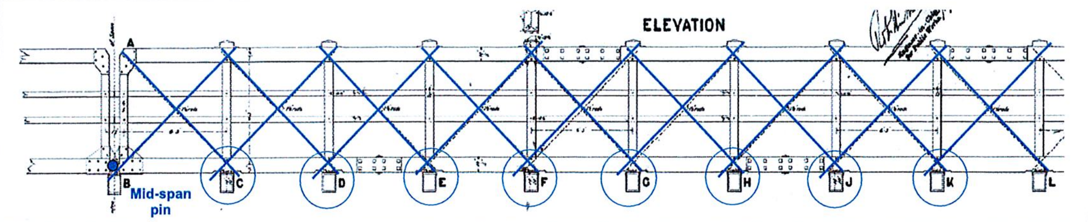


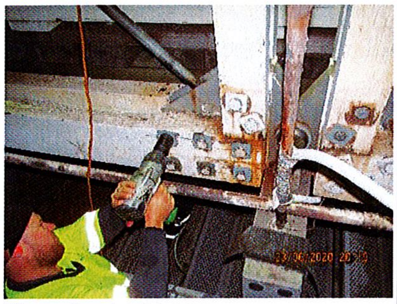


Many critical parts of the bridge had failed and had been replaced. Continued safe operations had required frequent inspections by dedicated inspectors and subsequent repairs. The first items to fail were:

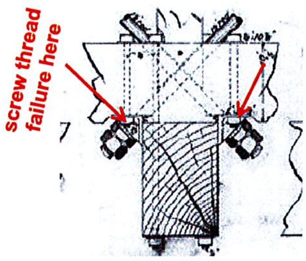
- Timber stringers and cross girders,
- The abutment bearings and the mid-span pin,
- Parts of the top and bottom chords of the timber stiffening truss at splice locations,
- Diagonal rods at the stiffening truss were failing and falling into the river,
- Few hangers were slipping down the main cables.

Some examples of failures are shown in the photographs below.



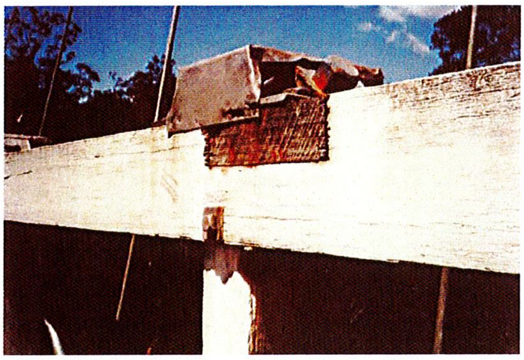


New pin at mid-span

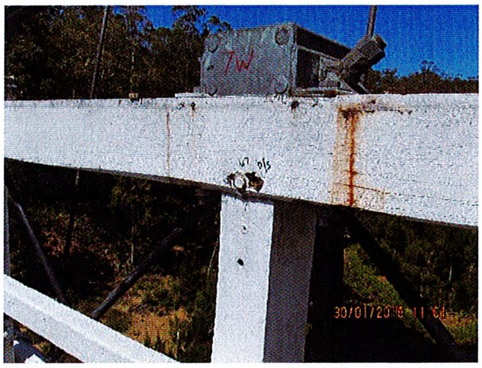


Failure of the truss diagonal rods at its thread

Failure at its thread

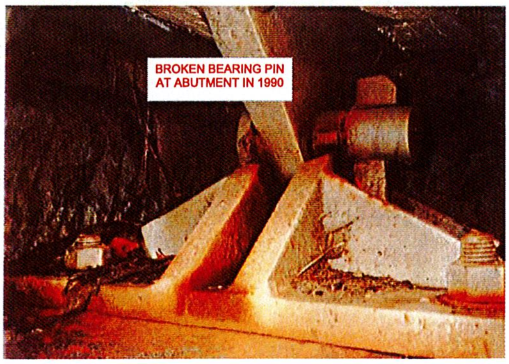


Timber block at top chord crushed.



Original timber block replaced with a steel block

Hidden damage at timber bottom chord. Mode of failure was examined.



Broken abutment bearing due to uplift forces.

3. Major rehabilitation in 2010 & other repairs

The problems at this bridge had challenged many structural engineers and project managers. Since 1990, at least 8 engineering consultants had worked to resolve the problems. They were under the supervision of the technical services team of the ex-RTA and the ex-RMS. Many improvement/strengthening designs had been developed.

In 2010, the bridge had major rehabilitation works. The following works were carried out:

- Replaced timber cross girders with steel cross girders,
- Added more stringers to complement existing stringers,
- Added lateral bracings,
- Replaced existing timber decking,
- Replaced mid-span pin,
- Replaced abutment bearings which were anchored into the rock,

In addition to the above works, there were other works carried out at different times:

- Replaced broken timber chords with new chords & new splice plates,
- Replaced broken timber blocks on top chords with new steel blocks,
- Replaced truss diagonal steel rods with new macalloy bars

Most important, these improvements had significantly reduced the following risks:

- Bridge breaking into two halves due to broken mid-span pin,
- One end of the bridge jumping off the abutments due to broken abutment bearing,
- Cross girders and stringers breaking due to overloading,
- Broken truss diagonal rods falling into the Kangaroo River and harming the people canoeing in the river,
- Timber stiffening trusses breaking up.

However, all the above improvements have added 50tonne of dead loads to the bridge. This increase in dead loads had created a new set of problems (discussed below)

4. Structural Health Monitoring (SHM)

SHM is one part of the Risk Management. The Bridge Assessment unit of the ex-RTA, ex-RMS and TfNSW has been conducting this type of monitoring for bridges since 1995. The primary objective has been to ensure safe operation of some problematic bridges.

For this complex bridge, the Bridge Assessment unit adopts a wider scope for SHM than what was defined in the current standard AS5100:2017. The aim of SHM was to detect the damages as early as feasible. The normal scope of the SHM consisted of:

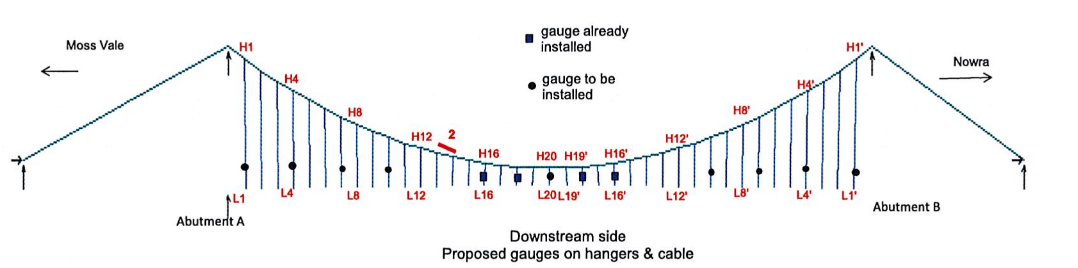
- Performance load tests using a defined test vehicle to provide the reference parameters,
- Subsequent ambient monitoring of parts of the bridge using the latest technology,

In addition to the above scope,

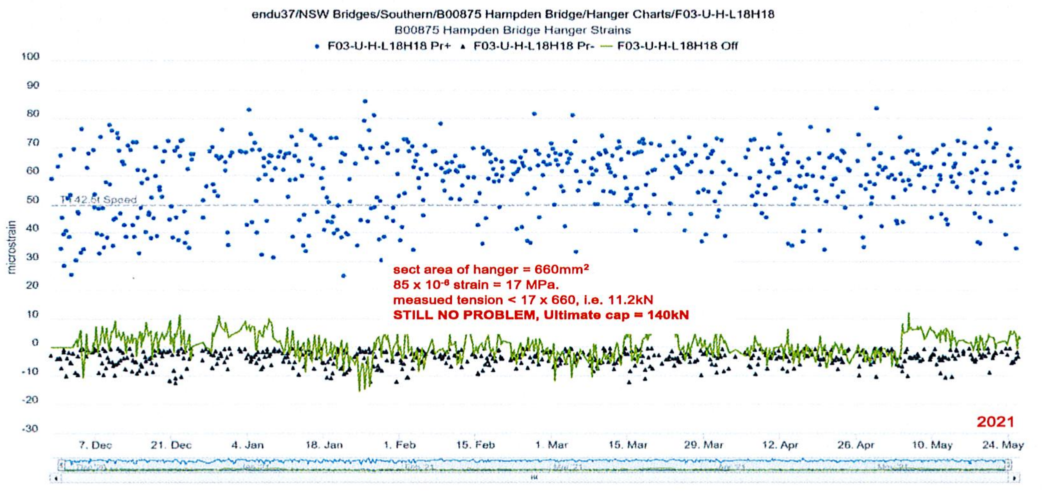
- Visual inspections by dedicated bridge inspectors, Structural Health Monitoring (SHM) cont'd

Visual inspection by dedicated inspectors was the most effective risk managing tool because it covered unexpected changes. Dedicated inspectors were the inspectors who had been following the bridge for many years. Generally, dedicated inspectors were permanent employee of the Transport for NSW.

Ambient monitoring was installed on the bridge. This monitoring was carried out after a load performance test using a known test vehicle. Strain instrumentations of some parts (i.e. hangers, splice plates, chords and cables) provided data remotely. This had helped the safe operation. The disadvantage was that only limited parts of the bridge could be monitored. Visual inspections were still required.



One part of bridge monitoring - strain gauges on the hangers



One hanger with the monitoring data compare to the reference test vehicle

Realistically, there are constraints to ambient monitoring. It is simply not feasible to monitor every part of the bridge. Visual inspection shall continue as a vital activity.

5. Non-Destructive Tests (NDT).

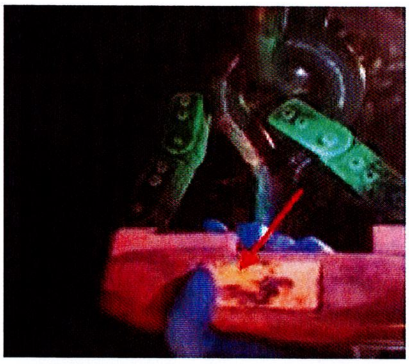
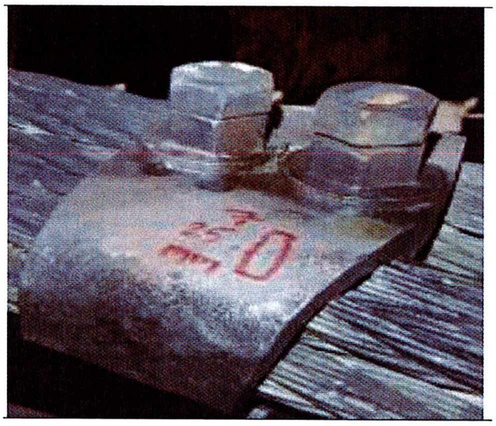
Visual inspection of bridge has limitations as they could not reveal hidden defects. To counter this risk, NDT helped to validate the integrity of the parts. However, NDT had its constraints which would require careful selection of parts for investigation. It was simply not feasible to test every part of the bridge.

The responsibility of selecting the parts for NDT was best carried out by the dedicated bridge inspection team. This team consisted of one structural engineer and one level 2 inspector.

For this bridge, the following members were selected for NDT:

- All the hangers & its connections for Ultrasonic tests,
- Limited number of hanger connections for Radiography tests,
- Limited number of hanger connections for Magnetic Particle tests,
- Limited number of hanger connections for Eddy Current tests,
- Limited number of anchorage connections for Radiography tests.

Technical constraint had limited the number of NDT.

 Magnetic Particle test	 X-ray of one connection
 Eddy Current test finding.	 Conducting Ultrasonic test on one hanger

6. Further Investigations/New Challenges

The repairs and strengthening had improved the risk profile of the bridge. However, new problems had challenged the structural engineers and project managers. The repairs, addition members, modifications and other improvement had added another 50tonne of dead loads to the bridge. As a result, the strengths of these members would require investigations:

- Existing hangers & main cables (> 120 years old)
- Existing anchorage of the cables in the sandstone below ground. See diagram below.
- Existing timber stiffening trusses had continued to break. (Not a new problem)

The constraints faced by the structural engineers and the project managers were:

- Heritage appearance to be maintained,
- Certain parts of the bridge were irreplaceable (the main cables, anchorages and the masonry towers)

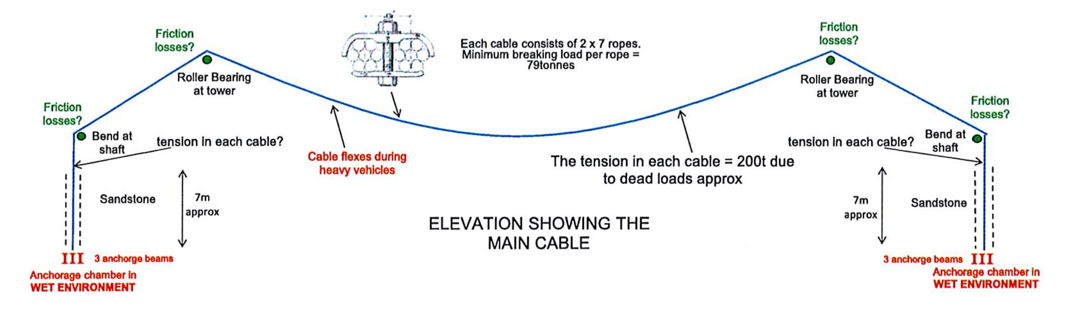
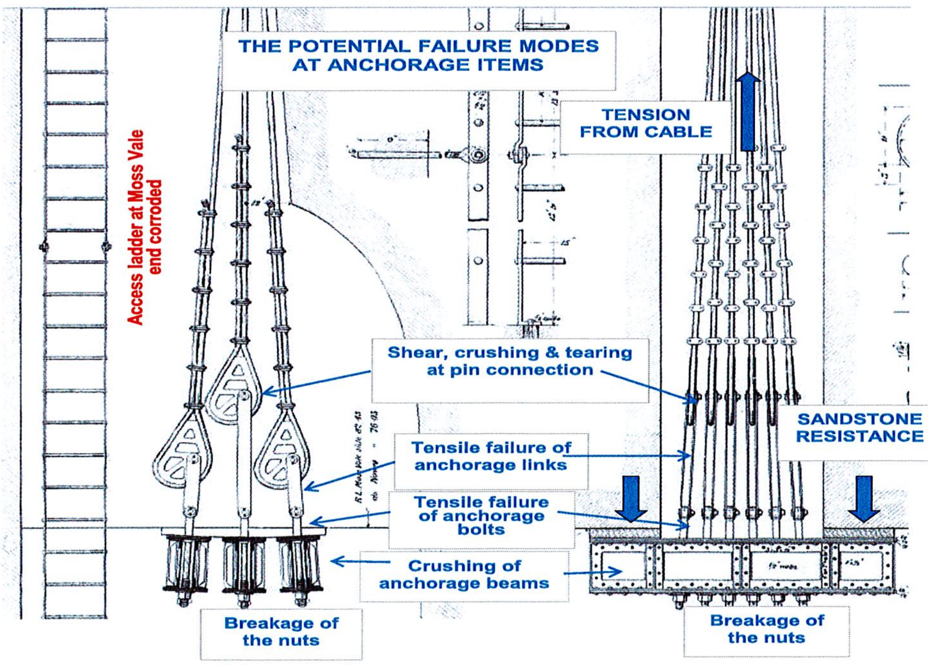


Diagram showing the anchorage of the main cable below ground



Anchorage members below ground

7. Risk management

A 6 x 6 matrix was adopted to capture the risk profile. The stakeholders for this bridge were the Southern Bridge Maintenance unit, legacy Bridge Assessment unit, local residents and the transport industry.

Risk matrix		Illness, first aid or injury not requiring medical treatment. No lost time	Minor injury or illness requiring medical treatment. No lost time post medical treatment	Minor injuries or illnesses resulting in lost time	1 to 10 serious injuries or illnesses (as defined in s36 WHS Act) resulting in lost time or potential permanent impairment	Single fatality and/or 11 to 20 serious injuries or illnesses (as defined in s36 WHS Act) resulting in lost time or potential permanent impairment	Multiple fatalities and/or more than 20 serious injuries or illnesses (as defined in s36 WHS Act) resulting in lost time or potential permanent impairment
		Insignificant	**Minor**	**Moderate**	**Major**	**Severe**	**Catastrophic**
Expected to occur multiple times (10 or more times) during any given year. Expected to occur at least 1 in every 4 times the event or action occurs (more than 25% chance of occurrence). This risk is known to occur frequently.	Almost certain	Medium	High	High	Very High	Very High	Very High
Expected to occur occasionally (1 to 10 times) during any given year. Expected to occur between 1 in 4 and 1 in 10 times the event or action occurs (10% to 25% chance of occurrence). This risk is known to occur often.	Very likely	Medium	Medium	High	High	Very High	Very High
Expected to occur once during any given year. Expected to occur between 1 in 10 and 1 in 100 times the event or action occurs (1% to 10% chance of occurrence). This risk is known to have occurred on occasions.	Likely	Low	Medium	Medium	High	High	Very High
Expected to occur once every 1 to 10 years Expected to occur between 1 in 100 and 1 in 1,000 times the event or action occurs (0.1% to 1% chance of occurrence). This risk could occur but not often.	Unlikely	Low	Low	Medium	Medium	High	High
Expected to occur once every 10 to 100 years Expected to occur between 1 in 1,000 and 1 in 10,000 times the event or action occurs (0.01% to 0.1% chance of occurrence). It is unusual that this risk occurs but it has happened.	Very unlikely	Low	Low	Low	Medium	Medium	High
Not expected to occur in the next 100 years (less than once every 100 years). Expected to occur less than 1 in 10,000 times (if ever) the event or action occurs (less than 0.01% chance of occurrence). Any risk can occur but this risk it is very improbable that it will occur within the large number of events.	Almost unprecedented	Low	Low	Low	Low	Medium	Medium

So far, the ex-RTA, ex-RMS and the current Transport for NSW had managed to keep the bridge in safe operation.

For any bridges, a good risk management depends good inspection procedures. For this complex bridge, additional features complement the inspection procedures. Therefore, the risk management for this bridge consisted of:

A. Inspection by dedicated inspectors (frequency depends on findings)
B. Structural Health Monitoring (using latest technology, remote sensing etc)
C. Traffic control (number of vehicles allowed on bridge and its speed)

8. Community Consultation:

As the local community of Kangaroo Valley has a special association and regards for the bridge, a dedicated project manager was embedded into the project team to develop a communication plan and to engage with the community.

Due to the complexity of repair works, some day and night closures are usually needed to ensure the works are completed safely. Local stakeholders were contacted with the community to ensure details of the proposal are to be known including duration of works, working hours, changed traffic or access arrangements, how to lodge a complaint or obtain more information in addition to any relevant contact names and details and how the effects can be minimised.

The consultation mediums to achieve this include community newsletters, direct consultation, a VMS Strategy, updates on the Live Traffic website and inclusion in the Road Report.

To mitigate construction noise during night works, all properties within a 150 m radius of the works were directly notified prior to commencement. Majority of drilling (the loudest activity) also took place before 11pm and scheduled for a maximum of two consecutive nights, to allow a respite period.

A comprehensive stakeholder register was prepared and populated for the project and there were face-to-face meetings with the community. This information was used to help TfNSW finalise its work schedule.

9. Issues encountered:

Various issues encountered in executing the repairs efficiency which includes but not limited to the following:

Bridge closure/Assess:

- As the community being very vocal and there is a long detour (115km – circa 2 hours via Gerringong, Macquarie Pass and Robertson) Bridge closures are hard to achieve and needs a lot of planning/ consultation.
- Having a very small window (10-hour closures) to complete change over, there is a high risk that if something were not to go according to plan, the bridge would not be able to be opened by the morning going over ROL, specially with truss members replacement (when pulling out a broken flitch the new timber must go back in to have the bridge operational again).
- The gantry is for routine small works only – (deck tightening, inspections) 250kg point load and 500 kg on one side of the gantry at any time. Large size scaffold is required for any restoration works which is time consuming and costly.
- Due to the nature of the rehabilitation works, tight access and limited space had consequently caused a couple of serious shoulder injuries trying to drift and remove bolts.

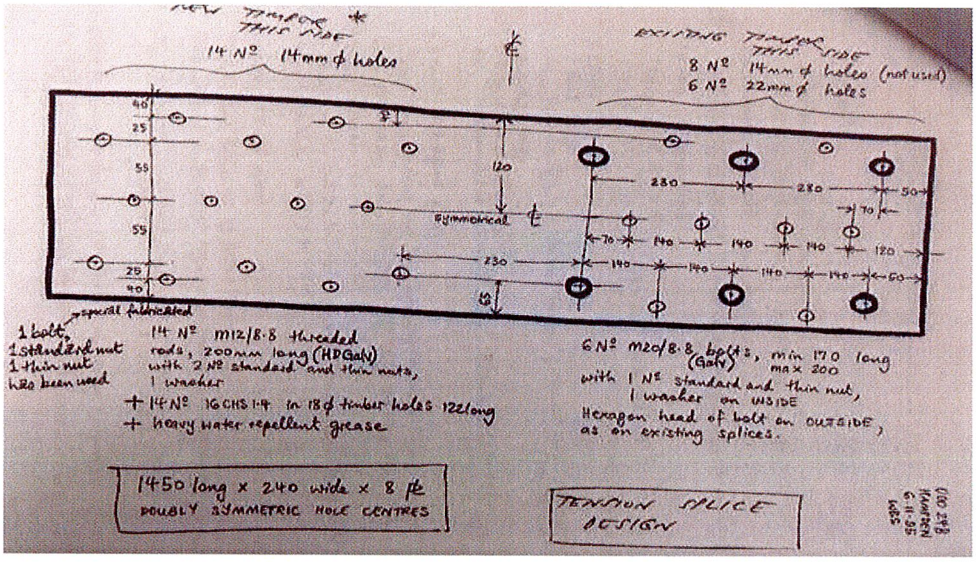
Utilities:

Inadequate/ no agreement with the utility's agencies, cost fortune to relocate and takes time to plan any work (up to six- eight months)

- Sydney waters pipe has to alter each time to prevent damage when we lower girders. again extremely time consuming and costly
- Telstra cable issues- There is a NBN cable attached to the bottom chords which was needed to relocate and that too delayed the process

Different types of splice plates/connections

- There is multiple different splice plates and bolting connections installed in the top and bottom chords along the truss. Resulting in Splice connections showing distress and affecting distribution of loads across hangers, also changing over the M12 splice bolts consistently and tightening of diagonal tension rods which causes weakness in the timber chords resulting in tensile failure.
- The original splice plate has shear keys, It appears that shear keys were removed in the new designed splice plate (Ray Taylor design) to prevent section loss in the timber elements which were compensated by a large numbers of small diameter shear connectors (bolt).



- The diagonal tension rod bracket that is welded to the cross girders are not square or of the same height, and so require precision marking out to allow the flitch to seat correctly, there are multiple different measurements across 3 girders. Potentially wrong measurements, mean that the seating would not be correctly placed-in therefore would not preform as they are supposed to.
- when cracking and undoing bolts and re tightening them prior to closures it was found that some of the diagonal tension bolts due to the age were seized and were hard to be undone. Consequently, the nuts were cut in a closure only because there was not enough time to try and remove.

In general, the top chords are easier to replace whereas the bottom chords can be quite difficult. It's the individual flitch replacement that takes time and cannot be done so promptly. Minor repairs like replacing bolts can be quite simple.

Lately we have been chasing our tail and more locations have popped up requiring repairs

10. A rare Near Miss (Potential collapse of tower /Bridge)

On October 2018 at about 4pm, a southbound (from the Moss Vale side towards the Kangaroo side) truck with an attached loader crane (aka "hi-ab") failed to lower the arm of the crane, which struck the centre of the elliptical arch of the northern suspension tower. The collision caused a piece of the centre dressed masonry to be dislodged and damage to the attached plaque

Immediately following the collision, the bridge Asset team and members from the regional maintenance delivery bridge works team attended the site. Bridge Maintenance Southern unit in consultation with Bridge Engineering Rehabilitation unit and the personnel at the site, determined that concrete patching material was to be installed in the damaged area immediately to help take the compressive forces of a stone arch.

A section of standard plywood was strapped to the underside of the arch with six 2.5 tonne capacity straps to support the concrete patch and minimise the falling of any small debris.

Strap and plywood sheet

A subsequent inspection was arranged after the initial repair to determine the scope of a remedial solution to the collision damage. The inspection was carried out by an appropriately skilled stonemason, as required by the draft Hampden Bridge Conservation Management Plan (CMP), a TfNSW structural engineer from the bridge engineering rehabilitation unit and the southern region bridge maintenance planner

The inspection found that the collision had caused cracks to appear along the interface between the dressed masonry at the bottom of the arch and the quarry faced masonry above. Cracks were also found between the vertical joints of the quarry faced masonry.

A remedial solution was adopted by Installing Four tie rods (two at front, two at rear) x 316 grade stainless steel 16mm diameter into the 20mm drilled holes, these tie rods were mechanically attached top and bottom with 50mm stainless steel washers and nuts set inside stone surface. These were rebated and chemset into the existing stone and the drill hole were patched with colour matched mortar.

11. Conclusion:

Even though there have been numerous major planned and unplanned works required on the bridge, the Southern Asset and Bridge Engineering team did not lose focus on the need to stick with the maintenance strategy. In the last ten years, Southern Assets have performed numerous upgrades and improvements to ensure the ongoing effective and reliable use of the Bridge.

Considering the complexities, desire to minimise impacts on the community, uncertainties of carrying out the physical work within a short window and constraint access incl. confined space, while identifying as many improvements as possible within budgeting limits, TfNSW were extremely pleased with the result of this project thus far.

For such a high-profile site, these works have been successful in creating a period in the Bridge's history of unprecedented, reduced maintenance, closure /delas to traffic including semitrailers, demonstrated high standard of maintenance, and recognised increased confidence within the community.

12. Disclaimer

The opinions expressed in this paper are entirely those of the authors, and do not necessarily represent the Policy of TfNSW.

13. References

1. Brown, L., Parvez, S., (2009) 'Route Assessment for Higher Productivity Vehicles - An RTA Perspective', 7th AUSTROADS conference, Auckland.
2. Parvez, S., Yeung, E., (2011) 'The Intelligent Access Program (IAP) for mobile crane, Route Assessment RTA Perspective, 8th AUSTROADS conference, Sydney.

Acknowledgments

The authors would like to acknowledge the Secretary, Transport for NSW to support the development of this tool and his permission to present this paper.

All the project engineers and graduates who worked on heavy vehicle access since 2000.

Southern Bridge Assets team (Dony Castro and Steve Watson) who are managing and inspecting this bridge

Author contacts

Henry Fok, Transport for NSW, Bridge Inspection Engineer

Email: henry.fok@transport.nsw.gov.au

Syed Nowmani, Transport for NSW, Bridge Planner

Email: syed.nowmani@ transport.nsw.gov.au

Shah Parvez, Transport for NSW, Senior Bridge Engineer

Email: parvez.shah@transport.nsw.gov.au