Non-Destructive Testing of Australian Hardwood Timber Bridges

Dan A. Tingley

Dan Tingley is a Senior Engineer/Wood Technologist at Wood Research and Development in Jefferson, Oregon. He specializes in the design and restoration of timber structures, with a significant interest in timber bridges. He travels the world ensuring timber bridges are preserved and is currently acting as senior engineer providing oversight on 20 timber bridge restoration projects worldwide. Here, Tingley takes Wood Design & Building along for the ride and shares his insights in a special from-the-field account of a recent trip to Australia.
In Australia there are an estimated 43,000 timber bridges of which the vast majority are owned by local governments and railways. Unfortunately, local governments can least afford to maintain this vital infrastructure asset and they are struggling to maintain these timber bridges. In many cases local government asset managers may not even know how many timber bridges they have and even those who do are not always fully aware of the condition of their timber bridges. Australia’s size (larger than all of Europe combined) and small population (17 million) mean that there are a large number of bridges to be maintained by a few people. To further complicate matters for the bridge owners, most of the old timber bridges were designed at the turn of the century for less than 15-tonne loads. They now are regularly carrying 44-tonne loads.

Further contributing to the situation is a dwindling knowledge base and lack of practical experience within the local governments in the area of timber bridge inspection and maintenance. Filling this gap are external consultants and contractors who provide inspection and construction services, but these parties most often have more experience with concrete and steel bridges and very little experience with timber bridges, particularly old ones. With minimal timber bridge expertise in-house, the local governments seek to utilize state timber bridge inspection and maintenance standards that are published by state highway authorities as tender criteria for timber bridge inspection offerings. The state highway authorities have divested themselves of their timber bridges and over time have lost their own timber bridge brain trust since they mostly build their new bridges with steel and concrete.

Asset managers in local governments have, in many cases, based their actions on the misperception that they are dealing with old, worn out timber bridges. Rather than investing in maintenance to extend the service life of these bridges, they have cut timber bridge maintenance budgets in favor of short-term solutions (by inexperienced bridge crews) while they prioritize their timber bridges for replacement and request money from their councils for these replacements. This activity is often mirrored by the railways in Australia. This strategy leads to poor maintenance practices and only serves to accelerate the decline of the timber bridges held in the registry.

This approach of Band-Aid solutions and replacement has led to the development of ranking systems to prioritize the timber bridge conditions from bad to worst. They seek independent concurrence from external consultants to justify their management plans for their timber bridges. They determine the minimum expenditure required to push the bridge replacement or major works out the furthest time period while still protecting the safety of taxpayers. In some areas where there is no money to follow this strategy, the local governments reduce load ratings and speeds, or in many cases where reroutes are available, simply close the old timber bridges.

This government strategy is counter to taxpayer sentiment, where these historic timber bridges are considered an important part of Australia’s heritage. With growing public awareness of sustainable construction, environmental impacts and the carbon economy, there has been pushback on the replacement strategy proffered by local governments. After all, timber bridges are 22 times more carbon-friendly than steel bridges and 16 times more friendly than concrete bridges. Further, footprints for new bridges are larger, the costs are greater, and the environmental considerations are complex.

In order to properly manage their timber bridge assets, most asset managers have external consultants conduct Level I inspections (or their own Level I inspections if they have certified inspectors on staff). These inspections basically serve to provide an inventory record of bridge locations, composition, overall site conditions and other important bridge characteristics. The Level I inspection does not speak to bridge load rating except in cases where elements are clearly under duress and can be identified as a failed element such that the bridge might be shut down until further, more detailed inspections can be conducted. Bridge owners often proceed to Level II and III inspections with their old timber bridges when they realize they need a better understanding of the bridge’s condition so that they might determine a way
forward with the asset. With limited budgets and an aging population of bridges, owners need to improve the accuracy of these timber bridge inspections while cutting costs. To meet these seemingly competing directives, they have hired consultants who can provide more advanced techniques for timber bridge inspections that can be performed at lower cost with great accuracy. I have been assisting many local government agencies in proper non-destructive testing techniques utilizing such advanced equipment as through compression wave testing particularly calibrated to detect lousy wood and cavities in Australian hardwood timber elements.

Australia has more hardwood timber bridges than all other nations of the G-20 combined. What makes Australia unique is the number of hardwood timber bridges still in service. This is both good and bad. On one hand, the hardwood timber bridge elements tend to be more durable, resisting decay, insect degradation and other environmental factors better than softwood bridges. On the other hand, Australian timber bridge inspection, maintenance and restoration practices have not kept pace with global trends and many of the mistakes made in timber bridge construction a hundred years ago are still being made today. This shortfall has been somewhat obscured by the fact that timber is very forgiving with redundancy within its systems.

Wood has superior impact properties (compared to steel and concrete) and superior performance when subjected to acceleration loads, particularly compared to concrete, due to its low Modulus of Elasticity (MOE) characteristics in various directions and its anisotropic nature. In recent history, however, the cost of replacement hardwood timber parts has been driven upward significantly by the green movement and heavy restrictions on timber harvesting in Australia; adding more pressure to improve timber bridge maintenance practices. The typical component lifespans which have been historically 10 to 15 years for decks, 20 to 30 years for superstructure and 35 to 45 years for piles are no longer attractive with the high cost of hardwood and installation.

There are many forms of timber bridges in Australia. The classic Australian hardwood timber bridge is typically three or four spans long and has a transverse timber plank deck on a log girder system that rests on log corbels. This deck system in turn rests on a timber pile bent system with a dimension timber head stock. Over the years, these bridges, many more than 100 years old, have been modified during maintenance works and have had critical structural elements switched out in a wide variety of ways. Some of these modifications have been good, but most have been bad in terms of longevity. For example, one bridge in Northern Queensland is a log girder curtain bridge with transverse dimension timber diaphragm beams that have been placed in deep notches in the center of the girder span. This action is unacceptable structurally. The problem could have been minimized by slope cutting the notches with a 12:1 slope but they weren’t. The degradation was much more than the advantage gained, however, the log girders in this bridge (Figure 1) are still in service and have not decayed because they were exposed on their tops to the sun and were able to breathe out moisture and thereby reduce the rate of decay since the typical concrete deck was not spiked to the girders. The bridges shown in Figure 2 are no longer in service and they are one-third the age.

The resisting stresses in a timber bridge must exceed the applied stresses with a minimum composite adjustment factor (CAF) (1.3 for safety times 1.6 for duration of load) of 2.1 depending on the design characteristic. The inspection activity must seek to provide a way of understanding what the real capacity is within the bridge’s structural elements. These resisting capacities are then compared to the desired applied loads to establish the resulting load rating with the proper CAF. The inspection team then interacts with the owner to manage risk associated with the CAF, residual capacity, and the load capacity afforded the local taxpayer in brownfield sites.

Bore sounding is one of a number of assay-type test methods for timber bridges and requires less time than core test-

**DO**

1. Change vertical through bolting to horizontal bolting (verticals that don’t pass through the upper surface).
2. Ensure positive drainage that does not fall onto other timber structural elements.
3. Provide for moisture content change induced in dimensional change in timber elements (e.g. oval side plates).
4. Provide proper clearance for breathing of timber elements.
5. Use properly sized timber in pile bents by investigating the shear capacity of the cap/head stock if the girder/stringer loads are not applied to the cap/head within a distance D (depth of cap/head) of cap/head to prevent micro-checking (horizontal shear cracking) in cap/head stock.

**DON’T**

6. … use malthoid barrier between timber strata.
7. … use near end drift pinning in an attempt to stop end feathering to connect timber elements.
8. … use coatings containing more than 29% solids on large dimension timber elements that are green with a minimum dimension over 50 mm.
9. … use heavy notching.
10. … use concrete wrapping of timber piles.
ments indicated that the bridge was safe for use. Relating global stiffness to a load capacity is confounded by so many factors that it is highly inaccurate in estimating the load capacity of a bridge. This method does not establish the weakest link in structural elements but instead an overall average stiffness of the bridge. Further, different configurations of timber bridges are improperly analyzed by typical global stiffness systems. Such is the case of a concrete top on a log girder curtain where the two systems no longer connect such that plane sections do not remain plane between the two strata. A false negative develops which dramatically increases risk.

The weakest link in old timber bridges is where they will fail first. Typically, the weakest link is not closely related to the global stiffness. For a non-destructive testing (NDT) method to be successful, it must isolate these critical zones in the structural elements. It is unlikely that a global failure average stiffness assessment will indicate where degraded zones are in a structural element and how close to failure that element may be. In the case of the Kirrama Range bridges, the concrete deck, which caused the decay of the log girders, masked the poor girder condition at the reaction point and the girder collapsed under its own dead weight. The concrete deck was not cracked upon inspection and there was a 75 mm decayed wood gap between the concrete deck and the girders.

Finally, MOE in transverse shear is not considered at all in global stiffness assessments. One area in a typical Australian hardwood log girder bridge where this is a particularly big problem is where the girders become completely decayed at the ends of bridges due predominately to vertical fastening systems in the first meter of the bridge’s girders. Vibrational analysis usually completely misses impending catastrophic collapse due to transverse shear strength and Shear Modulus (G) loss. Figures 4-6 show another bridge in Northern Queensland called North Davidson’s Road Bridge Number 6 which failed within months of being tested with a vibrational damping NDT system.

CONCLUSION

In summary, it is known that a reduction in Specific Gravity (SG) of 10 per cent can lead to as much as an 80 per cent loss in compressive strength perpendicular to grain and a 75 per cent reduction in Modulus of Rupture in bending.

The above photographs show failed timber bridges that were tested with sound bores and global stiffness systems and deemed safe. No indication was found of impending failure triggered by the compromised structural components. This is a strong argument for including Stress Wave Technology (SWT) test methods in NDT methods when inspecting Australian hardwood timber bridges. Proper NDT techniques need to be utilized to allow an accurate understanding of the in-situ condition of these bridges. False negative reporting is a high risk in timber bridge inspection that local governments can ill afford to take. Identifying poor quality or non-existent quality zones over the entire timber structure, not just the high bending stress zones, is critical in any proper timber bridge inspection regime. In order for NDT systems to be effective in properly identifying degraded elements and zones within structural elements that are under duress, the system must be accurate and robust. The weakest links are not accurately understood or located without the proper NDT system.

Dan Tingley is a Senior Engineer/Wood Technologist at Wood Research and Development in Jefferson, Oregon. He can be reached at dant.tingley@gmail.com or (503) 385-8379.