Extending the Life of Hardwood Timber Bridges in Australia

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1.0 INTRODUCTION

Timber bridges comprise a smaller percentage of the total bridges in the world today as the number of concrete and steel bridges increases. Most highway timber bridges are owned by local governments. This is particularly true in Australia. In North America there are approximately 1 million timber bridges with many timber bridges still in service in local government jurisdictions as well as in the railway infrastructure. In Australia there are an estimated 43,000 timber bridges of which the vast majority are owned by local governments and railways. The state highways authorities have divested themselves of these bridges by giving them to local governments to maintain and the few timber bridges remaining on their registries are slowly being replaced with new concrete and steel bridges.

For the most part, timber bridge ownership rests with local governments who least can afford to maintain this vital infrastructure asset. They are struggling to maintain these timber bridges. Further, a large number of these timber bridges service a few taxpayers where the value based decisions to maintain these bridges leave the local government asset managers unsure of what to do to maintain service for their ratepayers. In many cases local government asset managers may not even know how many timber bridges they have or their condition.

To make matters worse there is a constantly dwindling knowledge and practical experience base within the local governments in the area of timber bridge inspection and maintenance. Often external consultants and contractors offer inspection and construction services. These parties usually have proper experience with concrete and steel bridges but very little experience with timber bridges, particularly old ones. With minimal timber bridge expertise in house local governments seek to utilize state timber bridge inspection and maintenance standards that are published by state highways 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 bridge infrastructure using steel and concrete.

The state highway authorities reluctantly republish their timber bridge maintenance and inspection manuals with very few upgrades to reflect the current state of the art with timber bridges based on the world wide developments in timber bridge inspection, restoration and maintenance and greenfield construction. For the most part they don't want the liability associated with publishing new methods of maintaining and inspecting timber bridges since they do not have timber bridges themselves.

Asset managers in local governments have, in many cases, incorrectly accepted the fact that they have what they perceive to be old, worn out timber bridges, and have resorted to cutting timber bridge maintenance budgets in favor of bandaid short term solutions by inexperienced bridge crews (if they have bridge crews at all) while they prioritise their timber bridges for replacement and request money from their councils for these replacements. This strategy leads to poor maintenance practices and only serves to further escalate the demise of the timber bridges held in the registry.

This philosophy of short term repair and replacement has led to a system of prioritising timber bridge conditions from bad to worst. Local governments seek independent concurrence from external consultants to justify their plans to local governing councils for replacement, they ask, "which is the worst bridge and how long can they leave a bridge in place before they must replace it? Or what is the least they can spend to push the bridge replacement or major works out the farthest time period while protecting ratepayers? In local governments where there isn't enough money to follow this strategy the local governments reduce load ratings and speeds or in many cases, where reroutes are available, they just close the old timber bridges.

This strategy runs local government directly into opposition with ratepayers who often look kindly on old timber bridges as part of the heritage of Australia. Further, with the green revolution CO2 footprints and carbon trading have pushed back on this replacement strategy proffered by local governments. After all timber bridges are twenty-two times more carbon friendly than steel bridges and sixteen times more than concrete bridges. Footprints for new bridges are larger, the costs are greater, DERM issues are complicated and environmental considerations 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 overall characteristics. The level I inspection does not speak to bridge load rating except in cases where elements are clearly in 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 as they understand the need to develop a better understanding of what condition the bridge is in so they might determine a way forward with the asset. With limited budgets and an ever aging population of old bridges, owners need to improve the accuracy of these timber bridge inspections while cutting costs. Subsequently they have moved to utilise consultants who provide more advanced techniques for timber bridge inspections which can be performed at lower cost with great accuracy.

The old methods of inspection are still used by many local governments and railways. These consist of many methods, the most popular of which is sounding bores. Sounding bores fit into a broad group of older inspection methods with pick testing and hammer sounding. More advanced modern methods are now utilized around the world such as through compression wave testing.

2.0 AUSTRALIAN TIMBER BRIDGES

Australia has more hardwood timber bridges than the rest of the G-20 countries 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 have better average durability against decay, insect degradation and other environmental degradation factors 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. The old axiom “if it was good enough for daddy it must be good enough for me” or “we have been doing it that way for 100 years must be okay” certainly holds true in many parts of Australia. This is reinforced by the fact that timber is very forgiving with redundancy within its systems. Further, it has superior impact properties as compared to steel and concrete. Finally, it has 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. However, the cost of replacement of hardwood timber parts has been driven upwards significantly by the green movement and heavy restrictions on timber harvesting in Australia. This adds more pressure to improve timber bridge maintenance practices. The typical timelines of longevity which have been historically ten to fifteen years for decks, twenty to thirty years for superstructure and 35 to 45 years for piles are no longer attractive with the high cost of hardwood and installation.

Of the top 200 bridge failures that have occurred in the last two centuries only three timber bridge failures led to a loss of life. While this is good, it is not to be relied on as a reason to neglect the old timber bridges. Timber bridge failures in Australia could yet lead to a loss of life and no local government wants that risk. Figures 1 to 6 contain photographs of bridge failures around the world where, in some cases, great loss of life resulted. Figures 3 through 6 are examples of timber bridge failures. None of these timber bridge failures resulted in a loss of life but it serves as a sobering reminder of the need for proper due diligence during inspection. Note that the timber bridge shown in Figure 4 was several times older than the new steel bridge that failed in Indonesia shown in Figure 2.

Figure 1: I35 Steel Truss Bridge over Mississippi failure Minnesota August 2, 2007. Bridge constructed 1963 to 1967. Thirteen people died, 98 injured, 38 million dollars in compensation paid.

Figure 2: Photographs of the steel truss Mahakam II Bridge built in 1996 in Kutai Kartanegara, East Kalimantan which failed in November 2011. Four people died and 40 missing.

Figure 3: Concrete Overpass Bridge I70, PA, USA.

Figure 4: Timber truss Tuross River Bridge built in 1896 in near Bodalla, NSW failed in 1954. Stranded 200 people.

Figure 5: Timber pile bent/cross head concrete T section deck failure due to collapse of a timber pile bent near Brisbane Australia.

Figure 6: Douglas Shire (Northern Queensland, Australia) log girder timber bridge failure

The images seen above provide a stern warning to all bridge inspectors; "know what you are doing and do it well".

There are many forms of timber bridges in Australia. The classic Australian hardwood timber bridge has a transverse timber plank deck on a log girder system that rests on log corbels, and is typically three or four spans long. This deck system in turn rests on a timber pile bent system with a dimension timber head stock as shown in Figure 6 above. Over the years these bridges, many over 100 years old, have been modified during maintenance works and have had critical structural elements switched out in a wide variety of ways, some good, but most bad for longevity. For example the bridge shown in Figure 7 below on the road to Cape Tribulation is a log girder curtain bridge with transverse dimension timber diaphragm beams that have been heavily notched into the center portions of the girders leading to reentrant corner cracking and degradation of the log girders. The degradation was much more than the advantage gained by causing all the girders to function as a unit, which they never would have due to stiffness differential between girders. However, the log girders in the bridge in

Figure 7 are still in service and have not decayed. They were exposed and able to breathe since a concrete or timber deck had not been spiked to the girders. The bridges shown in Figure 8 are no longer in service and they are 1/3 the age. The same log girder curtain construction was utilized in the bridges in Figure 8 built in 1987. However, a concrete deck was placed on top of the curtain and the attachment method led to accelerated decay and the bridges had to be removed from service.

Figure 7: Noah River Bridge on the road to Cape Tribulation (Northern Queensland), log girder curtain bridge built by the US Army Core of Engineers during the second world war with improperly installed transverse diaphragm beams. Lower photograph shows the logs serving as a wearing surface. They have been allowed to breath and are still in good condition.

Figure 8: One of 11 Kirrama Range Road Bridges (northern Queensland) built in 1987 (top). Log girder curtain bridge with a concrete deck that was connected to the logs with spikes and rebar into the timbers and a poly malthoid barrier between the concrete and timbers that caused the timbers to decay aggressively. Second photo shows bridge being removed to keep traffic off of it. The 11 bridges were closed to traffic due to decayed elements collapsing. Improper construction techniques shortened the life of the bridge by 75%. The girder to concrete interface in the photographs above shows where the top portion of the log sapwood is completely decayed and out of service. It has disintegrated and shrunk away from the concrete by as much as 75 mm in some areas. Obviously plane sections don't remain plane anymore and these bridges are not satisfactory to carry loads. The concrete decks could fail catastrophically at any time.

Figures 9 through 16 show some of the different types of timber bridges in Australia. These bridges all require different inspection considerations since wood is anisotropic and will exhibit different strength and Modulus of Elasticity (MOE) values in different directions. Bridges carry loads over a gap utilizing different resisting stresses.

The resisting stresses in a timber bridge must exceed the applied stresses with at least a composite adjustment factor (CAF) (1.3 for safety and 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 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 ratepayer in brownfield sites.

Figure 9: Lockyer Creek RR bridge, built at the turn of the century, has side cast iron through truss center span and log girders resting on tall (20 m) timber pile bents and frame bents.

Figure 10: Highway bridge built at the turn of the century in Lockyer Valley was closed to traffic. Ironbark logs worth an extremely high dollar amount. Not one single element in the whole bridge was degraded beyond repair. Poor inspection practices and understanding of timber bridge condition and composition led to premature closure of the bridge causing ratepayers to travel a 16km reroute.

Figure 11: Highway bridge built at the turn of the century, combination of composite steel I beams, log girders and timber pile bents. Northern Queensland.

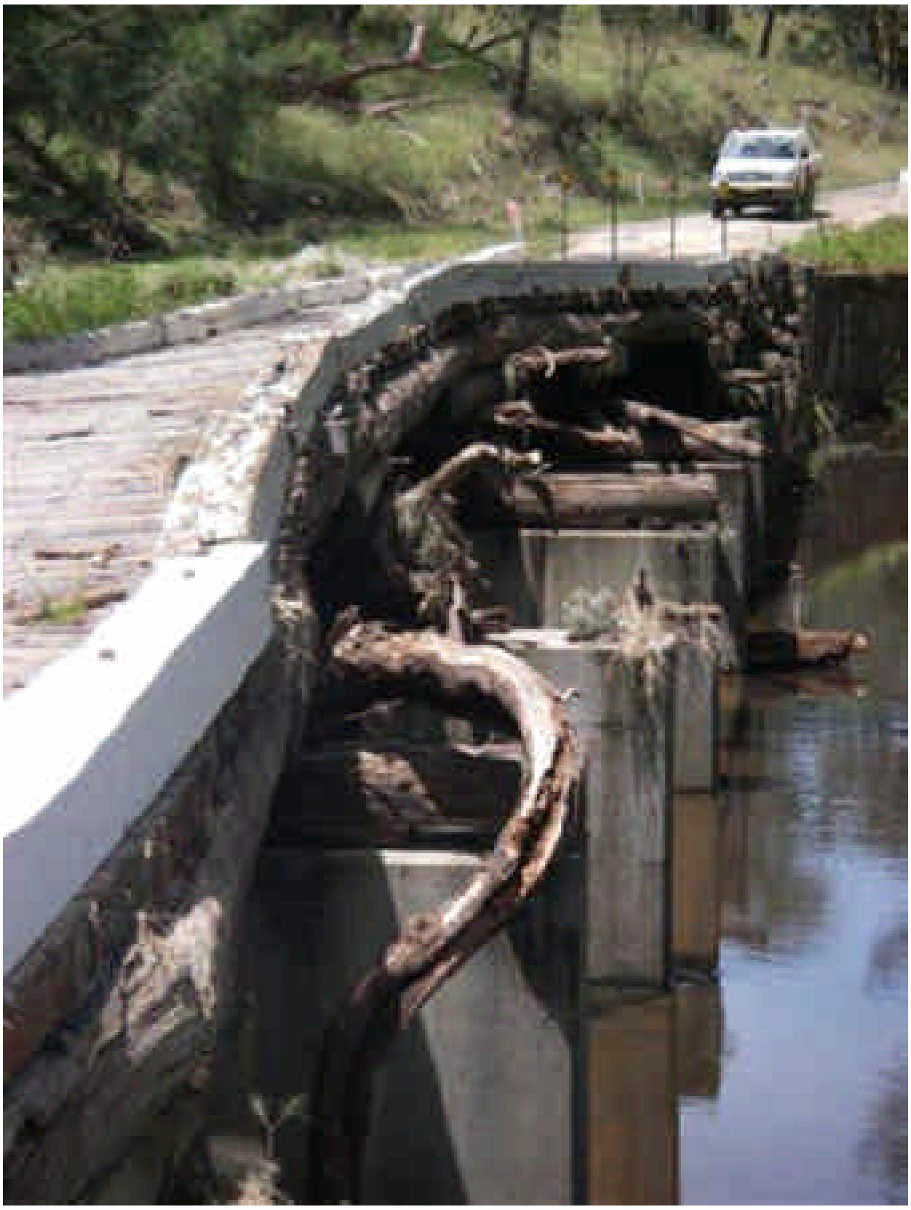


Figure 12: Highway bridge built at the turn of the century. Log girder/log corbel superstructure where vertical through bolts led to accelerated decay in the girder, corbel to concrete head stock connection. When the flood waters came, it could not withstand lateral forces. Glen Innes area NSW.

Figure 13: Improper posting detail on a highway bridge built in Northern Queensland at the turn of the century (top photo left). Posting element size too large, lag joint which leads to reentrant corner cracking and lap joint in the wrong orientation to river flow. Second photograph (top photo right) shows the river flooding and debris forming against the bridge. Lateral loads increased during the flood and since the Global Stiffness testing did not isolate the weakest link created by the improper posting, the bad actor had not been fixed and the whole bridge was lost. The bridge analysis inspection method failed the local government. Bottom two photos show the bridge currently closed. It is to be demolished and must be replaced at a cost of 2 million dollars all caused by one improper posting and then inspection methods!

Figure 14: Highway bridge with concrete piers built during 1930's. Log corbel and girders are less than 20 years old with a CCA treated plywood panel deck 10 years old. The deck is decayed and totally degraded requiring immediate replacement as vertical connectors through the deck have allowed leaching of the CCA from the deck panels. Northern Queensland.

Figure 15: Highway bridge built at the turn of the century in Southern Victoria with longitudinal deck on top of cross bearers and resting on RSJ's (top photo). Vertical fasteners which passed through the malthoid barrier into the cross bearers caused moisture to flow down the spike trace underneath the barrier which prevented the cross bearers from breathing and they all decayed (bottom photo). The $4000/m3 Iron Bark cross bearer and deck system were destroyed in only 8 years because of poor construction and maintenance practice!

Figure 16: Percy Allen three span (33 m per span) Highway Bridge built in late 1800's. Timber trusses prematurely decayed and degraded due to poor maintenance practices such as bent metal flashing, malthoid barrier, vertical connectors, and placement of a new plywood deck with the joints directly over the transverse girders so that water dropped directly onto the primary structural members below. Wagga Wagga NSW. The bridge is being demolished and this famous heritage icon is lost to the public forever.

3.0 WOOD DETERIORATION AND INSPECTION TECHNIQUES

3.1 Wood Deterioration

Wood deteriorates for numerous reasons and as deterioration implies, adversely affects the wood properties. The two primary causes of deterioration in wood are biotic (living) agents and physical (nonliving) agents. In many cases, the agents that first alter the wood also provide the conditions for other agents to attack (e.g. insects bring woodpeckers). The effectiveness of an inspection of deteriorated wood depends upon the inspector's knowledge of the agents of deterioration. A timber bridge inspector must be well-trained in all aspects of wood technology. A solid understanding of the way wood transfers stresses through different directions (it is anisotropic) and its subsequent response to degradation, both biotic and physical, is essential for accurately assessing wood deterioration. Deterioration is most commonly caused by decay causing fungi, and so decay causing fungi will be the focus of this discussion. There are other common forms of degradation such as ferric embrittlement which leads to loss of connector capacity and moisture retention induced degradation due to application on heavy dimension timbers (over 50 mm minimum dimension) of heavy solids content paints and coatings (greater than 30% solids).

3.2 Wood Deterioration Due to Biotic Agents

Biotic organisms that attack wood include bacteria, fungi, insects, and marine borers. As living organisms, they require certain conditions for survival such as moisture, oxygen, temperature, and food, the latter usually being the wood. When the basic living conditions are provided, biotic agents of wood deterioration will freely proliferate. But if any one condition is removed, the wood is safe from further biotic attack.

Fungi cause the most common form of wood deterioration. When exposed to favorable conditions, most types of wood become an attractive food source for a variety of decay-producing fungi. The fungi require moderate temperature, oxygen, and a moisture content of approximately 20% or greater (oven dry basis) to become active. Decay in wood caused by fungal growth progresses most rapidly at temperatures between 5C (40F) and 50C (120F). Outside this range, fungal activity slows considerably and ceases when the temperature drops to 2C (35F) or below or rises to 38C (100F) and above. Wood can be too wet for decay also. If the wood is water-soaked (saturated), the supply of oxygen may be inadequate to support development of typical decay fungi[1]. Thus, wood will not decay, and decay already present from prior infection will not progress if appropriate conditions are not met.

Decay fungi may be generally classified into two categories by the appearance on the wood surface.

Brown rot: Appears darker and can crack across the grain. Brown rot fungi attack the cellulose in the wood fibers. The brown color is due to the remaining lignin (the binder which holds the cellulose structure together), which is not consumed by the fungi. The

[1] Forest Products Laboratory. 1999. Wood Handbook: Wood as an Engineering Material. U.S. Government Printing Office. Agric. Handbook. 72. Washington DC: U.S. Department of Agriculture; rev. 1999.

decayed wood tends to form into small cubic shaped sections, which is a sign of advanced decay.

White rot: Appears lighter in color and does not crack across the grain until severely degraded. In contrast to brown rot, white rot fungi consume both the lignin and cellulose and leave the surface appearing generally intact, but with little or no significant mechanical strength. The surface of the decayed wood tends to have a "white" appearance. White rot impacts longitudinal shear resistance and is very common in cross heads in Queensland which are often governed by applied longitudinal shear. The wood often appears cubed and cracked across ray or longitudinal cell lines.

Dry rot is a common type of decay fungi in which the wood becomes brown and crumbly in an apparent dry condition. However, dry rot is a misnomer because the wood must have some moisture in it to decay, although it may become dry later. A few fungi have water-conducting strands (hyphae) which are capable of carrying water, usually from the soil, into buildings or wood piles where they moisten and rot wood that would otherwise be dry.

Interior decay damage can occur even when some precaution has been taken. Surface-treated wood material can form cracks, which extend beyond the treated surface into untreated core material. Water can also get into the core of "protected" wood by the fungi hyphae. In either case, water enters the core material and provides adequate conditions for decay fungi to live.

Surface decay can be identified by both visual and probing techniques. Decayed wood tends to be very rough in texture with closely spaced cracks and grooves. With a pocketknife or flat-head screwdriver, decayed wood can easily be penetrated and partially removed. These techniques are only suitable for identifying possible surface decay. The depth of the damage may be determined by taking core samples.

3.3 Effects of Fungal Decay of the Properties of Wood

The primary effects of fungi attack on wood can be characterised by the following points[2]:

1. Change of color
2. Change of odor
3. Decreased weight
4. Decreased strength
5. Decreased stiffness
6. Increased hygroscopicity (easier absorption of water)
7. Increased combustibility
8. Increased susceptibility to insect attack

The incipient stages of fungi attack are characterised by a change of color and perhaps a change in the odor and may not be detected by changes in hardness or by surface tests. This stage may be very difficult to detect visually. Decay may reduce the mechanical properties by 10 percent before any significant weight reduction is noticed. When weight loss is between 5 and 10 percent, the reduction in mechanical properties may be reduced 20 to 80 percent[3]. Usually when decay is discovered by visual inspection, the damage has already been done.

Advanced stages of fungi attack reduce the specific gravity (weight) which decreases nearly every other mechanical property, including strength and is indicated by soft, punky, or crumbly wood. This factor is one of the primary misunderstandings by engineers that have not been trained in wood technology practices. A very common method of checking the quality of a timber pile is to core with a drill bit, to establish the amount of piping or cavities. No attention is paid to the loss of Specific Gravity (SG) of the outer ring of apparently sound wood (annulus). The test involves assessing the amount of piping or coring. Without a clear

[2] Bodig, J., Jayne, B.A. Mechanics of Wood and Wood Composites. Krieger Publishing Co. Florida, 1993. pp. 586-589.
[3] Forest Products Laboratory. Wood Handbook: Wood as an Engineering Material. U.S. Government

understanding of the quality of the outer ring of wood which can be obtained utilizing Stress Wave Timing and core recovery and testing, there is no way to properly assess the ability of the timber pile to continue to resist vertical axial loads and vertical axial loads combined with lateral forces (e.g. water flow, wind or impact (vehicular traffic). Simple piping estimates gained by drilling a hole and inserting a feeler to measure the thickness of the annulus, to access section loss and not annulus quality, often leave the bridge substructure open to excessive deflections and lateral deformations. See Figure 17 for photograph of annulus, where a log is cavitated with an annulus that is apparently sound. In this figure the decay is shown in area at 2 o'clock in the annulus and again in an area around a non-galvanized steel spike, which has allowed ferric degradation and condensation hydration for decay to propagate. This area would not support axial compression loads and could initiate buckling failure or bending movement failures, if it were a pile in service.

Figure 17: Cavitated/piped timber pile section where the area at about 2 o'clock is decayed in the annulus and SG is significantly reduced. Also note in this area an old spike where there is ferric degradation and decay propagated by moisture content (MC) in the wood at the fastener caused by condensation off the spike.

Without a proper assessment of the outer ring of remaining timber pile, in a piped or cavitated timber pile, excessive super structure movement and deck movement and constant maintenance can occur. In addition, eventually greater localised failures in the piles will occur such as brooming/feathering of the pile. Other related failures are feathered tops, loose; cross brace, sash brace, waler and cross head connections from elongation of the connector holes. Finally, cracked and spread piles occur, laterally buckled piles and skewed piles. All of these characteristics will usually be associated with more pronounced lateral and vertical movement in bridge decks under lower and lower vehicle loads and speeds.

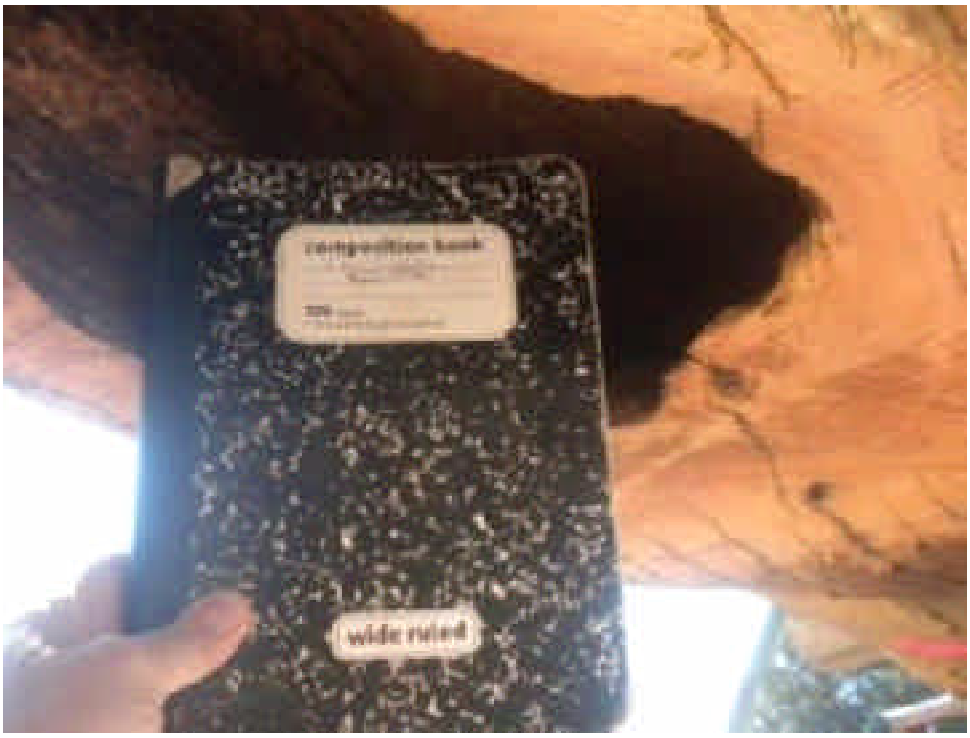
The typical approach to fix this problem is to band with heavy steel bands (hopefully galvanized) which do not protect against lateral inward movement of the outer annulus. When inward motion occurs, the bands become loose and slip downwards or out of place. Another problem with bands on piles that have very little piping or cavities is that the wood develops extremely high tensile stresses in the band due to outward moisture related expansion of the timber pile. Bands are simply not effective in providing continuous collective action against compression parallel to grain in the timber pile. In fact they are in many cases a detriment, as they hold moisture against the timber pile, allowing ferric degradation to occur in non-galvanized or poorly galvanized bands. Infilling and epoxy welding are generally accepted current state-of-the-art techniques used to replace section loss and reduced mechanical properties in timber piles. This remedial work should be followed by diffuser treatment to prevent further decay. See Figure 18 below for photographs of ineffective steel banding in the Shackells Folly Bridge, a bridge found in Moira Shire, Victoria.

(a)

(b) **(c)**

Figure 18: Photographs of banded piles. See (a, b and c) above for band in Shackell's Folly bridge pile. If the wood expands due to the moisture, it will develop 1000 mpa in the band, well over its maximum stress capability. The thin gage banding intended to conform to the surface better still makes no contact and is loose! Totally ineffective for the intended purpose! Shackell's Folly Bridge is particularly interesting for the steel banding as the steel deck ballast tray is leaking and during the inspection there was ample water flowing onto the log piles causing them to swell, note the water on the cross head and log pile in (c) above. Further, this bridge has a steel ballast tray with vertical through connectors into the log girders similar to the vertical connectors into the cross bearers used in many timber bridges throughout Australia, which has led to decay in the centers of the cross bearers in many timber bridges.

In addition to timber piles, the effect of SG reduction in the annulus can have very detrimental effects in round log girder performance in bridges. See Figure 19 below where a round log girder in a log girder/log corbel bridge in Mitchell Shire (Costello's) had received a clean bill of health in a Level III report and was found to have a very high Stress Wave Time across the diameter (8-9,000 ms) by WRD inspectors. When the round log girder was prepared for application of the retrofit lamination by removing a slab from the bottom face, a branch butt end was removed with a chain saw. When the branch butt end was removed a very large cavity that ran 2/3 of the length of the girder was exposed with an annulus that had a SG reduced by nearly 35%. In addition the annulus thickness at the bottom in the high tensile bending stress zone was thinned to 15 mm due to the cavity growth. This girder barely held its own dead weight and fortunately was a side girder or it would have collapsed under low traffic loading of 1T or less. Other such girders were found in interior positions in the bridge. It is actual testimony to the need for utilisation of advanced inspection methods when inspecting old timber bridges. Simple sounding bores at the end of the log girder in a single location will not properly allow assessment of the girder condition.



(a)

(b)

(c)

(d)

(e)

(f)

(g)

Figure 19. Cavitated timber bridge girder (a, b and c) in place at Costello's Bridge in Mitchell Shire. In addition to the large cavity running 2/3 the length of the log, the annulus SG is significantly reduced. Decay propagated by constant elevated MC in the wood around the metal vertical through bolts was caused by condensation on the through bolt shank and shelf water following the bolt channel into the core of the log. This constant hydration source provided fertile ground for the decay fungal colony to grow. Such excessively decayed, cavitated, reduced SG annulus log girders can be retrofitted utilising keyways and new treated hardwood keys (d and e) and interior injection with fire proof polymers that slowly polymerize as they work their way into all the open cavities in the log. In addition, high strength fiber retrofits (f and g) are applied and diffused to prevent further decay from occurring in the annulus wood. Note the oak bungs in the side of the log plugging the hole where the diffusers are placed in the log annulus (f and g)

3.4 Detecting Deterioration

Methods for detecting wood deterioration can be divided into two categories: interior detection and exterior detection. In each case, specific methods or tools are appropriate for different types of damage and structures. There is no certain method that will accurately determine the condition of a given structure save sectioning and destructive testing which is not practical, but a combination of methods, tools, and a well-trained inspector can provide a reasonably accurate assessment of any deterioration.

3.5 Exterior Detection Methods

Exterior detection methods are easy to employ, because of easy access to exterior wood. The methods most commonly used include visual inspection, probing, and the pick test. These methods provide a basis for further interior detection methods to define the extent of damage.

3.5.1 Visual Inspection

Visual Inspection is the simplest method for locating wood decay on the outside (exterior) of the member and is suitable for detecting decay in more advanced stages. Visual inspection may not be an effective method to find early stages of decay when control is most effective. Some common indicators of decay, which can be found by a visual inspection, are listed below[4]:

Fruiting bodies: Some types of fungi produce fruiting bodies, which appear on the surface during the decay process. These types of indicators can easily be partially cleaned off by weathering. If fruiting bodies are observed on exterior wood members, the decay is most likely extensive. See Figure 19 below for a photograph of white fruiting bodies on log girders in Hamilton's Road Bridge and Bridge 10 on the range road in CCRC.

[4] Forest Products Laboratory. 1999. Wood Handbook: Wood as an Engineering Material. U.S. Government Printing Office. Agric. Handbook. 72. Washington DC: U.S. Department of Agriculture; rev. 1999.

(a)

(b)

c).

Figure 19. Photograph of fruiting bodies (brown) on timber element in the tenth timber bridge found in the Kirrama range in CCRC (a). Note the shelf water from the leaking deck and shelf water from outside the deck rain shadow, falling on the outer timber log girder. This coupled with the girder being on the south side of the bridge, the uphill side and closer to moisture all led to increased levels of moisture and elevated decay conditions. Proper drainage techniques for decks and protection from the elements are important in timber bridges. Proper steps should be taken to allow water to move quickly away from timber bridge structural elements. See photograph in (b). (particularly interesting hyphae at 9 o'clock on left side of photograph coming out of pore and into another adjacent pore) above, taken with a microscope, of a wood core taken from a timber bridge in Murrindindi Shire in Victoria, where fungal hyphae can be seen growing through the large pores in the core cross section. These hyphae tips secrete enzymes on the wood that break the cellular structure down as discussed earlier. When fruiting bodies are evident, hyphae are present in the wood at work breaking down the cellular structure and causing loss of structural capacity. Photograph in c) above shows a log girder in Hamilton's Road Bridge with a fruiting body due to similar conditions discussed above.

Sunken faces: Localised surface depressions are often a sign of decay near the surface. The wood may be intact or partially intact at the surface. See Figure 20 below for sunken faces found in typical timber bridge cross bearers which looked to be in great condition from the outside and had been installed just years early at great expense to the shire in Victoria.

(a)

(b)

Figure 20. Photograph of sunken face on a cross bearer in a timber bridge (a). This is strong evidence of decay from excessive water migration into the cross bearer vertically along deck spike traces. Even though hot petroleum jelly (see black stain beneath the square edge) was used, it is obvious how ineffective this method is in preventing decay caused by such improper timber construction practices. Proper deck clips fastened to the cross bearers with horizontal through bolts are required (b). Advanced decay of the type witnessed in the timber cross bearers causes significant loss of structural capacity.

Staining or discoloration: A surface blemish can indicate if the wood member has been subjected to surface water contact.

Bulging of wood over the bearing points in beams. The decrease in specific gravity caused by fungi attack greatly diminishes the perpendicular-to-the-grain bearing capacity of wood. See Figure 21 below for photographs of bulging in cross bearers in a timber bridge.

Figure 21. A bulging face on a cross bearer in a timber bridge. This is strong evidence of decay from excessive water migration into the cross bearer along deck spike traces. Even though hot petroleum jelly (see black stain beneath the square edge) was used, it is obvious how ineffective this method is in preventing decay caused by such improper timber construction practices. Advanced decay of the type witnessed in the timber cross bearers causes significant loss of structural capacity. These cross bearers were only a few years in service but had their useful lifetime shortened by 80% or more because of poor connector installation practices.

Insect activity can be identified by holes, piles of wood powder, or frass.

Plant or moss growth indicates that a relatively high moisture level is present, a condition suitable for decay.

3.5.2 Interior Decay Detection

Due to lack of visible indicators, interior deterioration is difficult to detect. Several methods and tools exist for assessing interior damage they include moisture meters, core sampling, and stress wave timing.

3.5.2.1 Moisture Meters

Moisture meters can help identify wood at high moisture content internally. Typically up to 50 mm deep with a face MC meter and deeper up to 100 mm with a prong MC meter. High moisture content wood is a suspected area of potential decay. Untreated wood with moisture content higher than 20-25% indicates conditions suitable for decay.

3.5.2.2 Core Samples

Core samples, a type of assay sample, can be recovered from bridge structural timbers by using an increment borer, widely used by the forestry industry on living trees. These can be used to obtain a core sample of a wood structural member. Core samples are a solid wood core that can be examined for evidence of decay, or void pockets. Core samples can show the limit and extent of deterioration and provide lab samples. Lab samples can be cultured to indicate the presence of decay fungi to provide an assessment of future risk, and also to analyze the specific gravity of the wood. Suspected decay areas, determined by moisture meters, visual inspection, or other methods, can be confirmed by coring.

3.5.2.3 Stress Wave Propagation

The use of stress wave measurement techniques to locate internal decay, have recently become popular because of their non-destructive nature. Stress wave analysis consists of sending a “compression” wave through a medium (wood) and measuring its velocity. The compression wave is introduced into the material by striking it with a hammer or blunt object. When the compression wave is initiated by the hammer, an accurate timer is started; when the sound reaches a second accelerometer, the timer is stopped. The distance between the “start” and “stop” accelerometer is measured. By measuring the distance (gage length) and time, the average velocity of the stress wave (compression wave) can be measured. The Modulus of Elasticity (MOE) and strength of the material is theoretically related to the velocity of the stress wave and the density. It is the measured velocity of the compression wave that indicates if decay is present or not.

If the sample has been subject to fungi decay, the specific gravity (weight) of the wood will decrease. The decrease in specific gravity causes a decrease in the velocity of the stress wave. Therefore, if decay is present the stress wave times are greater over a fixed distance (i.e. velocity decreases). The EPHOD™, Electronic Pulse Highlight and Outline Diagnostic, is a type of stress wave analysis procedure that was developed by WRD for Australian by Tingley.

3.6 Preventing Decay

There are many types of man-made chemical preservatives, which are used to prevent fungi attack. The best known is creosote, which is often used to preserve wood utility structures. Pentachlorophenol (Penta) and Copper Naphthenate (CN) are also used to treat bridge girders and other wood members where human exposure is limited. Problems such as the leaching of creosote into the water in rivers and its' toxicity have caused its' use to be slowly limited. Chromate copper arsenate (CCA) is an effective wood preservative which is safe to handle for humans. The CCA treatment has been changed in recent years due to carcinogenic concerns over its use. A less carcinogenic substitute called *ACQ* (Alkaline Copper Quaternary) has taken its place around the world. The ACQ option adversely affects galvanized steel and much thicker coatings of galvanizing on steel must be utilized to protect the steel connector from accelerated degradation from the ACQ.

Unfortunately, the treatment process for CCA and ACQ uses water as the transport mechanism which can cause splits and checks, especially for larger wood members. The effectiveness of CCA in the heartwood is in question due to generally poor penetration (often caused by tyloses, a naturally occurring occlusion of the cell cavities which prevents preservative travel through the wood cellular structure).

In summary, Penta and CN are the most commonly utilised bridge treatments methods. Both treatments should be applied with petroleum based solvent to prevent water related degradation that can occur during and after treatment. Further, the water borne preservatives tend to leach up against the cell wall and will in similar form leach back out whereas Penta and CN treatments with petroleum based solvents fix against the cell wall and do not tend to leach out like a water borne solvent based treatment. In addition, the CN should be borne in the solvents at high concentrations of at least .1%, not like typical hardware store diluted solutions such as .05%. The Penta can be borne in light or heavy solvents and should be treated to at least and uptake of 5 kg/mm (3) (or refusal). Finally, all bridge timbers should be treated after all holes are drilled and other forms of machining completed. It is important that minimal machining occurs after the pressure treatment on the site. Also incising of the elements should be completed prior to treatment. Incising exposes more end grain and deeper side grain and thus improves uptake of preservative and better distribution of same. See photographs in the following sections of new bridge decks installed at Alpine Shire in Victoria with incised pressure treated glulam decks. If machining is required after treatment it should be followed by preservative with at least .1% CN field treatment, followed by end sealing with paraffin wax in solvent solution e.g. anchor seal to prevent end grain feathering.

Most chemical treatments require special pressure tanks to obtain the necessary penetration depth for effective decay resistance. Surface treating is not nearly as effective as pressure treatment because once the protective coating is broken by localised splits, checks, and moisture cracks an avenue for fungi attack is created. This creates a problem for post treating of treated wood elements in existing wood structures or components in-situ.

There are other forms of preservation of timber bridge elements such as fumigants and diffusers. Fumigants were developed to provide chemical protection without the requirement for pressure treatment and moisture content in-situ in the timber elements. This allowed structures already in the field to be treated. The first use of the technology was applied to wood utility poles and has developed from there to use in beams and columns in bridges. Diffusers act similarly to fumigants except that they begin to diffuse or deplete and vaporise through the wood when moisture contents exceed 20% whereas fumigants deplete and vaporise through the wood at all moisture contents. Fumigants are toxic to fungi as the vapour kills the fungi, whereas diffusers are naturally occurring basalts that neutralize the PH wave that is created by fungi hyphae secreting acidic enzymes that break down the wood. When the wood is not at or above 20% moisture content diffusers don't deplete and stay intact until needed when the MC again exceeds 20%. This means that they travel more effectively and are utilized with the wood reaches decay causing levels of moisture This MC triggered dissipation reduces the maintenance cost for maintaining diffusers versus fumigants which dissipate continuing and need constant recharging. Further, fumigants are often very toxic to humans whereas diffusers are not. This is an excellent feature of diffusers versus fumigants which deplete continuously regardless of the moisture content in the wood.

Boron is a type of fumigant and is very effective in controlling wood decay but is not as toxic to humans as the chemical preservatives noted above. Boron can be processed into rods, gels, and liquids, and inserted into predrilled holes in a structural wood member. The boron preservatives slowly dissolve over time and the natural moisture in the wood facilitates the migration of the boron through the pores.

A type of diffuser is a basalt diffuser with a borate compound that is fused into the basalt. These rods are sold under the trade name Decaystop™. This type of diffuser combines the positive decay toxicity with the PH wave neutralising effects of the basalt (decay hypae secrete an acidic enzyme on the wood to break it down and become edible thus reducing the strength of the wood by reduced SG). Since the borate/basalt diffuser preservatives depend on moisture to transport the preservative, treatment with rods may not be appropriate in areas where construction detailing, flashing, or roof repair has been performed which eliminated the moisture supply for the fungi. Research has indicated that the moisture content of the wood needs to be greater than 40% for adequate boron transport through Douglas-fir heartwood[5]. Basalt/borate diffusers operate well at MC's over 22%. For exposed beams or structural members in contact with the ground, water or in close proximity to these conditions, Decaystop™ diffusers are ideal. Typical high quality Basalt/borate rod treatments are excellent ways to stop further decay by diffusion.

4.0 LEADING CAUSES OF TIMBER BRIDGE DEGRADATION IN AUSTRALIA

Many of the degradation problems seen in timber bridges today could be prevented by better construction and maintenance practices, adding many years of service to the life of the structures. The leading causes of this degradation focus around two main areas of concern: allowing moisture to penetrate and remain trapped within the timber elements where it promotes decay. The top modifications to design and maintenance practices are as follows.

Change vertical through bolting to horizontal bolting that does not pass through the upper surface. Examples of through bolt degradation are shown in Figures 23 and 24.

Figure 23. Vertical through bolts have allowed moisture to penetrate from the bridge deck above, causing premature decay in the structural members below.

[5] Morrel, J. J. Sexton, C. M., Preston, A. F.1990. Effect of Moisture Content of Douglas-fir Heartwood on Longitudinal Diffusion of Boron from Fused Borate Rods. Forest Products Journal. 40(4):37-40.

Figure 24. Through connections all channeled water to the interior of this pile in a fire lookout tower. .

Stop the use of malthoid barrier that traps moisture on the top of the timber elements where it is unable to evaporate. The long term high MC causes excessive decay. See Figure 25 below.

Figure 25. Malthoid barrier was used between the girders and deck panels. Vertical fasteners through the deck panels penetrate the malthoid barrier, allowing water to follow the fastener through the barrier, trapping it in the girder below and causing decay. These girders were only a few years old when they failed.

Insure positive deck drainage that does not fall directly onto structural elements such as shown in Figure 26 below.

Figure 26. Improperly placed downspouts caused accelerated decay in the structural members above. On the right, additional timbers were added without correcting the cause of the problem.

Provide for moisture content induced dimensional change in timber elements, such as oval holes in side plates. Stop the use of banding to stabilise timber piles that are degraded with decay, splits, cracks and broomed/feathered tops as shown in Figure 27 below.

Figure 27. Banded piles. When the wood expands due to moisture, it can develop 1000 Mpa in the band, well over its maximum stress capability, expanding the band. Piles are driven tip first, tapering down. When the moisture level changes, the bands become loose, sliding down the pile as shown on the left. The banding also does not stop the inward buckling of feathered, cavitated pile tops.

Stop the use of near end drift pinning in an attempt to stop end feathering.

Provide clearance for timber members to breathe. Debris around the abutments is often left in place for prolonged periods of time as shown in Figure 28. This debris should be cleared away from the girders and abutments. It holds moisture around the timbers which leads to accelerated decay.

Figure 28. Debris has built up around this abutment leading to higher moisture contents in the adjacent timbers and subsequent accelerated decay conditions. This debris should be cleared away from the timbers and abutment during routine regular maintenance.

Stop the use of heavy percentage solids coatings (over 29% solids) on large dimension timber elements over 50mm. These coatings trap moisture against the timber, promoting decay.

Stop the use of heavy notching and slope cut notches with a minimum 1:6 slope to prevent stress concentrations and re-entrant cracking as shown in Figure 29 below.

Figure 29. Girder with a heavy notch way beyond allowable depth as per the timber design standard in Australia. Longitudinal tension perpendicular to grain and horizontal shear cracks are originating in the notch area. This girder will crack further along the grain and the grain is traveling upward, compromising the girder in a short period of time with continued use.

Use properly sized timbers in pile bents and place loads within D of the pile to prevent horizontal shear cracking in undersized cross heads as is shown in Figure 30.

Figure 30. Girders are placed more than depth D of the cross head away from the pile. The cross heads are deflecting and horizontal shear cracks are forming.

Stop the use of concrete jackets which trap moisture around the timber members as shown in Figure 31.

Figure 31. The concrete jacket poured around this pile has done more damage than good, causing widespread rot in the timber members.

5.0 CONCLUSION

There is a widespread perception that timber bridges have a shorter service life than those constructed of other materials. However, with a thorough understanding of the properties of timber and proper techniques in the design, inspection and maintenance, timber bridges are capable of many years of service at a reasonable cost. The use of advanced non-destructive testing techniques to find the degradation in the timber elements coupled with advanced restoration methods provides an excellent solution for local governments as they seek to reduce life cycle and maintenance costs for their timber bridges.