Durability of Wood Bridges

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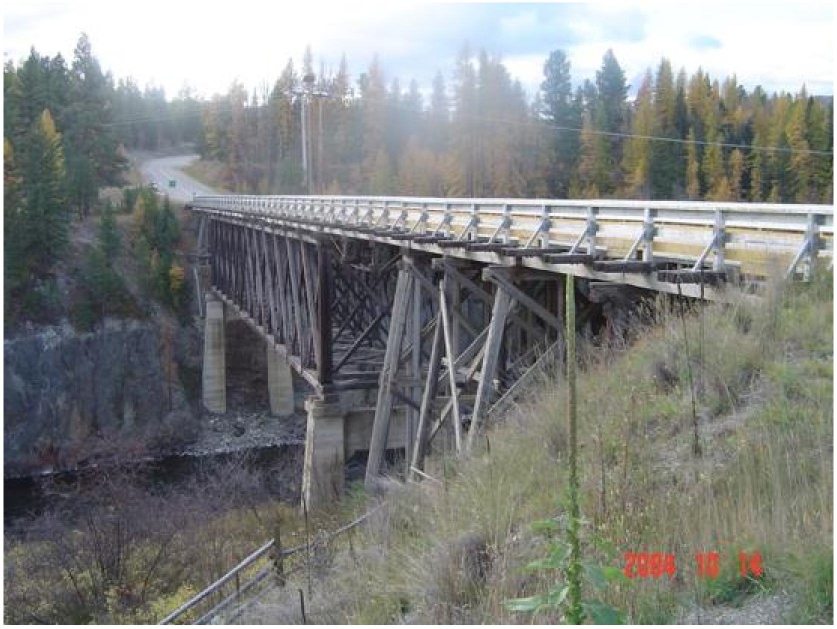

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Timber bridges are an excellent way to showcase the strength and durability of wood structures, even under harsh conditions, when material selection, design, construction and maintenance are done well. They could also be critical infrastructure elements that span fast rivers or deep gorges. Consequences of failure of these structures can be severe in loss of life and loss of access to communities. Durability is as critical as engineering to ensure safe use of timber bridges for the design life, typically 75 years in North America.

There are numerous examples of old wood bridges still in service in North America (Figure 1). The oldest are traditional covered bridges (Figure 2), three of which are around 190 years old. In Southeast China, Fujian and Zhejiang provinces have numerous covered bridges that are almost 1000 years old (Figure 3). The fact that these bridges are still standing is a testament to the craftsmen that selected the materials, designed the structures, built them, monitored their condition and kept them maintained and repaired. They would have selected the most durable wood species available, likely Chestnut or cedars in North America, china fir (china cedar) in southeast China. They would have adzed off the thin perishable sapwood exposing only the naturally durable heartwood. The fact the covered bridges around today all look similar is because those were the tried and tested designs that worked. They clearly designed those bridges to shed water with a wood shingle roof, vertical siding projecting below the deck and structural elements sheltered from all but the worst wind-driven rain. Any rain that did not drip off the bottom of the vertical siding and wicked up the end grain would also dry out reasonably rapidly. Slow decay that did occur at the bottom of these boards was inconsequential because it was remote from connections to structural elements. Construction must have been meticulously performed by experienced craftsmen. Those craftsmen may well have been locals that would continue to monitor the bridge over its life and make any repairs necessary. Of course, not every component in those ancient bridges is original, particularly shingle roofs that typically last 20-30 years depending on climate. These bridges have all been repaired due to decay and in some cases dismantled and re-built over the years for various reasons (e.g., due to changes in traffic loads, arson, flooding, fire, hurricanes, etc.). The Wan'an Bridge in Fujian is known to have been built in 1090, refaced in 1708 and rebuilt in 1845, 1932 and 1953. The apparently increasing frequency of rebuilding may suggest a loss of knowledge and skills, but all repairs and reconstruction prior to 1845 may not have been recorded.

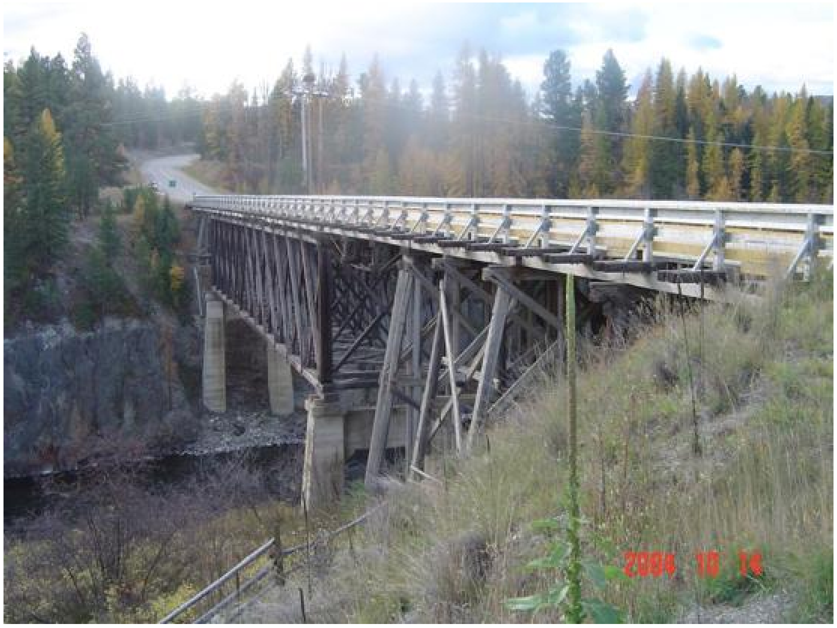

Figure 1. St Mary's Wycliffe Bridge, near Cranbrook BC, built 1931. Photograph, prior to reconstruction, courtesy of the BC Ministry of Transportation and Infrastructure.

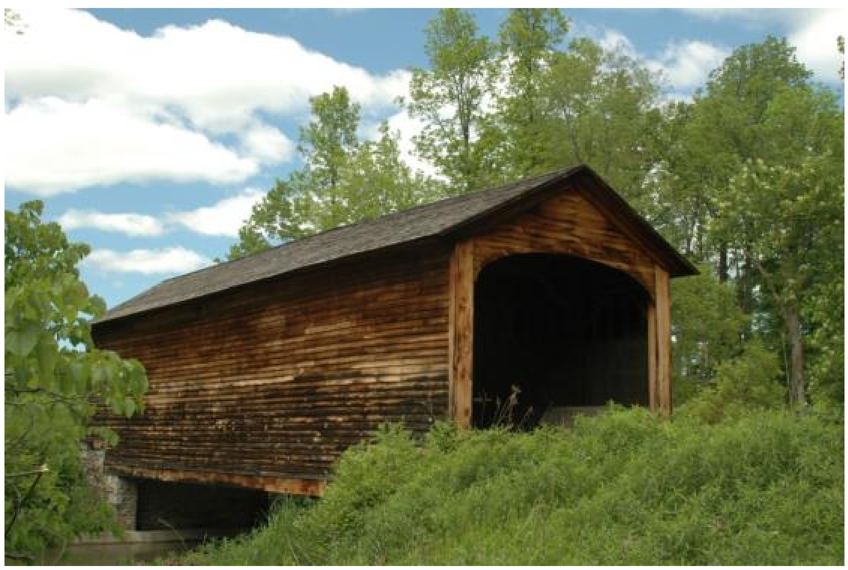

Figure 2. Hyde Hall bridge, Springfield, New York, built in 1823. One of the oldest covered bridges in North America. Courtesy: Trish Kane/Theodore Burr Covered Bridge Resource Center, Oxford, NY.

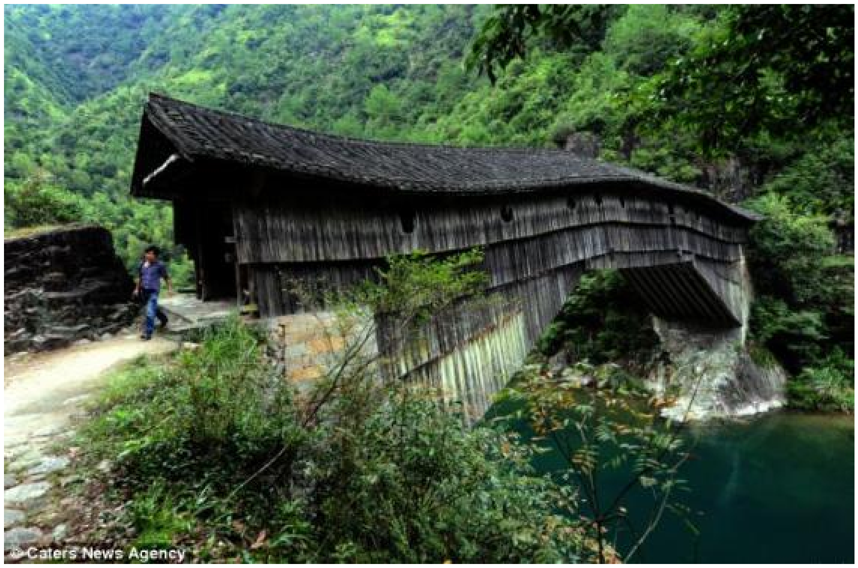

Figure 3. Yangmeizhou bridge, in the Kengdi village of Shouning County, built during the Ming Dynasty (http://www.dailymail.co.uk/news/article-2253793/The-1-000-year-old-wooden-bridges-modern-China-moving-Stunning-timber-structures-withstood-test-time.html)

The durability of historic covered bridges relied on roofs that are not appropriate for many crossings that must accommodate tall or wide loads. For a modern (non-covered) timber bridge, relying entirely on protection by design for a 75 year service life assumes a degree of perfection in design, construction and maintenance never achieved in practice. It has been suggested that non-durable untreated wood structural components can be protected by a concrete bridge deck. However, concrete is rigid whereas wood construction moves in response to moisture changes. Concrete bridge decks require at least one expansion joint. Cold joints eventually leak. Concrete slabs eventually crack. Similarly waterproof membranes and mastic eventually break down. There are numerous examples of failure of “waterproofing” causing moisture ingress and decay in wood structural components. However the basic principles that made covered bridges last can show us how to reduce the moisture load on the structure and ensure the longevity of a new generation of modern timber bridges. The CSA S6-14 - Canadian Highway Bridge Design Code requires that all wood in permanent structures shall be preservative treated in accordance with CSA O80 Series or AWPA U1 and T1.

Relying entirely on preservative treatment and ignoring design is equally risky. In the past in Canada and other parts of the world, the long service life of many non-covered timber bridges has relied on heavy application of creosote. Some specifiers would reject material that was not dripping with creosote, on the basis that it was not adequately treated. That meant there was a reservoir of mobile creosote that could move into any holes or cuts in the timbers during construction, or cracks that opened up in service, preventing decay fungi from getting deep into the wood. With increasing environmental concerns, new bridge timbers are being treated using the Best Management Practices for The Use of Treated Wood in Aquatic and Wetland Environments developed by the Western Wood Preservers Institute, Wood Preservation Canada, Southern Pressure Treaters Association and Southern Forest Products Association. These processes eliminate dripping of creosote, but they are also likely to reduce the protective effect in checks. Today it is critical to combine durability by treatment and durability by design to achieve a 75 year design life, in other than frigid or arid climates.

With appropriate inspection, maintenance and repair, such bridges could have service lives over 200 years.

1 SELECTION OF MATERIALS

Wood components for modern timber bridges must have sufficient decay resistance for the anticipated and potential exposure to moisture. The heartwood of naturally durable woods such as yellow cedar and western red cedar can work well in covered bridges with considerable protection by design, but in all other bridge designs preserved wood should be used. Typically the choice of wood will be made on the basis of strength properties and Douglas-fir is commonly specified. However, other wood species which are more receptive to preservative treatment can also be used with appropriate design.

Due to the large dimensions of solid bridge timbers, the preferred preservatives are those that reduce splitting and checking. These include creosote, pentachlorophenol in oil, copper naphthenate in oil and ammoniacal copper zinc arsenate (ACZA is aqueous). Modern glue-laminated timbers are fabricated in a dry condition so oil-type preservatives should be used. One approach used in Norway is to pressure treat lamina with a waterborne copper-based preservative, fabricate into beams, cut to length and prepare all joints, pressure treat the bridge components with creosote (Figure 4). This works well because they use Scots pine which has wide treatable sapwood. For Canadian wood species which are predominantly heartwood, dual treatment with borates and oil-type preservatives should provide better protection since borates will penetrate heartwood and the oil-type preservative keeps away the moisture that would cause the borate to leach out. Dual borate/oil-type preservative treatment processes have been developed for solid timbers and are under development for glue-laminated beams. Chromated copper arsenate (CCA) can be used for timbers, but is preferred for smaller dimension bridge components, particularly those where incidental human contact is likely. The CSA O80 series of standards on wood preservation should be specified in Canada and the American Wood Protection Association standards should be specified in the USA. The preservative treatment of parallel strand lumber and laminated veneer lumber should be in accordance with AWPA U1 and T1, since there are no specifications for these materials in the CSA O80 series.

Figure 4. Dual copper/creosote treated glulam in the Åset Bridge in Norway, built 2014.

Bridge components should be prefabricated as much as possible prior to treatment to minimize the potential for exposure of unpenetrated interior zones by on-site drilling and cutting during construction. If additional protection is required for the interior of wood components that are not fully penetrated by pressure treatment, borate rods can be inserted at strategic locations near end grain, checks and joints.

2 DURABILITY BY DESIGN

As with wood buildings, the 4Ds are helpful in thinking through durability by design.

2.1 Deflection:

- Use metal flashing to deflect rain from horizontal and sloped surfaces and any V joints (copper lasts longest). The upper surface of timbers tends to develop checks that trap water (Figure 5).
- Use naturally durable or preserved wood louvers or cladding to deflect rain from sides of beams.
- Avoid end grain of timber components bearing directly onto concrete that can be damp. Use durable damp-proof membrane or provide small gaps at all interfaces.
- Preserved wood bridge decks can be protected with a bituminous waterproofing layer and an asphalt wear surface requiring no expansion joint.
- A concrete bridge deck can provide considerable protection against precipitation but is not perfect (see comments above).

2.2 Drainage:

- Use wood-metal-plate-wood connections to space wood components apart at least 10mm (Figure 6).
- Support columns on metal fittings that permit water to drain from the wood surface.

- Slope horizontal components where possible.
- Avoid exposing nail laminated or otherwise closely appressed components to rain since the vertical capillaries between the components will trap water.
- Minimize water traps.
- Promote rapid runoff of rain, particularly on bridge decks making allowances for build-up of detritus.

2.3 Drying:

- Expose wood components to drying winds as much as possible.
- It is most important to permit drying from the end grain of wood components.
- Avoid large solid metal plate connectors on the sides or ends of wood components (Figure 7).
- Use flashing or waterproofing on no more than two sides of wood components.
- Smaller components dry faster than larger components.

2.4 Durable Materials:

- For wood components, see Selection of Materials above.
- If metal components are expected to last as long as preserved wood components, they should be galvanized and powder coated. That includes metal plates and dowels.

Drawings of specific details designed for durability (and strength), and the reasoning behind them, should be communicated to the construction team. Detailed recommendations on structural design are provided in the Canadian Wood Council publication Wood Highway Bridges and in the USDA publication: Timber Bridges: Design, Construction, Inspection, and Maintenance

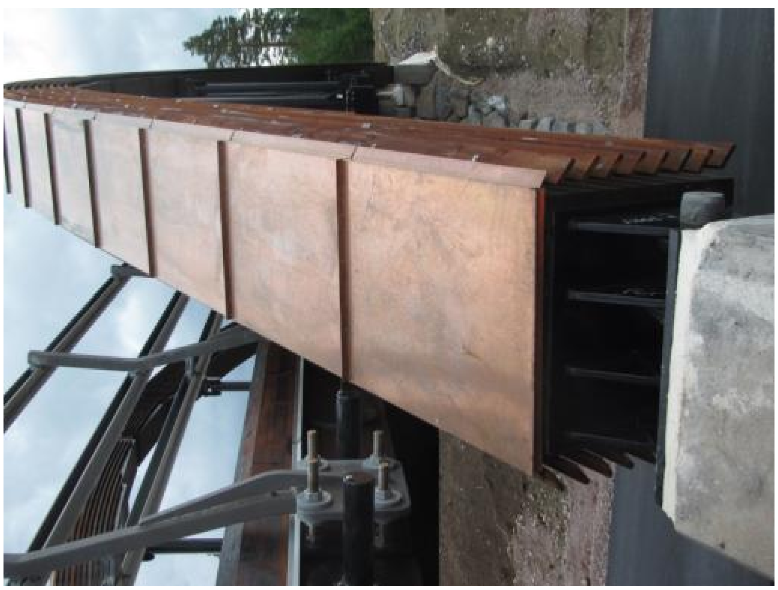

Figure 5. Copper flashing, louvres and drainage promoting connection on Åset Bridge in Norway, built in 2014.

Figure 6. Wood components spaced apart by metal connectors on the Flisa bridge in Norway.

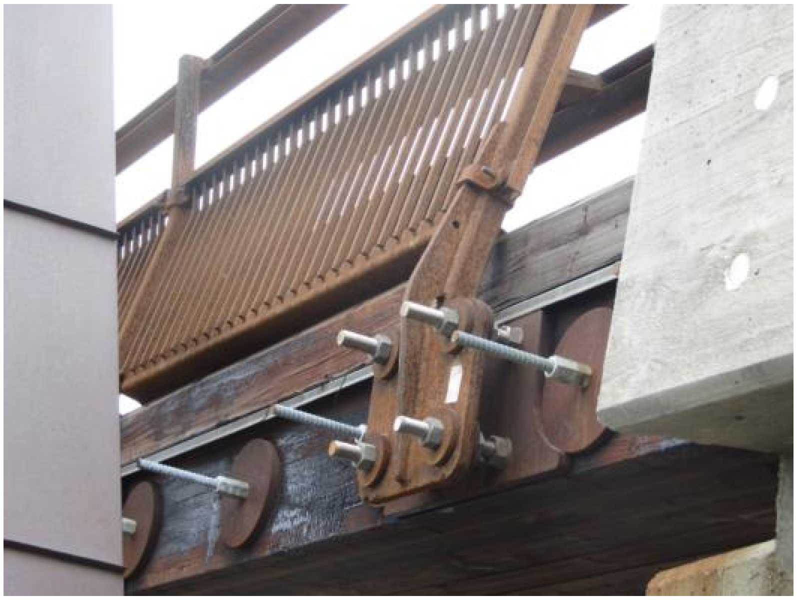

Figure 7. Metal plate connectors not too large to prevent drying on Sletta Bridge in Norway.

3 CARE IN CONSTRUCTION

Refer all proposed material substitutions to appropriate experts in the field. Understand and avoid compromising all details designed for durability. Any unavoidable holes and cuts during construction should be given at least two brush coats of a field-cut preservative, such as copper naphthenate containing 2% copper as metal. Ensure continuity and appropriate lapping of waterproofing layers. Avoid creating water traps. Borate rods can be put into drilled holes in locations where observation of the finished structure reveals that durability by design provisions are not providing sufficient protection against moisture. Make these holes ideally on the underside or if necessary on the sides of the components to minimise moisture ingress. Detailed recommendations on construction are provided in the USDA publication: Timber Bridges: Design, Construction, Inspection, and Maintenance

4 INSPECTION

With appropriate, design and construction, the inspection intervals for wood bridges need be no more frequent than for bridges constructed of other materials. However, inspectors should be trained in the causes and process of decay in exposed wood structures. Non-destructive evaluation techniques are commonly available and should be used to detect any hidden decay or other defects in the structural wood components. Detailed recommendations on inspection are provided in the USDA publication: Timber Bridges: Design, Construction, Inspection, and Maintenance.

5 MAINTENANCE AND REPAIR

Where decay of wood components is suspected or anticipated, but the structural integrity of the component has not been compromised, supplementary treatments may be used. Where untreated wood is exposed at the surface, perhaps due to physical damage, two brush coats of a field-cut preservatives should be applied. Where checks have opened in service, borate rods can be placed in drilled holes alternating each side of the check at a spacing based on the manufacturers instructions. Where wood components are decayed beyond repair, replacement of those components with freshly treated wood should be made. Detailed recommendations on maintenance are provided in the USDA publication: Timber Bridges: Design, Construction, Inspection, and Maintenance.

6 ACKNOWLEDGEMENTS:

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