TIMBER BRIDGES

RESEARCH BULLETIN

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TIMBER BRIDGES

RESEARCH BULLETIN

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EXECUTIVE SUMMARY

TIMBER BRIDGES play a critical role at local, state, and national levels. They provide rapid and cost-effective transportation solutions. To that end, this bulletin addresses the benefits of constructing bridges with timber, including low carbon footprint, short construction time, environmentally benign aesthetics, high strength-to- weight ratio, off-site fabrication, extended service life, long spans, and favorable economics.

Methods for improving timber bridge durability and protection are critical aspects of this bulletin. Physical, chemical, and design-based protection strategies against biotic organisms and abiotic stressors, methods of protection and maintenance as well as choice of structural form are included in this document.

Options for use of hardwood species, treatment techniques, connection details, and deck design are described. Nationally recognized standards, including AWPA, ASTM, and AASHTO are referenced to facilitate knowledge transfer.

Examples of timber bridge construction from around the world are illustrated. It is hoped that this bulletin will inspire, promote, and educate many stakeholders, designers, supervisors, and engineers in the field of timber bridges for years to come.

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ADVANTAGES OF TIMBER BRIDGES

TIMBER BRIDGES

Forest and Wildlife Research Center Bulletin, Mississippi State University

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INTRODUCTION

Wood was one of the first materials used to construct bridges. It is relatively abundant and easily obtained in most regions of the world. It is relatively easy to work with using either rudimentary or sophisticated tools. In flexure, it has favorable span to depth ratios, and is easily installed during bridge construction. While steel and concrete have joined wood as primary materials for bridge construction in the nineteenth and twentieth centuries, wood is still routinely used for short- and medium-span bridges. Currently, 17,500 bridges with spans longer than 20 feet are made of timber in the United States (United States Department of Transportation – Federal Highway Administration, 2021).

Timber is a remarkable material for bridge construction because of its strength, light weight, energy-absorbing properties, natural appearance, longevity, sustainability, and market availability.

Timber bridges can support short-term overloads without adverse effects. Large wood members in timber bridges provide fire performance that meets or exceeds that of other materials, and they appear to be an environmentally and economically friendly alternative to steel and concrete (Ritter, 1990; Dugdale, 2015). Timber bridges can be built rapidly in virtually any weather condition without detriment to the material and offer excellent resistance to salt and other deicing chemicals. Compared to steel and concrete, timber structures offer significantly better carbon sequestration. Installation of timber bridges does not require the use of special equipment, and they can generally be constructed without the use of highly skilled labor. Lastly, they can provide a natural and aesthetically pleasing appearance (Crocetti, 2014; Brashaw et al., 2020).

EXTENDED SERVICE LIFE

Most longevity related issues with timber bridges are associated with either upgrading of roads for wider lanes and heavier loads or degradation of structural timber caused by weathering and wood-destroying organisms. When appropriately constructed, bridges may achieve more than 50 years of service life. A notable example is the Keystone Wye bridge (Figure 1) in South Dakota (Gilham, 2015). This bridge was finished in 1968 and supports ~2,044 daily traffic crossings over a span of 290 feet. Data from the latest condition rating and evaluation indicated that the deck, superstructure, and substructure conditions were classified as being in fair condition (NBI condition rating of 5) (U.S. DOT – FHWA, 2021). Note: SD-DoT is currently replacing the existing concrete deck roadways with transverse glulam deck panels as part of an overall rehabilitation effort.

Several assessments by Wacker et al. (2014) show that properly designed timber bridges remain in excellent condition for many years. These authors describe a timber bridge in Yakima County Washington (Figure 2) in service for 75 years with no record of repair or rehabilitation at the time of the study. In 2021, after 82 years in service, this bridge maintains an average daily traffic of ~1,805 vehicles and trucks. When last inspected in 2019, the bridge was noted to be in satisfactory condition (NBI condition 6) (U.S. DOT – FHWA, 2021).

FIGURE 1. Keystone Wye bridge built in 1968 in South Dakota (South Dakota Department of Transportation, 2022).

FIGURE 2. The 82-year-old Yakima County, Washington bridge (Wacker et al., 2014)

STRENGTH

Another common misconception regarding timber bridges is that their use is limited to rural roads and minor structures with low traffic volume. With proper design and support, timber can handle longer spans, heavier vehicular loads, and greater traffic volumes. Individual timbers have characteristics such as knots that affect strength and stiffness, but these factors are addressed in the lumber grading stage and are thus accounted for in design. With respect to solid sawn materials, the size of the tree can be a limiting factor in bridge design (Dugdale, 2015). However, modern technology offers a wide variety of solutions to the aforementioned issues such as glue laminated timber, or glulam. Glulam is an engineered wood product made by laminating individual pieces of dimensional lumber using heat, pressure, and glue (waterproof resin). The resulting engineered product is a larger and stronger beam (The Engineered Wood Association – APA, 2008). For example, the allowable bending stress of a Douglas-fir select structural grade beam is 11.0 MPa (1600 psi), while a glue laminated member may achieve bending stresses of 16.5 Mpa (2400 psi). Engineered wood makes manufacturing of beams up to 228.6 cm (90 inches) deep (Gilham, 2015) possible. Additionally, supports or "bents" can be constructed to divide long spans into multiple shorter spans, using solid sawn timber.

Gilham (2013) provides several case studies detailing the strength properties of modern timber bridges. A remarkable example was the Lower Burnett Road Bridge in Buckley, Washington with a deck-arch system incorporated into the structure (Figure 3). The secondary framing system used a 17.1 cm (6 ¾ inches) longitudinal glulam deck and the horizontal curvature was accommodated by curving the deck panels to a 198 m (650 feet) radius. The deck was supported by timber bents that were supported by a series of main arches. The total bridge span is 118.9 m (390 feet), and 5.49 m (18 feet) wide. It was designed to carry H15 vehicle loading in addition to a 4.07 kPa (85 psf) pedestrian load.

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FIGURE 3. The Lower Burnett Road Bridge in Buckley, Washington (Turner, 2010).

LONGER SPANS

With engineered products and/or creative designs, long spans can be achieved. According to Gilham (2015), glulam technology enables the manufacture of longitudinal stringers up to 41.14 m (135 feet). Truss and arch bridges are also options for supporting longer spans. Timber arch bridges can be designed to span 60 m (200 feet) and timber truss bridges can reach 90 m (300 feet). Legg and Tingley (2020) detailed the Overpeck Park Bridge in Teaneck, New Jersey (Figure 4). This bridge uses a pair of glulam through arch-bridges, each with span of 43 m (140 feet) and has a roadway width of 9 m (30 feet) incorporating a 3 m (10 feet) wide walkway. Each arch segment of this bridge is broken into two segments. This bridge supports an HS20 loading as per the American Association of State Highway and Transportation Officials (AASHTO standards).

In July 2013, the longest clear-span glulam timber truss bridge in North America was engineered by the Western Wood Structures and funded by the American Recovery and Reinvestment Act. The Placer River Trail bridge (Figure 5), located in the remote Alaskan wilderness, has a clear span of 85 m (280 feet), can sustain wind gusts up to 193 km/h (120 mph), and can support 1.37 MPa (200 psf) of ground snow load, flooding potential, and high seismic events. The 4.5 m (15 feet) wide structure features a 1.8 m (6 feet) walkway that is wide enough to accommodate administrative vehicles. The 85 m (280 feet) trusses are 4.5 m (15 feet) high at each end and more than 8 m (27 feet) high at midspan. This bridge was designed to carry a 6.04 kN/m2 (126 psf) snow load that is roughly equivalent to HL-93 AASHTO vehicle loading (APA, 2014).

FIGURE 4. Overpeck Park Bridges in Teaneck, New Jersey (Bridge Hunter, 2022a).

ECONOMICS

Cost effectiveness is one of the primary goals for any bridge construction. In a case study by Brashaw et al. (2020), the St. Louis County bridge was selected. The design featured steel girders with a transverse glulam deck, longitudinal deck stiffeners, and guard rail system. The superstructure included steel, pentachlorophenol treated southern pine glulam, abutment steel plates, wearing surface, waterproof membrane, deck flashing, and miscellaneous supplies and had a total cost of $245,140. Prefabricated timber bridge elements are relatively light, easily installed, and do not require highly skilled labor for installation. This reduces freight charges and cost of lifting equipment. Additionally, the construction time for timber bridges can be significantly lower than a comparable steel or concrete bridge by using prefabricated components. In the case of St. Louis County bridge, the duration for installation was 13 days (Ritter, 1990; Brashaw, et al., 2020).

FIGURE 5. Placer River Trail Bridge in Alaska. (Tomasulo, 2014).

AESTHETICS

According to the AASHTO (2017), bridges should complement their surroundings, be graceful in form, and present an appearance of adequate strength. Timber bridges can be designed and constructed with single or multiple wood species enabling a wide range of color variations and adding aesthetic value in rural and natural settings. They readily blend into their natural Environments. For example, the consortium between The Oregon Department of Transportation and the U.S. Bureau of Land Management chose timber bridges to provide access to hiking trails in southwestern Oregon. The result was the Tioga Bridge that fits beautifully into its location spanning the North Umpqua River (Figure 6) (Gilham, 2015).

FIGURE 6. Tioga Bridge over the North Umpqua River in Oregon (Bridge Hunter, 2022b).

BEST PRACTICES FOR DESIGN, CONSTRUCTION, INSPECTION AND REPAIR

Timber bridges show remarkable performance in different environments with various designs. However, it is important to follow best design and implementation practices when using timber. There are concerns associated with biotic and abiotic deterioration, and frequency of maintenance associated with timber construction (Crocetti, 2014). However, with proper design, wood protection, and planning, potential attacks by wood-destroying organisms are mitigated. Similarly, by using heavy or large dimension timbers, wood bridges have been shown to have favorable fire performance characteristics as flames on heavy timbers are, for the most part, self-extinguishing (Ritter, 1990). All construction materials require periodic inspection and repair whether it be sandblasting, painting, filling gaps, or repairing rust. Timber is not unique in these respects. For timber bridges, preventive or remedial techniques can be done without affecting traffic and public safety. These techniques are relatively inexpensive and usually do not require highly skilled labor (Dahlberg et al., 2015).

CONCLUSIONS

Case study analysis from different environments, designs, and road conditions has shown that timber bridge construction can be effective, stable, and safe. Timber bridges support a wide range of load requirements, have excellent service lives, are economically favorable, and provide aesthetic value to communities. Attention to the ways in which wood interacts with each stressor can assist engineers, designers, and architects in their efforts to design and construct bridges with greater safety, longer service life, lower overall construction cost, and increased durability in the name of public service.

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TIMBER BRIDGE DESIGNS

TIMBER BRIDGES

Forest and Wildlife Research Center Bulletin, Mississippi State University

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INTRODUCTION

Historically, timber was the primary material used to construct roadway bridges. During the past 150 years, steel and concrete have displaced much of these owing to longer span requirements on primary roadways. However, timber bridges still provide excellent serviceability throughout the USA, primarily on secondary roads at the state, county, and municipal levels. Contemporary timber bridges provide many societal benefits, including favorable aesthetics, minimal road-outages during construction, long service-life, low cost and environmental sustainability, particularly a low carbon footprint, and sequestration perspective.

Currently, there are four general classes of timber bridges. These are utilitarian, historical, high visibility, and iconic (Johnson, circa 2000). Utilitarian bridges are basic, inexpensive, low-profile bridges. These blend into the environment and are often nearly invisible. This classification describes the majority of timber bridges in service today. Historical bridges are those with some form of historical value or context. These are most often seen as wooden covered bridges. The covering on these bridges provided many benefits. It served to tie left and right trusses together and thereby prevent racking, it provided a roof which served to keep the wood members below dry, and perhaps most importantly, the entryway looked somewhat like a barn door which facilitated cattle and other animal entry and crossing (Mettem, 2019). New construction of historical-type bridges often seeks to preserve or recreate classical traditions and styles associated with a given location.

High visibility bridges serve as a type of focal point in a community where timber material and design are highlighted and brought out. Design details may include highly visible timber guard rails, bents, abutments, and other structural elements that let a user or bystander know that timber is an important component of the structure. Iconic bridges are designed to make a strong statement. These serve as focal points and often highlight the importance of the river, the river crossing, or that area to the community. Elevated truss, suspension, cable stay, or hybrid bridges also serve in this classification (Figure 1).

FIGURE 1. Example of trestle and roofed beam bridge (Porta, 2019).

INTRODUCTION (CONTINUED)

This publication focuses on utilitarian bridges. These are the most common and typically the most cost effective for moving vehicles, cargo, and people across waterways. Modern timber bridges are the result of technological advances in manufacturing, construction, and fabrication of engineered wood products (Ritter, 1990; Duwadi and Ritter, 1997; Dugdale, 2015). Some of these evolved from designs developed between 50 and 100 years ago. Typically, utilitarian designs incorporate readily available commodity type materials (treated lumber and nails) and can be constructed and installed with relatively common equipment (backhoes and excavators). By understanding and adhering to fundamentals or “first principles,” timber bridge designers and engineers can continue to provide rapid, low cost, environmentally friendly bridge solutions to communities throughout the USA for the foreseeable future.

DESIGNS

To improve transfer of knowledge regarding the use of wood in modern transportation structures, three sets of standard plans are considered: standard plans for timber bridge superstructures, standard plans for southern pine bridges, and standard plans for glued-laminated timber bridge superstructures (Lee et al., 1995; Wacker and Smith, 2001; 2019). These standard plans were developed through cooperative research between the United States Department of Agriculture (USDA) Forest Products Laboratory (FPL) and several other interested and cooperating entities.

The Standard plans for timber bridge superstructures was developed by Wacker and Smith (2001) through cooperative research between FPL, Laminated Concepts Incorporated, and the Federal Highway Administration. This standard follows specifications from American Association of State Highway and Transportation Officials (AASHTO) (AASHTO, 1991; 1995; 1996), American Society of Testing and Materials (ASTM) (ASTM, 1996), American National Standards Institute/American Institute of Timber Construction (ANSI/AITC) (ANSI/AITC, 1992), and the American Wood Protection Association (AWPA) (AWPA, 1996). The standard includes design and detail of seven superstructure types, nail-laminated decks, spike-laminated decks, stress-laminated sawn lumber decks, stress-laminated glulam decks, longitudinal glulam panel decks, glulam stringer and transverse glulam decks, and transverse glulam decks for steel beam bridges. Figure 2 summarizes two longitudinal deck systems.

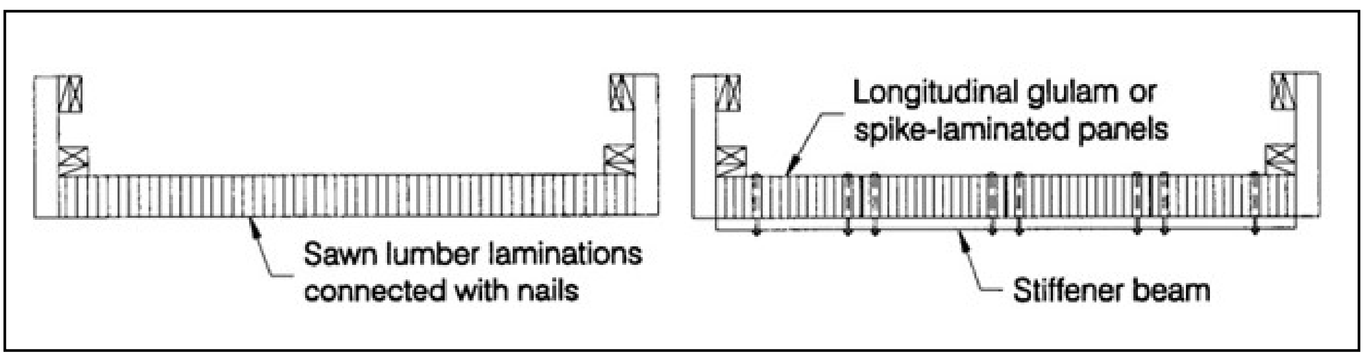

FIGURE 2. Typical configuration of the end view of a nail laminated deck system and a longitudinal glulam or spike-laminated panel deck system. (Summary only, full details in Wacker and Smith, 2001).

DESIGNS (CONTINUED)

The intent of this standard is to aid engineers who may not be familiar with timber bridge design by summarizing key configuration and design features of each system. The engineer can then utilize this standard during the preliminary design phase to determine a viable timber bridge superstructure system for their site location. **TABLE 1** provides a summary of the deck systems included in the Standard plans for timber bridge superstructures.

TABLE 1. Summary of deck systems for the standard plans for timber bridge superstructure.

Superstructure type[1]	Bridge length (ft)	Deck thickness (in.)	Roadway width (ft)
Sawn lumber deck systems			
Nail-laminated	10–28	8–16	Variable
Spike-laminated	10–34	8–16	Variable
Stress-laminated	10–34	8–16	Variable
Glulam deck systems			
Longitudinal panel	12–38	8–16	12, 16, 24, 28, 32
Stress-laminated	10–60	9–24	Variable
Stringer with transverse deck	20–80	5.125	12, 16, 24, 28, 32, 36
Transverse deck for steel stringers	N/A	5–8.75	Variable

[1]Refer to Lee and Wacker (1996) and Wacker and Smith (2001) for full descriptions.

DESIGNS (CONTINUED)

Published by Lee et al. (1995), the Standard plans for southern pine bridges was developed under cooperative research agreements among the FPL, the University of Alabama, and the Southern Forest Products Association. This standard follows specifications from American Association of State Highway and Transportation Officials (AASHTO) (AASHTO, 1990; 1991; 1992), American Society of Testing and Materials (ASTM) A47, A36, A722, A307 (ASTM, 1984; 1990a; 1990b; 1992), American National Standards Institute/American Society of Mechanical Engineers (ANSI/ASME) (ANSI/ASME 1981), the American Wood Protection Association (AWPA) (AWPA, 1994), the National Design Specification for Wood Construction (NDSWC) (NDSWC 1991), and the Society of Automotive Engineer (SAE) (SAE, 1989). The publication includes designs for three southern pine timber bridge superstructures, namely stress-laminated sawn lumber bridges, stress-laminated glued laminated timber (glulam), and longitudinal stringer with transverse plank deck bridges. Figure 3 displays two standard plan examples from Lee et al. (1995).

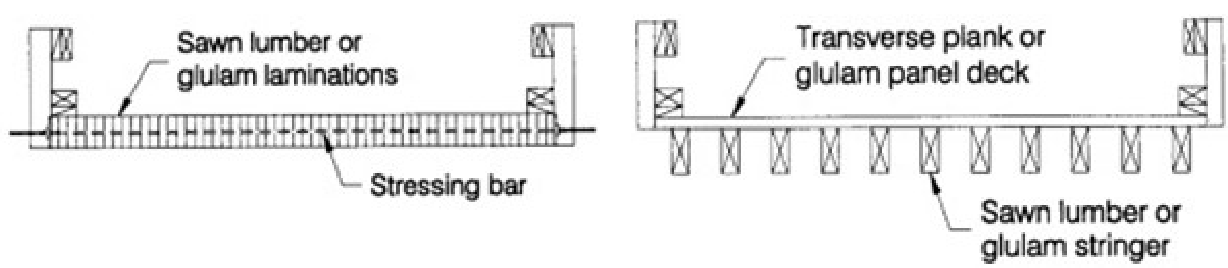

FIGURE 3. End view of stress-laminated deck system and longitudinal stringer bridge (Lee et al., 1995).

The objective of the Standard plans for southern pine bridges was to provide complete information regarding all aspects of the design and construction of the bridge superstructure, enabling engineers that may be unfamiliar with timber to easily understand and implement the design (Lee and Wacker, 1996). Materials lists, fabrication details, construction recommendations, and design examples are included in the plan, as well as deck details, railing and curb configurations and suggested substructure attachments. The designs are based on the AASHTO HS20-44 and HS 25-44 vehicle loading standards, as well as two options for live-load deflection criteria, L/360 and L/500. The superstructure designs are suitable for non-skewed, simple-span bridges with single and double lanes. Table 2 summarizes each superstructure design included in standard plans for southern pine bridges.

As southern pine lumber design values were changed in or around 2012/2013, the allowable span ratings also changed for bridges that incorporate dimension lumber therein. Similarly, as the use of other wood species structural lumber design values change, their respective span ratings change. That said, the principles of design remain constant over time. These include avoiding water traps, designing for drainage, maintaining pitch or grade on the bridge, using appropriately preservative- treated wood, and providing for routine inspection and maintenance as appropriate.

The Standard plans for glued-laminated timber bridge superstructures was developed to provide simplified information to facilitate the design of glued-laminated timber bridges that conform to the AASHTO-Load and Resistance Factor Design (LRFD) methodology. Included in this specific set of standards are four superstructures, namely longitudinal glulam decks, stress-laminated glulam decks, glulam stringers, and transverse glulam decks. Additionally, this standard plan covers a wide range of specifications and design considerations that include qualifications of fabricator; codes and standards for compliance; required certifications; structural design; timber materials; preservative treatment; hardware; bearing pads; and methods for delivery, storage and handling of materials.

DESIGNS (CONTINUED)

TABLE 1. Summary of superstructure designs in **Standard Plans for Southern Pine Bridges**.

Bridge type[1]	Material Grade	Member Size (nominal in.)	Bridge length (ft)
Stress-laminated sawn lumber	No. 2	2 by 8 2 by 10 2 by 12	10-20
Stress-laminated glulam	24F-V3	Up to 6.75 by 11-16.5	20-32
Longitudinal stringer with transverse plank deck	No. 1 Dense or No. 2	6 by 14 6 by 16 6 by 16	5-23

[1]Refer to Lee et al. (1995) for full descriptions.

CONCLUSIONS

This document highlights utilitarian timber bridges. The Standard plans for timber bridges referenced herein describe timeless transportation solutions that balance safety and long-term social, environmental, and engineering performance against the stewardship of public funding. These bridges are particularly well suited for traffic volume and loads on state, county, and municipal roads. The plans assist engineers, architects, and designers to fully understand timber bridge structure, design, and installation which can help make designing with wood easier. In total, these standard plans provide complete information for ten different timber bridge options from the design phase through the construction phase with clear specifications and standards that foster safe, durable, and cost-effective transportation solutions. Lastly, these plans are available to the public at no cost, which reduces the economic burden for public employees or contractors, when constructing with timber.

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DESIGN AND CONSTRUCTING FOR DURABILITY

TIMBER BRIDGES

Forest and Wildlife Research Center Bulletin, Mississippi State University

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INTRODUCTION

Wood is a low cost, readily available, and sustainable material commonly used for residential, light commercial, and industrial applications. As wood is a natural organic material, it responds and reacts to its surrounding environment. For example, unprotected wood in exterior applications develops a grayish "weathered" appearance over time. In outdoor situations, there are a variety of design attributes to consider in an effort to maximize structural durability and longevity. This document describes environmental factors that can impact long-term timber bridge performance and presents design considerations to maximize service life.

As a natural material, when not preservative treated, wood in service can be susceptible to decay, insect attack, and weathering in exterior and some above-ground, protected situations. Wood can be protected by designing wood structures to mitigate the impacts of these detractors as well as by preservative pressure treatment. Well designed and protected timber structures can provide decades of service to support their function(s) with minimal or programmed maintenance (Reinprecht, 2016).

Designing for durability is dependent upon two key factors: performance requirements of the elements or structure as dictated by commonly used regulatory standards or other contractual specifications, and durability of wood in service (Lebow et al., 2019). Several North American standards and specifications address these issues. The most prominent of these standards and specifications are provided by the American Wood Protection Association (AWPA), American Society for Testing and Materials (ASTM), American Association of State Highway and Transportation Officials (AASHTO), and globally, the International Organization for Standardization (ISO).

Regarding durability, the AWPA designates chemical preservative systems and retention levels necessary for protecting wood products under specified exposure conditions. These exposure conditions and associated use category system is described in Table 1 (AWPA, 2019). Generally, the more critical the application or the more severe the threat for insects and decay, the greater the required preservative retention on a weight-per-volume basis.

TABLE 1. Summary of AWPA use categories, for pressure treated wood.

Use Category	Service Conditions[1]
UC1	Interior construction. Above ground dry
UC2	Interior construction. Above ground damp
UC3A	Exterior construction. Above ground. Coated and rapid water runoff; Protected by design from liquid water
UC3B	Exterior construction. Above ground. Uncoated or poor water run-off
UC4A	Ground contact or fresh water. Non-critical components (Includes above ground contact application with ground contact type hazards or that are hard to replace)
UC4B	Ground contact or fresh water. Critical component or difficult replacement
UC4C	Ground contact or fresh water. Critical structural components
UC5A	Salt or brackish water and adjacent mud zone (northern zones)
UC5B	Salt or brackish water and adjacent mud zone (southern zones)
UC5C	Salt or brackish water and adjacent mud zone (southern to tropical zones)

[1]Abbreviated summary. Refer to AWPA standards for full specifications.

INTRODUCTION (CONTINUED)

One of the most critically important applications for pressure-treated wood in the United States is in timber bridge construction. Approximately 17,500 timber bridges are currently in service across the United States (US Dept. of Transportation Federal Highway Administration, 2021). Because highway bridges are structurally critical, most components are treated to UC4C (Table 1). This includes round and sawn support piles, pile caps, stringers, abutment materials, and deck components. Rail posts and rails, which are above ground, are typically treated according to UC4A class or UC3B (Lebow et al., 2019). An example of a timber bridge and its supporting wood elements that are considered important and structurally critical is shown in Figure 1. Glulam members are specified under a different commodity specification than most other components (structural composite lumber) and those treatment options vary somewhat from traditional sawn lumber specifications. Refer to the AWPA book of standards for the most recent approved treatments for glulam and other engineered composites as well as the American Plywood Association (APA) for guidance on selection and sourcing of treated glulam. The most important considerations are that a suitable preservative is incorporated, and the resin system used in creating the glulam is rated for exterior use.

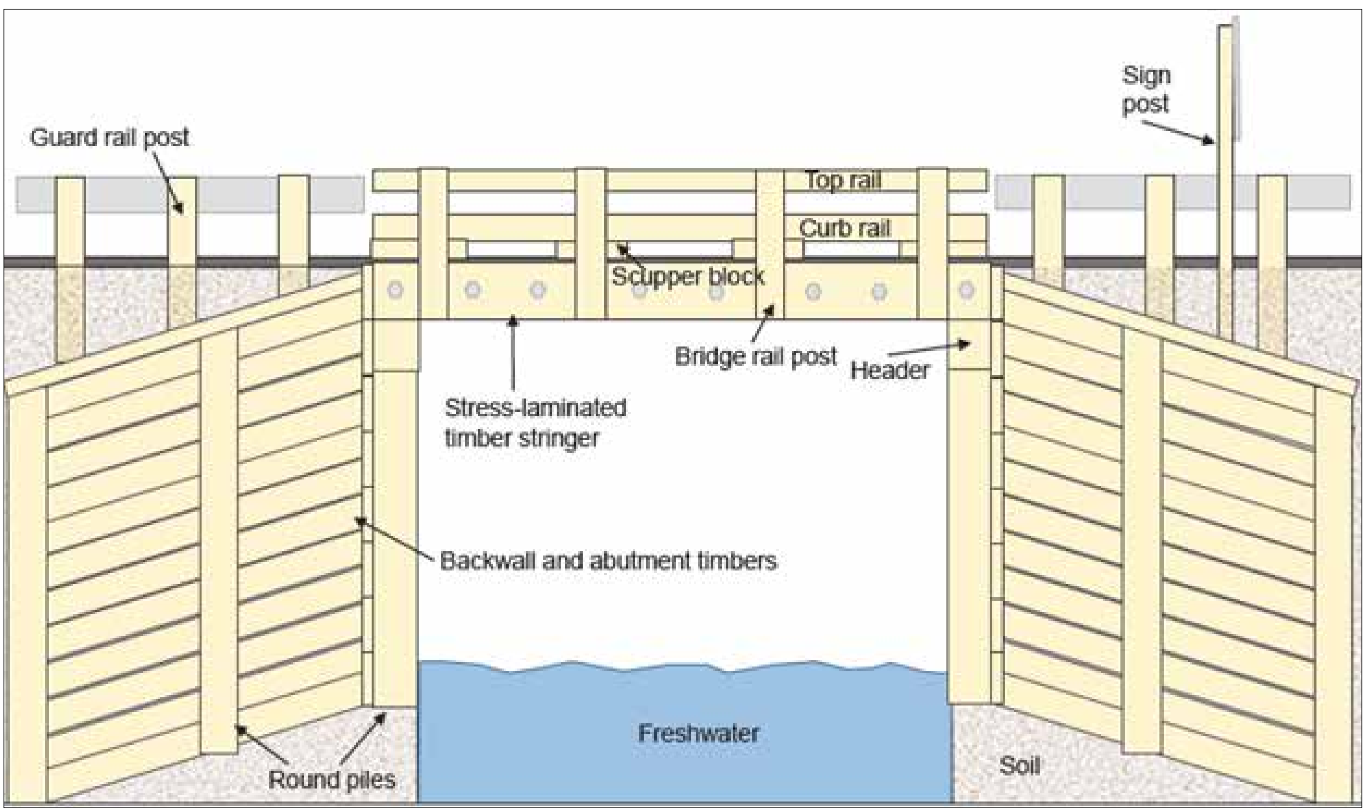

FIGURE 1. Critically important wood components supporting timber bridges (Lebow et al., 2019).

INTRODUCTION (CONTINUED)

According to Lebow et al. (2019), depending on the wood species, the standardized UC4C preservative options for round timber piles are the oilborne preservatives creosote, copper naphthenate, and pentachlorophenol type-A, C and the waterborne preservatives ACQ-C, ACZA, CCA, MCA, and copper azole A, B, C. Headers, abutment timbers, and bulkhead timbers are also specified as UC4C and the standardized preservatives (depending on the wood species) are the oilborne preservatives creosote, copper naphthenate, and pentachlorophenol type-A, and type-C, and the waterborne preservatives ACQ-B, C; ACZA; copper azole B, C; CCA; MCA; and MCA-C. These members are both critical to structural integrity and difficult to replace, hence the higher use category.

The protection of timber bridges with respect to their design is associated with preexisting site conditions as well as anticipated environmental conditions to which the bridge will be subjected to during its service life (Mahnert and Hundhausen, 2017). Attack by decay fungi is hastened by ports of entry on each wooden bridge element as well as its localized conditions. For example, cracks and crevices that may trap water and contribute to increased biological attack as moisture is a key factor. The natural dimensional changes of wood associated with the presence of moisture often cause non-uniform dimensional changes, which contributes to increased points of entry for moisture (Lopes et al., 2018).

Drying related defects, like checks and splits can hasten decay. The three different orthogonal planes of wood (radial, tangential, and longitudinal) may cause uneven shrinkage of wood members incurring rupture of the wood tissue particularly at the surface (Simpson, 1991). As most of the timber used for bridges is kiln-dried, drying related checks and splits can be minimized by following appropriate drying schedules. The most frequent seasoning defects observed are surface checks, end checks and splits, boxed-heart splits and warping (Brischke et al., 2012; Brischke et al., 2015). In addition to seasoning defects, routine, and cyclic wetting and drying can cause moderate to severe checks and shake. When the shell or outer surface of an already wet and swollen wooden member dries too rapidly the surface develops checks. Over time, these checks can deepen and reach significant depths within the wood. If the processed timber is not fully treated to these depths decay can develop. Figure 2 shows examples of ports of entry resulting in premature breaking of preservative barriers.

A **B** **C**

FIGURE 2. Premature breaking of the preservative barrier resulting in incipient decay caused by: (a) mechanical damage, (b) weathering damage, (c) fire damage (Lebow, 2022).

INTRODUCTION (CONTINUED)

A relatively simple method to prevent decay and biological attack is to keep wood dry to the extent possible (Eslyn and Clark, 1979). For example, designing a bridge that is covered by a roof provides long-term protection (Figure 3). This type of coverage largely prevents liquid rain, snow, or other precipitation-related water intrusion.

FIGURE 3. Grist Mill Covered Bridge, Lamoille County, Vermont (Bridge Hunter, 2022).

INTRODUCTION (CONTINUED)

FIGURE 3. Grist Mill Covered Bridge, Lamoille County, Vermont (Bridge Hunter, 2022).

Covered bridges provide long-term protection to the bridge elements as liquid (e.g. rain and snow) water exposure to critical components is minimized (Pierce et al., 2005). Additional measures to ensure long-term serviceability of timber bridges are the use of cladding, inclined upturning surfaces, avoiding water traps, designing joints to shed water, applying remedial liquid or paste preservatives to exposed surfaces, and covering end grain surfaces with sheets of commonly used metals such as zinc galvanized steel, copper, aluminum, or stainless steel (Figure 4) (Simon and Koch, 2016).

INTRODUCTION (CONTINUED)

FIGURE 4. Side cladding for efficient timber bridge design in (a) Germany, (b) Switzerland, and arch girders protected by stainless steel flashing plates (c) in Germany (Simon and Koch, 2016).

INTRODUCTION (CONTINUED)

In situations where timbers have direct contact with liquid water, drying must be assured. Drying is important to avoid prolonged moisture exposure, which is one of the four critical factors for fungal growth and decay. The four factors are oxygen (in air), moisture (above about 19% moisture content on a dry basis), food source (such as untreated wood), and temperature (most favorable between about 70°–90° F, although decay can occur more slowly at temperatures outside of this range). Structural elements that are difficult to inspect should receive greater attention during the design phase as improper design will increase cost due to repair and maintenance (Ritter, 1990).

Joints between timber elements such as V-shaped columns in the lower end of piers can help water drainage. Water slides down the timber and can be captured or deflected by a concavity installed at the bottom of the shape. In this case, a stainless- steel concavity must be built to promote water runoff. Inclined frames also provide protection near important connections. These designs may provide a lifetime of protection for the critical elements of timber bridges (Massaro and Malo, 2014). Figure 5 displays examples of V-shaped and inclined frame).

In several timber bridge designs, where there is no way to keep the deck protected from weathering conditions, decks should be protected with chemical preservatives or covered with a waterproof coating to avoid water accumulation that can result in fungal growth and decay (Williams and Feist, 1999; Massaro and Malo, 2014). Figure 6 shows exposed timber decks with surface damage due to water accumulation. Decks should also be pitched slightly to encourage drainage and discourage ponding.

Site surroundings are also an important factor in timber bridge design. Dirt, debris, or the close proximity of vegetation may raise moisture content. Furthermore, structural details should be developed to shed water and prevent moisture accumulation close to the structure (Simon and Koch, 2016). Figure 7 shows vegetation touching the timber elements and the accumulation of dirt. Vegetation management is an important factor in timber bridge longevity.

A

B

FIGURE 5. V-shaped joint (a) and cladding of an inclined frame (b) to promote water escaping (Massaro and Malo, 2014).

INTRODUCTION (CONTINUED)

FIGURE 6. Damage on the deck due to water accumulation (Massaro and Malo, 2014).

FIGURE 7. Vegetation near to timber bridge elements (Source: Authors). This situation facilitates prolonged moisture exposure and inhibits routine inspection.

CONCLUSIONS

Design is one of the most important factors in constructing bridges. Designing for durability can increase service life and reduce maintenance at little or no additional cost. In short, timber bridges must be designed in accordance with AASHTO-LRFD, be constructed with appropriate preservative treated timber members, and be designed to shed and drain water as quickly and easily as possible to avoid ponding and other water accumulation points. If they do get wet, they need the opportunity to redry quickly in-service. During initial bridge conception, careful analysis of intended bridge's surroundings, environmental exposure, anticipated traffic volume and loads, and other factors must be taken into consideration. New issues such as carbon sequestration, life cycle analysis (environmental cost accounting), and other sustainability aspects are becoming more popular which favors timber construction wherever possible. In summary, timber remains a favorable bridge construction material with a bright future. Designing for durability helps ensure public confidence in wood as a building material, long term utility, economic value, and environmental sustainability.

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4

PRESERVATIVE TREATMENT OPTIONS AND SPECIFICATIONS

TIMBER BRIDGES

Forest and Wildlife Research Center Bulletin, Mississippi State University

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INTRODUCTION

Many of the wood species used in timber bridge construction are not naturally durable and if not properly treated with preservatives, these wood species may be vulnerable to attack by decay fungi, wood-boring insects, and natural stressors, particularly if they are frequently exposed to moisture (Alden, 1995; 1997; Wacker and Cesa, 2005).

Designing and constructing timber bridges that keep wood dry and thereby prevent biotic and abiotic degradation is both possible and recommended. Covered bridges are classic examples. Currently, covered bridges are often either impractical or not cost-effective. Thus, most modern timber bridges in the United States are designed for exposure to cyclic wetting and drying, heating and cooling, and varying levels of biological and non-biological stressors. To mitigate the effects of these factors, chemically treated wood is used (Wacker and Duwadi, 2010; Yang and Clausen, 2014). The chemical agents available for the treatment of timber bridge components have been shown to be highly effective in providing protection from wood destroying organisms (Johnson, 2011).

The term preservative is sometimes applied to water-repellents, hardeners or finishes that maintain the appearance or act as wood stabilizing agents. In this publication, preservatives are defined as substances that extend the service life and structural integrity of wood products by preventing attack by wood destroying organisms or by making the wood less vulnerable to biodegradation. According to Lebow (2010), preservatives contain biocidal ingredients meeting the definition of pesticides under federal law and must have registration with the U.S. Environmental Protection Agency as well as state or territory agencies.

In commercial practice, pressurization is routinely used to force liquid preservatives into wood for use in timber bridges. Shmulsky and Jones (2019) describe the wood treatment process, including how wood products are placed into large steel retorts and subjected to pressure and vacuum. For wood products treated with oilborne preservatives, the treatment cylinders are often heated to reduce liquid viscosity and increase chemical penetration. Pressure- treated wood products typically have much deeper and more consistent penetration and retention throughout the bulk of each wood member, than non-pressure treated alternatives (Tarmian et al., 2020). To maximize efficacy of preservative treatment in timber bridge members, the pieces are typically cut to length, drilled, and otherwise machined to final specifications before treating. This sequence minimizes the need for retreatment in the field during bridge construction and maximizes the long-term durability of the bridge (Ritter, 1990).

Methods for pressure treatment and evaluations of pressure-treated wood are commonly reviewed by technical and standard associations namely, American Wood Protection Association (AWPA) and The American Association of State Highway and Transportation Officials (AASHTO) (AASTHO, 2016; AWPA, 2019). Both specifications and guidance from AASHTO and AWPA enable quality control and quality assurance of treatment procedures for structurally critical applications such as timber bridges.

WOOD PRESERVATIVES

WOOD PRESERVATIVES ARE DIVIDED INTO TWO GENERAL CLASSES:

(1) oilborne preservatives which usually use a petroleum-based carrier for the preservative chemical (E.g. creosote, pentachlorophenol) and (2) waterborne preservatives that are soluble in water (Lebow et al., 2019). The most common oilborne preservatives used in timber bridge applications are coal-tar creosote, pentachlorophenol (PCP), and copper naphthenate (Ritter, 1990). Commonly used waterborne preservatives are chromated copper arsenate (CCA), ammoniacal copper arsenate, alkaline copper quaternary (ACQ), ammoniacal copper zinc arsenate (ACZA), and copper azole (Ritter, 1990; Lebow et al., 2019). Copper is the most common element found in most of these wood preservatives. It is highly effective against most biological detractors, but usually is used with a co-biocide to counteract copper tolerant organisms.

CREOSOTE

Creosote is a black or brownish oil made from the distillation of coal tar, which is obtained by carbonizing coal at high temperatures (Bigelow et al., 2009). Advantages of creosote include high effectiveness, relative insolubility in water therefore resistant to leaching, generally low corrosivity, ease of application, low cost, and lengthy record of satisfactory use. Creosote is classified as either coal tar distillate (CR), coal tar solution in coal tar distillate (CR-S), or a 50:50 creosote-petroleum solution combination (CR-PS) according to AWPA standards (AWPA, 2019). Neat, undiluted creosote is preferred for most bridge applications due to its greater efficacy against fungi, better penetration properties, and cleaner wood surfaces throughout the bridge life (Bigelow et al., 2009). Creosote is effective toward protecting both hardwoods and softwoods and is thought to improve the dimensional stability of the treated wood (Lebow et al., 2019). The AWPA P1/P13, P2, and P3 standards define and specify creosote preservative and derived solutions (AWPA, 2019). Creosote is currently used for heavy timbers, poles, piles, and railroad ties.

PENTACHLOROPHENOL

Pentachlorophenol (PCP) is typically dissolved in an organic solvent that acts as a carrier. A heavy oil solvent, such as diesel or biodiesel fuel (PCP-A), may be preferable when the treated wood product will be used in ground contact because wood treated with lighter solvents (PCP-C), may not be as durable in such exposures (Lebow et al., 2019). The letter code following the initials “PCP” refers to the formulation nature and type of carrier oil. The AWPA standard P35 defines the composition of pentachlorophenol preservative, indicating two purity criteria actives, which are (a) it shall contain not less than 95% of chlorinated phenols as determined by titration of hydroxyl and calculated as pentachlorophenol, and (b) it shall contain no more than 1% of matter insoluble in 1 N aqueous sodium hydroxide solution (AWPA, 2019). According to Ritter (1990), PCP is a highly effective wood preservative, however, it is not recommended for marine use. PCP-C has treatment characteristics similar to those of PCP-A. PCP-C can penetrate refractory species and does not accelerate corrosion. The surface of PCP-C-treated wood is paintable and provides some weather resistance; however, the protection is not as long-lasting as PCP-A treated wood. Timber that has been treated with Type C pentachlorophenol should only be used aboveground (Bigelow et al., 2009).

At the time of this writing, production and availability of PCP in the USA is declining and being phased out of service due to regulatory concerns. It is anticipated that PCP will no longer be used in wood preservation, but existing treated materials may still be available for use over the 5-year phase out period in order to use up existing inventory.

COPPER NAPHTHENATE

Copper naphthenate is an organometallic compound that imparts a dark green color to wood. It comes as both water and oilborne formulations (Brient et al., 2004). According to Bigelow et al. (2007), copper naphthenate is the product of the reaction between petroleum derived naphthenic acids and copper salts. It is effective against wood decaying organisms such as fungi and insects. It may be used for superficial treatment, namely brushing with a copper content solution of 1% to 2% (Lebow, 2010). The AWPA P36 standard defines and specifies the properties of copper naphthenate (AWPA, 2019).

WOOD PRESERVATIVES (CONTINUED)

COPPER NAPHTHENATE (CONTINUED)

Copper naphthenate is effective for use in ground contact, freshwater contact, and above ground applications such as utility poles, structural lumber, posts, and glulam beams due to the clean surface and resistance to in-service bleeding (Brient et al., 2004; Lebow et al, 2019)). Additionally, with proper treatment practices, dimensional stability is improved, metal fastener corrosion is limited, and engineering properties remain unchanged (Brient et al., 2004; Bigelow et al., 2007). Copper naphthenate is considered one of the leading preservatives to replace PCP as it is phased out of future production. Copper naphthenate is currently listed for exterior above ground, ground contact, below ground, and freshwater contact use applications.

CHROMATED COPPER ARSENATE (CCA)

Chromated copper arsenate is a group of pesticides containing chromium, copper, and/or arsenic that protect wood against wood-destroying organisms that degrade or threaten the integrity of wood and wood products (Environmental Protection Agency – EPA, 2021). The EPA has limited its use to certain industrial and commercial applications such as timber bridges, utility poles and crossarms.

The formulation CCA type-C is covered by the AWPA P23 standard and is the most commonly used formulation (AWPA, 2019). The AWPA P23 standard defines the composition of CCA on a 100% oxide basis of 47.5% hexavalent Cr as $CrO3$, 18.5% of copper as CuO, and 34% of arsenic as $As2O5$ (AWPA, 2019). Acting in concert, the copper deters most insects and fungi, the arsenicals deter the organisms that are copper tolerant, and the chromium chemically "fixes" or attaches the preservative to the wood.

CCA-C protects wood above-ground, in ground contact, or in contact with freshwater or seawater. Adequate penetration with CCA may be difficult to obtain in some difficult-to-treat species and is not recommend for hardwood treatments. Chromium inhibits the corrosion of fasteners in wood treated with CCA as compared to preservatives that do not include chromium (Bigelow et al., 2007). CCA is currently used for lumber, timber, plywood, bridges, piles, poles, posts, glued-laminated timber, below ground, and fresh water or foundation applications.

ALKALINE COPPER QUATERNARY (ACQ)

ACQ is a two-chemical-component preservative system, containing ammoniacal copper and a quaternary ammonium compound (quat). The combined biocidal effect of copper and quat protects wood against wood-decaying organisms, has low mammalian toxicity, and low environmental impact (Chen, 1994). ACQ is one of the multiple preservatives that was developed as a substitute for CCA, and its use has extended to timber bridges and guard rail structures (Bigelow et al., 2007). Multiple ACQ formulations have been standardized, the most commonly used being type-B (ammoniacal copper formulation), type-D (amine copper formulation), and type-C (combined ammoniacal-amine formulation with different quat compound) (Lebow, 2010).

The ACQ formulations are listed in the AWPA standards, namely AWPA P26, P27, P28, P29 (AWPA, 2019). The different formulations of ACQ allow flexibility in achieving compatibility with wood species and application. All ACQ treatments accelerate corrosion of metal fasteners relative to untreated wood. Therefore, hot-dipped galvanized or stainless-steel fasteners must be used in structurally critical applications (Bigelow et al., 2007; Bigelow et al., 2009). Additionally, the mass loss of copper from ACQ is higher than the rate from CCA, which suggests that copper is not strongly fixed in ACQ-treated wood compared to CCA-treated wood. ACQ-C is currently listed for lumber, timber, plywood, bridges, in soil and fresh water, and above ground, utility poles (ACQ-B), building, round and sawn timber (ACQ-B and D), posts in agriculture, round and sawn, fence, commercial- residential construction, guard rail and spacer blocks.

WOOD PRESERVATIVES (CONTINUED)

AMMONIACAL COPPER ZINC ARSENATE (ACZA)

Ammoniacal copper zinc arsenate is another waterborne preservative used for timber bridges in the United States. ACZA contains copper oxide, zinc oxide, and arsenic pentoxide that are dissolved in a solution of ammonia in water. ACZA's chemical composition and stability during treatment at elevated temperatures allows it to penetrate refractory wood species, for instance Douglas-fir (Bigelow et al., 2009).

ACZA contains bivalent copper, bivalent zinc and pentavalent arsenic dissolved in a solution of ammonia in water. The weight of ammonia contained in a treating solution and obtained from ammonium hydroxide should be at least 1.38 times the weight of copper oxide. To aid the dissolution, ammonium bicarbonate (H4HCO3) is added (AWPA, 2019).

ACZA is an established preservative that is used to protect wood from decay and insect attack in a range of applications under aboveground and ground-contact conditions, which include critically important timber bridge components. It also has similar performance characteristics as CCA (Bigelow et al., 2009; Lebow, 2010). ACZA is currently listed for lumber, timber, plywood, bridge, piles, poles, posts, and glued-laminated timber.

COPPER AZOLE (CA-B, CA-C, MCA, AND MCA-C)

According to AWPA P32 (AWPA, 2019), copper azole is a formulation composed of copper (96%) and 4% of azole as tebuconazole. Azole compounds are organic, nonmetallic biocides. They are widely used in topical antifungal ointments. The triazole is either tebuconazole or a 50:50 mixture of propiconazole and tebuconazole (C designation). Copper azole may be prepared with copper solubilized in ammonia and/or ethanolamine (CA-B and CA-C) or with the copper ground to very fine particles (micronized), which are then dispersed in the treatment solution with surfactants (MCA and MCA-C) (Lebow et al., 2019).

Wood treated with copper azole has a greenish brown color with little to no odor. Both copper azole formulations are commonly used to pressure-treat decking and dimension lumber commonly found at lumber yards but are also standardized for treatment of posts, poles, and timbers that are used in timber bridges. Copper azole formulations using particulate copper may be less corrosive to metal fasteners than the soluble copper formulations (Bigelow et al., 2007; Lebow et al., 2019). Copper azole is currently listed for residential projects, namely decks, fences, access ramps, docks, and landscaping as well as freshwater and marine decking applications.

BORON

Borates are another commonly used wood preservative system. Boron can act as both a fungicide and insecticide when used as a wood preservative. In the timber bridge arena, borates are most commonly used as a remedial treatment for bridge timber components that show incipient biological attack or are structurally located where there is a high level of water contact or ingress. This can be bridge timber cross-sectional components or exposed ends of vertical timbers. Boron as a remedial treatment, is most often used as a solid rod of borate that is placed into a drilled hole in the bridge component where there is high wood moisture.

Boron is a diffusible preservative and as the borate rod contacts moisture in the wood it slowly dissolves and boron disperses into the wood protecting it without having to tear out and remove the particular wet or decayed component. Borates can also be combined with copper in rod form or copper-boron pastes can be applied as ground line wraps to some bridge timber pilings in service. Borates can also be dissolved in water and sprayed onto timbers where the boron will diffuse from the surface into the wood as it follows the moisture gradient in the wood. (Ambergey and Freeman, 1993; Lebow et al., 2012; Barnes et al., 2011).

CONCLUSIONS

Lumber used to build timber bridges is not naturally durable and thus requires preservative pressure treatment to ensure longer service life, durability, low maintenance, and safety of important timber bridge structural members.

Impregnation by wood preservatives using pressure and vacuum at specialized treating plants provides thorough penetration and retention which are essential for timber bridge elements. There are a variety of available wood preservative systems, each of which have pros and cons and attributes that may favor one application and/or species group over another.

The wood preservation industry has evolved to provide a variety of safe, economically feasible, and high-performance chemical formulations. These chemical formulations and technologies require stringent national standards that are developed by experts in the field and critically analyzed by years of research and development to assure long-term wood protection. Addi- tionally, some chemical treatments (lower active ingre- dient chemical retentions) provide protection for wood products in above-ground contact use, whereas higher active chemicals will support the use of products in ground contact. In either case, the manufacturer's recommendations for application should be followed.

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5 OPTIONS FOR HARDWOOD

TIMBER BRIDGES

Forest and Wildlife Research Center Bulletin, Mississippi State University

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INTRODUCTION

Hardwood timbers have been predominately used as cross ties, switch ties, or sleepers, in the United States railroad industry for over 150 years. Board roads (similar to corduroy roads) are still used to some degree in temporary access situations like logging and construction. Early in the 19th century, hardwood timber bridges were relatively common. These were often made from durable white oak or chestnut stringers on short span bridges or truss members on longer covered bridges. In that era, white oak plank decking was routinely used on bridges. In the mid- to late-nineteenth century, steel production and its use in bridge construction increased. The advent of steel bridges caused a decline in the use of hardwood timbers for bridge construction. Throughout the early and mid-twentieth century, in cases where timber bridges were proposed and used, treated softwood became the material of choice. Conversely, the use of hardwood timbers for highway bridge construction became popular again in the 1980s as a dual solution to an overabundance of secondary grade hardwoods and an aging highway bridge inventory with numerous replacement needs (Wacker and Cesa, 2005).

WOOD SPECIES OPTIONS

Highway timber bridges are structurally critical, required by the American Association of Highway and Transportation Officials to be treated to use category 4C (UC4C) according to the American Wood Protection Association, which includes both round and sawn support piles, stringers, abutment materials, and deck components (Lebow et al., 2019). This treatment level assures that the timber members associated with the bridge and its components will be highly durable and will resist decay, insects, and other natural stressors. Posts and rails are typically treated to use category 4A (UC4A) or use category 3B (UC3B). The AWPA standard U1 covers the use of hardwoods for UC4C, UC4A, and UC3B (AWPA, 2019). Table 1 describes the AWPA use category system, wood product, and wood species specified.

According to Wacker and Cesa (2005b), West Virginia, Pennsylvania, Iowa, and New York have substantial numbers of hardwood bridges. Additionally, 13 other states: Michigan, North Dakota, Ohio, Kansas, Maryland, Oklahoma, Virginia, Indiana, Rhode Island, Vermont, Arkansas, Massachusetts, and Missouri have constructed 36 bridges with red oak, yellow poplar, cottonwood, black locust, red maple, hickory, and other mixed hardwoods.

From 1989 to 2004, the state of West Virginia constructed 60 vehicular hardwood bridges with emphasis on stress-laminated deck, stress-laminated T-section, and stress-laminated box-section designs. In the late 1900s and early 2000s, the Pennsylvania Department of Transportation constructed 17 vehicular hardwood bridges and 1 pedestrian demonstration bridge primarily with red oak and red maple with adaption of glulam technologies. In Iowa, several counties along with the Iowa Department of Transportation constructed 10 vehicular hardwood bridges in the early 1990s using low-valued cottonwood species. The stress-laminated deck design and transverse glulam decks on steel beam girders were the main superstructure emphasis (Ritter, 1990; Wacker and Cesa, 2005b). Lastly, New York constructed 13 vehicular bridges using a variety of hardwood species. Table 2 summarizes the specification of some bridges highlighted by Wacker and Cesa (2005b). These timber bridges support high daily traffic volumes, which make them an excellent option for movement of goods and economic growth of communities throughout the country.

WOOD SPECIES OPTIONS

TABLE 1. Hardwood species, wood products, and use category listing by AWPA standards.

<table>
<tr><th rowspan="3">Species</th><th colspan="2">Sawn Products</th></tr>
<tr><th colspan="2">Use category listing</th></tr>
<tr><th>UC4A</th><th>UC3B</th></tr>
<tr><td>Red Oak[1]</td><td>X</td><td>X</td></tr>
<tr><td>White Oak[1]</td><td>X</td><td>X</td></tr>
<tr><td>Maple (Acer sp.)</td><td>X</td><td>X</td></tr>
<tr><td>Black Gum (Nyssa spp.)</td><td>X</td><td>X</td></tr>
<tr><td>Red (sweet) gum (Liquidambar spp.)</td><td>X</td><td>X</td></tr>
<tr><th rowspan="3">Species</th><th colspan="2">Round pile</th></tr>
<tr><th colspan="2">Use category listing</th></tr>
<tr><th colspan="2">UC4C</th></tr>
<tr><td>Oak (all Quercus sp.)</td><td colspan="2">X</td></tr>
<tr><th rowspan="3">Species</th><th colspan="2">Glue-Lam (Treated after gluing)</th></tr>
<tr><th colspan="2">Use category listing</th></tr>
<tr><th colspan="2">UC4A</th></tr>
<tr><td>Red Oak[1]</td><td colspan="2">X</td></tr>
<tr><td>Red Maple[1]</td><td colspan="2">X</td></tr>
<tr><td>Yellow Poplar
(Liriodendron tulipifera)</td><td colspan="2">X</td></tr>
<tr><th rowspan="4">Species</th><th colspan="2">Structural composite lumber</th></tr>
<tr><th>Parallel strand lumber</th><th>Laminated Veneer lumber</th></tr>
<tr><th colspan="2">Use Category listing</th></tr>
<tr><th>UC4A</th><th>UC4A</th></tr>
<tr><td>Yellow poplar
(Liriodendron tulipifera)</td><td>X</td><td>X</td></tr>
<tr><td>Red Maple (Acer rubrum)</td><td></td><td>X</td></tr>
</table>

[1]Verify AWPA standards for species listing.

WOOD SPECIES OPTIONS (CONTINUED)

TABLE 2. Summary of hardwood bridges in West Virginia, Pennsylvania, Iowa, and New York.

County	Bridge Length (ft)	Bridge Width (ft)	Superstructure type	Wood species	Preservative treatment	Design live load
West Virginia						
Mason	42	18	Stress-laminated box-beam	Red oak/ Southern pine	Creosote	HS-20
Logan	52	25	Stress-laminated box-beam	Red oak/ Southern pine	Creosote	HS-20
Mingo	220	15	Stress-laminated deck/ steel truss	Red oak	Creosote	HS-20
Pennsylvania						
Greene	47	33	Trans. Glulam deck on steel stringers	Red maple	Creosote	HS-25
Huntingdon	77	31	Glulam deck/glulam arch	Red maple/ Douglas fir	Creosote	HS-20
Elk	50	15	Trans. glulam deck on steel stringers	Red maple	Creosote	HS-20
Iowa						
Appanoose	40	26	Stress-laminated deck	Cottonwood	Creosote	HS-20
Decatur	24	21	Stress-laminated deck	Cottonwood	Creosote	HS-20
Ida	36	26	Trans. glulam deck on steel girders	Cottonwood	Creosote	HS-20
New York						
Allegany	29	26	Trans. glulam deck on steel stringers	Red maple	Penta	HS-20
Ontario	55	23	Trans. glulam deck on steel stringers	Sugar maple	Penta	HS-20
Allegany	29	28	Trans. glulam deck on glulam stringers	Red maple	Penta	HS-20

Source: Wacker and Cesa (2005a).

WOOD SPECIES OPTIONS (CONTINUED)

In research by Janowiak et al. (2005), the performance of red maple glulam beams was evaluated. Results indicated that structural glue-laminated (glulam) timber beams manufactured with E-rated red maple lumber in the outer zones and either No. 2 or No. 3 lumber in the core met or exceeded the target design bending stress of 2,400 psi and MOE of 1.8 x 106 psi. Additionally, results of this red maple glulam research were incorporated into the AITC 119 hardwood glulam standard.

In another study, the performance of Northern red oak glue-laminated timber bridge performance was assessed in a 5-year monitoring program (Manbeck et al., 1999). To minimize bridge deterioration by cracks, the authors modified the design specifications, including abutting of adjacent deck panels, location of waterproof membranes, and properly mating deck panels to beams prior to installation of lag bolt connectors. The results demonstrated that after 5 years the timber bridge remained structurally sound.

A commonality among states that have constructed significant numbers of hardwood bridges appears to be related to the acceptance by their respective state departments of transportation. As well as adoption of standardized plans for hardwood timber bridges (Wacker and Cesa, 2005a). For example, the state of Pennsylvania has developed standards for hardwood glulam timber bridge design (Commonwealth of Pennsylvania–Department of Transportation, 1994; 2013). These standards provide a rapid means of producing design drawings for single span timber bridges that support average daily traffic less than 750 vehicles, roadway widths of 7 to 9.75 m (23 to 32 ft), angles of intersection (skew) not less than 45 degrees, and spans of 5.4 to 30 m (18 to 97 ft).

Hardwood lumber and dimensional stock are available directly from manufacturers, through wholesalers, and brokers. Hardwood products are distributed throughout the United States. Local preference and the availability of certain species may influence choice. However, for building construction such as timber bridges, industrial uses, remanufacturing, and home use, wood species are generally available (Wiemann, 2010). In the case of hardwoods for timber bridges, structurally graded lumber and/or laminated beams are specified and need to be preservative treated.

CONCLUSIONS

Hardwood species can be used as timber bridge components in the form of round, sawn, and laminated support piles, stringers, abutment materials, deck components, rail posts, and rails. These critically important components are treated according to AWPA use categories UC4A, UC4C, and UC3B.

Several different hardwoods species such as red oak, cottonwood, and red maple have been used to construct a wide variety of structures that support different loads. These vehicular bridges have helped to promote economic growth in local communities through movement of goods in at least 17 states of the United States. Structural components from hardwoods are available for commercial and industrial use. Geographic location and proximity to timber resources may influence the choice for certain species when constructing bridges.

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