EXTENDING SERVICE LIFE OF TIMBER BRIDGES WITH PRESERVATIVES

James P. WACKER[1] and Douglas M. CRAWFORD[2]

Abstract

Treated timber bridges have been widely used for railroad and highway bridges throughout the United States during the 20th century. However, improvements in preservative technology are needed as a result of changing environmental views and public perceptions concerning the use of preservative treated wood in aquatic environments. Within the past 15 years, three national programs have been established to advance technologies related to timber transportation structures. A key design aspect for timber highway bridges is the selection of preservative treatment to improve durability while minimizing potential environmental impacts. This paper summarizes timber bridge preservation technology in the United States, including pressure treatment preservatives, field treatments, and remedial techniques.

Introduction

The versatility and durability of preservative-treated timber make it an important engineering material for bridge construction (AITC 1973). Wood has several properties that make it well-suited for bridge construction, including a high strength to weight ratio, energy-absorbing capabilities, and ability to carry short-term overloads. Timber bridges can typically be constructed by low-skilled labor in nearly all weather conditions and are not adversely affected by de-icing chemicals. In addition, wood is a renewable natural resource that uses substantially less energy in manufacture when compared to other bridge materials.

The misconception that wood provides a short service life has plagued timber as a construction material (Ritter 1992). Although most species of wood are susceptible to deterioration under specific conditions, the durability of wood substantially improves when the wood is protected from moisture and/or pressure-treated with preservatives. Designers of covered timber bridges in early America incorporated roof structure details that extended bridge service life to more than 80 years. The key benefit of the bridge roofs was to keep the main structural (untreated) members dry and eliminate their susceptibility to decay and insect attack. Today, modern wood preservatives are used in lieu of bridge roofs to extend the service life of timber bridges. However, in the past decade, the covered bridge design approach is again becoming an increasingly popular option in the United States, despite its higher initial costs.

The use of chemicals for preservation of timber bridges began in the United States around 1870 when railroad bridge ties were treated with creosote, an oil-based preservative (Webb

[1] Professional Engineer, United States Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA.
[2] Forest Products Technologist, United States Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA.

1976). By the 1920s, creosote had become the treatment of choice for the railroad industry; it was introduced for highway bridges shortly thereafter. Pentachlorophenol (Penta) is another oil-based preservative that has been widely used for timber bridges since the 1940s. Changing environmental views, stricter Federal and State regulations, and public perceptions related to the use of preservative treatment chemicals for highway bridges have reduced viable treatment options for bridge designers and emphasized the need to develop more environmentally friendly preservatives for timber bridge applications. This paper summarizes timber bridge preservation technology in the United States, including preservative treatment options, field treatments, and remedial techniques to extend service life.

U.S. Timber Bridges

The United States has approximately 32,400 timber bridges according to the National Bridge Inventory (NBI), a comprehensive database maintained by the Federal Highway Administration (FHWA) that includes bridge inspection data for nearly 591,000 highway bridges that span at least 6 m (20 ft) (FHWA 2002). An estimated 6,000 timber bridges, in addition to those recorded by the NBI, are located on Federal government lands and/or span less than 6 m. A large majority of these timber bridges are located on secondary highways in rural America. Timber beam bridges are the predominant superstructure type, simply supported with a typical span range from 5 to 20 m (16 to 65 ft).

National Programs for Wood In Transportation

Within the past 15 years, three national programs have been initiated by the U.S. Congress with the common goal of increasing the utilization and efficiency of timber as a structural material in transportation structures. The Wood in Transportation Program administered by the Department of Agriculture, Forest Service (FS) was established by the Enhancing Rural America Act of 1989 and placed a strong emphasis on the development of innovative bridge designs along with the utilization of non-traditional wood species for bridges (USDA 2003). The Federal Highway Administration's (FHWA) Timber Bridge Program was established by the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and placed a strong emphasis on conventional bridge designs accepted by the American Association of State Highway and Transportation Officials (AASHTO) *Standard Specifications for Highway Bridges* (AASHTO 2002). Both national programs funded demonstration bridge projects (up to 50% Forest Service and 80% FHWA) with grants awarded to State and local governments. In addition, each national program had research components that were merged into a joint FS/FHWA research program in 1991 within the following main research areas:

- System development and design
- Preservatives
- Inspection and rehabilitation
- Lumber properties
- Alternative transportation system structures
- Technology and information transfer

The goal of this joint research program is to advance technologies related to timber bridges and to increase utilization of timber in bridge and other transportation structures. A comprehensive review of the National Wood in Transportation Program (Duwadi and others 2000) and the joint FS/FHWA research program for wood transportation structures (Ritter and Duwadi 1998, FHWA 1998) are available.

Several research projects have addressed preservative-related issues applicable to bridges (Table 1). The three main study areas include field treatments, environmental considerations, and improved preservatives and treatments methods. Field treatments include both surface and internal methods. Surface treatment (liquid) preservatives are typically applied by brushing, spraying, or soaking methods to prevent decay where untreated wood has been exposed by field cuts and borings or by damage during construction. Internal treatment preservatives are typically inserted into pre-bored holes in timber components and then diffuse into the surrounding wood to arrest internal decay. Environmental considerations include monitoring preservative retention levels in the bridge members and the surrounding soil and water for potential impacts to aquatic life. Improved preservatives involve the development and efficacy testing of new and alternative preservatives that are more environmentally acceptable.

Table 1. Preservative-related research projects and available publications resulting from joint Forest Service/Federal Highway Administration research program

Study area	Project title	Available reports[a]
Field treatments	Development of a comprehensive manual on field treating with wood preservatives	Cassens and others 1995
	Evaluation of various wood preservatives and fumigants as remedial treatments for bridges	DeGroot and others 2000 Morrell and others 1996
Environmental considerations	Evaluation of environmental effects of creosote, penta, and CCA-treated timber bridges	Brooks 2000
	Environmental impact of a treated boardwalk	Lebow and others 2000
	Minimizing environmental impacts of treated wood	Lebow and Tippie 2001
Improved preservatives and treatment methods	Accelerated testing of new preservatives	DeGroot and Evans 1998 DeGroot and others 1998
	Moisture protection for timber members	Blankenhorn and others 1999
	Efficacy of copper naphthenate preservative	St. John and others 1998 Niemi and others 1998

[a] Complete citations are listed after the text.

In 1998, the Transportation Equity Act for the 21st Century (TEA-21) established the National Historic Covered Bridge Preservation Program (NHCBP). Administered by the FHWA, the NHCBP provides funding for (1) preservation, rehabilitation, and restoration of the Nation’s historic covered bridges and (2) research and technology transfer. Recognizing a need, the FHWA initiated a study to develop guidelines that identify suitable wood preservatives and fumigants to preserve and protect these historic structures, while meeting the requirements of the Secretary of Interior’s Standards for the Treatment of Historic Structures. Further information about the NHCBP program is available (FHWA 2003).

Pressure Treatment Preservatives

Wood preservatives are broadly classified as either oil-based or water-based, based on the chemical composition of the preservative and the carrier used during the pressure treating process (Lebow and Makel 1995). Table 2 summarizes wood preservatives commercially available and applied with pressure-treatment methods for timber bridges. Some key preservative characteristics important to timber bridge applications are chemical composition, surface cleanliness, migration potential, odor, and environmental status.

Table 2—Summary of wood preservatives applied by pressure-treatment methods for timber bridges in the United States

Common name	Chemical composition	Surface cleanliness	Migration potential	Odor	Environmental status[a]
Oil-based Preservatives					
Creosote	polycyclic aromatic hydrocarbons (PAHs)	oily residues	tends to exude, or bleed	strong	restricted use pesticide
Penta	pentachlorophenol (light oil carrier)	relatively clean	saltwater leachability	light	restricted use pesticide
Copper naphthenate	naphthenic acids, copper salts	relatively clean	leach resistant	light	unclassified pesticide
Water-based Preservatives					
CCA[c]	hexavalent chromium, copper, arsenic	clean	leach resistant	none	restricted use pesticide
ACZA[b]	Ammonia, copper, zinc, arsenic	clean	leach resistant	none	restricted use pesticide
ACQ[b]	copper, quaternary ammonium compounds	clean	leach resistant	none	restricted use pesticide
CC[b]	copper oxide, citric acid	clean	leach resistant	none	restricted use pesticide
CDDC	copper ethanolamine, sodium dimethyldithiocarbamate	clean	leach resistant	none	restricted use pesticide
Borates	sodium octa-, sodium tetra-, sodium penta-borate	clean	highly leachable	none	unclassified pesticide

[a] Based on current regulations of U.S. Environmental Protection Agency. “Restricted use pesticides” does not ban the use of treated wood, but requires certified applicators trained in proper and safe handling techniques. “Unclassified” does not require certified applicators and are commercially available.
[b] Waterborne preservatives using ammonium solutions are typically used to achieve good penetration in difficult-to-treat species.
[c] Beginning in 2004, the use of CCA wood preservative in the United States will be restricted to industrial and commercial uses (such as bridges) and not permitted for residential applications.

Timber bridges can provide over 35 years of low maintenance service life provided they are properly preservative-treated using modern techniques. The selection and use of preservatives for U.S. timber bridges is becoming more complicated as a result of changing environmental views, stricter Federal and State regulations, and public perceptions. Bridge design standards and specifications (AASHTO 2002) currently

Figure 1—Stress-laminated deck bridge treated with copper naphthenate preservatives.

require bridge timbers to be pressure-treated with a wood preservative approved for use by the American Wood Preservers' Association (AWPA 2002) industry standards. In addition, oil-type preservatives are highly recommended for bridge structures primarily because of their moisture-barrier properties over an extended service life. Oil-type preservatives typically exhibit an oily surface that acts to retard moisture movement in and out of timber bridge members. This "water repellency" characteristic helps to minimize in-service checking, which can potentially provide avenues for moisture and decay to penetrate the preservative protective shell produced during pressure treatment. However, environmental concerns have been raised as a result of excessive oil-type preservative exudation, or bleeding, at several creosote-treated bridges (Wacker and others 2003). Many bridge designers are specifying water-based preservatives for non-structural bridge components such as pedestrian walkways and railings. Another growing trend is the utilization of untreated, naturally durable wood species, despite their comparatively higher cost.

Figure 2—Stress-laminated deck treated with ACQ preservatives.

New interest has been focused on copper naphthenate (Fig. 1), an oil-based preservative that has been widely used for treating power transmission poles in the United States for many years, as an attractive alternative for timber bridges due to its relatively clean surface and resistance to exudation, or bleeding, in service. Waterborne preservatives are generally not recommended for structural members of timber bridges, due to their tendency for large surface checks, especially with large glued-laminated timber members. However, an increasing number of timber bridges are being pressure-treated with water-based preservatives because of their surface cleanliness and low migration potential. Effective water repellent additives are being considered for several water-based preservatives, which is advantageous for timber bridge applications. Potential concerns about oil-type preservative migration can be greatly reduced by following Best Management Practices (BMPs) for the use of treated wood in aquatic environments (WWPI 1996) and AWPA Standard M20-00 (AWPA 2000).

New wood preservatives are currently being developed that will potentially produce less environmental concerns and have improved surface cleanliness, water-repellent characteristics, and low corrosive properties when in contact with metal fasteners (Crawford and DeGroot 1996). If these new preservatives achieve approval from AWPA, they have the potential to be ideal alternatives for new timber bridges.

All preservative chemicals must be evaluated and approved by the U.S. Environmental Protection Agency (EPA) and registered for use as a preservative for wood. Most preservatives are registered as "restricted use pesticides," which does not ban the use of treated wood but requires certified applicators trained in proper and safe handling techniques (EPA 2003). Copper naphthenate (oil-based) and borates (water-based) are two exceptions that are unclassified; they are commonly available to consumers through local suppliers. New environmental regulations, placing additional restrictions on the use of CCA wood preservatives, have led to increased interest in the use and development of more environmentally benign preservatives. Beginning in 2004, new EPA voluntary restrictions on residential uses of CCA could significantly reduce its availability for timber bridges. Several new water-based preservatives, which do not contain arsenic and chromium, are being introduced as treatment alternatives for timber bridges (Figure 2). However, these new water-based preservative options may have accelerated corrosive interaction with metal fasteners and need further evaluations.

Field Treatments and Remedial Techniques

Field treatment methods for timber bridge components are vital to preventing deterioration from insects and decay. Field treatment methods involve moisture protection methods and field preservatives. Moisture protection methods aim to keep the main structural members dry enough to prevent decay deterioration by adding a roof structure (as in historic covered bridges) or by using a waterproof membrane beneath an asphalt concrete wearing surface. In addition, various design details can be utilized that reduce moisture accumulation in timber bridge components (Kropf 1996, Blankenhorn and others 1999). Other field treatment methods involve the application of liquid preservatives by brushing, spraying, or soaking methods to prevent decay where untreated wood has been exposed by field cuts, boring, or damage during construction and by deep checks, which may develop when large timber members dry in service.

Remedial treatments are especially important in arresting decay already present in timber bridge components, as with historic covered bridges and older timber trestle railroad bridges. To arrest decay in existing timber bridge components, liquid or grease-type preservative treatments are typically inserted into pre-bored holes that surround the decayed zone. Remedial treatments can be reapplied at periodic intervals in the same holes used for initial treatment, but these holes should always be plugged with newly treated wood dowels.

Field treatments and remedial treatments in conjunction with routine inspection are key factors in preventing and/or limiting deterioration and can significantly extend the service life of timber bridges. More details on preventive field treatments and remedial techniques can be found in Ritter (1992, ch. 14) and Eslyn and Clark (1979).

Concluding Remarks

Shifting environmental views, stricter Federal and State regulations, and public perceptions concerning the use of treated wood for highway bridges in the United States have emphasized the need to develop more environmentally friendly preservative chemicals. As part of three National Wood in Transportation Programs within the past 15 years, significant research has been conducted to address preservative treatment issues related to timber bridge applications. The technological advancements related to wood preservatives, along with ongoing research efforts, should help to provide more designer options, improve bridge performance, and extend the service life of timber highway bridges.

References

AASHTO. 2002. Standard specifications for highway bridges, 17th edition. Washington, DC: American association of state highway and transportation officials.

AITC. 1973. Modern timber highway bridges—A state of the art report. Englewood, CO: American Institute of Timber construction. 79 p.

AWPA. 2000. Standard M20-00. Guidelines for minimizing oil-type wood preservative migration. Granbury, TX: American Wood Preservers' Association.

Blankenhorn, P.R.; Bukowski, S.; Kainz, J.A.; Ritter, M.A. 1999. Moisture protection for timber members. Pp. 240–248 in Walford, G.B.; Gaunt D.J. (Eds.) In: Proceedings, Pacific Timber Engineering Conference Vol.2, 14–18 March 1999, Rotorua, New Zealand. New Zealand Forest Research Institute, Forest Research Bulletin No. 212.

Brooks, K.M. 2000. Assessment of the environmental effects associated with wood bridges treated with creosote, pentachlorophenol, and chromated copper arsenate. Res. Pap. FPL-RP-587. Madison, WI: U. S. Department of Agriculture, Forest Service, Forest Products Laboratory. 100 p.

Cassens, D.L.; Johnson, B.R.; Feist, W.C.; DeGroot, R.C. 1995. Selection and use of preservative-treated wood. Madison, WI: Forest Products Society, Publication No. 7299. 104 p.

Crawford, D.M.; DeGroot, R.C. 1996. Evaluation of new creosote formulations. In*:* Proceedings, National Conference on Wood Transportation Structures. Ritter, M.A., S. R. Duwadi, P.D.H. Lee (Eds.). Gen. Tech. Rep. FPL-GTR-94.Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 494 p.

DeGroot, R.C.; Evans, J.W. 1998. Patterns of long-term performance—how well are they predicted from accelerated tests and should evaluations consider parameters other than averages? In: Proceedings, 29th Annual IRG Meeting, Maastricht, The Netherlands, June 14–19, 1998. Stockholm, Sweden: International Research Group.

DeGroot, R.C; Evans, J.W.; Forsyth, P.G.; Freitag, C.M.; Morell, J.J. 1998. Soil-contact decay tests using small blocks—procedural analysis. Res. Pap. FPL-RP-571. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 7 p.

DeGroot, R.C.; Felton, C.C.; Crawford, D.M. 2000. Distribution of borates around point source injections in wood members exposed outside. Res. Note FPL-RN-0275. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 5 p.

Duwadi, S.R.; Ritter, M.A.; Cesa, E. 2000. Wood in transportation: an overview. Transportation Research Record 1696, Paper No. 5B0105 Vol. 1: 310-315.Washington, DC: Transportation Research Board. National Research Council.

EPA. 2003. Consumer safety information sheets for pressure- treated wood. Washington, DC: U.S. Environmental Protection Agency.

Eslyn, W. E.; Clark, J. W. 1979. Wood bridges: decay inspection and control. Agric.Handbk. 557. Washington DC: U.S. Department of Agriculture, 32 p.

FHWA. 1998. Timber bridge related research summary. www.tfhrc.gov/structur/struc98/ch4set.htm. McLean, VA: Federal Highway Administration, Turner–Fairbanks Highway Research Center.

FHWA. 2002. The National Bridge Inventory Program. www.fhwa.dot.gov/bridge/nbi.htm. Washington DC: Federal Highway Administration.

FHWA. 2003. The National Historic Covered Bridge Program. www.fhwa.dot.gov/bridge/covered.htm. Washington DC: Federal Highway Administration.

Kropf, F.W. 1996. Durability and detail design— the result of 15 years of systematic improvements. In*:* Proceedings, National Conference on Wood Transportation Structures. Ritter, M.A., S. R. Duwadi, P.D.H. Lee (Eds.), p 321–327. Gen. Tech. Rep. FPL-GTR-94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 494 p.

Lebow, S.T.; Makel, W.J. 1995. Selection and use of preservative treated wood in forest service recreational structures. TEO1A35. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology and Development Center.12 p.

Lebow, S.T., Lebow, P.L.; Foster, D.O. 2000. Environmental impact of preservative-treated wood in a wetland boardwalk. Res. Pap. FPL-RP-582. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 126 p.

Lebow, S.T.; Tippie, M.; 2001. Guide for minimizing the effect of preservative-treated wood on sensitive environments. Gen. Tech Rep. FPL-GTR-122. Madison, WI: US Department of Agriculture, Forest Service, Forest Products Laboratory. 18 p.

Morrell, J.J.; Love, C.S.; Freitag, C.M. 1996. Integrated remedial protection of wood in bridges. In: Proceedings, National Conference on Wood Transportation Structures. Ritter, M.A., S. R. Duwadi, P.D.H. Lee (Eds.), p. 445-454. Gen. Tech. Rep. FPL-GTR-94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 494 p.

Niemi, B.; St. John, W.; Woodward, B.; DeGroot, R.; McGinnis, G.; 1998. Development of naphthenic acid fractionation with supercritical fluid extraction for use in wood decay testing. In: Proceedings, 94th annual meeting of American Wood Preservers' Association, 17–19 May, 1998, Scottsdale, AZ. p. 165–177.

Ritter, M.A. 1992. Timber bridges—design, construction, inspection, and maintenance. Engineering Management Series EM7700-8. Washington, DC: U.S. Department of Agriculture, Forest Service. 944 p.

Ritter, M.A.; Duwadi, S.R.; 1998. Research accomplishments for wood transportation structures based on a national research needs assessment. Gen. Tech. Rep. FPL-GTR-105. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 30 p.

St. John, W.P.; Rughani, J.; Green, S.A.; McGinnis, G.D. 1998. Analysis and characterization of naphthenic acids by gas chromatography–electron impact mass spectrometry of tert.-butyldimethylsilyl derivatives. J. Chromatog. A 807: 241–251.

USDA. 2003. National Wood in Transportation Information Center program.. www.fs.fed.us/na/wit. Morgantown, WV: U.S. Department of Agriculture, Forest Service, State and Private Forestry, Northeastern Area.

Wacker, J.P.; Crawford, D.M.; Eriksson, M.O. 2003. Creosote retention levels of timber highway superstructures in Michigan's lower peninsula. Res. Note FPL-RN-289. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 17 p.

Webb. D.A. 1976 Environmental considerations on creosote: A step in the right direction. Pittsburg, PA: Koppers Company, Inc.

WWPI. 1996. Best management practices for the use of treated wood in aquatic environments. Vancouver, WA: Western Wood Preservers' Institute. 35 p.

Wacker, James P. and Douglas m. Crawford -- Extending service life of timber bridges with preservatives. IN Proceedings of the 19th US-Japan Bridge Engineering Workshop, UJNR Panel on Wind and Seismic Effects, Tsukuba, Japan, October 27-30, 2003 / Edited by m. Ishida and M. Shirato. [Japan] : Public Works Research Institute, [2003?].