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Durability and Wood Protection for Historic Covered Bridges in the United States

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ABSTRACT

A majority of the covered wooden bridges in United States were built in the mid -1800's. These structures represent a unique cultural and technological heritage from that era. Over time, these bridges have been deteriorated by microorganisms and insects or damaged by acts of vandalism and arson. The National Historic Covered Bridge Preservation (NHCBP) Program sponsored by the Federal Highway Administration (FHWA) provides funds to support preservation and restoration efforts for historic covered bridges. The focus of the NHCBP Program is support and technology transfer efforts to preserve, restore and protect covered bridges in conjunction with providing educational resources to the general public. In this paper, an overview of NHCBP research on the durability and wood protection of covered bridges is provided. Research results assist the general public, field investigators and states in their efforts to restore, repair and preserve national historic bridges.

Keywords: historic covered bridges, deterioration, decay fungi, insects, preservation, restoration

This study is part of the Research, Technology and Education portion of the **National Historic Covered Bridge Preservation** (NHCBP) Program administered by the Federal Highway Administration. The NHCBP program includes preservation, rehabilitation and restoration of covered bridges that are listed or are eligible for listing on the National Register of Historic Places; research for better means of restoring, and protecting these bridges; development of educational aids; and technology transfer to disseminate information on covered bridges in order to preserve the Nation's cultural heritage.

This study is conducted under a joint agreement between the Federal Highway Administration – Turner Fairbank Highway Research Center, and the Forest Service – Forest Products Laboratory.

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1. INTRODUCTION

According to the World Guide to Covered Bridges, there are approximately 1600 covered bridges in the world and roughly 880 are located in the United States (WGCB 2009; Phares et al. 2010). Covered wooden bridges once numbered 14,000 but now, fewer than 900 of the historic structures survive in the United States (Pierce et al. 2005). Among these bridges, many similar construction styles are observed, yet no two bridges were built absolutely alike. The National Historic Covered Bridge Preservation (NHCBP) Program sponsored by the Federal Highway Administration (FHWA) was established in 1998 to preserve historic covered bridges in the United States. The broad objectives of the NHCBP research program are to find means and methods to restore and replace historic covered bridges (Wacker and Duwadi 2010). The program includes application of advanced technology, resource sharing, public awareness and education, and provides comprehensive support for research studies that involve maintaining, assessing, strengthening and protecting covered bridges. As a result of this effort, guidance and recommendations for maintenance, restoration, and rehabilitation were published in the Covered Bridge Manual (Pierce et al. 2005).

An on-line searchable database of U.S. covered bridges has been produced by the National Center for Wood Transportation Structures (NCWTS) at Iowa State University (http://www.woodcenter.org/CoveredBridges/queryMain.cfm). The database provides the location, condition, description and the history of each covered bridge, and is a useful tool for visitors and field investigators alike.

In the United States, covered bridges are primarily located in several states east of Mississippi river and a few states west of the Mississippi River. A majority of these surviving bridges are in Vermont (100 bridges), New Hampshire (57), Pennsylvania (227), Ohio (143) and Indiana (93). Although some of these bridges are functioning for vehicular and pedestrian traffic, many of them have undergone restoration and preservation work over their lifetime. Restoration may include replacing deteriorated materials, roofs, siding, or decking to strengthen the loading capacity and sustain bridge function. More intense restoration to reengineer the truss design is sometimes required to maintain structural integrity as well as the external appearance.

NHCBP's highest office recognizes the historic properties of covered bridges and nominates covered bridges for National Historic Landmark status. Two bridges have been granted the status of National Historic Landmark. They are Knight's Ferry covered bridge in California, a 1864 Howe truss design (Figure 1) and Humpback covered bridge in Virginia, a 1857 multiple Kingpost truss design (Figure 2).

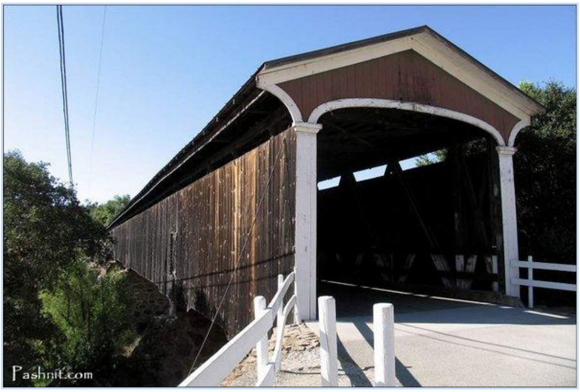

Figure 1: Knight's Ferry covered bridge in California

Figure 2: Humpback covered bridge in Virginia

2. DETERIORATION OF WOODEN BRIDGES

Covered bridges built in the 18th century were constructed without modern preservatives to protect the wood. Despite the roof and sides providing protection from moisture, biodeterioration in the bridges is inevitable in weatherboarding, wood components near the ends of the bridges that are chronically wetted from wind driven rain, and places where moisture is trapped inside the wood; joints are particularly susceptible (Figure 3). The support timbers, the roof, the deck and the connection members are all vulnerable to deterioration under high moisture conditions (Lebow 2012).

Decay fungi are the most destructive organisms for wood structures at any location when growth conditions are ideal. Temperature, moisture and oxygen are the critical factors for fungal growth. There are three major groups of decay fungi: brown-rot, white-rot and soft-rot fungi. The first two are the most destructive for above ground wood structures (Clausen 2010).

Termites damage wood as well and can be more aggressive and faster to degrade wood than decay fungi. The most damaging termite species in the United States are the subterranean termites. Damage by subterranean termites is anticipated to increase especially with changes in climate aiding their migration toward northern regions of the United States. Other types of insects and microorganisms such as beetles and carpenter ants have caused some damage in some areas, but not as severe as decay fungi and termites. The latter two cause significant economic losses.

Figure 3: Deterioration of a covered bridge support joint

3. NHCBP DURABILITY RESEARCH

3.1 Remedial preservative treatments

Proper preservative treatment creates a protective layer against decay fungi and insect damage. Most bridge members are too large and inter-connected to be effectively treated with surface application of preservatives. Therefore internal treatments are more practical. Internal treatments can be categorized into water diffusible liquids, non-diffusible liquids and fumigants. Borates, in rod, gel, or paste form, are commonly used in above-ground applications. The extent of the effectiveness of diffusible treatment varies with the wood moisture content, wood species and environmental conditions. Non-diffusible treatments commonly contain some form of copper; they do not diffuse in water and only move a few inches within the wood. The advantage of the non-diffusible treatment is that it is non-leachable against weathering or flooding.

Manufacturers have developed specific guidance for product applications. In general, the method for treating with diffusible rods, non-diffusible rods or encapsulated fumigants involves drilling holes downward or slanted through the center of the pile, inserting the treatment, and plugging the hole with a treated wooden plug. Fumigants must be applied in a location where they will not leak away or diffuse into the atmosphere. Structures treated with fumigants should be marked and care should be taken when removing components of the structure (Lebow et al. 2012).

Some of the formulations used for internal treatments can be used for external treatment of wood that has not been pressure treated. Surface application with gels, pastes and water diffusible materials can sometimes achieve deep penetration into wood, especially if application is directed to the end-grain of the wood. Borates are a commonly used water-diffusible liquid preservative for low pressure spray application or brushing to flood the cracks, checks, joints, and other areas in the wood that are susceptible to high moisture or moisture entrapment. But borates are easily depleted from rain, precipitation or exposure to standing water. A water repellent formulation containing a preservative can slow down depletion if it is applied after borate treatment.

A practical "how to" guide for selection and application of in-place treatments of use to preservationists, engineers and maintenance personnel to rehabilitate and restore these bridges was published under the NHCBP program titled "Guide for In-Place Treatment of Wood in Historic Covered and Modern Bridges" (Lebow et al. 2012).This guide provides an overview of the durability and wood protection research on covered bridges for restoration, repair and preservation of our national historic heritage.

3.2 Corrosion of fasteners

Metallic fasteners have performed well in covered bridges comprised of untreated wood for centuries. During rehabilitation, wood pressure-treated with copper-based preservative is being used for an increasing proportion of replacement components, raising concerns about accelerated corrosive effects on iron fasteners. An NHCBP-funded study on corrosion performance, and the role of moisture on corrosion of metals in contact with treated wood, resulted in a compilation of publications to aid engineers that address corrosion rates of metals embedded in treated wood, the mechanism of corrosion in treated wood, the effect of extractives on corrosion, methods for predicting service life of metals in treated wood, and suitable non-metallic replacement fasteners (Zelinka 2013a; 2013b).

3.3 Naturally-durable wood

Covered bridge designers relied on local sources of wood for bridge components, some of which were known from experience to be naturally durable. While preservative-treated wood is suitable for replacement of critical structural components, naturally durable locally-sourced wood for above-ground replacement components better conforms to the original bridge design and reduces environmental concerns associated with the use of chemically-treated wood over water. As old-growth materials have diminished, naturally-durable alternatives were considered for replacement of bridge components. Research findings from above-ground field tests combined with chemical analysis of extractives for each wood species resulted in a publication for the selection of locally-sourced durable wood species suitable for above-ground replacement components for covered bridges (Kirker et al. 2013).

3.4 Fire prevention

Fire is the leading cause of loss and damage for covered bridges. Some fires are accidental but many are set by vandals or arsonists. Contributing factors to fire can be grouped by bridge location, design, and organic debris around the bridge, roof material and use of fire retardant treatments (FRT).

In order to protect bridges from fire, bridge components can be treated with FRT to delay ignition, reduce heat release, and slow flame spread. Pressure impregnation with FRT is similar to the process of wood preservative treatment. FRT treatment with boron can also serve as preservative protection. The efficacy of the FRT depends on wood species, structure, and moisture content. Some inorganic salts are commonly used as fire retardants for exterior wood products. These salts include ammonium sulfate, zinc chloride, boric acid, and mono- and di-ammonium phosphate. Some water insoluble retardants have been developed to meet the need for leach resistant systems (White and Dietenberger 2010).

Some kinds of fire protection technology have been installed on bridges such as alarms, sprinklers, lights and remote monitoring systems. Alarms can be used to alert fire departments and activate warnings for nearby residents. One drawback is that heat or smoke detectors require routine maintenance to ensure proper function. Sprinkling systems are the most effective form of immediate fire suppression but installation may be costly. Lighting may deter vandalism but may also make it a favorable gathering place (Lebow et al. 2012).

Iowa State University collaborated with the USDA Forest Products Laboratory (FPL) to evaluate the use of remote monitoring by flame detectors, fiber optic sensors, and infra-red (IR) cameras. Flame detectors detected fire based on the burning flame wavelength. Fiber optic sensors also detected flame, but only if the fire source was located within a few feet of the sensor. An IR camera, mounted on a pole some distance from the bridge, can detect fire and also the heat of a human body. The IR camera could alert authorities for possible vandalism. All these monitoring technologies will not prevent catastrophic loss from a fire unless an effective sprinkling system is installed and rapid response from a fire station is available (Phares et al. 2010).

3.5 New technologies under development

In order to increase awareness of the covered bridges' place in American history, documentation is important to preserve their service life histories. Under a cooperative study between FPL and University of Minnesota, a new laser scanning technique has been developed to record physical dimensions and construction features for several bridges in a rapid, accurate and cost-effective manner. Figure 4 shows 3D laser scanning technology being used to document as-built conditions of historic structures. This bridge was built in 1905 by A.Y. Bayne & Co. (Brashaw and Ross 2009).

Several new technological advances have resulted from cooperative research between Iowa State University and FPL in sensor systems specific for timber bridges. The idea is to have sensors integrated into timbers so that the condition and performance of the bridge can be reported continuously and remotely. To date, this technology will be the key components for so-called "smart bridges". Moisture sensing technology will help to identify areas to monitor for decay. The moisture sensors will trigger an alarm and alert maintenance personnel for future inspection and remedial action. This decay detection approach is highly valuable for historic covered bridges especially the ones that have been recently rehabilitated with new materials (Wacker and Phares 2011).

Figure 4: 3D laser scanner documents as-built details

4. SUMMARY

Covered bridges are unique and iconic structures in the United States. However, covered bridges are vulnerable to biological and physical deterioration as well as structural damage by vandalism and arsonists. The NHCBP Program sponsored by the FHWA was established to preserve these historic structures through research to restore, rehabilitate and protect them. Measures are being taken to protect them from decay and insect damage through in-place remedial treatments. Research has identified naturally-durable wood species that are suitable alternatives to treated wood for replacement components during bridge rehabilitation. Likewise, guidance for selection of metallic and non-metallic replacement fasteners is available. Traditional fire prevention measures such as sprinklers, alarms, and FRT have been evaluated along with the development of new technologies based on flame detectors, fiber optic sensors, and IR cameras. 3D laser scanning is being used to document as-built design details to authenticate restoration efforts. A variety of new remote sensing technologies are under development that will focus on continuous, remote monitoring of biological and physical conditions in bridges. On-going research cooperation between universities and government agencies will preserve, restore and protect our Nation's covered bridges.

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