Preservation Treatment for Wood Bridge Application

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Timber can often be a cost-effective construction material for new bridges. The durability of the bridge greatly depends on proper attention to construction details and fabrication, as well as proper preservative treatment before, during, and after construction. Material repair and replacement costs for bridges are a considerable expense for highway agencies. To address these needs, the objectives of an investigation were to determine the field effectiveness of various treatment alternatives used on Iowa roadway projects and to provide information on preservative treatments, inspection techniques, and current specifications for bridge owners. Special emphasis was placed on providing up-to-date synthesized information for county engineers to maintain their timber bridge inventory more effectively. The project scope included a literature review, identification of testing techniques, on-site inspections of bridges in Iowa, and a review of current specifications and testing procedures. On the basis of information evaluated, these general conclusions were made: copper naphthenate was recommended as the plant-applied preservative treatment for timber bridges, American Wood Protection Association Standards and Best Management Practices should be followed to ensure high-quality treatment of timber materials, and bridge maintenance programs would be enhanced by the development of an effective construction and remedial treatment process to improve bridge durability.

Timber can be a cost-effective building material for bridge construction. The use of timber in transportation structures (e.g., bridge superstructures, substructures, abutment retaining walls, guardrail components) is common across the United States on low-volume roads. Unfortunately, premature deterioration of these timber components is also a common problem. The durability of the bridge greatly depends on proper attention to construction details and fabrication, as well as proper preservative treatment before, during, and after construction. The life span of existing timber bridges can be increased with careful attention to common problem areas during field inspections.

In some cases, problems occur because of inadequate attention to construction details that can lead to moisture problems regardless of the type of treatment used. In other cases, the particular treatment method used may be incorrect. Various products are currently being used for the treatment of wood materials in Iowa; however, creosote has been the most common choice due to its proven performance and availability. Recently changing environmental concerns, public perception, and material costs have made creosote less available and more expensive. Other products used in Iowa, such as copper naphthenate (CuNap), have recently been used as a creosote replacement.

The primary objectives of this research were to (*a*) evaluate (by field inspection) the performance of different wood preservatives used in Iowa; and (*b*) provide bridge owners with current information on plant-applied preservatives, in-place preservatives, testing procedures, and specifications to be used as tools for maintenance and repair of existing or new bridges. The Iowa State University Bridge Engineering Center (BEC), in cooperation with the U.S. Department of Agriculture Forest Products Laboratory (FPL), evaluated the various types of wood preservatives used for highway applications (*1*).

BACKGROUND

There is a long history of using wood as a construction material for bridges in the United States. Before 2000, the United States had more than 38,000 timber bridges with an additional 39,000 bridges using timber decks (*2*). Of Iowa's 20,800 bridges it was estimated in 1998 that 4,300 of them were constructed primarily of timber (*3*). These bridges have predominately been located in rural areas, providing a vital link for secondary, local, and rural highways. The uses have varied from simple, temporary log bridges to more complex structures serviceable for more than 150 years. Wood is a natural choice for a construction material because it is inexpensive, relatively simple to fabricate, and locally available in most areas. However, for structures that are expected to last for 40 to 50 years or more, the susceptibly of wood to biodegradation is a major disadvantage. To prevent biodegradation from taking place, wood preservatives have been developed and used to extend the service life of timber bridges. Inevitably, when deterioration does take place, it can often be difficult to identify. However, there exist tools and techniques to quantify the amount and location of the deterioration.

Preservatives

Wood preservatives can be separated into two areas based on the time the preservative is applied. Plant-applied preservatives are generally applied at a pressure treatment facility before construction of the structure, while in-place preservatives are applied during or after construction. Preservatives are expected to protect timber members from attack by a broad range of organisms without posing significant

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risks to people or the environment. Preservatives must also resist weathering and other forms of depletion for extended periods of time. Because of toxicity, however, many of the preservatives are labeled by the Environmental Protection Agency (EPA) as restricted use pesticides (RUPs). The RUP classifications restrict the use of the chemical preservative, but not the treated wood, to certified pesticide applicators only.

Most preservatives can also be broadly classified as either oil-borne or waterborne, based on the chemical composition of the preservative and the solvent or carrier. Generally, oil-borne preservatives are used with petroleum-based solvents ranging from heavy oils to liquefied gases. Waterborne preservatives are applied using water-based solutions such as water or ammonia (*4*).

Inspection

After bridges have been in service for several years, periodic inspections should identify locations of deterioration. The deteriorated areas can often be difficult to detect. Both destructive and nondestructive testing techniques are available to determine the extent of deterioration that has occurred and the remaining amount of preservative. Inspection tools and techniques allow bridge owners to make educated decisions about in-place treatment practices.

PLANT-APPLIED PRESERVATIVE TREATMENTS

The following list and description of preservatives is not intended to be exhaustive. This list is limited to preservatives that have been standardized for some type of application in highway construction and that have been produced commercially.

Oil-Borne Preservatives

The most common oil-borne preservatives are creosote, pentachlorophenol, and CuNap. Conventional oil-borne preservatives, such as creosote and pentachlorophenol solutions, have been confined largely to uses that do not involve frequent human contact. The exception is CuNap, a preservative that has become more available recently but has been used less widely. EPA and treated timber producers have created consumer information sheets (CIS) with guidance on appropriate handling and site precautions when using creosote and pentachlorophenol.

Oil-borne preservatives are generally preferred for bridge structural elements due to their ability to dimensionally stabilize members and to act as good moisture barriers (*5*). The oil or solvent that is used as a carrier also makes the wood less susceptible to cracks and checking, and it helps prevent moisture movement through the member. With oilborne preservatives, corrosion of metal fasteners is not significantly increased, and no noticeable changes in engineering properties occur with proper treatment.

Creosote

Creosote is the oldest and most common type of oil-borne preservative in service today. It is produced by the distillation of coal tar or oil shale (*4*). Straight, undiluted creosote is preferred for most bridge applications due to its higher toxicity to fungi, better penetration properties, and less bleeding.

Creosoted timber has been found to be effective in most environments. Due to its age and extensive use, creosote has a proven record of satisfactory service and case histories have shown 50-plus years of good service (*4*). Although the preservative is not dissolved in oil, it often has an oily appearance and feel. Members with fresh creosote surfaces can be ignited and will burn; however, after a few months of seasoning, the volatile parts of the oil components are gone from the surface and ignition properties are similar to those of untreated wood (*5*).

In the past decade, the use of creosote has declined because of handling issues and environmental concerns. Creosote can easily soil workers' clothing, and vapors irritate skin by photosensitizing exposed areas. However, no serious health dangers have been found in workers directly handling and working near treated wood during construction. Sensitive growing plants and foodstuff can be harmed by creosote vapors and should not be stored with creosoted members in unventilated areas. The EPA classifies creosote solution as an RUP.

Pentachlorophenol

Pentachlorophenol has been widely used in the United States since the 1940s (*3*). Typically, pentachlorophenol is dissolved in an organic solvent that acts as a carrier. The two most common solvents are Types A and C. These solvents have been found to heavily influence the preservative performance of treated wood and should be carefully chosen for the specific application. Type A solvents are generally heavy oils and are recommended for structural members including glue-laminated beams and pilings. Pentachlorophenol in heavy oil is effective when used in ground contact, freshwater, and aboveground applications, but not in marine environments. The effectiveness of Type A pentachlorophenol is similar to that of creosote in protecting both hardwoods and softwoods. Pentachlorophenol in heavy oil can improve the dimensional stability of the treated wood.

Type C pentachlorophenol uses light petroleum oil as the solvent carrier. Type C pentachlorophenol is preferred for glue-laminated lumber treatment before gluing (*4*) and can be used in applications where human contact is likely. Type C pentachlorophenol has treatment characteristics similar to those of Type A pentachlorophenol. Type C pentachlorophenol can penetrate difficult-to-treat species and does not accelerate corrosion. The surface of Type C-treated wood is paintable and provides some protection from weathering; however, the protection is long lived. Timber that has been treated with Type C pentachlorophenol should be used only aboveground.

All types of pentachlorophenol chemicals are classified by the EPA as RUPs. Due to the toxicity of those chemicals, humans should avoid excessive contact with the solution and vapor (*5*).

Copper Naphthenate

CuNap has been commercially available since the 1940s, and formulations were added to the American Wood Protection Association (AWPA) standards in 1948. CuNap is the product of the reaction between petroleum-derived naphthenic acids and copper salts. CuNap has low animal toxicity, which allows it to be purchased at hardware stores and lumber yards for in-place treatment (*6*). CuNap can be dissolved in a variety of solvents similar to those of pentachlorophenol. However, AWPA has standards only for heavy oil solvents.

CuNap-treated wood is bright green in color and weathers to a light brown. Freshly treated wood has an odor that can dissipate over

time. CuNap is effective for use in ground contact, water contact, and aboveground applications. It is not standardized for saltwater applications. The most common use has been for utility poles, but it is becoming popular for structural lumber, post, and glulam beams due to the clean surface and resistance to in-service bleeding (*7*). The clean surface of CuNap-treated wood can be painted. However, the paintability depends on the solvent, treatment procedures, and time allowed for the member to cure properly.

CuNap is not listed as an RUP by EPA, nor are there any CIS available for guidance on handling and site precautions. Even though health concerns do not require CuNap to be an RUP, commonsense precautions should be followed when handling treated wood.

Overall, CuNap seems to be a good alternative for treatment of all timber bridge structural elements. Reasons for recommending CuNap include dimensional stability, good handling characteristics, clean surfaces, comparable availability and longevity with other preservatives, and potential for fewer environmental impacts.

Waterborne Preservatives

The first waterborne preservatives were developed in the late 1800s. However, they were not heavily used until the 1960s due to demand for clean paintable surfaces (*4*). Traditional waterborne preservatives are formulations of copper or inorganic arsenical compounds, or both, that react with or precipitate in treated wood. The reaction takes place when members are treated, fixing the precipitants (e.g., copper, chromium, and arsenic) within the cells of the wood to help prevent leaching and migration potential. Waterborne preservatives usually do not cause skin irritations, and they are suitable for use where mammalian contact is likely. Thus, waterborne preservatives are frequently used for guard railings and floors on walkways. Waterborne preservatives are not recommended for large glue-laminated beams (laminated before treating) because wetting and drying during the treatment process may result in unwanted dimensional changes, warping, splitting, and cracking (*7*).

Waterborne preservatives have been found to reduce the mechanical properties of wood under some conditions. Treatment standards include processing requirements intended to prevent or limit strength reductions. The effects are related to species, mechanical properties, preservative chemistry or type, preservative retention, post-treatment drying temperature, size and grade of material, product type, initial kiln drying temperature, incising, and both temperature and moisture in-service. Waterborne preservatives affect each mechanical property differently, with thicker material undergoing fewer changes. Air drying after treatment also causes no significant reduction in the static strength. Several waterborne treatments accelerate the corrosion of fasteners relative to untreated wood, requiring the use of special fasteners. For waterborne treatments that are classified as an RUP and contain inorganic arsenic, the producers of treated wood, in cooperation with the EPA, have created CIS that provide guidance on handling and precautions at sites where treated wood is used.

Chromated Copper Arsenate

Chromated copper arsenate (CCA), often called green-treat, dominated the market from 1970s until 2004. EPA no longer approves the use of CCA for residential construction and has limited its use to certain industrial and commercial applications, including bridge components.

The most common standard formulation of CCA is CCA Type C (CCA-C). It is still available because it has the best leach resistance and field efficacy. CCA-C has decades of proven performance and is the reference preservative used to evaluate the performance of other waterborne wood preservatives. Because of the long usage history, CCA-C is listed in AWPA standards for a wide range of wood products and applications. CCA-C protects wood aboveground, 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 CCA is not recommended for hardwood treatments. Chromium inhibits the corrosion of fasteners in wood treated with CCA more than for preservatives that do not include chromium. CCA contains inorganic arsenic, and EPA classifies it as an RUP.

Ammoniacal Copper Zinc Arsenate

Ammoniacal copper zinc arsenate (ACZA) is another waterborne preservative used for bridges in the United States. ACZA is a refinement of an earlier formation of ammoniacal copper arsenate (ACA). ACZA has less arsenic than did ACA. ACZA-treated wood varies in color from olive to bluish-green. The wood may a have slight ammonia odor that will generally dissipate.

ACZA contains copper oxide, zinc oxide, and arsenic pentoxide that are dissolved in a solution of ammonia in water. ACZA has performance and characteristics similar to those of CCA. However, ACZA's chemical composition and stability during treatment at elevated temperatures allows it to penetrate difficult-to-treat wood species. ACZA is an established preservative that is used to protect wood from decay and insect attack in a range of applications in aboveground and ground-contact conditions. ACZA contains inorganic arsenic, and EPA classifies it as an RUP.

Alkaline Copper Quaternary Compounds

Alkaline copper quaternary (ACQ) is one of several wood preservatives that have been developed in recent years to meet market demands for alternatives to CCA. The fungicides and insecticides in ACQ are copper oxide and a quaternary ammonium compound. Several variations of ACQ have been standardized or are being standardized. ACQ type B (ACQ–B) is an ammoniacal copper formulation that penetrates difficult-to-treat wood better than other non-ammoniacal formulations. ACQ type D (ACQ–D) is an amine copper formulation that provides more uniform surface appearance and is used for retail treated wood.

Timber treated with ACQ–B is dark greenish-brown and fades to a lighter brown. ACQ-B–treated wood may have a slight ammonia odor until the wood dries. Wood treated with ACQ–D is light brown and has little noticeable odor. ACQ treatments with these formulations have demonstrated their effectiveness against decay fungi and insects in aboveground and ground-contact areas, but not in saltwater applications (*5*).

The number of pressure-treatment facilities using ACQ is increasing. Since ACQ does not contain arsenic and has an overall lower toxicity, EPA does not classify it as an RUP.

IN-PLACE PRESERVATIVE TREATMENTS

For best performance, as much fabrication as possible should be completed before pressure treatment, to allow all exposed surfaces to be protected (*8*). On-site fabrication of timber components inevitably results in breaks in the protective barrier. Pile tops, which are typically cut to length after installation, specifically need reapplication of a preservative to the cut ends. Likewise, the exposed end grain in joints, which is more susceptible to moisture absorption, and the immediate area around all fasteners, including drill holes, require on-site reapplication of preservative.

Several different in-place preservatives exist that can be used for various bridge applications. Periodic inspections should seek to identify cracks, splits, and checks that result from normal seasoning as well as areas of high moisture or exposed end grain. These areas require periodic reapplication of supplemental preservative. Several of the in-place preservatives are RUP and require certified applicators licensing. Following is information about these treatment methods.

Surface Treatments

The simplest method for applying supplemental preservative treatment involves brushing or spraying a preservative or over the suspected problem area (e.g., joints, fasteners, pile tops). Flooding of bolt holes and the tops of cut-off piles is particularly important. Cracks, checks, and splits should be retreated during subsequent inspections. Because surface treatments do not penetrate deeply into the wood where deterioration is most likely to occur, and because their application does present some risk to the environment, their use should be limited to problem areas such as bolt holes, exposed end grain, checks, and splits.

CuNap is the product most commonly used for surface treatment; it should contain 1% to 2% elemental copper. Borate solutions are also used; however, leaching will occur during subsequent precipitation.

Pastes, such as CuNap, sodium fluoride, copper hydroxide, or borate, are another form of surface treatment. With paste treatment, the diffusible components (i.e., boron or fluoride) move through the wood, while the copper components remain at the surface of a void or check. Generally, a protective covering is applied to prevent long-term loss.

Diffusible Chemicals

An alternative to surface-applied treatments is installation of internal diffusible chemicals. These diffusible treatments are available in liquid, solid, or paste form and are applied into treatment holes that are drilled deeply into the wood. They are similar (and in some cases identical) to the surface-applied treatments or pastes. Holes are drilled in the member to maximize the chemical diffusion and minimize the number of holes needed. The treatment holes are plugged with tightly fitting treated wooden plugs or removable plastic plugs.

Solid rod treatments are a good choice in environmentally sensitive areas or in applications where the treatment hole can be drilled only at an upward angle. Further, the chemical does not diffuse as rapidly or move as great a distance as compared with a liquid (*9*). One reason that the solid forms may be less mobile is that diffusible treatments need moisture, which is lacking in a solid rod, to be able to move through wood. Concentrated liquid borates may also be poured into treatment holes, and they are sometimes used in conjunction with the rods to provide an initial supply of moisture. The diffusible treatments do not move as far into the wood as do fumigants. Thus, the treatment holes must be spaced more closely.

Currently, diffusible chemicals are not listed as RUPs and have the advantages of relatively low toxicity and ease of handling. Although many diffusible chemicals list piles as a suitable application, the treatment should be applied so the chemical is deposited above the mean high watermark.

Fumigants

Like diffusibles, fumigants are applied in liquid or solid form in predrilled holes. Four fumigants commonly used are chloropicrin, methylisothiocyanate, metham sodium (Vapam), and granular dazoment. Fumigants volatilize into a gas that moves through the wood. To be most effective, a fumigant should be applied at locations where it will not leak away or be lost by diffusion. When fumigants are applied, the timbers should be inspected thoroughly to determine an optimal drilling pattern that avoids metal fasteners, seasoning checks, and severely rotted wood. The amount of fumigant needed and the size and number of treatment holes depends on the timber size.

Fumigants will eventually diffuse out of the wood, allowing decay fungi to recolonize. Fortunately, additional fumigant can be applied to the same treatment hole. Fumigant treatments are generally more toxic and more difficult to handle than the diffusible treatments are. Some are considered by EPA to be RUPs (*10*) and should only be applied above the mean high watermark. Another disadvantage of preencapsulated fumigants is the relatively large size of treatment hole required.

FIELD INVESTIGATIONS

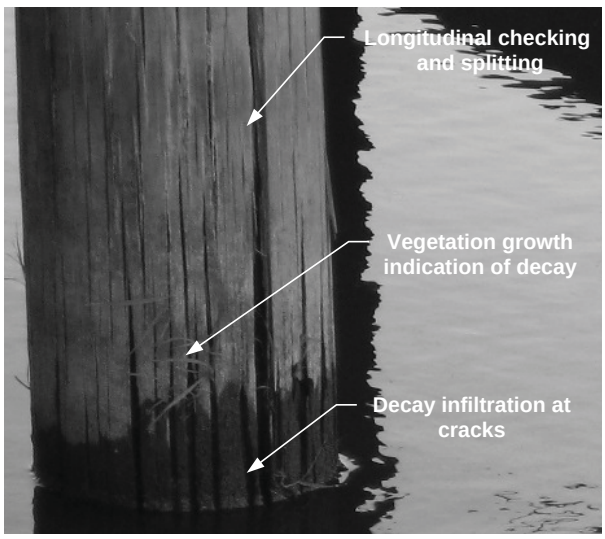
On-site visual bridge inspections were conducted in Iowa. The goal of these inspections was to evaluate the performance of current preservatives. Creosote, pentachlorophenol, CuNap, and ACZA were positively identified preservatives being used. Table 1 summarizes data on the 47 bridges inspected in eight different Iowa counties.

Creosote was found to have a wide use in Iowa and is still a popular choice for piles because of its record of good performance. Bridges had creosoted timbers for piles, cap beams, abutment backwalls, stringers, and decking, with the oldest elements dating back to 1933. During the past decade, there has been a decline in the use of creosote due to previous handling complaints by workers, increase in cost, decreasing availability, and environmental concerns. Figure 1 shows bridge piles with commonly observed problematic conditions. Figure 2 shows protected and unprotected pile tops. The large number of creosote bridges investigated did reveal general trends for individual bridge elements. Creosote abutment piles that were kept up and back from the stream channel were found to last longer than did piles located in the stream channel or in constantly moist areas. Creosoted elements that were not in contact with the ground (e.g., stringers) were generally found to last 50 years or more.

Field investigations revealed that only sawn pentachlorophenol-treated timber elements were being used for bridge construction. Specifically, cap beams, abutment backwalls, stringers, decking, and

TABLE 1 Summary of Field Inspections of Iowa Timber Bridges

Preservative	Number Inspected	Approx. Age Range (years)	Comments on Use and Condition
Creosote	35	20 to 70	Piles and range of sawn members. Condition varied with age, exposure, and construction and maintenance practices. Aboveground members sound for over 50 years. Piles in water or moist areas were most prone to decay.
Pentachlorophenol	5	5 to 25	Cap beams, abutment backwalls, stringers, decking, and guard railing all in good to excellent condition.
Copper naphthenate	3	1 to 7	Cap beams, abutment backwalls, stringers, decking, and guard railing all in good to excellent condition.
ACZA	4	1 to 20	Stringers, decking, backwall plank, and guard railing all in good to excellent condition.



(a)

(b)

FIGURE 1 Bridge piles: (*a*) common visual signs of interior decay of older piles located in stream channels and (*b*) creosote bleeding able to be minimized by vacuum steaming or expansion bath during processing.

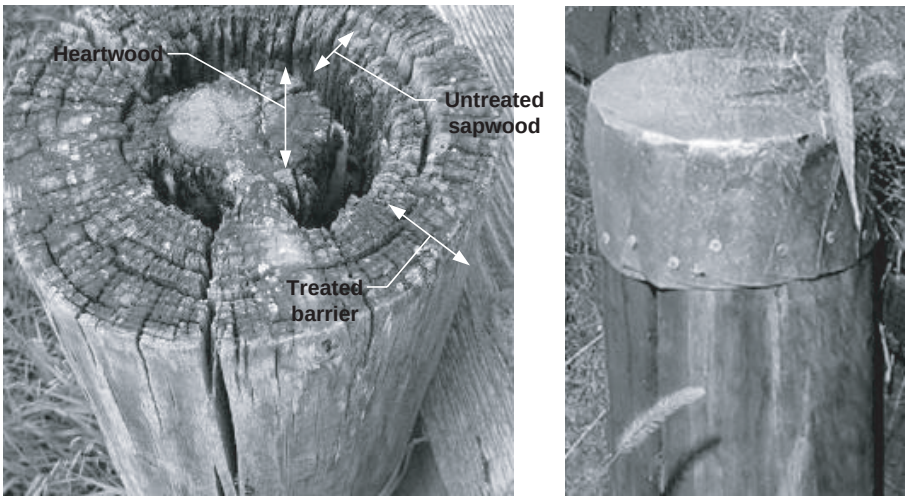
guard railing were all seen. The age of pentachlorophenol-treated material was about 25 years, with the earliest bridges dating back to the early 1980s. Generally, members were in good to excellent condition. Several counties reported that they preferred the use of pentachlorophenol over creosote due to better handling issues and less bleeding. Figure 3 shows a member that has been field cut and an older non–field-cut member.

Few bridge structures have been constructed with CuNap-treated wood; however their prevalence is becoming larger due to availability, cost, and ease of handling. Only relatively new bridge structures were identified with only sawn timber elements. Cap beams, abutment backwalls, stringers, decking and guard railing were all investigated. These members were all performing well. Several counties had reservations about using piles treated with CuNap due to lack of information and experience when used in water and high moisture areas. Although the bridges built with copper naphthenate are still relatively new, the counties gave positive feedback on performance and excellent handling properties. Figure 4 shows CuNap-treated cap beams and stringers.

The use of ACZA was identified in only one Iowa county. The oldest ACZA materials were stringers and bridge decking. The newest elements identified were placed as backwall plank for a bridge under construction. The county used ACZA because it was proposed by the supplier, it is an approved preservative, and it has good handling properties. Figure 5 shows ACZA-treated members.

Field investigations revealed that regardless of treatment type, member protection also contributed to the longevity and performance of the bridge. Bridge elements that seemed to be field cut and treated in place generally had less decay than did untreated cut members. Interior stringers had very little decay and physical defects. However, the exterior stringers tended to have checking along the length of the members. The overall condition of piles and cap beams that had metal or felt covers was much better than with piles and cap beams left uncovered. Specifically, a reduction in end-grain decay and checking was seen on all piles and caps with covers. Metal and building felt caps were used for protection; metal caps were found to have better longevity and durability.

Although the small number and newness of the field-investigated bridges did not reveal the life expectancy of pentachlorophenol, CuNap, and ACZA, research has been conducted by the FPL on treated round fence posts for the past several decades (*11*). The tests were conducted in high-decay and termite hazard zones in Mississippi. Failure of the posts was determined by periodically administering a 50-lb pull test on the post. The most recent testing



(a) (b)

FIGURE 2 Pile tops: (*a*) exposed end grain providing direct path for infiltration of decay and heavy weathering and (*b*) good metal pile cover provided to prevent pile top decay.

was conducted after 53 years of exposure, at which time sufficient posts had failed to allow calculation of expected service life. Service life was statistically predicted by assuming a Weibull lifetime distribution and estimating the 60th percentile. From the analysis, the estimated service life is as follows: CuNap, 65 years; creosote, 54 years; pentachlorophenol, 74 years; ACZA and ACA, 60 years; and untreated, 2.4 years.

INSPECTION TOOLS AND TESTING

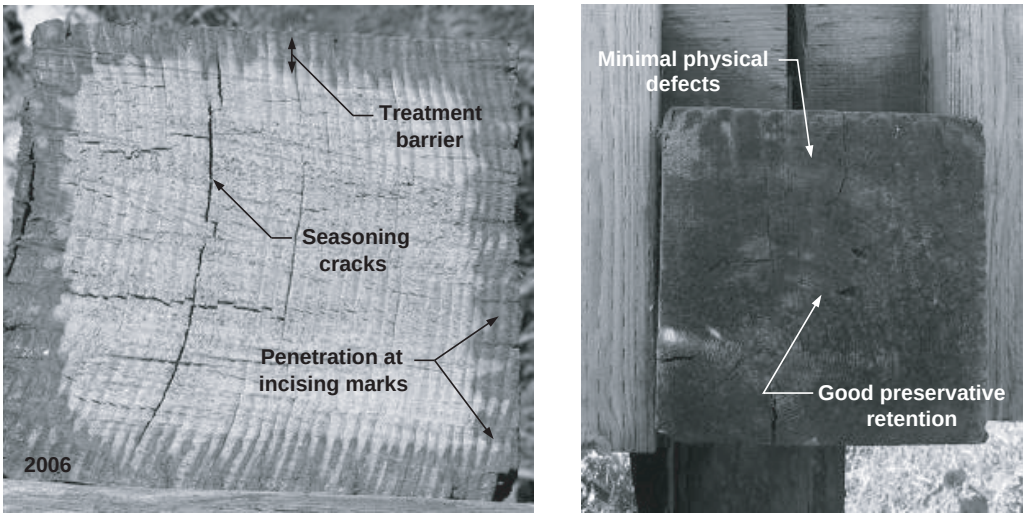
A number of tools exist to assist the inspector with the diagnosis of deterioration. These tools vary considerably in the amount of experience required for reliable interpretation, accuracy in pinpointing a problem, ease of use, and cost. No single test should be relied on for inspection of timber components. Rather, a standard set of tools should be used to ensure conformity in inspections and uniformity between inspectors.

Visual Assessment

A general visual inspection can give a quick, qualitative assessment for corroded fasteners, split, cracked, and checked wood; and crumbling, collapsed, fuzzy, or discolored wood. All color changes in the wood should be noted; they are indicators of possible decay.

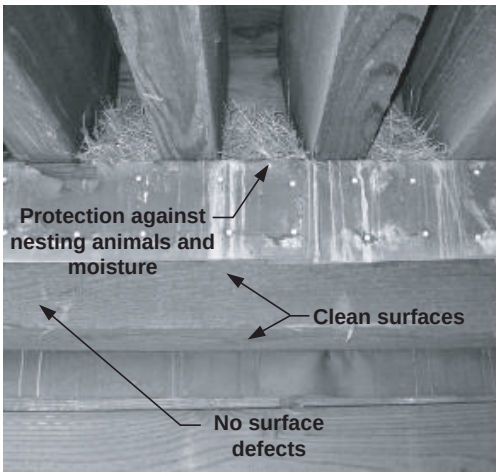
Probing and Pick Test

Use of a pointed tool can detect soft spots created by decay fungi or insect damage. Probing can locate pockets of decay near the surface



(a) (b)

FIGURE 3 Views of member end grain: (*a*) railing post with field-cut end grain and no in-place treatment, which increased the amount of physical defects, and (*b*) cap beam with good end-grain treatment, preventing decay and providing good dimensional stability.



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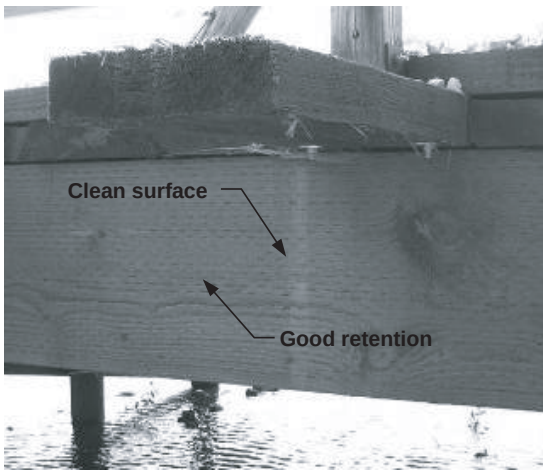
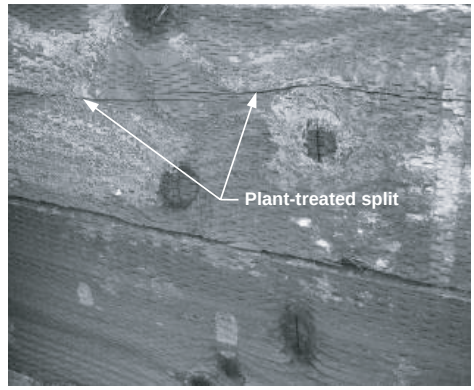


(b)

FIGURE 4 Use of CuNap: (*a*) CuNap-treated cap beam with building felt cover for protection from nesting animals and (*b*) CuNap-treated exterior stringer with no physical defects or excess preservative bleeding.



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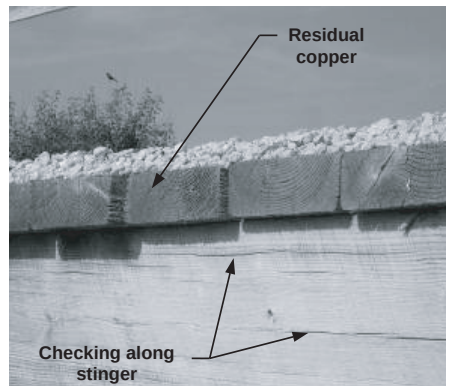

(b)

FIGURE 5 Use of ACZA: (*a*) new ACZA-treated backwall planks properly seasoned before treatment and (*b*) ACZA-treated in-service decking and stringer in good condition with only minor physical defects.

of the wood member or can be used to test the splinter pattern of a piece of wood. A pick test on decayed wood will result in a brash or brittle failure across the grain with few, if any, splinters.

Moisture Measurement

Moisture measurements are taken with an electronic handheld moisture meter. Moisture content greater than 20% indicates that enough moisture is present for decay to begin. The measurements provide information on areas where water is being trapped, such as joints, and they serve as an indicator that a more thorough assessment is necessary.

Sounding

In the sounding method, a hammer is used to strike the wood surface. On the basis of the tone, the inspector must be able to differentiate a hollow sound created by a void or pocket of decay from the tone created by striking sound wood. Some experience is necessary for interpretation of soundings since many conditions can contribute to variations in sound (*12*).

Stress Wave Devices

Stress wave devices measure the speed (transmission time) at which stress waves travel through a member. These measurements locate voids in wood. Stress wave signals are slowed significantly in areas containing deterioration, but signal changes do not distinguish among active decay, voids, ring shakes, or other defects (*13*).

Drill Resistance Devices

Drill resistance devices record the resistance required to drill through a piece of wood. The amount of resistance is related to the density of the wood in that particular area and can be used to determine if deterioration exists (*14*).

Core Boring

Increment core borings of representative areas should be taken perpendicular to the face of the member being sampled. Increment

cores can be visually examined for signs of deterioration and may be submitted to a laboratory for biological or chemical analysis, or both.

Preservative Retention Analysis

In most cases, the pressure-treated shell in bridge members contains more than enough preservative to protect the wood. However, in older members, or in situations where deterioration is evident in the treated shell, this analysis may be a worthwhile means to determine the preservative retention characteristics. Preservative retention can be determined from a wood sample by an analytical chemist using AWPA standardized test methods.

SPECIFICATIONS AND GUIDELINES

AWPA Standards

AWPA is the primary standard-setting body for preservative treatment in the United States (*15*). The Use Category System (UCS) Standards and Miscellaneous Standards, located in AWPA Standard-07, are the most applicable to timber bridge preservatives. UCS standards identify proper preservative retention and penetration for various timber materials. In the miscellaneous standards are sections pertaining to the care of preservative treated wood and guidelines for pole maintenance programs. Although the information is presented for utility and pole owners, the same maintenance principles may be applicable to bridges.

To specify the proper treatment and penetration of different bridge elements, the use category designations are used in conjunction with the commodity specifications (U1) and the processing standards section (T1) of the UCS. Most applications for highway construction fall into categories UC4B and UC4C. The commodity specifications have nine classifications (Sections A through I) for relating appropriate preservative retentions and the member usage. The processing standard, Sections 8.1 through 8.9, provides penetration requirements appropriate to species and use categories.

AWPA's Standard for the Care of Preservative-Treated Wood Products (Standard M4) describes requirements for the care of treated piles and lumber at storage yards and on job sites.

American Institute of Timber Construction

The American Institute of Timber Construction (AITC) has a Standard for Preservative Treatment of Structural Glued-Laminated Timber, AITC 109-2007. It incorporates the AWPA UCS for the treatment of glued-laminated timber members.

The AITC standard also has design considerations for selecting the proper preservative treatment. One important consideration is whether glued-laminated timber should be manufactured with lumber treated before gluing or after gluing. Southern Pine is generally the only species available for pre-gluing treatment. The preservatives that can be used for pre-gluing treatment are limited to pentachlorophenol Type C and waterborne treatments. Unlike the AWPA standards, the AITC standards do not recommend waterborne treatments pre- or post-lamination. The treating facility limitations must also be considered when designing large glued-laminated members.

Best Management Practices for Use of Treated Wood in Aquatic Environments

Due to the increased concerns for the aquatic ecosystems where treated wood bridges and walkways are placed, best management practices (BMPs) (*16*) have been developed as a guideline to reduce their impact on the environment. Many BMPs are dedicated to the plant-applied treating process of timber. However, the BMPs also include guidelines for the construction and maintenance of these structures to reduce biological risks.

BMPs are a combined effort of all parties involved with the construction of timber bridges. The treatment producer, designer, owner, and contractor all have important roles in ensuring a clean environment at a bridge location.

To ensure minimal contamination of the aquatic environment, all materials should be inspected at delivery. Field cutting and fabrication should be done away from water and sensitive areas to eliminate direct infiltration of sawdust and shavings. The importance of ensuring a clean environment should be stressed in planning and budgeting for the project, so that the construction crew clearly understands that debris collection is an integral part of the construction process. Any untreated wood that is exposed during field fabrication should be treated to prevent decay. Whenever possible, the field treatment should be applied to the member before it is placed in a structure over water.

State and Local Requirements

Although WPA is the primary standard-setting body for preservative treatment in the United States, bridge designers need to also satisfy state and local requirements. The Iowa Department of Transportation specifications, for example, are the governing body for handling and preservative treatment for timber bridge elements using state or federal funding within Iowa. In many, cases the AWPA standards are the basis for state and local preservative requirements.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of evaluated preservative information, field observations, and review of specifications and testing procedures, conclusions related to timber bridge preservative performance are as follows:

1. CuNap is recommended as the plant-applied preservative treatment for timber bridge elements. CuNap has been tested extensively by the FPL in past years and has shown that it has comparable, if not better, performance to other commonly used preservatives such as creosote. Additional reasons for recommending CuNap include good handling characteristics, clean surfaces, comparable availability to other preservatives, and the potential for fewer environmental impacts.
2. During construction of timber bridges, the BMPs should be followed to minimize environmental impacts to the surrounding ecosystem and ensure quality treatment of both plant-applied and in-place preservatives. In addition to using BMPs, bridge owners need to ensure that pile tops and cap beams are protected from moisture by use of metal covers, and that all field cuts are treated with in-place treatments.

3. Timber bridge maintenance programs need to be developed and implemented. A maintenance program that uses combinations of inspection tools and various in-place treatments can easily extend the service life of a bridge.

4. Future workshops or short courses presenting biodeterioration and preservative concepts to timber bridge owners, designers, and inspectors are recommended to implement information presented in this study.

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