Field Evaluation of Timber Preservation Treatments for Highway Applications

BRIDGE ENGINEERING CENTER

Final Report
December 2007

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About the Bridge Engineering Center

The mission of the Bridge Engineering Center is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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16. Abstract

Timber material repair and replacement cost for timber bridges is a considerable expense to highway agencies in Iowa, especially to county road departments. To address these needs, the objectives of this investigation was to study the field effectiveness of various treatment alternatives used on Iowa roadway projects and to determine if the current specifications and testing are adequate for providing proper wood preservation. To satisfy the research needs, the project scope involved a literature review, identification of metrics, questionnaire survey of Iowa counties, onsite inspections, and a review of current specifications and testing procedures. Based on the preservative information obtained, the following general conclusions were made: Copper naphthenate is recommended as the plant-applied preservative treatment for timber bridges. Best Management Practices should be followed to ensure quality treatment of timber materials. Bridge maintenance programs need to be developed and implemented. The Iowa Department of Transportation specifications for preservative treatment are the regulating specification for bridges constructed with state or federal funding in Iowa and are also recommended for all other bridges.

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FIELD EVALUATION OF TIMBER PRESERVATION TREATMENTS FOR HIGHWAY APPLICATIONS

Final Report
December 2007

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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EXECUTIVE SUMMARY

Timber can often be a cost-effective building material for new bridge construction. The durability of the bridge is greatly dependent upon proper attention to construction details and fabrication, as well as proper preservative treatment before, during, and after construction. The repair and replacement cost of deteriorated or damaged material is a considerable expense to highway agencies in Iowa, especially to county road departments. To address these needs, the primary objective of this investigation was to evaluate the performance of different wood preservatives in the field and to review current specifications and testing procedures to determine if they provide the level of timber treatment required for acceptable performance.

The Iowa State University Bridge Engineering Center (BEC), in conjunction with the United States Department of Agriculture Forest Products Laboratory (FPL), evaluated the various types of wood preservatives used in Iowa. To encompass all aspects of timber bridge preservatives and to obtain comprehensive conclusions, several variables were studied during the evaluation processes including preservative type, age, exposure condition, bridge element location, engineering properties, environmental information, and handling issues. To satisfy these research needs, the project scope involved a literature review, identification of metrics, a questionnaire survey of Iowa counties, on site inspections, and a review of current specifications and testing procedures.

Based on the preservative information obtained the following general conclusions were made in regards to timber bridge preservative performance. Copper naphthenate is recommended as the plant-applied preservative treatment for timber bridge elements. Copper naphthenate has been tested extensively by the FPL and has good handling characteristics, clean surfaces, and comparable availability. During the construction of timber bridges the Best Management Practices should be followed to minimize environmental impacts to the surrounding ecosystem and ensure quality treatment of both plant-applied and in-place preservatives. Timber bridge maintenance programs need to be developed and implemented and should include routine inspections, evaluations, routine in-place treatment applications, and data management for fleets of timber bridges. Although the American Wood Protection Association standards are the basis for the specifications, the Iowa Department of Transportation specifications for preservative treatment are the regulating specifications for bridges constructed with state or federal funding in Iowa and are also recommended for all other bridges.

1. GENERAL

1.1. Introduction

Timber can often be a cost-effective building material for new bridge construction. The durability of the bridge is greatly dependent upon 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 also be increased with careful attention to design or construction details during field inspection. The use of timber in transportation structures (e.g., bridge superstructures and substructures, abutment retaining walls, guardrail components, etc.) is common in Iowa. Unfortunately, premature deterioration of these timber components is also a common problem.

In some cases, problems occur due to inadequate attention to construction details that can lead to moisture problems regardless of the type of treatment used prior to construction. 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 for treatment due to is proven performance and availability. Recently changing environmental concerns and public perception has made creosote less available and more expensive for bridge owners in the state of Iowa. Other products recently used in Iowa, such as copper naphthenate, have just recently been used as a creosote replacement.

There is existing performance data on all preservative systems at various retention levels and in various wood species. However, most of these data are on samples at either 100 percent penetration or a complete envelope treatment. In practice, wood preservatives provide excellent barriers against deteriorating agents (e.g. fungi and insects), but performance can be compromised in applications requiring field fabrication (Silva et al. 1999). Timber bridge installations frequently involve cutting members, driving spikes into decking, and/or drilling holes, which are all common causes of treatment barrier compromise that may affect performance and long-term durability.

In summary, timber material repair and replacement cost is a considerable expense to highway agencies in Iowa, especially to county road departments. There is a need to study the field effectiveness of various treatment alternatives used on Iowa roadway projects and to determine if the current specifications and testing are adequate for providing proper wood preservation. This report provides bridge owners and engineers with information on the current preservative treatments, the field effectiveness of preservatives currently being used on Iowa bridges, testing techniques for preservative evaluation, and the status of current specifications.

1.2. Research Objectives

The primary objective of this research was to evaluate the performance of different wood preservatives in the field and to review current specifications and testing procedures to determine if they provide the level of timber treatment required for acceptable performance.

The Iowa State University Bridge Engineering Center (BEC), in conjunction with the United States Department of Agriculture Forest Products Laboratory (FPL), evaluated the various types of wood preservatives used in Iowa. To encompass all aspects of timber bridge preservatives and to obtain comprehensive conclusions several variables were studied during the evaluation processes including the following: preservative type, age, exposure condition, bridge element location, engineering properties, environmental information, and handling issues.

To satisfy these research needs, the project scope included the following tasks:

1. **A literature review** was conducted to learn about the preservatives that are available, preservative properties, and their effectiveness in the field. A brief summary of these preservations are presented herein.

2. **The identification of metrics** identified a set of tools for bridge inspectors to use in order to make educated decisions regarding preservative evaluations.

3. **A survey of Iowa counties** was completed to obtain information on utilization of timber bridges, preservatives, factors influencing timber usage, life expectancy, problematic/successful details, and bridge inspection practices.

4. **On site inspections** were completed to investigate elements in different counties with problem and non-problem conditions on which different preservative types have been employed.

5. **The review of specification and testing procedures** were compared and evaluated to determine if Iowa specifications needed additional information or updating.

6. **The final conclusion and recommendations** were developed from the gathered information in the previous tasks.

2. BACKGROUND

2.1. Protection of Timber Bridges

There is a long history of the use of wood as construction material for road bridges in the United States. These uses have varied from simple, temporary log bridges to more complex structures that have remained serviceable for over 150 years. Wood is a natural choice for a construction material because it is inexpensive, relatively simple to fabricate, and locally available in most parts of the United States. However, for structures that are expected to last more than a few years, the susceptibility of wood to biodegradation is a major disadvantage. In the 19^{th} century, engineers overcame this disadvantage by constructing covered bridges that kept the wood dry and prevented decay. Many of these covered bridges remain in use today. However, it is not always practical or economical to build structures in a manner that protects wood from moisture. Therefore, the need for more durable timber provided the driving force for the development of the pressure treatment industry in the United States. The successful use of pressure treated railroad ties led to the pressure treatment of other structural products, such as utility poles, piles, and bridge timbers. Preservative treated wood, however, faced stiff competition from steel and concrete for construction of road bridges. By the mid-1930's the cost of steel bridges became competitive with treated wood, and steel evolved as the primary construction material, with reinforced concrete the preferred material for bridge decks. In the 1960's and 1970's, the use of timber bridges was given a boost by the widespread acceptance of preservative treated glulam beams and more recently by the development of stress-laminated lumber. Timber bridges remain a viable alternative in many situations, and thousands have been built across the United States in recent decades (Ritter 1992).

Timber bridges remain cost-competitive, and the single most limiting factor for increased use of timber bridges continues to be concerns with durability. The durability of timber bridges is largely a product of the initial preservative treatment used to protect the wood, although construction practices and maintenance also play an important role. The efficacy of the initial pressure treatment is a function of the inherent properties of the wood type, the preservative chemical itself, and the quality of the treatment process (the degree of preservative penetration and retention achieved during treatment). In some cases the properties of the preservative also play a role in treatment quality. However, the ability to protect wood is not the only consideration for a preservative treatment. In recent years concerns about the environmental impacts of preservative treatments have increased, and this is especially true for treated wood used in or above aquatic environments. Other factors, such as color, odor and surface cleanliness may also be important in some applications.

2.2. Decay Mechanisms in Timber Bridges

In most applications for timber bridges, decay fungi are the most destructive organisms. Fungi are microscopic thread-like organisms whose growth depends on mild temperatures, moisture, and oxygen. There are numerous species of fungi that attack wood, and they have a range of preferred environmental conditions. Decay fungi are often separated into three major groups;

brown rot fungi, white rot fungi, and soft rot fungi. Soft-rot fungi generally prefer wetter, and sometimes warmer, environmental conditions than brown or white rot fungi.

Termites follow fungi in order of damage to wood structures in the US. Their damage can be much more rapid than that caused by decay, but their geographic distribution is less uniform. Termite species in the US can be categorized by ground-inhabiting (subterranean) or wood inhabiting (non-subterranean) termites. Most damage in the US is caused by species of subterranean termites.

Other types of insects such as powderpost beetles and carpenter ants can cause notable damage in some situations, but their overall significance pales in comparison to decay fungi and termites. Other organisms, including bacteria and mold can also cause damage in some situations, and several types of marine organisms degrade wood placed in seawater.

The two greatest factors influencing regional biodeterioration hazard are temperature and moisture (Highley 1999). The growth of most decay fungi is negligible at temperatures below 36 F and relatively slow at temperatures below 50 F. The growth rate then increases rapidly, with most fungi having optimum growth rates at between 75 F and 95 F. The natural range of native subterranean termites is generally limited to areas where the average annual temperature exceeds 50 F. Decay fungi require a moisture content of at least 20% to sustain any growth, and higher moisture contents (over 29%) are required for initial reproduction (Highley 1999). Most brown and white rot decay fungi prefer wood in the moisture content range of 40 – 80%. In almost all cases, wood that is protected from ground contact, precipitation, or other sources of water will have insufficient moisture to sustain growth of decay fungi. In contrast, wood that is in contact with the ground often has sufficient moisture to support decay, even in relatively dry climates. On the other hand, wood can be too wet to support fungal growth. For example, as the moisture content exceeds 80% void spaces in the wood are increasingly filled with water. The lack of oxygen and build-up of carbon dioxide in the water limits fungal growth.

2.3 Application of Preservatives

The structure and chemistry of wood affect the ability of preservatives to penetrate into the wood, as well as the efficacy of some types of preservatives. As a tree develops, new cells that grow around the outer circumference of the stem form the conductive tissues which comprise the sapwood. The thickness of the sapwood band varies greatly by species, but in almost all species the sapwood is the portion of the tree that is most easily penetrated with preservative. The older, inner sapwood cells eventually stop functioning and form a darker core of non-conductive tissues called heartwood. In many wood species the heartwood is difficult to penetrate with preservative.

There are also significant differences between the two broad classes of trees called hardwoods and softwoods. The wood structure of hardwoods is more complex than that of softwoods and the differences affect the distribution of some treatments, lessening their effectiveness in hardwoods. The structure of softwoods is generally simpler and more uniform than that of hardwoods. Softwoods represent the vast majority of treated wood produced in the US.

Even within softwoods and hardwoods there are major anatomical differences between species. The species group that is most often treated with preservatives is Southern Pine. Southern Pine trees are characterized by a large sapwood zone that is readily penetrated with most types of preservatives. In the western US the species most often treated are Douglas-Fir, Ponderosa Pine and the Hem-Fir species. With the possible exception of Ponderosa Pine, these species tend to be more difficult to treat with preservatives or demonstrate more variability in their treatability. Often they must be incised (small slits cut into the wood) in order to obtain adequate penetration. Another major species group is Spruce-Pine-Fir (SPF). This group contains a large number of species that grow in the northern United States and Canada. Like the Hem-Fir species, these wood species tend to be difficult to treat or vary widely in their treatability. The use of treated hardwoods is largely confined to railroad ties and bridge timbers. Red Oak is the most often utilized hardwood.

Even though proper preservative treatment creates an excellent barrier against fungi and insects, the barrier can be compromised during on-site installation or as a result of checks and cracks from normal weathering and moisture changes. Any break in the treatment barrier may expose untreated wood to fungal or insect attack (Highley 1999). Although the rate of decay will vary with the wood species and decay hazard conditions, eventual development of deterioration will reduce the service life of the structure (Scheffer 1971).

There is a considerable need for periodic inspection and preventative in-place treatments for timber in bridges (AASHTO 1983; Ritter 1990). Ideally, though not always practical, annual in-place treatment of checks will provide protection from decay. Bridge timbers, like utility poles and rail sleepers, need to be on an inspection rotation, so that they are periodically inspected for signs of physical, chemical or biological deterioration. Physical, chemical and biological deterioration of wood are interrelated and their collective effects need to be considered during a bridge inspection.

2.4 Timber Pile Research

Past research has been conducted by the BEC on timber abutments that have undergone physical and biological deterioration (White et al. 2007). The deterioration influences the load carrying capacity of timber substructures and thus affects the overall performance of the bridge system. Prior to this work, there was no reliable means to estimate the residual carrying capacity of an in-service deteriorated pile, and thus, the overall safety of the bridge could not be determined. The lack of a reliable evaluation method can result in conservative and costly maintenance practices such as replacing the entire substructure system when only one of the piles needs replaced. The research evaluated procedures for detecting pile internal decay using nondestructive ultrasonic stress wave techniques, correlated nondestructive ultrasonic stress wave techniques to axial compression tests to estimate deteriorated pile residual strength, and evaluated load distribution through poor performing timber substructures by instrumenting and load-testing the abutments of six in service bridges. The research also evaluates selected rehabilitation, strengthening, and replacement techniques for timber pile substructure components or entire substructures.

3. USE OF PRESERVATIVES IN IOWA

Highway applications of timber material in Iowa vary greatly from bridge pilings, abutment backwalls, guardrail posts, bridge deck planking and many others. Currently, various in-plant preservative treatments are being used in Iowa to extend the service life of structures. Creosote has been the in-plant preservative of choice for many years, however, due to environmental concerns and handling issues a movement is being made away from creosote to other preservative alternatives. Additionally, remedial or in-place preservative treatments have seen minimal usage in the state of Iowa. As Iowa's timber bridges become older, the implementation of in-place treatments will be necessary to reduce future costly repair and replacement.

3.1. State Specification requirements

The Iowa Department of Transportation Standard Specifications with GS-01013 Revisions have several divisions that mention timber products used for timber bridge structures. Division 41 states that creosote, pentachlorophenol, copper naphthenate, chromated copper arsenate (CCA) and ammoniacal copper zinc arsenate (ACZA) must be used as the specified treatment of timber bridge elements. The division also requires American Wood Protection Association (formerly American Wood Preservers' Association) AWPA standard to be met for preservative retention and penetration. For the purpose of this report the five DOT specified preservatives will be discussed in detail plus other recommended preservatives that have been standardized application in highway construction. The state specification will be discussed further in Chapter 7.

3.2. Iowa County Survey Results

A survey of Iowa's 99 counties was completed to obtain information on current timber bridge preservation practices in Iowa. The survey was divided into six categories: utilization of timber bridges, preservatives used, factors influencing timber usage, life expectancy, problematic or successful details, and bridge inspection practices. A copy of the survey can be seen in Appendix A. Sixty three counties responded, in varying degrees, to the survey.

Of the 63 counties that responded approximately 88% utilize timber in their bridge structures and 52% had reservations about using timber for new bridges. Several counties commented that short lifespan, low durability, and the use of concrete or steel were reasons for their reluctance to use timber. Counties were also asked if they are constructing or not constructing new bridge components with timber materials. The results of the new construction usage are shown in Figure 3-1.

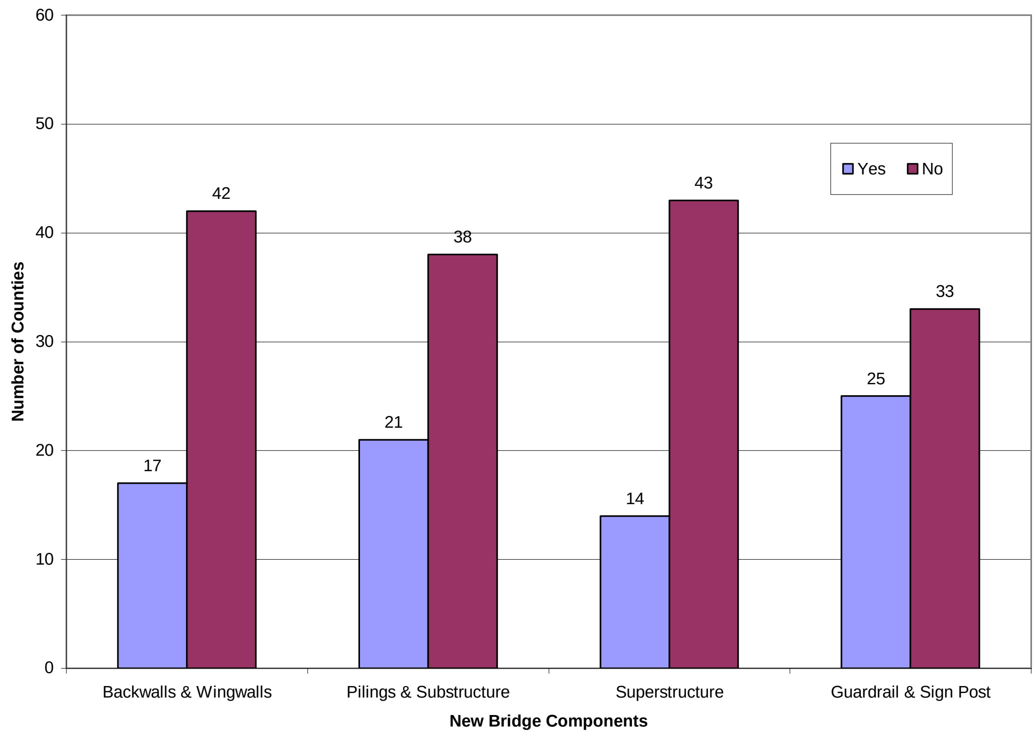

Figure 3-1. Iowa counties timber usage in new construction (63 respondents)

Forty counties identified the use of plant-applied preservatives. Figure 3-2 shows the resulting number of counties using a particular plant-applied treatment. Note that several of the counties use multiple preservatives causing the sum of the preservative usage to be greater than 40.

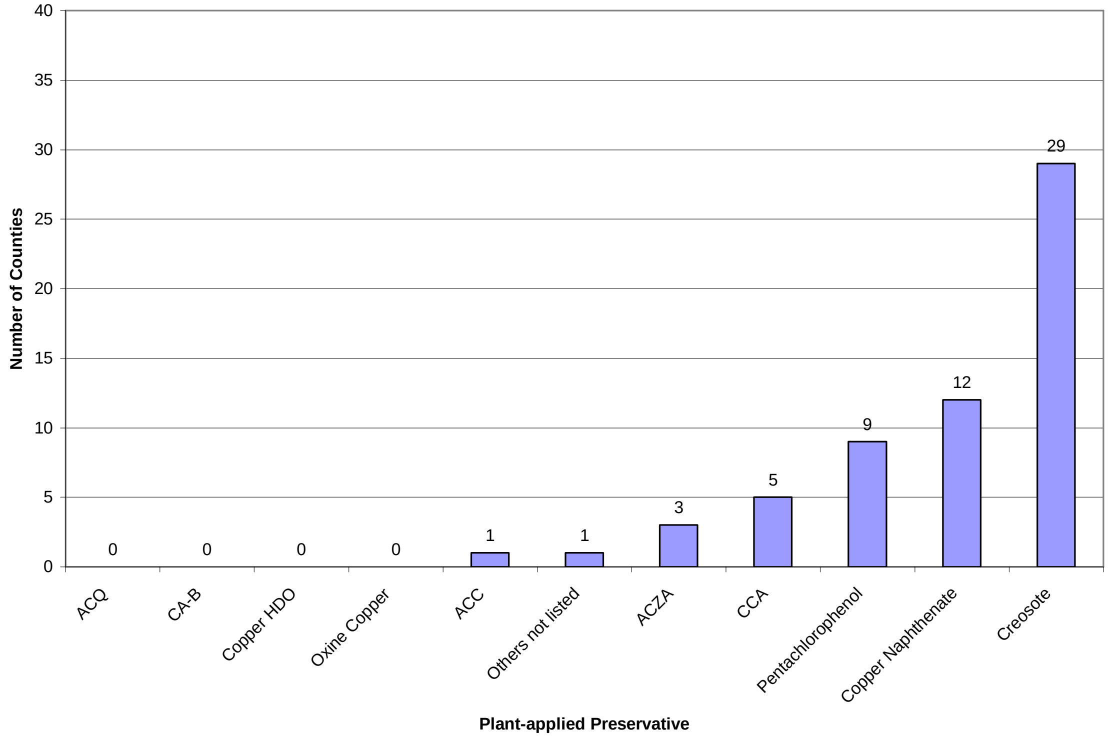

Figure 3-2. Iowa county plant-applied preservative usage (40 respondents)

Counties were also questioned on their usage of in-place preservative treatment methods. The results, shown in Figure 3-3, found very few counties using in-place treatments. One county, however, stated it used all seven methods listed in Figure 3-3 for in-place preservative treatment.

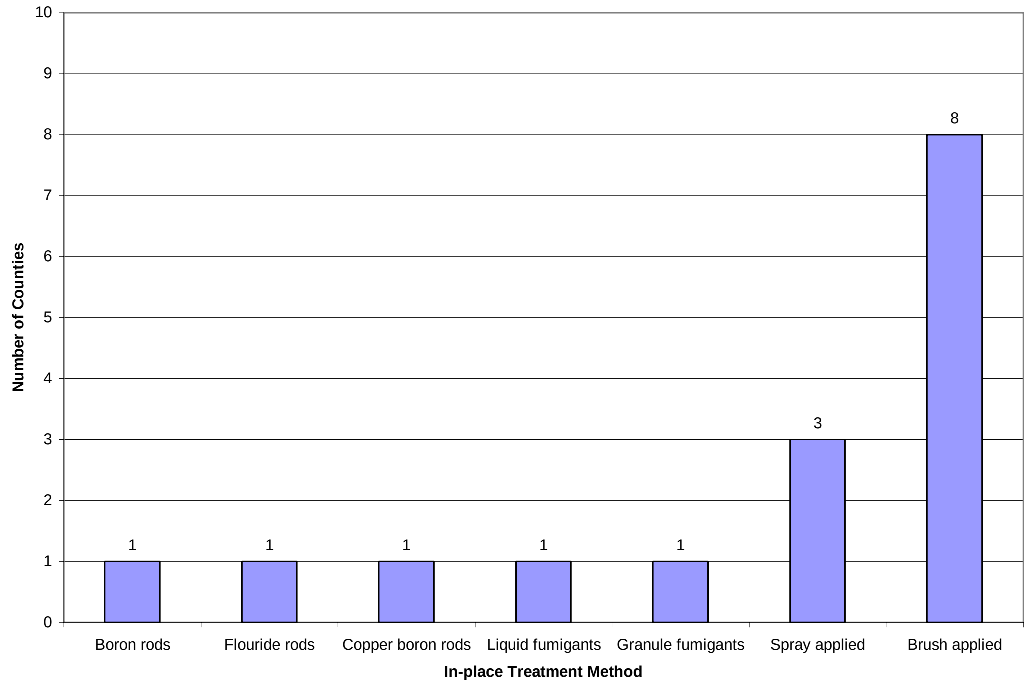

Figure 3-3. Iowa counties in-place preservative treatment methods (63 respondents)

Thirty-two counties identified the specification they use for preservative treatment requirements. The majority of counties use the Iowa DOT state specification. Listed below is the distribution of counties using different specifications. Note that none of the 32 counties specify a scheduled reapplication of the preservative treatment.

- 26 counties used state specifications
- 3 counties used their own county specification
- 2 counties used specification not listed on the survey form
- 1 county used AWPA standards
- 0 counties used AASHTO standards

The counties were asked to rank 11 different disadvantages of timber bridges. The ranking is listed below with one being the biggest disadvantage.

1. Durability concerns
2. Maintenance concerns
3. Cost
4. Strength properties
5. Odor or surface cleanliness (handling concerns)
6. Difficulty in specifying preservative treatment
7. Material availability
8. Ease of installation
9. Not accustomed to using timber

10. Concerns about corrosion of connectors
11. Appearance

The counties were also asked to rank the advantages for using timber bridges. Seven criteria were given for rating. The ranking is listed below with one being the most advantageous.

1. Ease of installation
2. Cost
3. Material availability
4. Appearance
5. Maintenance
6. Strength properties
7. Durability

The counties were asked for an estimation of the life expectancy of deck, stringer, piling, and backwall components. The results are displayed in Figure 4. From Figure 3-4 one can see the predicted life expectancy of timber decking was highly variable, however, stringers, pilings, and backwalls were generally expected to last 31 to 50 years.

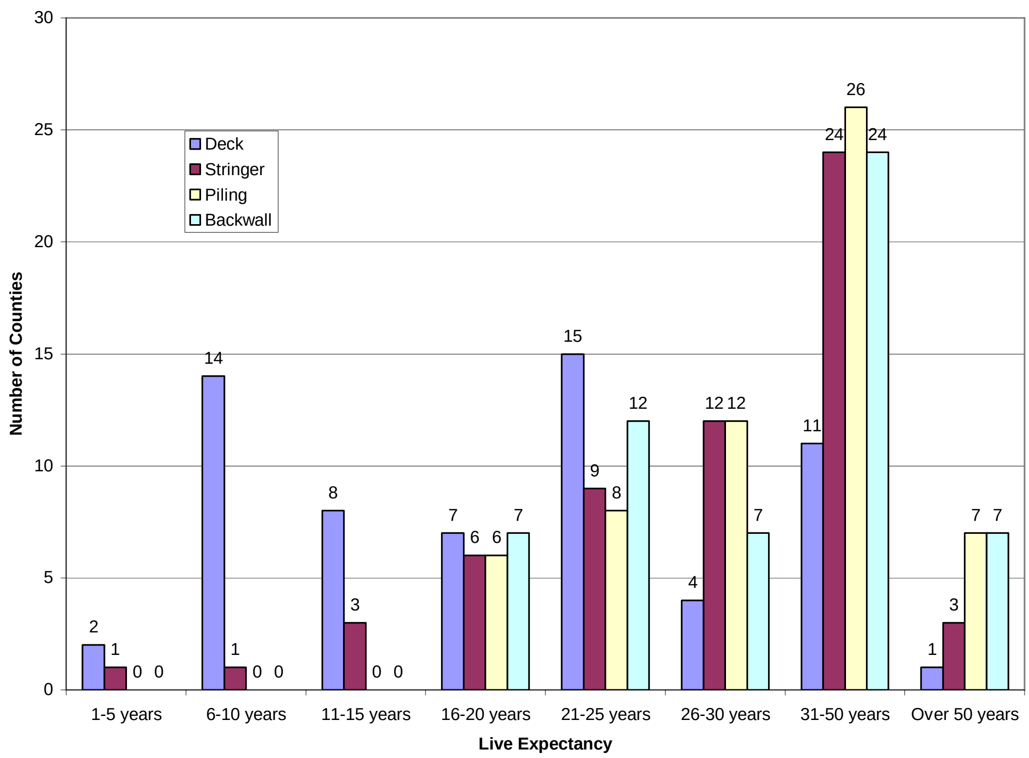

Figure 3-4. Iowa counties expected life of timber bridge components (63 respondents)

Counties were asked about their current timber bridge details and if they had problematic or successful details. Nine counties responded stating they were having good success with their timber detailing; however, 19 counties responded stating they had problematic details.

Lastly, the counties were asked to contribute information pertaining to their inspection and testing methods. Fifty-six counties have scheduled inspections and of these 56 counties, 40 of them have a consultant perform the inspections. The counties also identified external and/or internal inspection and testing methods they perform to determine structural soundness. Internal detection is used far less than external methods as shown in Figure 3-5. Visual inspection was the most commonly identified inspection method.

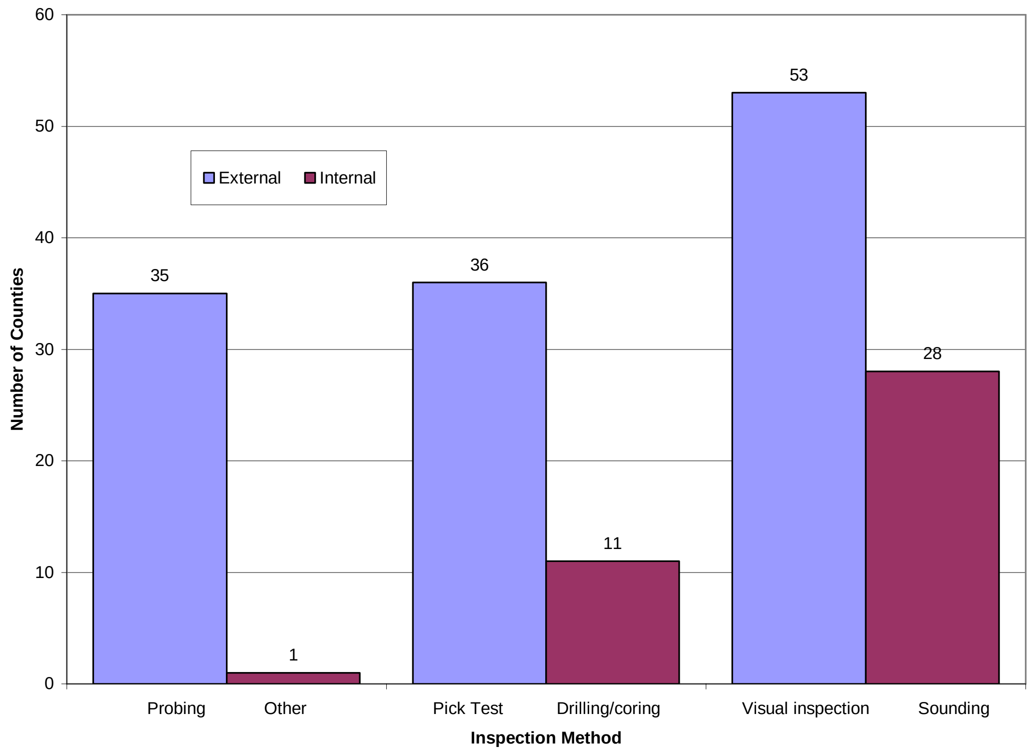

Figure 3-5. Inspection methods used by Iowa counties (56 respondents)

3.3. Field Investigation

On-site visual inspections were conducted by the research team in counties with problem and non-problem conditions and with different preservative types. The goal of these inspections was to evaluate the in-place performance of current preservatives used in Iowa. Creosote, pentachlorophenol, copper naphthenate, ammoniacal copper zinc arsenate (ACZA), chromated copper arsenate (CCA) and Alkaline Copper Quaternary (ACQ) were positively identified preservatives. In total 47 bridges were investigated in eight different Iowa counties. Figure 3-6 shows the counties investigated and the corresponding preservatives investigated.

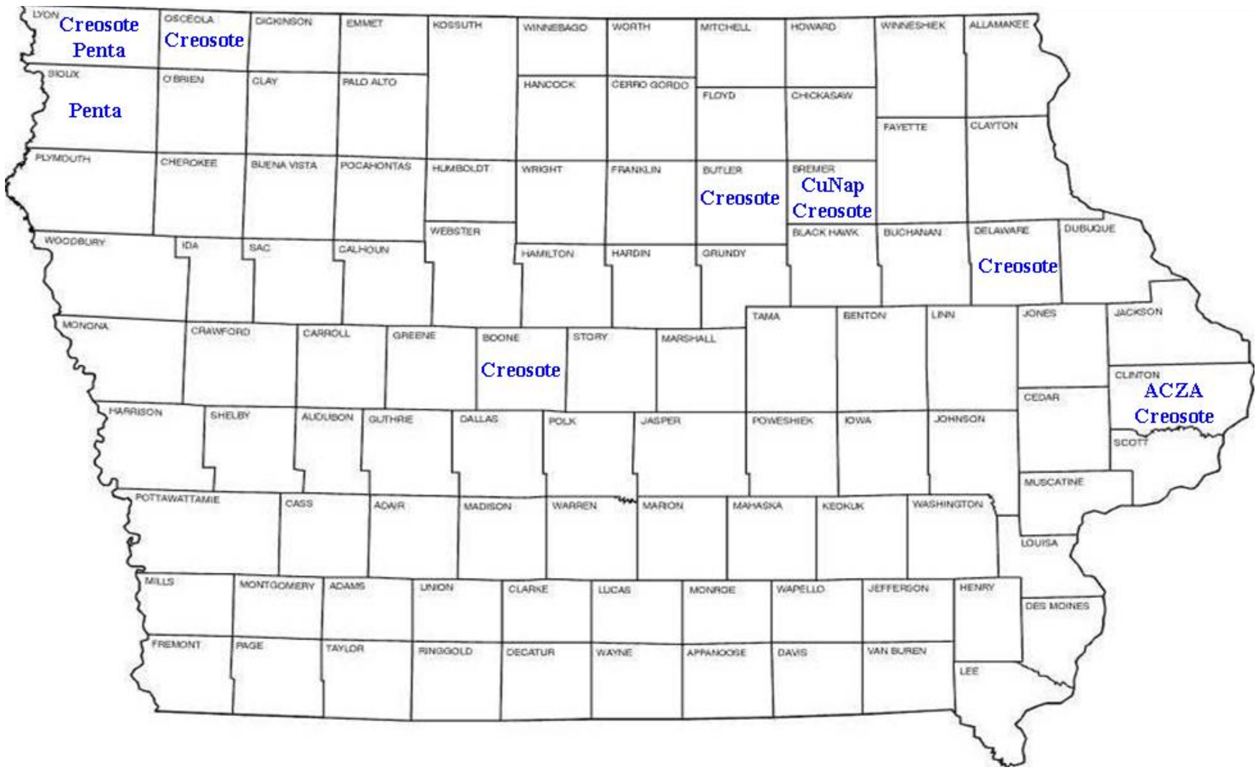

Figure 3-6. Iowa counties and preservatives inspected

When conducting the inspections, all available piles, cap beams, backwalls, stringers, decking, and guard railing were inspected for decay, physical defects, and damage. Decay, physical defects, and damage are all signs that the preservative treatment is not performing effectively, or may have been compromised for future protection. In order to be consistent when inspecting the bridges a checklist was kept for each bridge. The checklist was based on the FPL rating criteria for stakes in ground contact, FPL rating criteria for decks above-ground (Crawford et al. 1999), and the National Bridge Inventory (NBI) condition rating system (US DOT 1995). A summary of the overall findings and a general assessment of the in field preservative performance follows in Chapter 4.

4. PLANT-APPLIED PRESERVATIVE TREATMENTS

Wood preservatives are expected to protect timber members from attack by a broad range of organisms without posing significant 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 preservatives are labeled by the Environmental Protection Agency (EPA) as Restricted Use Pesticides (RUP). The RUP classifications restrict the use of the chemical preservative, but not the treated wood, to certified pesticide applicators only. The State of Iowa requires that personnel applying supplemental preservatives to bridges on public property undergo Pesticide Applicator Training (PAT) and become certified Commercial Pesticide Applicators under Category 7E (Wood Preservatives). More information on obtaining this training and certification can be found by contacting the Pest Management and Environment Program at Iowa State University (http://www.extension.iastate.edu/pme/pat/ or 515-294-1101).

Wood preservatives can be broadly classified as either oilborne or waterborne, based on the chemical composition of the preservative and the solvent/carrier used during the treating process. Generally, oilborne 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 and ammonia (Ritter 1992). There are advantages and disadvantages associated with using each type that depend upon the application.

Generally, wood preservatives also are categorized by the exposure environment in which they are expected to provide protection. Ground contact preservatives have sufficient leach resistance and broad spectrum efficacy to protect wood that is exposed directly to soil and water. Above ground contact preservatives have intermediate toxicity or leach resistance that allows them to protect wood that is fully exposed to the weather, but not in contact with the ground. Marine exposure preservatives have high resistance to decay and marine organism, good leach resistance, and may require heavy duty treatment (Ibach 1999)

Evaluation of a preservative's long-term efficacy in all types of exposure environments is not possible and there is no set formula for predicting exactly how long a wood preservative will perform in a specific application. When the application is structurally critical, such as a support member in a bridge, increased retentions are often specified to help ensure durability. Over-treatment, however, may provide little additional durability while increasing the risk of environmental concerns. The following listing and description of preservatives is not intended to be exhaustive. The list is limited to preservatives that have been standardized for some type of application used in highway construction and have been produced commercially.

4.1. Oilborne Preservatives

The most common oilborne preservatives are creosote, pentachlorophenol, and copper naphthenate. The conventional oilborne preservatives, such as creosote and pentachlorophenol solutions, have been confined largely to uses that do not involve frequent human contact. The exception is copper naphthenate, a preservative that has become available more recently but has been used less widely. Oilborne preservatives may be visually oily, oily to the touch, and sometimes have a noticeable odor. However, the oil or solvent that is used as a carrier makes the wood less susceptible to cracks and checking and helps prevent moisture movement through the member. Oilborne preservatives ability to dimensionally stabilize timber members and act as moisture-barriers, make them the preferred preservative for bridge structural elements (Wacker and Crawford 2003).

4.1.1. Creosote

Creosote is the oldest and the most common type of oilborne preservative in service today. It was first patented in 1831 and is produced by the distillation of coal tar or oil shale (Ritter 1992). Creosote is a chemically complex mixture, and due to variations in the distillation processes from plant to plant, small differences can be found in the resulting chemical make up. The main ingredient found in all creosotes, however, is polycyclic aromatic hydrocarbons (PAH). If leached from the wood, these PAH's are considered pollutants and can contribute to environmental concentrations that come from a variety of activities such as motor fuel combustion, coal burning, and forest fires (Wikipedia 2007). Creosote can be mixed in many different coal-tar and petroleum solutions. Straight, undiluted creosote, however, is preferred for most bridge applications due to its higher toxicity to fungi, better penetration properties of both hardwood and softwood species, and less bleeding.

The small differences in the composition of modern creosotes do not affect their performance as a wood preservative. Creosoted timber has been found to be effective in most environments including ground contact, water contact, and above ground locations. The primary uses for creosote in the past have been for bridge components, utility poles, marine piling, and railroad ties. 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 in-place service (Ritter 1992). The treated wood is dark brown to black and has a distinct smoky odor. The preservative does not dissolve in oil; however, it often has an oily appearance and feel. After treatment, members often have an oily-like surface residue that causes members to be unpaintable and not ideal for handrails or places were skin contact is highly probable. The properties of creosote do not accelerate and can inhibit the corrosion of metal fasteners. 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 that of untreated wood (Ibach 1999). As with most oilborne preservatives, creosote is thought to improve the dimensional stability of the members and causes no noticeable changes in engineering properties.

In the past decade the use of creosote has declined because of handling issues and environmental concerns. Creosote can easily soil workers clothing and the vapors irritate skin by photosensitizing exposed areas. However, no health dangers have been found in workers directly handling and working near treated wood. Sensitive growing plants and foodstuff can be harmed by creosote vapors and should not be stored with creosoted members in unventilated areas. The U.S. Environmental Protection Agency (EPA) and treated timber producers have created Consumer Information Sheets (CIS) with guidance on appropriate handling and site precautions when using treated wood. For further details an EPA approved CIS can be found in the Wood Handbook Chapter 14 (Ibach 1999). The EPA classifies creosote solution as a RUP and can only be handled by state licensed applicators. The use of creosote treated wood, however, is not restricted. Creosote solution is no longer available for use as an in-place treatment.

4.1.1.1. Creosote Preservative Field Investigations

During the field investigations Iowa counties were found to have wide historic use of creosote preservative on timber bridges. The bridges had creosoted timbers for piles, cap beams, abutment backwalls, stringers, and decking, with the oldest elements dating back to 1933. Of these, the most common creosoted bridge elements were piles. Creosoted piles are still being used today; however, there has been a decline in the use of creosote for back wall and superstructure elements. As stated previously this decline is attributed to handling complaints by the workers and environmental concerns. Creosote piles are still very popular because of their historical good performance and uncertainty of other newer preservative products. Figures 4-1 through 4-28 display performance issues, both good and poor, associated with bridges investigated.

Figures 4-1 through 4-9 show creosote bridge piles.

Figure 4-1. Good piles kept above and back from stream channel lasted longer than other pile locations

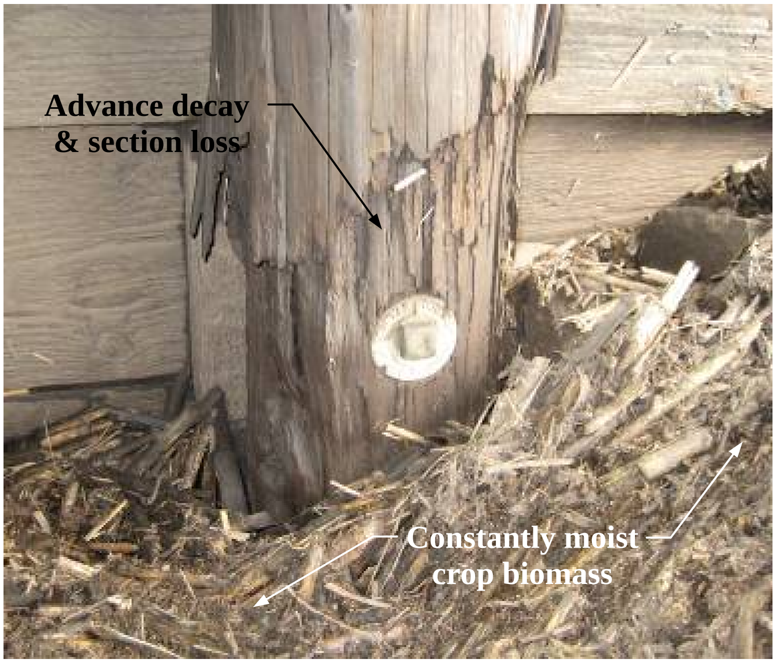

Figure 4-2. Poor piles with suspected improper treatment in contact with constantly moist ground

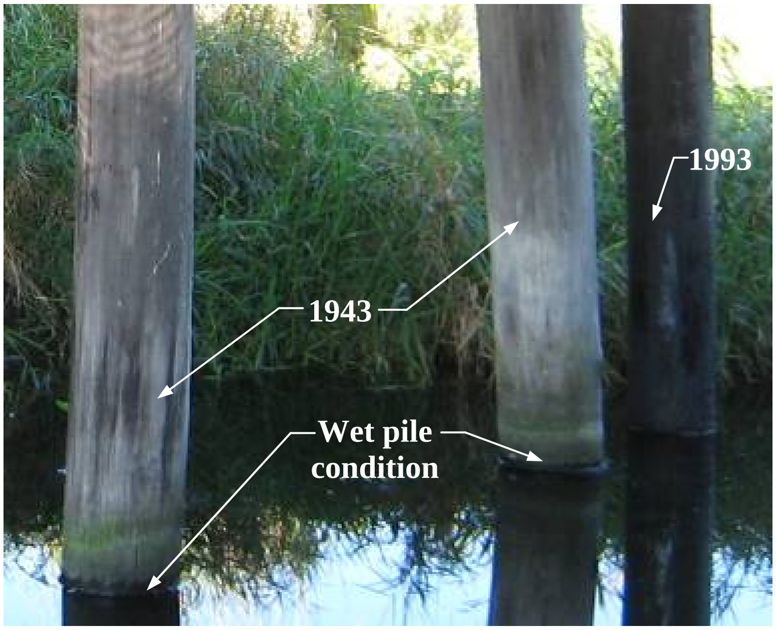

Figure 4-3. Comparison of different aged bridge piles located in stream channel; all piles in good condition

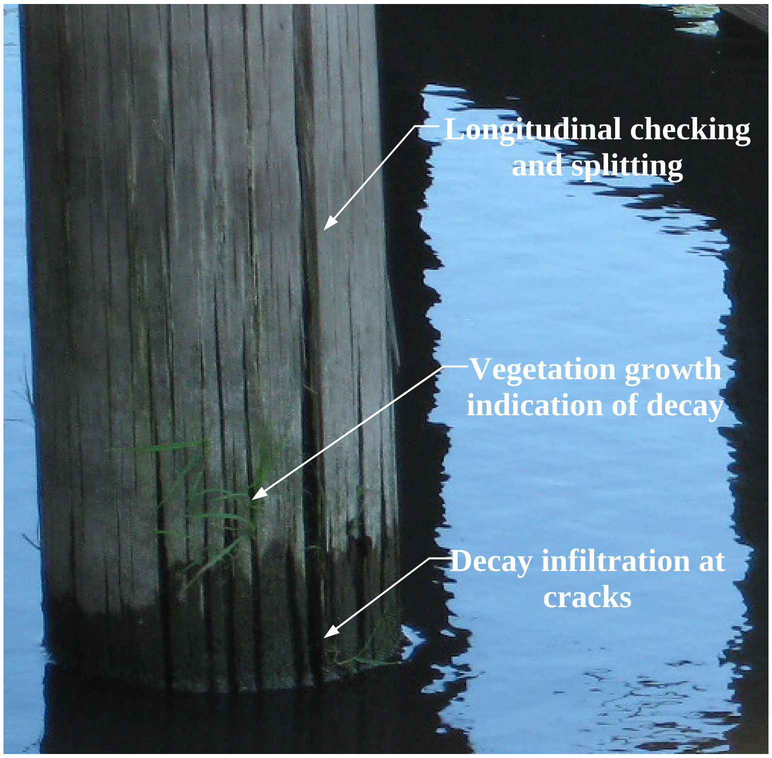

Figure 4-4. Common visual signs of interior decay of poor piles located in stream channels

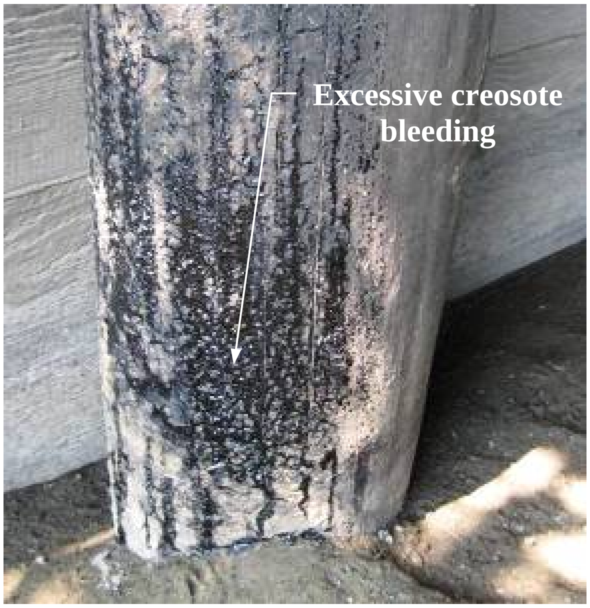

Figure 4-5. Creosote bleeding on the sun exposed side of pile can be minimized by vacuum, steaming, or expansion bath during post-treatment process

(a) (b) (c) (d)

Figure 4-6. Breaks in preservative barrier by exterior damage leads to premature decay (a)Mechanical damage, (b)Debris damage, (c)Fire damage, (d) Weathering damage

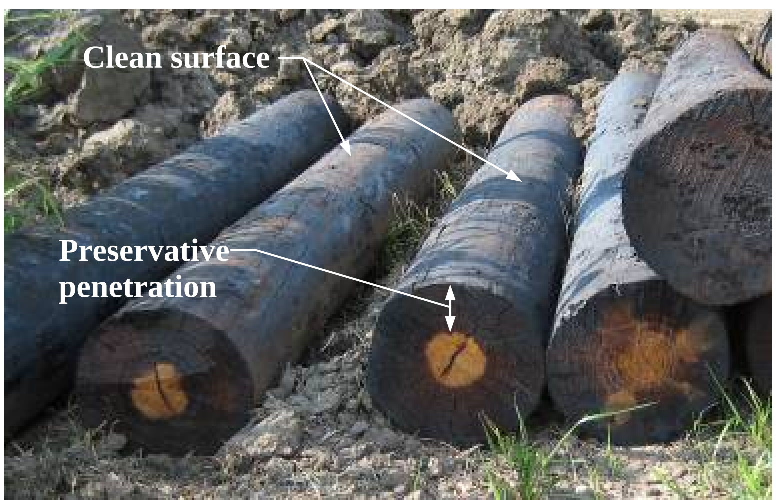

Figure 4-7. New piles showing good preservative penetration of sapwood

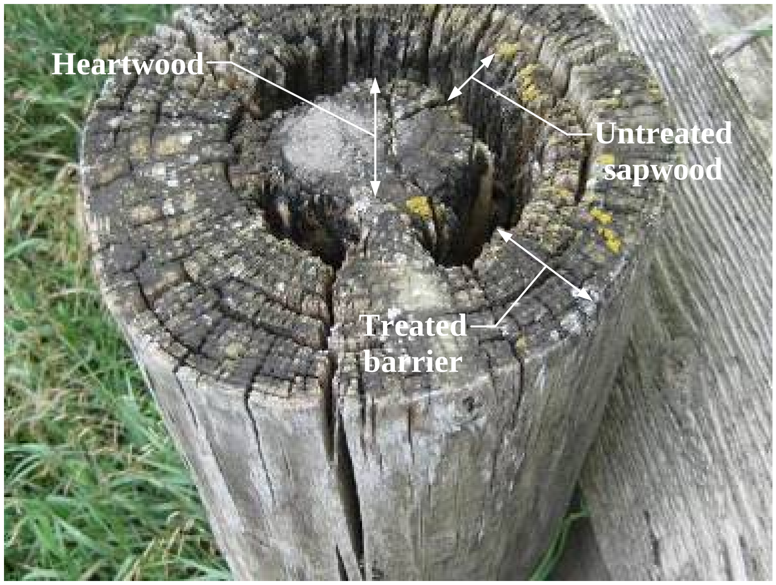

Figure 4-8. Exposed end grain provides direct path for infiltration of decay and heavy weathering

Figure 4-9. Good metal pile cover to prevent pile top decay

Figures 4-10 through 4-13 show creosote bridge cap beams.

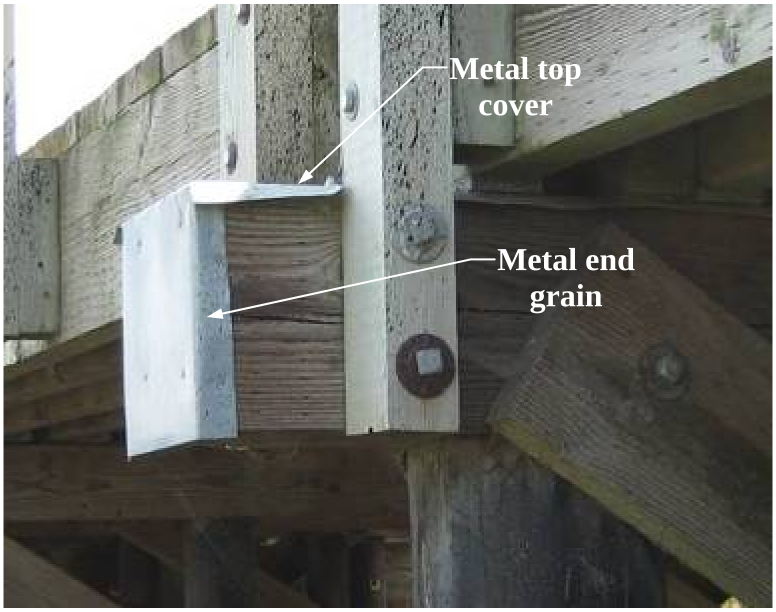

Figure 4-10. Good cap cover provides moisture protection and extends life of the member

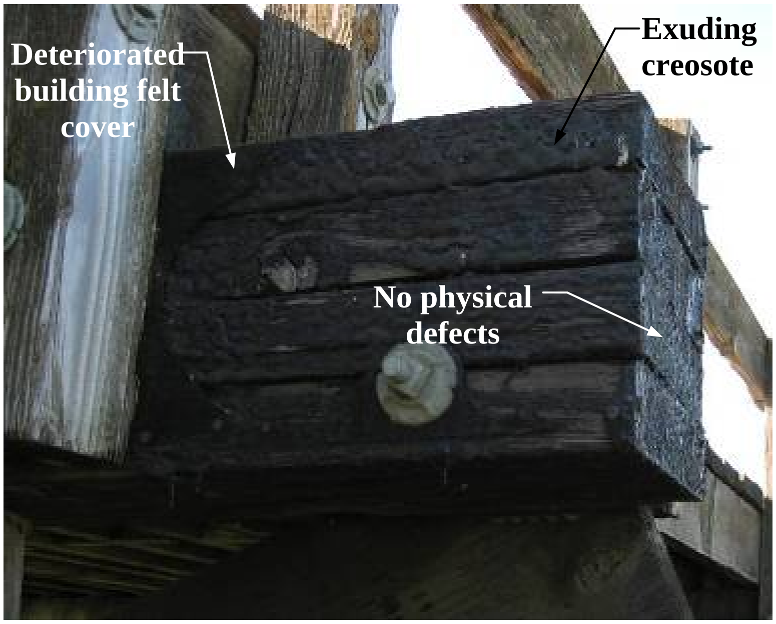

Figure 4-11. Good individually treated multiple member cap beams allow better seasoning of wood prior to treatment and better penetration

Figure 4-12. Poor pile cap with exposed end grain and decay

Figure 4-13. Members must be properly seasoned prior to treatment to avoid unwanted checking and associated deterioration

Figures 4-14 through 4-18 show creosote bridge backwalls.

Figure 4-14. Good backwall with treated end grain

Figure 4-15. Poor end grain with decay was most common defect found in backwalls.

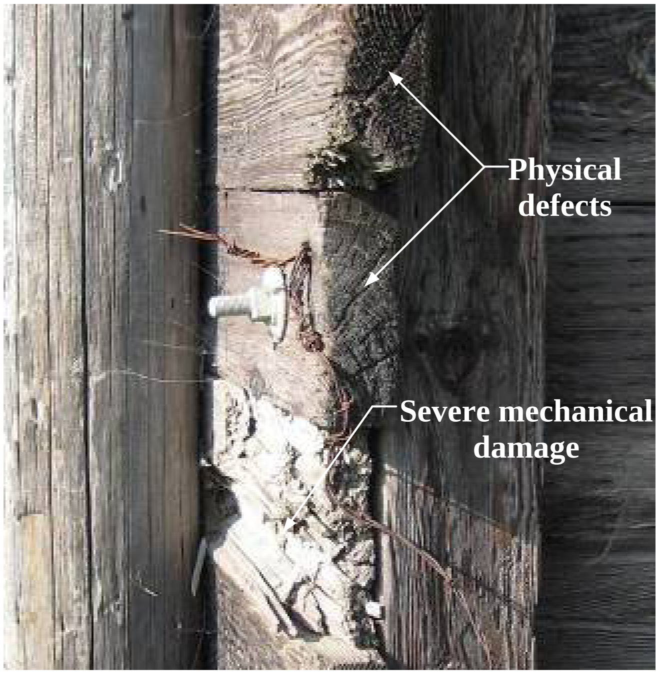

Figure 4-16. Mechanical damage and physical defects have exposed possible untreated wood

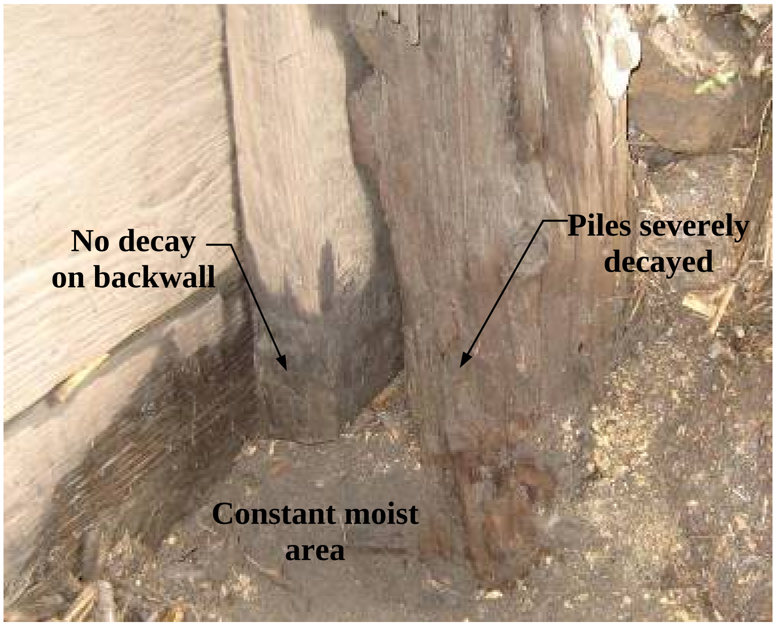

Figure 4-17. Backwalls performed well in highly moist area with little visible decay

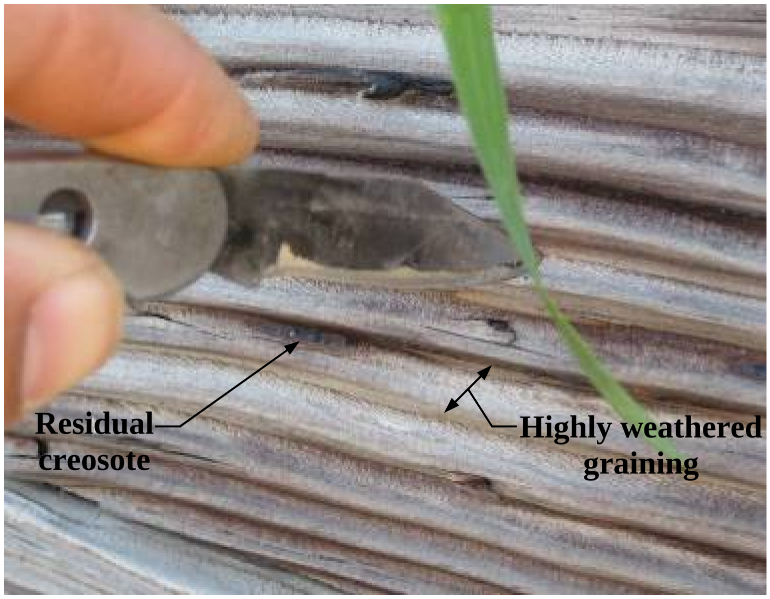

Figure 4-18. Good performing wing wall member with good preservative retention

Figures 4-19 through 4-22 show creosote bridge stringers.

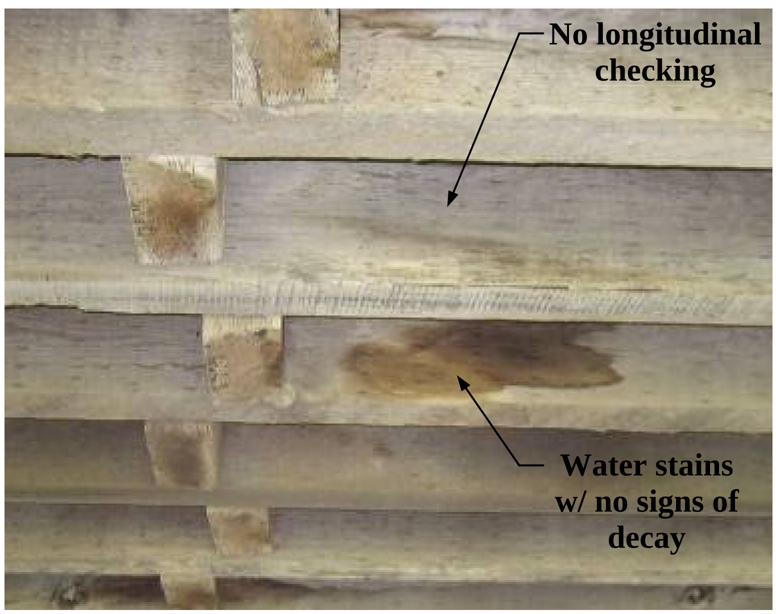

Figure 4-19. Good interior stringers protected from moisture and sunlight by deck

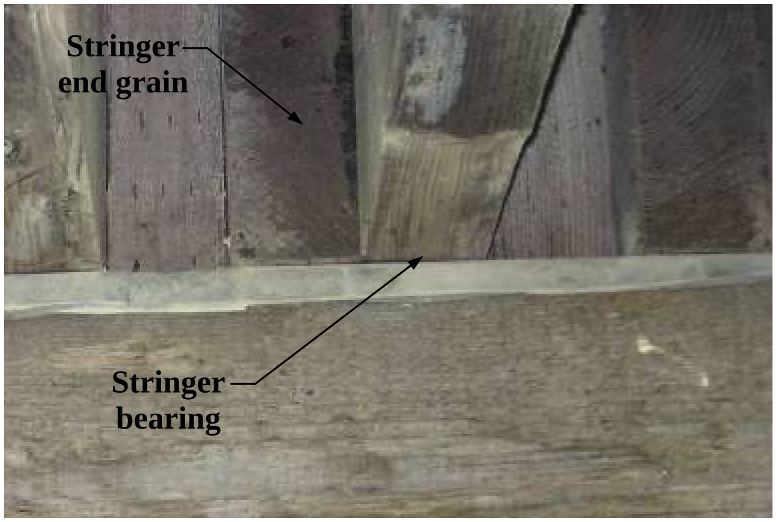

Figure 4-20. Good stinger end grain treatment with no physical defects or decay

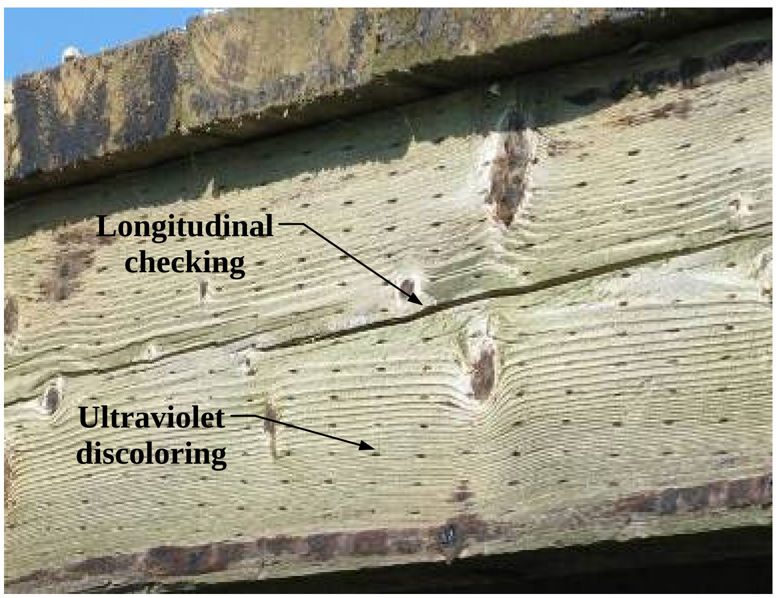

Figure 4-21. Typical checking seen on exterior stringers due to seasoning and direct sunlight

Figure 4-22. Poor exterior stringer with creosote bleeding and severe split.

Figures 4-23 through 4-28 show creosote bridge decks.

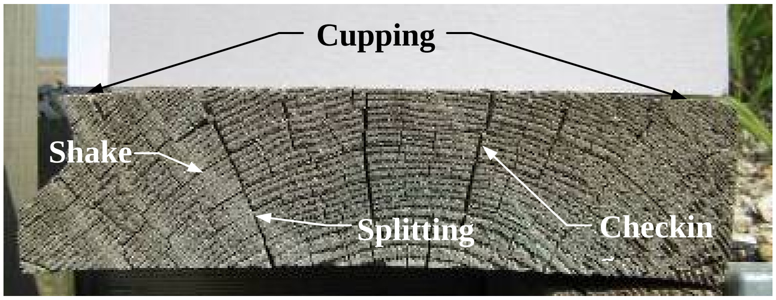

Figure 4-23. Typical physical defects at end grain

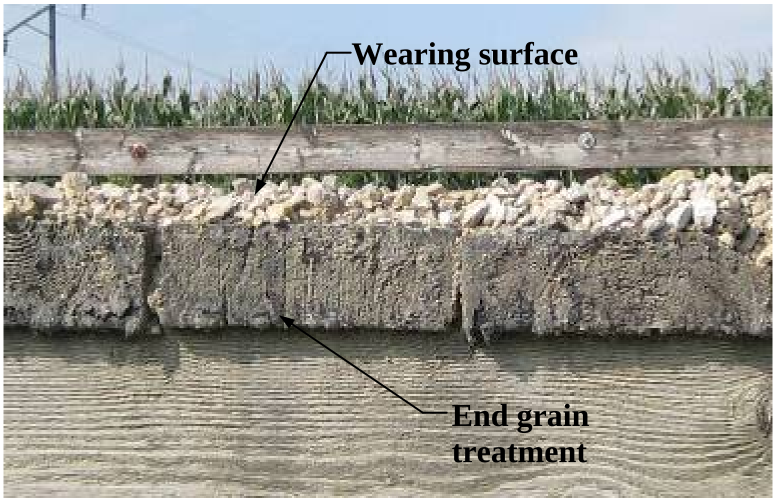

Figure 4-24. Good end grain preservative treatment showing less physical defects and decay with a protective wearing surface

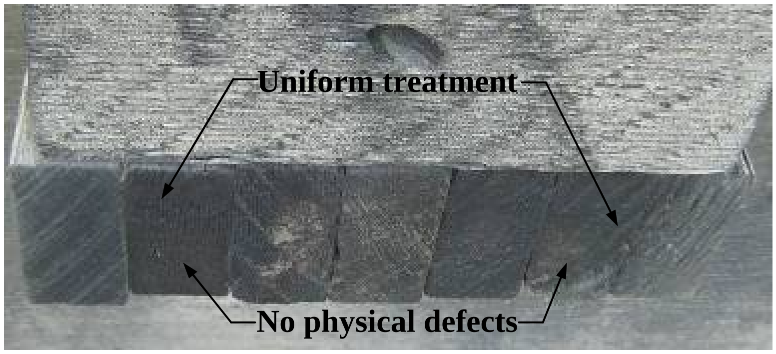

Figure 4-25. Nail laminated deck with individually treated 2x4's on edge showed very good performance and good preservative penetration

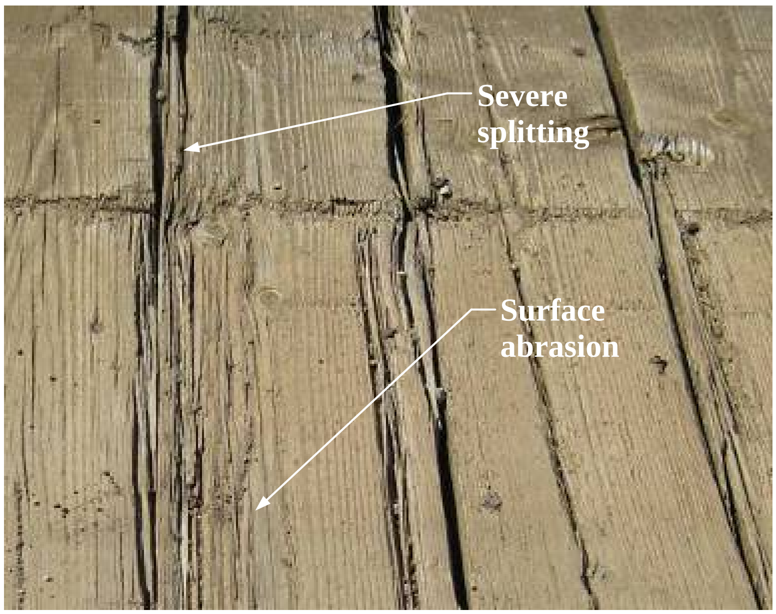

Figure 4-26. Poor decking with mechanical damage allowing water to penetrate preservative barrier or pool in cracks leading to decay

Figure 4-27. Pooling water allowed brown rot to grow on mechanically damaged deck surface

Figure 4-28. Creosote visibly migrating upward through wearing surface presents environmental concerns and possible tire traction issues

4.1.2. Pentachlorophenol

Pentachlorophenol (penta) was first patented in 1935 and has been widely used in the United States since the 1940's. Penta is the first synthetically produced preservative which allowed its production to meet industry demand for preservatives. Currently, penta is used to treat approximately 30 percent of the preservative protected wood each year in the United States. Poles, posts, and timbers have been the primary timber elements penta has been used to treat (Ritter 1992).

Chlorinated phenols are the active ingredients of penta and are highly effective at preventing the decay organisms from obtaining energy from the wood (Ritter 1992). At one time, dioxins were also found in trace amounts in penta, but this problem has largely been overcome. Dioxins are organic compounds that have been found to bioaccumulate in animals and are suspected carcinogens (Wikipedia 2007). Typically, penta is dissolved in an organic solvent that acts as a carrier during the treatment process. The two most common solvents are Type A and C. These solvents, which are described below, have been found to heavily influence the preservative performance of the treated wood and should be carefully chosen for the specific field applications. Penta-based preservatives do not accelerate the corrosion of metal fasteners and do not cause a change in the engineering properties of the treated wood.

Type A solvents are generally heavy oils and are recommended for bridge structural members including glue-laminated beams and foundation pilings. Penta in heavy oil is effective when used in ground contact, freshwater, and above-ground applications but not in marine environments. Members treated in heavy oil penta have a brown color and may have an oily surface that is difficult to paint and should not be used in locations were human, plant, or animal contact is likely. Some odor does occur with this treatment however it is generally associated with the solvent. The effectiveness of Type A penta is similar to creosote in protecting both hardwoods and soft woods. Solution temperature and length of pressure periods can allow penta to penetrate woods that are otherwise difficult to treat. Penta in heavy oil can improve the dimensional stability of the treated wood.

Type C penta uses light petroleum oil as the solvent carrier. Type C penta is primarily used for glue-laminated lumber were the lumber is treated prior to gluing and can be used in applications where human contact is likely. Type C penta has similar treatment characteristics as Type A penta. Type C penta 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 not sustained over time (Ritter 1992). Timber that has been treated with Type C penta should only be used in above ground applications.

All types of penta chemicals are classified by the EPA as RUPs and can only be plant applied by licensed applicators. The EPA also has set limitations on the amount of dioxins that can be present in penta. Due to its toxicity humans should avoid excessive contact with the solution and vapor. The EPA and treated timber producers have created Consumer Information Sheets (CIS) with guidance on appropriate handling and site precautions when using treated wood. For further details an EPA approved CIS can be found in the Wood Handbook Chapter 14 (Ibach 1999).

4.1.2.1. Pentachlorophenol Preservative Field Investigations

The field investigations revealed that only flat sawn penta treated timber elements were being used for bridge construction. No bridge piles were investigated. Specifically, cap beams, abutment backwalls, stringers, decking, and guard railing were all seen. The range in age of penta treated material was about 25 years with the earliest bridges dating back to the early 1980’s and the most recent bridge constructed in 2006. In some counties entire new bridges were being constructed of penta-treated wood while other counties are only using penta treated wood for repair of their existing timber bridge fleet and constructing new bridges with alternate material. Several counties commented they preferred the use of penta over creosote due to better handling issues and less preservative bleeding. Figures 4-29 through 4-44 show good and bad bridge elements treated with penta.

Figures 4-29 through 4-32 show pentachlorophenol bridge cap beams.

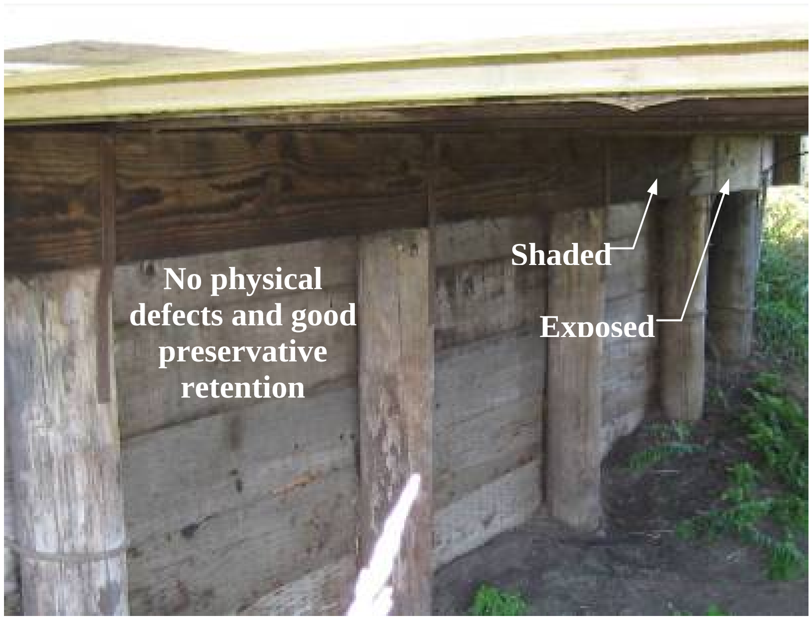

Figure 4-29. Good cap beam with complete preservative barrier

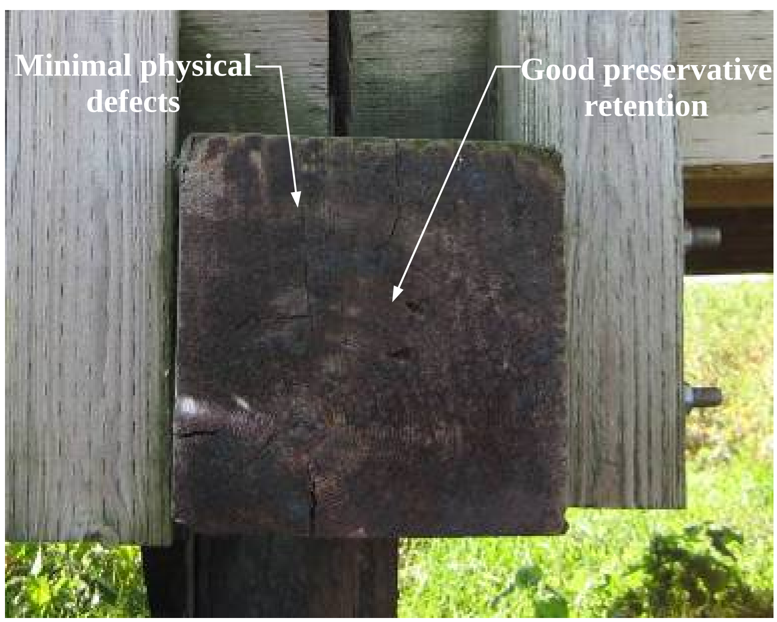

Figure 4-30. Good end grain treatment prevents decay and gives good dimensional stability

Figure 4-31. Good cap beam with seasoning prior to treatment allowing preservative to infiltrate longitudinal checks creating a complete preservative barrier

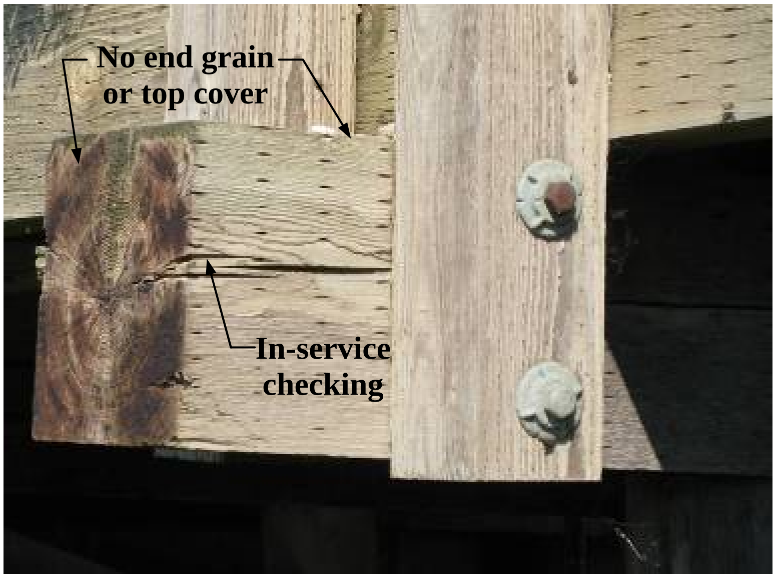

Figure 4-32. Post treatment seasoning and checking creates avenues for decay to reach untreated wood

Figures 4-33 and 4-34 show pentachlorophenol bridge backwalls.

Figure 4-33. Good wingwall with very little ultraviolet degradation and no treatment bleeding.

Figure 4-34. Backwall with good in-service condition kept high and away from stream channel

Figures 4-35 through 4-38 show pentachlorophenol bridge stringers.

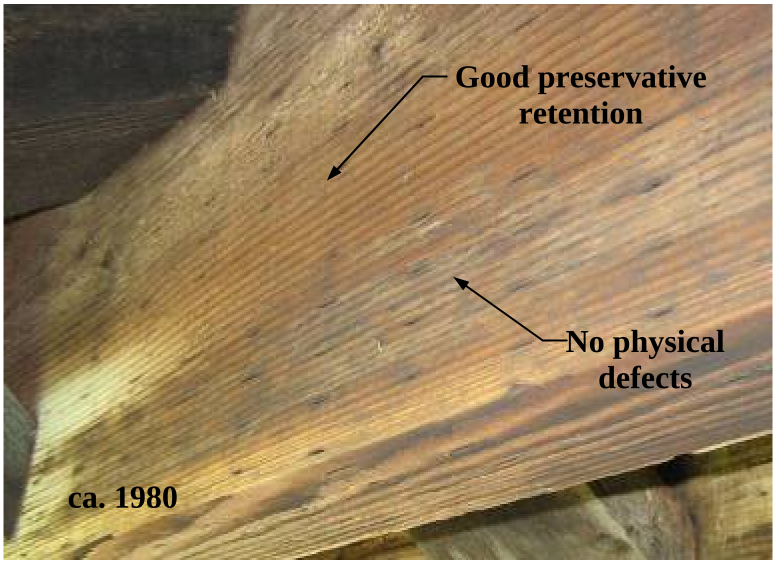

Figure 4-35. Good interior stingers were shaded and protected from moisture by deck above

Figure 4-36. Stringer end grain with good treatment and no visible decay

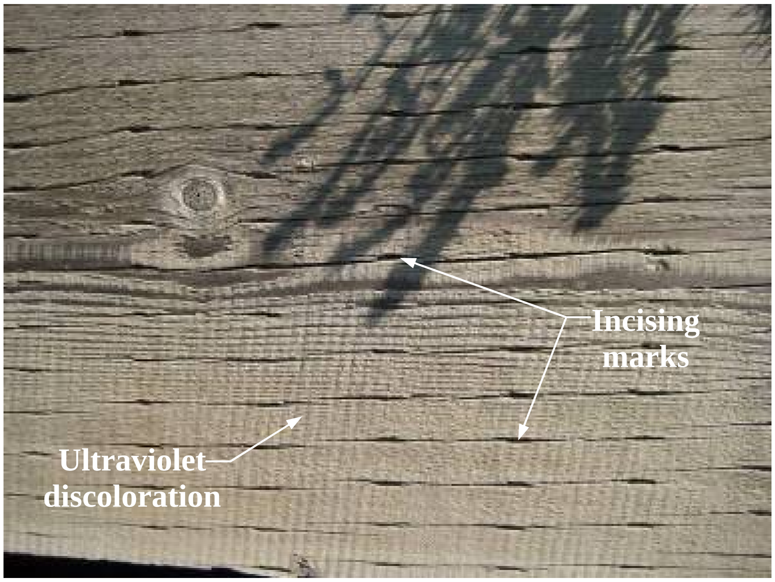

Figure 4-37. Satisfactory stringer with checking at incising marks

Figure 4-38. New exterior string with seasoning checks forming on the surface

Figures 4-39 through 4-42 show pentachlorophenol bridge decking.

Figure 4-39. Treated bridge deck with excellent preservative treatment and member condition

Figure 4-40. Underside of deck in good condition with no visible defects or bleeding

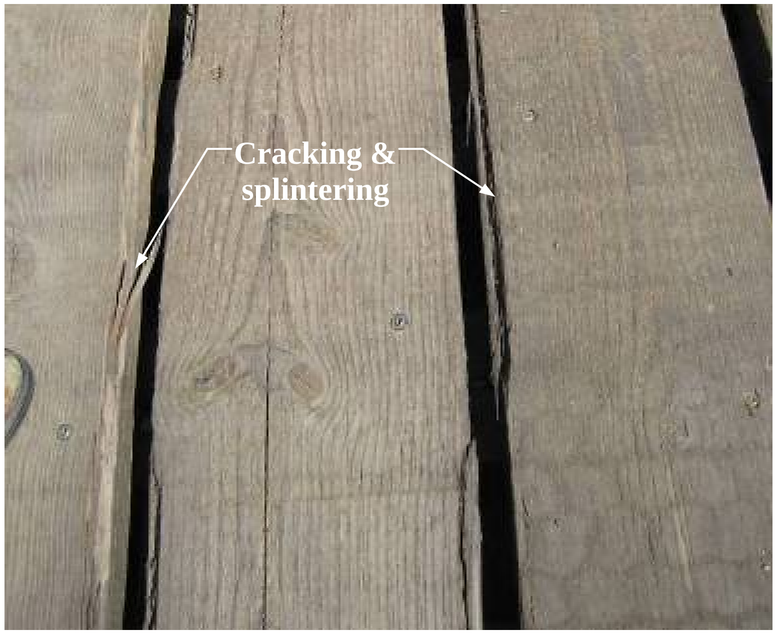

Figure 4-41. Mechanical damage caused by spacing members apart; deck is screwed down which helped prevent rocking of planks and severe damage

Figure 4-42. Physical defects at endgrain, ca. 1980

Figures 4-43 and 4-44 pentachlorophenol bridge guard railing.

(a) (b)

Figure 4-43. Good guard railings (a) placed 2006 (b) placed 1988

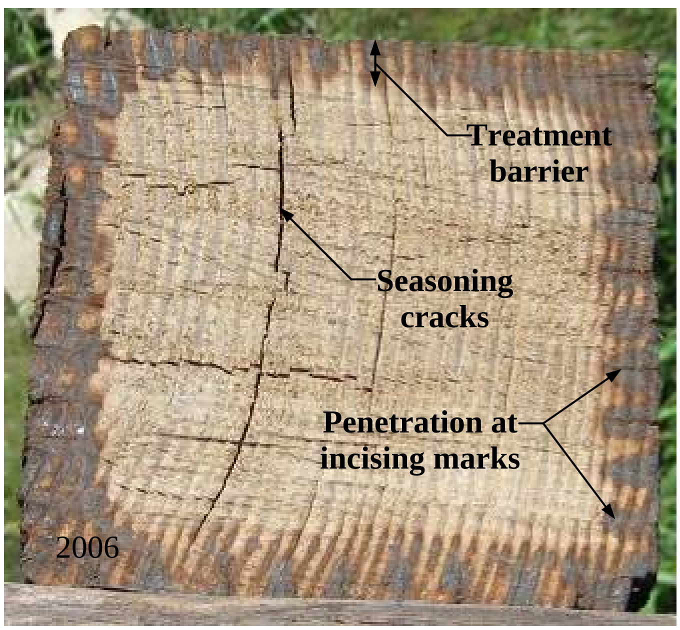

Figure 4-44. Railing post with field cut end grain and no in-place treatment which increased the amount of physical defects

4.1.3. Copper Naphthenate

Copper naphthenate has been commercially available since the 1940's and formulations were added to the AWPA standards in 1948. Copper naphthenate is the product of the reaction between petroleum derived naphthenic acids and copper salts. Copper naphthenate has low animal toxicity allowing it to be purchased in small quantities at retail hardware stores and lumber yards for in-place treatment (Brient et al. 2004). Copper naphthenate can be dissolved in a variety of solvents similar to pentachlorophenol, however, AWPA only has standards for heavy oil solvents. With the use of lighter oils copper naphthenate can penetrate difficult to treat wood. No standards have been developed for treatment of hardwood species except for railroad ties.

Copper naphthenate-treated wood is bright green colored and weathers to a light brown. Freshly treated wood has an odor that can dissipate over time. Copper naphthenate is effective for use in ground contact, water contact, and above ground applications. It is not however, 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 (Wacker 2003). The clean surface of copper naphthenate-treated wood can be painted, however, the paintability depends on the solvent, treatment procedures, and the time allowed for the member to cure properly. Similar to other oilborne preservatives, in-place dimensional stability is enhanced, corrosion of metal fasteners is not significantly increased, and engineering properties are unchanged with proper treatment practices.

Copper naphthenate is not listed as a RUP by the EPA, nor are there any consumer information sheets available for guidance on handling and site precautions. However, in Iowa an applicators license may still be needed for in-place applications on public property. Even though health concerns do not require copper naphthenate to be a RUP, common sense precautions such as the use of dust masks and gloves should be followed when handling treated wood.

4.1.3.1. Copper Naphthenate Preservative Field Investigations

The field investigations showed that very few bridge structures have been constructed with copper naphthenate-treated wood; however their prevalence is becoming more apparent due to comparable availability, cost, and easier handling. Only relatively new bridge structures were identified with only flat sawn timber elements. Cap beams, abutment backwalls, stringers, decking and guard railing were all investigated. Several counties had reservations about using piles treated with copper naphthenate due to lack of information on water and high moisture area performance. Although the bridges built with copper naphthenate are still relatively new, the counties have good feedback on its performance and excellent handling properties. Figures 4-45 through 4-54 show copper naphthenate bridge elements in good condition.

Figures 4-45 and 4-46 show copper naphthenate bridge cap beams.

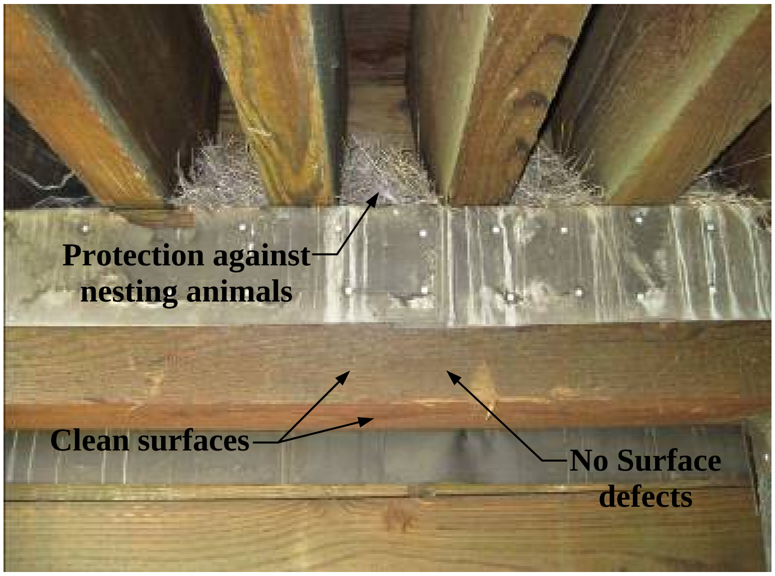

Figure 4-45. Copper naphthenate treated cap beam with building felt cover for protection from nesting animals

Figure 4-46. End of pile cap with building felt cover providing protection from moisture and weathering

Figures 4-47 and 4-48 show copper naphthenate bridge backwalls.

Figure 4-47. Good copper naphthenate backwall

Figure 4-48. Good end grain treatment

Figure 4-49 through 4-51 show copper naphthenate bridge stringers.

Figure 4-49. Good copper naphthenate-treated stringers

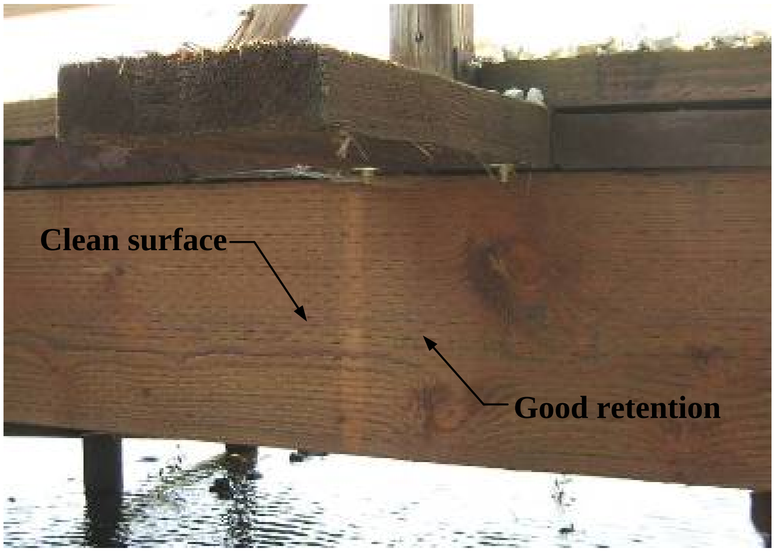

Figure 4-50. Good exterior stringer with no physical defects or excess preservative bleeding

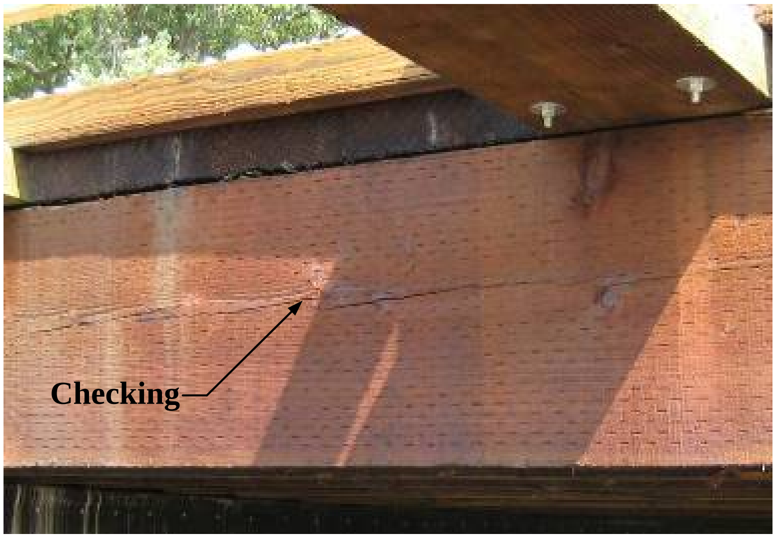

Figure 4-51. Exterior stinger with checking due to in-place seasoning

Figures 4-52 through 4-54 show copper naphthenate bridge deck.

Figure 4-52. Top side of cantilevered copper naphthenate-treated decking

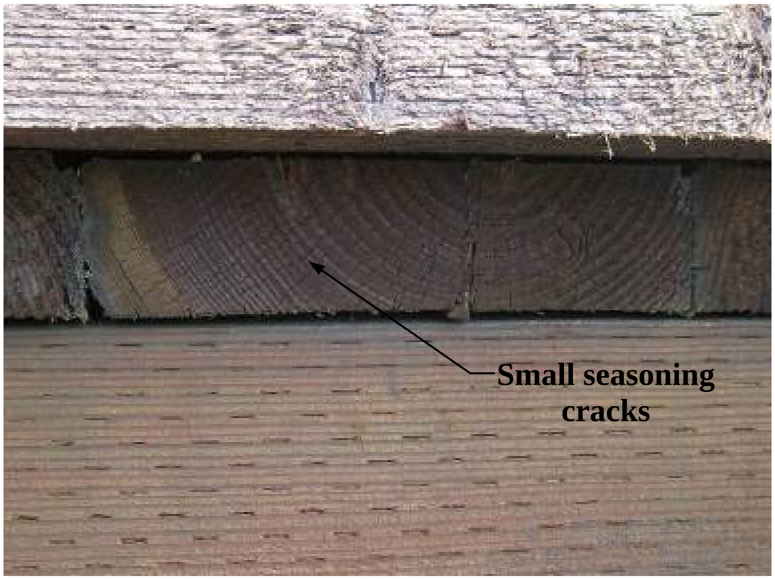

Figure 4-53. Good end grain of copper naphthenate-treated bridge deck

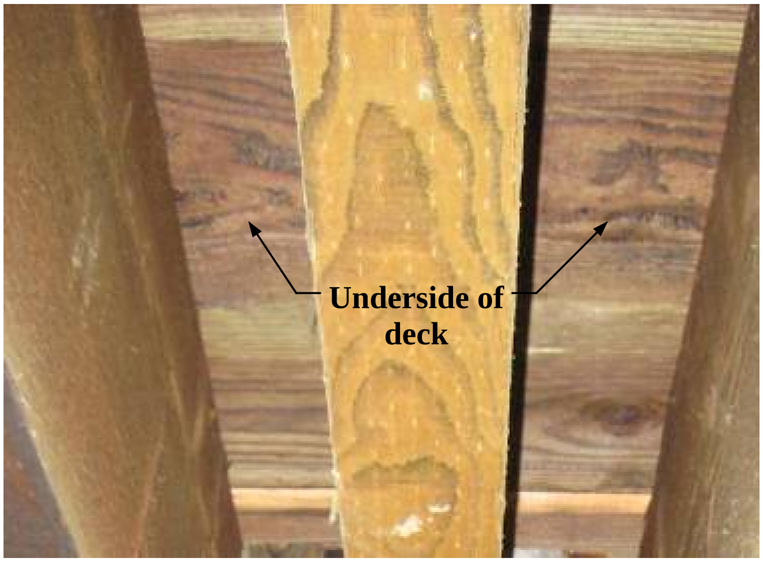

Figure 4-54. Good treatment retention on underside of deck

4.1.3. Oxine Copper

Oxine copper is an inorganic compound consisting of formulations of copper, nickel, and other inert ingredients. Oxine copper is listed in the AWPA Standards for treating several softwood species used in exposed, above-ground applications. Oxine copper can be dissolved in a range of hydrocarbon solvents, but provides longer protection when it is delivered in heavy oil.

Oxine copper solutions are greenish brown, odorless, toxic to both wood decay fungi and insects and have a low toxicity to humans and animals. Oxine copper solutions are heat sensitive, which limits the use of heat to increase penetration of the preservative. However, oxine copper has been found to provide good penetration in difficult-to-treat species. Oilborne oxine copper does not accelerate corrosion of metal fasteners. Oxine copper is not widely used by pressure-treatment facilities.

Wood treated with oxine copper presents fewer toxicity or safety and handling concerns than other oilborne preservatives. Oxine copper is listed by the U.S. Food and Drug Administration (FDA) as an indirect additive that can be used in packaging that may come in direct contact with food. Precautions such as wearing gloves and dust masks should be used when working with wood treated with oxine copper. Because of its somewhat limited use and low mammalian toxicity, there has been little research to assess the environmental impact of wood treated with oxine copper.

No bridges were investigated with oxine copper preservative treatment.

4.2. Waterborne Preservatives

The first waterborne preservatives were developed in the late 1800's, however; they were not heavily used until the 1960's due to a changing demand for clean paintable surfaces (Ritter 1992). Waterborne preservatives are formulations of inorganic arsenical compounds that react with or precipitate in treated wood. The reaction takes place when members are treated, "fixing" the precipitants (e.g., copper, chromium, and/or arsenic) within the cells of the wood to help prevent leaching and migration potential. Waterborne preservatives usually do not cause skin irritations and are suitable for use where mammalian contact is likely. Thus, waterborne preservatives are frequently used for guard railings and floors on pedestrian walkways.

Waterborne preservatives are used primarily to treat softwoods, because they may not fully protect hardwoods from soft-rot attack and because of their micro-distribution within the wood structure. Waterborne preservatives are also 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. Waterborne preservatives, however, are used due to their preferred handling properties, clean surfaces, and low leaching (Wacker 2003).

Waterborne preservative treatments have been found to reduce the mechanical properties of wood under some conditions. Treatment standards include specific processing requirements intended to prevent or limit strength reductions resulting from the chemicals and the waterborne preservative treatment process. The effects of waterborne preservative treatment on mechanical properties 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 than thinner material. Waterborne preservative retention levels of less than 1.0 lb/ft^3 (16 kg/m^3) have no effect on modulus of elasticity or compressive strength parallel to grain and a slight negative effect (-5% to -10%) on tensile or bending strength.

Energy-related properties (e.g., load duration and brittle fracture), however, are often reduced 15% to 30%. Air drying after treatment also causes no significant reduction in the static strength.

4.2.1. Chromated Copper Arsenate (CCA)

Chromated copper arsenate (CCA), often called green treat, was approved for wood use in the 1940's and has dominated the treatment market from 1970's until 2004. The EPA no longer approves the use of CCA for residential construction and has limited its use to certain industrial and commercial uses which includes timber bridge components.

CCA previously had three standardized formulas: Type A, B, and C, but only CCA Type C (CCA-C) is still used commercially 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 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 more than preservatives that do not include chromium.

CCA contains inorganic arsenic and the EPA classifies it as a RUP. CCA is not available as a field treatment. Producers of treated wood, in cooperation with the EPA, have created the CIS, subsequently replaced with the CSIS (Consumer Safety Information Sheet) that gives guidance on handling and precautions at sites where wood treated with inorganic arsenic are used. Although CCA has very good handling properties, the CSIS should be available to all persons who handle wood treated with CCA. For further details an EPA approved CIS can be found in the Wood Handbook Chapter 14 for inorganic arsenicals (Ibach 1999).

4.2.1.1. Chromated Copper Arsenate Preservative Field Investigations

During the field investigation no bridges were identified that were constructed of CCA treated wood. The only elements investigated were guard railing and guard rail post. Several of the railing posts appeared to be reused sign posts. Overall the few CCA treated elements showed very little decay. Figures 4-54 through 4-57 show performance of CCA-treated guard rail posts investigated.

a) b)

Figure 4-55. a) Guard rail post with mechanical damage and no decay present; b) close up of damaged area

a) b)

Figure 4-56. a) Reused CCA guard rail post; b) close up of guard rail post

Figure 4-57. Top of a guard rail post showing end grain physical defects

4.2.2. Ammoniacal Copper Zinc Arsenate (ACZA)

Ammoniacal copper zinc arsenate (ACZA) is another common 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 and is less expensive than ACA which has lead to ACA no longer being available in the United States. ACZA treated wood varies in color from olive to bluish green. The wood may a have slight ammonia odor that will generally dissipate as the wood dries.

ACZA contains copper oxide, zinc oxide, and arsenic pentoxide that are dissolved in a solution of ammonia in water. ACZA has similar performance and characteristics as CCA. However, ACZA's chemical composition and stability during treatment at elevated temperatures allows it to penetrate difficult to treat wood species such as Douglas fir. ACZA is an established preservative that is used to protect wood from decay and insect attack in a range of exposure applications in above-ground and ground contact conditions. The ACZA treatment can accelerate corrosion relative to untreated wood, requiring the use of hot-dipped galvanized or stainless steel fasteners.

ACZA contains inorganic arsenic and the EPA classifies it as a RUP. ACZA is not available as a field treatment. Producers of treated wood, in cooperation with the EPA, have created the CIS, subsequently replaced with the CSIS (Consumer Safety Information Sheet) that gives guidance on handling and site precautions at sites where wood treated with inorganic arsenic are used. Although ACZA has very good handling properties, the CSIS should be available to all persons who handle wood treated with ACZA. For further details an EPA approved CIS can be found in the Wood Handbook Chapter 14 for inorganic arsenicals (Ibach 1999).

4.2.2.1. Ammoniacal Copper Zinc Arsenate Preservative Field Investigations

The use of ACZA was identified in only one county investigated. The oldest ACZA material inspected were stringers and bridge decking from the early 1990's. The newest elements investigated were being placed as backwall plank for a bridge under construction. The county used ACZA because it was proposed by the supplier, it is an approved IA DOT preservative, and it has good handling properties for the construction crew. Figure 4-58 through 4-60 show timber elements treated with ACZA that were investigated.

Figure 4-58. New ACZA treated back wall planks properly seasoned prior to treatment

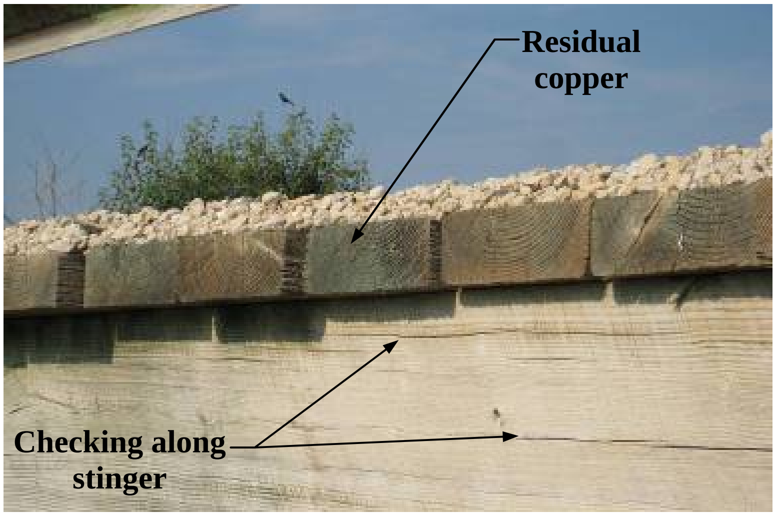

Figure 4-59. ACZA treated decking and exterior stringer in good condition with only minor physical defects

4.2.3. Alkaline Copper Quaternary (ACQ) Compounds

Alkaline copper quat (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-ammonical formulations. ACQ type D (ACQ–D) is an amine copper formulation that provides more uniform surface appearance and is generally used for treated wood sold at retail lumber yards. ACQ type C (ACQ–C) is a combined ammoniacal-amine formulation with a slightly different quat compound.

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 three formulations have demonstrated their effectiveness against decay fungi and insects in above-ground and ground contact areas but not in salt water applications (Ibach 1999).

The ACQ formulations are listed in the AWPA standards for a range of applications and many softwood species. The different formulations of ACQ allow some flexibility in achieving compatibility with a specific wood species and application. All ACQ treatments accelerate corrosion of metal fasteners relative to untreated wood. Hot-dipped galvanized or stainless steel fasteners must be used in structurally critical applications. The number of pressure-treatment facilities using ACQ is increasing. Researchers at the USDA Forest Service's Forest Products Laboratory in Madison, WI are evaluating the performance of a secondary highway bridge constructed using Southern Pine lumber treated with ACQ–D (Ritter and Duwadi 1998).

Since ACQ does not contain arsenic and has an overall lower toxicity it is not classified as a RUP by the EPA. Field treatment is possible; however, ACQ is not readily available for field application purposes. Even though health concerns do not require ACQ to be a RUP, precautions such as use of dust mask and gloves should be followed when handling treated wood.

4.2.3.1. Alkaline Copper Quaternary Preservative Field Investigations

ACQ is not listed in the Iowa DOT specifications for treatment use, however, it was found to be used for guard rail repairs. All elements seen were very new and in good condition. Figures 4-60 and 4-61 show the ACQ treated guard rails.

Figure 4-60. ACQ treated lumber used as guard railing members

Figure 4-61. ACQ railing post with splitting that is generally associated with waterborne treatments

4.2.4 Other Waterborne Preservatives

Acid copper chromate (ACC) has been used as a wood preservative in Europe and the United States since the 1920's. ACC contains copper oxide and chromium trioxide which causes the treated wood to have a light greenish-brown color and little noticeable odor. The high chromium content of ACC helps reduce the corrosion of fasteners. ACC does not penetrate difficult-to-treat wood species easily and is also more prone to leach than other waterborne treatments (Ibach 1999). The EPA restricts the use of ACC to only non-residential applications, while the AWPA limits its recommended uses to signpost, handrails, guardrails and glue-laminated beams used above-ground only.

Copper Azole is a recently developed preservative that relies primarily on amine copper and some additional biocides to protect the member from decay and insect attack. Copper azole type B (CA-B) is the only formulation currently used in the United States. CA-B contains mostly copper with some tebuconazole. The treated wood has a greenish brown color with little to no odor. CA-B is listed by the AWPA for above-ground, ground contact, and critical structure components. Ammonia can be added to CA-B in order to improve treatment of difficult to treat wood species. CA-B does increase the rate of corrosion of steel fasteners requiring galvanized, copper, or stainless steel to be used. CA-B is currently not restricted by the EPA and treatment plants are becoming more prevalent across North America.

Copper HDO (CX-A) is an amine copper-based preservative that has been used in Europe and was recently standardized by the AWPA. The active ingredients are copper oxide, boric acid, and copper-HDO. The appearance and handling characteristics of wood treated with CX-A are similar to the other copper-based treatments. CX-A formulations have only been standardized for uses above ground. The availability of CX-A treated material is limited.

4.3. Plant-Applied Preservative Summary

A summary of the discussed plant-applied preservatives is presented in Table 4-1. For comparison the table includes information on material usage, surface characteristics, color, odor and fastener corrosion. Not listed in the table are changes in engineering properties, however, as stated previously oilborne preservatives generally do not reduce engineering properties because no chemical reaction occurs in the wood’s cellular structure. All waterborne preservatives affect the engineering properties of the wood and should be accounted for in the design process.

Table 4-1. Properties and uses of plant-applied preservatives for timber bridges

Standardized Uses	Preservative	Solvent Characteristics	Surface Characteristics	Color	Odor	Fastener Corrosion
All uses	Creosote	Oil-type	Oily, not for frequent human contact	Dark brown	Strong, lasting	No worse than untreated
All uses	Ammoniacal copper zinc arsenate	Water	Dry, but contains arsenic	Brown, possible blue areas	Mild, short term	Worse than untreated wood
All uses	Chromated copper arsenate	Water	Dry, but use is restricted by EPA	Greenish brown, weathers to gray	None	Similar to untreated wood
All uses (except in seawater)	Pentachlorophenol Type A (heavy oil)	No. 2 fuel oil	Oily, not for frequent human contact	Dark brown	Strong, lasting	No worse than untreated wood
All uses (except in seawater)	Copper naphthenate	No. 2 fuel oil	Oily, not for frequent human contact	Green, weathers to brownish gray	Strong, lasting	No worse than untreated wood
All uses (except in seawater)	Alkaline copper quat	Water	Dry, okay for human contact	Greenish brown, weathers to gray	Mild, short term	Worse than untreated wood
All uses (except in seawater)	Copper azole	Water	Dry, okay for human contact	Greenish brown, weathers to gray	Mild, short term	Worse than untreated wood
Aboveground, fully exposed	Pentachlorophenol Type C (light oil)	Mineral spirits	Dry, okay for human contact if coated	Light brown, weathers to gray	Mild, short term	No worse than untreated wood
Aboveground, fully exposed	Oxine copper	Mineral spirits	Dry, okay for human contact	Greenish brown, weathers to gray	Mild, short term	No worse than untreated wood
Aboveground, fully exposed	Copper HDO	Water	Dry, okay for human contact	Greenish brown, weathers to gray	Mild, short term	Worse than untreated wood

The longevity or service life of preservative treated wood depends on a range of factors including type of preservative, treatment quality, construction practices, type of exposure, and climate. To better understand these factors for long term performance the USDA Forest Service, Forest Product Laboratory has conducted various field tests since the 1930's. The most common of these tests are the stake test that utilizes 2- by 4- by 18 in. Southern Pine sapwood stakes treated with various preservatives and installed in southern Mississippi. The stakes are half buried in the soil and then periodically removed and inspected for the extent of decay and insect attack. The stakes were given a rating based on a scale that ranges from 10 (no attack) and 0 (failure, easily broken into pieces). Long term stake performance data were collected for creosote, penta, ACZA/ACA, and CCA-C. Figure 4-62 shows the average rating of stakes when treated with ground contact structural critical retentions of each preservative type. The results of preservatives at this retention level showed CCA-C with the best performance followed by ACZA/ACA, creosote, and penta. The same trend was found for stakes treated at retentions for bridge pile usage. No data were available for ACZA/ACA at pile retention values, however, Figure 4-63 shows CCA-C with the best decay rating relative to creosote and penta.

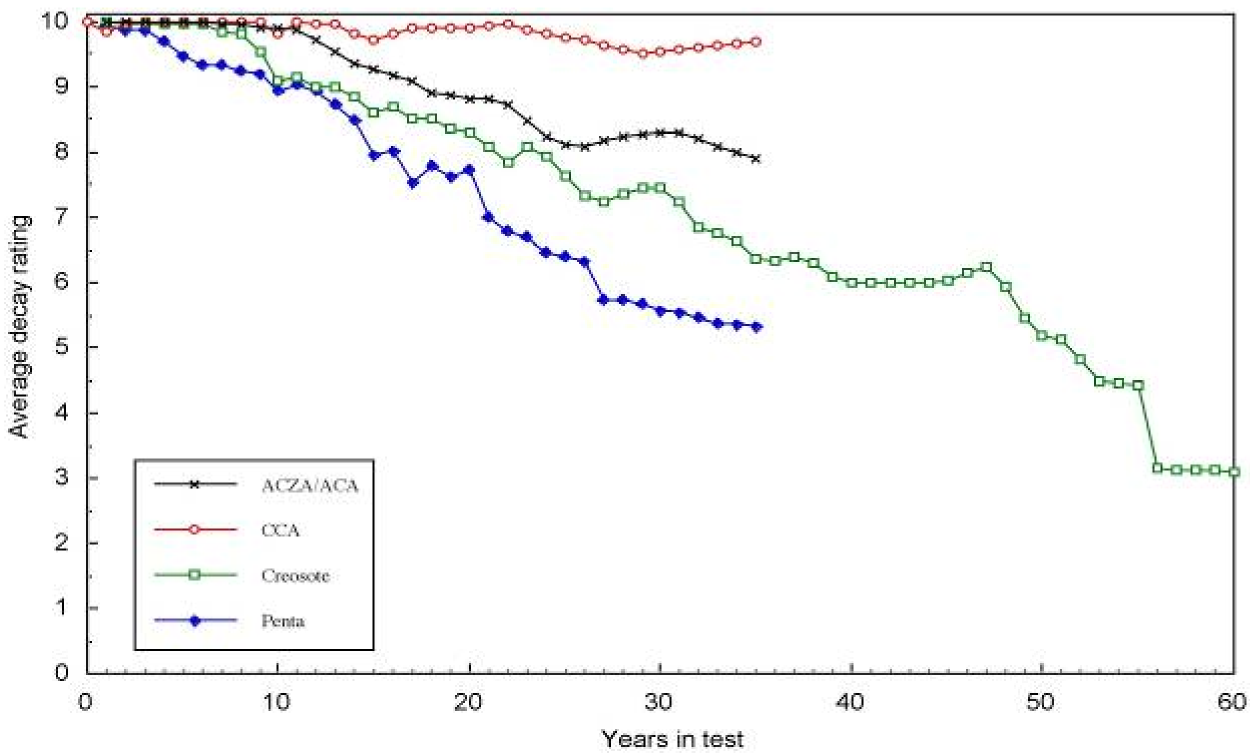

Figure 4-62. Average ratings of stakes when treated with retentions for structurally critical structures in ground contact.

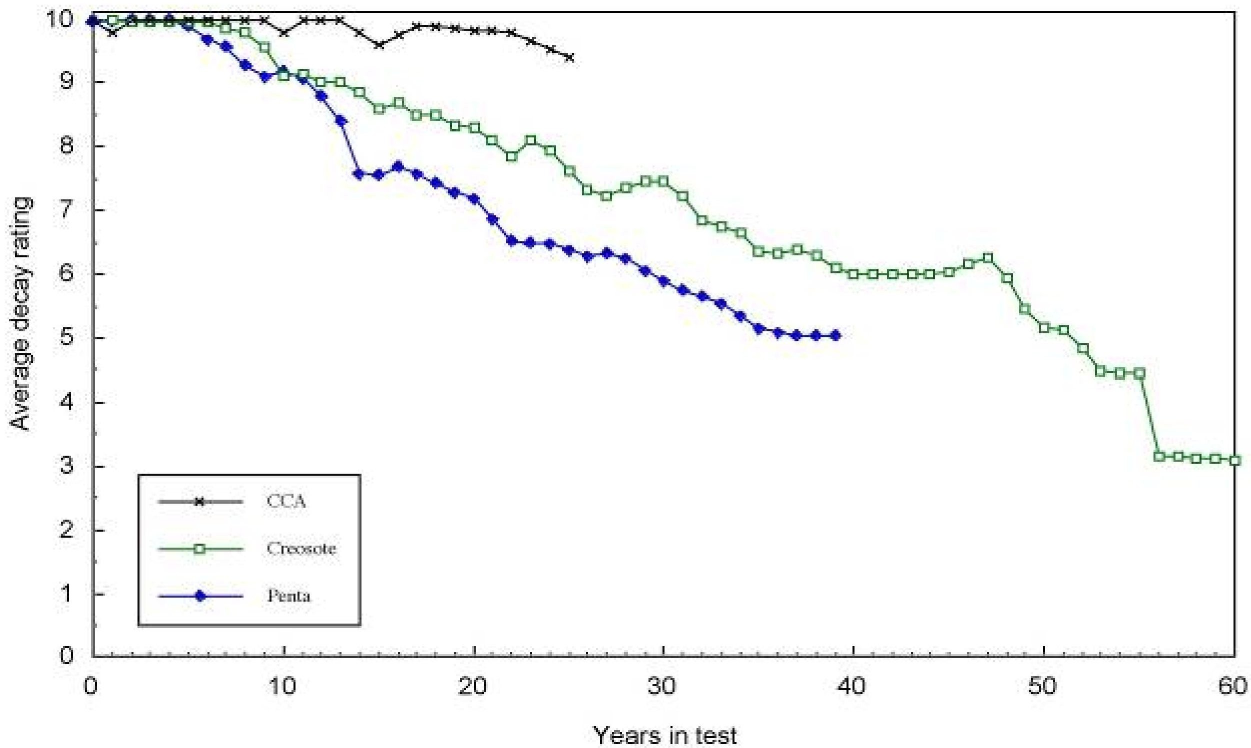

Figure 4-63. Average ratings of stakes when treated with retentions intended for piling

The superior performance of the waterborne preservatives (CCA and ACZA) in comparison to creosote and pentachlorophenol in these 2 by 4 stake plots is interesting but may be somewhat misleading. Unlike the waterborne preservatives, creosote and pentachlorophenol are not chemically bound to the wood and resist depletion because the oils have low water solubility. But, the oil-type treatments do very gradually redistribute over time because of the effects of gravity and expansion and contraction of the wood. In a large member such as a pile or timber there is substantial reservoir of the oil-type preservative and it takes much longer for the effects of this redistribution to reduce the loading of preservative below the point of efficacy. In vertical members such as piles, posts and poles the downward movement from gravity may actually enhance long term durability by continually replenishing preservative within the wood in the critical ground-line area. The relatively small stakes used in tests are thus somewhat biased against the oil-based treatments because they overemphasize the effects of depletion in comparison to product-size material. The durability of fence posts treated with pentachlorophenol, creosote and copper naphthenate appears to be greater than that noted for the stakes (Crawford et al. 2002).

The FPLs comparison of treated posts is expected to be more representative of the performance of treated piles and poles. For these tests, Southern Pine posts, with diameters of 4 -5 in. were pressure-treated with preservatives and placed in the ground in southern Mississippi. The posts were periodically stressed to a possible failure point by the use of a 50 lb (22.73 kg) pull test (Freeman, et al. 2005). The most recent inspection was conducted after 53 years of exposure, at which time sufficient posts had failed to allow calculation of expected service life as shown in

Table 4-2. The post were treated to retentions below those currently specified in AWPA standards, however the preservative treatments are performing surprisingly well. Pentachlorophenol in particular is performing well in these post tests in comparison to the stake data discussed previously.

Table 4-2. Estimated service life of treated round fence post in southern Mississippi

Preservative	Average Retention (lb/ft^3)	Estimated Service Life (years)	90% Confidence Limits for Service Life (years)	
			Lower	Upper
Copper Naphthenate	0.03	65	55	78
Creosote	5.6	54	47	62
Pentachlorophenol	0.32	74	60	91
ACA	0.34	60	51	69
Untreated	0	2.4	2.1	2.7

Determining life expectancy based on the bridges that were field investigated in this project was quite difficult due to the multitude of variables that cause biodeterioration of different bridge elements. Comparisons were also difficult because of the small number of bridges constructed of non-creosote treated timber. The large number of creosote bridges investigated, however, 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 60 to 70 plus years. Creosoted piles located in the stream channel or in moist areas were generally found to have a have a life expectancy of 40 to 50 years. Creosoted elements that were not in contact with the ground (e.g., stringers) were generally found to last 50 years or more. The pentachlorophenol and copper naphthenate bridges were too few and too new to determine any longevity trends from field inspections.

Field investigations also revealed that regardless of treatment type, member protection also contributed to the longevity and performance of the bridge. Bridge elements that appeared to be field cut and treated in-place generally had less decay than untreated cut members. Several older bridges used bituminous coatings on cut or damaged areas helping extend the longevity of the bridge members. Bridge elements that were protected by the deck, such as interior stringers, had better performance and less decay relative to members that were exposed. Interior stringers had very little decay and physical defects, however, the exterior stringers tended to have checking along the length of the members. When comparing new and old exterior stringers all members had checking on the face regardless of age. Bridges with wearing surfaces, as seen in Figure 4-64, were also seen to have less damage and decay than when the deck also was used as the wearing surface. Although gravel decks can trap and hold moisture, the timber decks with gravel wearing surfaces were performing better than decks without any added wearing surface. Bridges without a wearing surface had more mechanical damage and weathering causing decay and physical defects. The additional damage seen in bridges without a wearing surface will likely lead to a shortened service life. The overall condition of piles and cap beams that had metal or felt covers was much better than piles and caps 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, however, metal caps were found to have better longevity and durability.

Figure 4-64. Good wearing surface protects the timber decking

5. IN-PLACE PRESERVATIVES TREATMENTS

For best performance, as much fabrication should be completed prior to pressure treatment to allow all exposed surfaces to be protected (Duwadi and Ritter 1997). In reality, on-site fabrication of timber bridge components typically results in breaks in the protective barrier. Pile tops, which are typically cut to length after installation, specifically need reapplication of the 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 supplemental on-site treatment.

Installers should be provided with supplemental preservative and instructions for its safe handling and proper use during the construction process. 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 in joint areas. These areas require periodic reapplication of supplemental preservative. Supplemental in-place treatments are available in several forms: surface-applied chemicals, pastes, diffusible chemicals, and fumigants. Several of the in-place preservatives are RUP and require certified applicators licensing as was discussed in Chapter 4.

5.1. Surface Treatments

The simplest method for applying supplemental preservative treatment during fabrication or routine maintenance involves brushing or spraying a preservative onto the known break in the treatment barrier or over the suspected problem area (e.g., joints, fasteners, pile tops). Flooding of bolt holes and the tops of cut-off piles are particularly important. Often these surfaces will be covered or closed during construction and will no longer be available for surface treatment. Cracks, checks and splits should be retreated during subsequent inspections. Because surface treatments do not penetrate deeply into the wood where deterioration is mostly 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.

5.1.1. CuNap

For brush or spray applications, copper naphthenate in oil is the preservative that is most often used. The solution should contain 1 - 2% elemental copper. Copper naphthenate is available as a concentrate or in a ready-to-use solution in gallon and drum containers.

5.1.2. Borate Solutions

Borate solutions can also be sprayed or brushed into checks or splits. However, because they are not fixed to the wood they can be leached during subsequent precipitation. Borates are sold either as concentrated liquids (typically formulated with glycol) or as powders that can be diluted with water

5.2. Pastes

Another type of surface treatment are the water soluble pastes containing combinations of copper naphthenate, sodium fluoride, copper hydroxide, or borates. The theory with these treatments is that the diffusible components (i.e., boron or fluoride) will move through the wood; while at the same time the copper component remains near the surface of a void or check. These pastes are most commonly used to help protect the ground-line area of poles. After the paste is applied, it is a covered with a wrap to hold the paste against the pole and prevent loss into the soil. In bridge piles this type of paste application should be limited to terrestrial piles that will not be continually or frequently exposed to standing water. These pastes may also be effective if used under cap beams/covers to protect exposed end-grain. Reapplication schedules will vary based on the manufacturers recommendations as well as the method and area of application.

5.3. Diffusible Chemicals

Surface-applied treatments often do not penetrate deeply enough to protect the inner portions of large bridge members. 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. Boron is the most common active ingredient, but fluoride and copper may also be incorporated. In timbers, deep holes are drilled perpendicular to the upper face on either side of checks. In round piles, steeply sloping holes are drilled across the grain to maximize the chemical diffusion and minimize the number of holes needed. The treatment holes are plugged with tight fitting treated wooden plugs or removable plastic plugs. Plugs with grease fittings are also available so that the paste can be reapplied without removing the plug.

Solid rod treatments are a good choice in environmentally sensitive areas or in applications where the treatment hole can only be drilled at an upward angle. However, solid rods may require more installation effort. Further, the chemical does not diffuse as rapidly or for as great a distance as compared to a liquid form (De Groot et al. 2000). One reason that the solid forms may be less mobile is that diffusible treatments need moisture, which is lacking in a solid, to be able to move through wood. Concentrated liquid borates may also be poured into treatment holes and are sometimes used in conjunction with the rods to provide an initial supply of moisture. Fortunately, when the moisture content falls below 30%, little chemical movement occurs, but growth of decay fungi is also substantially arrested below 30% moisture (Smith and Williams 1969). Since there is some risk that rods installed in a dry section of a timber would not diffuse to an adjacent wet section, some experience in proper placement of the treatment holes is necessary. The diffusible treatments do not move as far in the wood as do fumigants (described in the subsequent sections), and thus the treatment holes must be spaced more closely. A study of borate diffusion in timbers of several wood species reported that diffusion along the grain was generally less than 5 in. and diffusion across the grain was typically less than 2 in. (De Groot et al. 2000).

Currently, diffusible chemicals are not listed as RUP’s and have the advantages of having relatively low toxicity and ease of handling. Although many diffusible chemicals list piles for labeled usage, the treatment should be applied so the chemical is deposited above the mean high water mark on piles.

5.4. Fumigants

Like diffusibles, fumigants are applied in liquid or solid form in predrilled holes. However, they then volatilize into a gas that moves through the wood. One type of fumigant has been shown to move over 8 ft from the point of application in poles (Highley and Scheffer 1989). To be most effective, a fumigant should be applied at locations where it will not leak away or be lost by diffusion to the atmosphere. 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. In vertical members such as piles, holes to receive liquid fumigant should be drilled at a steep angle (45° to 60°) downward toward the center of the member, avoiding seasoning checks. The holes should be no more than 4 ft apart and arranged in a spiral pattern (Highley and Scheffer 1989). With horizontal timbers, the holes can be drilled straight down or slanted. As a rule, the holes should be extended to within about 2 in. (5.08 cm) of the bottom of the timber. If strength is not jeopardized, holes can be drilled in a cluster or in pairs to accommodate the required amount of preservative. If large seasoning checks are present, the holes should be drilled on each side of the member to provide better distribution. As soon as the fumigant is injected, the hole should be plugged with a tight-fitting treated wood dowel or removable plastic plug. For liquid fumigants, sufficient room must remain in the treating hole so the plug can be driven without squirting the chemical out of the hole. The amount of fumigant needed and the size and number of treating holes required depends upon 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. Some are considered to be RUP by the U.S. EPA, requiring extra precautions (Highley 1999) and should only be applied above the mean high water mark on piles. Another disadvantage of pre-encapsulated fumigants is the relatively large size of treatment hole required.

5.4.1. Chloropicrin

The most effective fumigant currently used is chloropicrin (trichloronitromethane). Chloropicrin is a liquid and has been found to remain in wood for up to 20 years; however, 10-year re-treatment cycles are recommended with regular inspection (Ritter. 1992). Chloropicrin is a strong eye irritant and has high volatility. Due to chloropicrin’s hazardous nature it should be used in areas away from buildings permanently inhabited by humans or animals. During application workers must wear protective gear including a full face respirator. Advances in chloropicrin formulations have allowed it to be placed in semi-permeable tubes for slow release. Using semi-permeable tubes reduces the risks presented to workers if chloropicrin leaks out of checks and splits in the wood. The tubes further allow for applications above ground were liquid material would flow out (Morrell et al. 1996).

5.4.2. Methylisothiocyanate (MITC)

Methylisothiocyante (MITC) is the active ingredient in several fumigants, but is also available in a solid-melt form that is 97% active ingredient. The solid-melt MITC is supplied in aluminum tubes. After the treatment hole is drilled the cap is removed from the tube, and the entire tube is placed into the whole. This formulation provides ease of handling and application to drilled treatment holes that slope upward.

5.4.3. Metham Sodium (Vapam)

Metham sodium (sodium N-methldithiocarbamate) is a most widely used fumigant. However, metham sodium must decompose in the presence of wood in order to create MITC which is the active fungicide. Metham sodium is not recommended for use in standing water. Metham sodium is also the least effective fumigant with an estimated protective service life of seven to 10 years in Douglas-Fir timbers. The lower effectiveness is due to lower amounts of active ingredients after decomposition. Decomposition of metham sodium can be inhibited by wood species, moisture, and temperature. Metham sodium is also corrosive to fasteners (Morrell et al. 1996).

5.4.4. Granular Dazomet

Dazomet (tetrahydro-3, 5-dimethyl-2-H-1,3,5, thiodazine-6-thione) is applied in a solid granular form that decomposes to a MITC content of approximately 45%. Dazomet is easy to handle, but slower to decompose and release MITC than the solid-melt MITC or liquid fumigants. Some suppliers recommend the addition of a catalyst to speedup the breakdown process.

5.5. In-Place Preservative Summary

A summary of the discussed in-place preservatives is presented in Table 5-1. For comparison the table includes information on application locations, leaching and diffusing characteristics, bridge applications, and handling.

Table 5-1. Properties and uses of in-place preservatives for timber bridges

In-place Preservative Type	Active Ingredient	Solvent Type	Internal vs. External	Leeching or Diffusing	Bridge Location	Handling & other
Surface treatment liquid	Copper naphthenate	Oil	External sprayed or brushed	Insoluble in water	Bolt holes, exposed end grain, checks & splits	Non-RUP
Surface treatment liquid or powder	Borate solutions	Water	External sprayed or brushed	Leach away by precipitation	Bolt holes, exposed end grain, checks & splits	Non-RUP
Surface treatment paste	CuNap, sodium fluoride, Cu-Hydrooxide, borates	Water	External & covered with wrap	Boron & fluoride move into wood, Copper stays at surface	Ground line area of terrestrial piles & under pile caps	Non-RUP
Diffusible Chemical Liquid	Boron, fluoride, copper	Water	Internal through drilled holes	Needs moisture to diffuse into wood	Pile & deep timbers w/ drill accessibility	Non-RUP, Low toxicity & ease of handling
Fumigant liquid	Chloropicrin	NA	Internal through drilled holes	Volatizes into gas & move into wood	Pile & deep timbers w/ drill accessibility	RUP
Fumigant Solid	Solid-melt MITC	NA	Internal through drilled holes	Volatizes into gas & move into wood	Pile & deep timbers w/ drill accessibility	RUP
Fumigant liquid	Methan Sodium (Vapam)	NA	Internal through drilled holes	Volatizes into gas & move into wood	Pile & deep timbers w/ drill accessibility	RUP
Fumigant Solid	Granular Dazomet	NA	Internal through drilled holes	Volatizes into gas & move into wood	Pile & deep timbers w/ drill accessibility	RUP

NA = Not Applicable

6. INSPECTION TOOLS AND TESTING

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

6.1. 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, such as darkening, presence of bleaching, staining, and signs of moisture accumulation in a joint or on any wood surface should be noted. Wood with advanced brown-rot decay turns dark brown and crumbly with a cubical appearance or may be collapsed from structural failure. White-rot decay is characterized by bleaching and the wood appears whiter than normal. White-rotted wood does not crack across the grain like brown-rotted wood and retains its outward shape and dimensions until it is severely degraded. Soft rot decay is most likely to occur at the water line. Soft rot is characterized by a shallow zone of decay on the wood surface that is soft to the touch when the wood is wet, but firm immediately beneath the surface. Staining of the wood can be caused by mold or stain fungi, watermarks or rust stains from metal fasteners. Stain generally points to areas that have been wet or where water has been trapped. Salt abrasion, from spills or splashes gives wood a fuzzy appearance and is primarily a concern because it can damage the protective barrier of the preservative.

Listed below are definitions of several physical properties and defects that can be visually seen as indications of protective performance or may suggest areas of future concern.

- Checks: Longitudinal separations that extend perpendicular to the growth rings at the end grain of a member.
- Decay at Fasteners: Biodeterioration at holes and cuts used to connect bridge members together.
- End Grain Decay: Biodeterioration at the ends of board or other timber members that extend into the member parallel to the grain
- Splitting: Damage at the end grain of a log or board that extends perpendicular through the board from face to adjacent face.
- Stain: Discoloration on the wood surface
- Surface Decay: Biodeterioration on the exterior faces of a timber member
- Ultraviolet degradation: Chemical reactions causing a grayish color of wood that is easily eroded from the surface exposing new wood cells; also called weathering.

Additional defects that may pose structural or aesthetic concerns but are not necessarily an indicator of preservative performance include:

- Bow: Curving or arching of a boards length perpendicular to the flat face or depth of the member.
- Crook: Curving or arching of a boards length perpendicular to the edge or breadth of the member
- Cup: Curving or arching of a board across its depth so the board no longer lays flat.
- Shake: A separation or plane of weakness between and paralleling the growth rings extending in the longitudinal direction of the member.
- Twist: Warping of a board about the longitudinal or length wise axis so that the four corners of the board no longer rest in the same plane.

6.2. Probing & Pick Test

Use of an awl or other sharp pointed tool can detect soft spots created by decay fungi or insect damage. Probing can locate pockets of decay near the surface of the wood member or can be used to test the splinter pattern of a piece of wood. Non-decayed wood is dense and difficult to penetrate with the probe and results in a fibrous or splintering break (Wilcox 1983). In a fibrous break, splinters are long and separate from the wood surface far from the tool. A splintering break results in numerous splinters directly over the tool. A pick test on non-decayed wood will give an audible sound that one would expect to hear when wood breaks. A pick test on decayed wood will result in a brash or brittle failure across the grain with few, if any, splinters. The sound will not be as loud. The pick test can subjectively differentiate between sound and decayed wood in weathered specimens that might otherwise be mistaken as decayed under comparable conditions. This simple test does require some experience to reliably interpret the results.

6.3. Moisture Measurement

Moisture measurements are taken with an electronic hand-held moisture meter. The moisture meter consists of two metal pins that are pushed into the wood. The meter displays a measurement of electrical resistance (moisture content) between the pins. Moisture content greater than 20% indicates that enough moisture is present for decay to begin. Moisture measurements provide information on areas where water is being trapped, such as joints, and serves as an indicator that a more thorough assessment of an area with high moisture content is necessary.

6.4. Sounding

In this method, a hammer is used to strike the wood surface. Based on 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 reliable interpretation of sounding since many conditions can contribute to variations in sound quality. Sounding method is best used in conjunction with other inspection methods (Ross et al. 1999).

6.5. Stress Wave Devices

Stress wave devices measure the speed (transmission time) at which stress waves travel through a wood member. Stress wave measurements locate voids in wood caused by insects, decay fungi or other physical defect. Stress wave signals are slowed significantly in areas containing deterioration. Because stress wave signals do not distinguish between active decay, voids, ring shakes or other defects, this method should be used with other inspection methods (Clausen et al. 2001).

6.6. 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. This method should be used with other inspection tools (Emerson et al.1998).

6.7. Core Boring

Increment core borings of representative areas should be taken perpendicular to the face of the member being sampled. All test holes must be plugged immediately after extracting the increment core with a tight-fitting wood plug treated with a preservative similar in performance to the member being sampled. Increment cores can be visually examined for signs of deterioration and may be submitted to a laboratory for biological and/or chemical analysis.

6.8. 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, 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. A list of recognized methods (A15-03) is provided by AWPA to assist in the determination of preservative retention in freshly treated or aged wood. Instrumentation necessary for analysis and associated methods vary for each preservative treatment. Recommended methods of analysis for preservative treatments commonly used in timber bridge construction during the past 10 years are provided and referenced here.

Creosote

AWPA standard A6-01 (AWPA 2007) is specified for the determination of oil-type preservatives in wood. Wood borings or samples that have been reduced to shavings, chips or slivers are extracted with toluene to provide a qualitative analysis of residual creosote in aged wood. The volume of wood extracted (i.e. diameter of the drill bit for drill shavings) must be known to calculate retention on a lb/ft^3 or kg/m^3 basis.

Pentachlorophenol

The Volhard Chloride procedure, commonly referred to as “lime ignition”, is one method of analysis of wood treated with pentachlorophenol. An alternative method, the copper pyridine method, can be used for the determination of technical pentachlorophenol and should be used when a method that is specific for chlorinated phenols is required. Both methods are described in AWPA standard A5-05 (AWPA 2007).

Copper naphthenate

The method for chemical analysis of wood treated with copper naphthenate (A5-05) is based on the oxidation of iodide to iodine by cupric ions followed by titration of iodine by thiosulfate. The method essentially determines the total copper in a sample. Results are expressed as copper metal (AWPA 2007).

Metallic elemental analysis

Elemental copper, chromium, arsenic, zinc and boron can be determined by inductively coupled plasma (ICP) emission spectrometric analysis for any of the following preservatives: CCA, ACC, ACZA. The test is conducted following AWPA standard A21-00 (AWPA 2007). Elemental determination in ppm (parts per million) should be converted to and reported in the oxide form of the metal. Metallic elemental analysis will be used for ACQ and CA-B determinations in the future for new installations. Copper, chromium, arsenic and zinc concentrations in treated wood can also be determined using X-ray spectroscopy as described in AWPA standard A9-01.

7. SPECIFICATIONS AND GUIDELINES

7.1. Iowa Department of Transportation State Specification

State of Iowa specifications pertaining to the handling and preservative treatment of timber used for bridges can be found in the Iowa Department of Transportation (Iowa DOT) Standard Specifications with GS-01013 revision. The Iowa DOT also has requirements for quality control protocol, approved treated timber suppliers, and treatment plants in Materials Instructional Memorandum Volume 1 Section 462. The specifications and memorandum can be found online at http://www.erl.dot.state.ia.us/.

Division 41 of the standard specifications contains specific information on wood preservatives and preservative treatments. Listed in this division are the AWPA chemical requirements for creosote, penta type A, copper naphthenate type A, CCA type A, B, and C, and ACZA. The five specific preservatives listed are required to be used unless no funding from state or federal sources are used.

The state specification requires preservative retentions to be in accordance with the recommendation of AWPA Standard U1 and the applicable AWPA Commodity specifications as shown in Table 7-1. The minimum preservative penetration required for Douglas-Fir and Southern Pine are also shown in Table 7-2 for different uses. The penetration requirements are based on AWPA standards.

Table 7-1. Minimum preservative retention requirements

	Retention (lb/ft^3)					
Material and Usage	**Creosote(2)**	**Pentachloro-phenol(2)**	**Copper Naphthenate(2)**	**ACZA(3)**	**CCA(1,3)**	**AWPA UC-Section-Special Req.**
Lumber and Timber for Structures	AWPA U1	AWPA U1	AWPA U1	AWPA U1	AWPA U1	AWPA U1
Piles for Foundation:						
Douglas Fir	17	NR	0.14	NR	NR	UC4C-E
Southern Pine	12	NR	0.1	NR	NR	
Post, Guardrail, and Spacer Blocks:						
Sawed Four Sides	NR	0.6	0.075	0.5	0.5	UC4A-B
Posts, Fence, Guide, and Sign:						
Round	NR	0.4	0.055	0.4	0.4	UC4A-B
Sawed Four Sides	NR	0.5	0.06	0.4	0.4	UC4A-A-4.3

Note: (1) CCA shall not be used for treatment of Douglas Fir
(2) Oil type preservatives
(3) CCA, ACA, and ACZA are waterborne preservatives
(4) Retentions based on AWPA. Use Category and Commodity Specification for different applications
NR = Not Recommended

Table 7-2. Minimum preservative penetration requirements

	Penetration (in and/or % of sapwood penetration)[1]		
Material and Usage	**Southern Pine**	**Douglas-Fir**	**AWPA Material Standard Section**
Lumber and Timber for Structures	AWPA U1 T1	AWPA U1 T1	AWPA U1 T1
Piles for Foundation	2.5 in. or 85%	0.75 in. and 85% up to 1.6 in. and 85%	T1-8.5
Post, Guardrail, and Spacer Blocks:			
Sawed Four Sides	2.5 in. or 85%	Under 5 in. thick: 0.4 in. and 90% 5 in. and thicker 0.5 in. and 90%	T1-8.1
Posts, Fence, Guide, and Sign:			
Round	2.0 in. or 85%	3/8 in. and 100% up to 1 in. or 85%	T1-8.2
Sawed Four Sides	2.5 in. or 85%	Under 5 in. thick: 0.4 in. and 90% 5 in. and thicker 0.5 in. and 90%	T1-8.1

Note: (1) Penetrations based on AWPA. Use Category and Commodity Specification for different applications

Other requirements for the treatment process found in Division 41 include the following information.

- Coastal Douglas-Fir shall be incised.
- Waterborne treated material is required to be seasoned prior to and after treatment. The moisture content requirements pre and post-treatment are 20% and 23% for kiln dried and air dried material, respectively. The moisture content shall be determined using a resistance type moisture meter.
- To avoid oil accumulation on guardrails and sign posts, the specification requires a steam and vacuum process prior to removal from the treatment cylinder.
- The full cell treatment process is to be used for waterborne preservatives and the empty cell process with initial air pressure is required for oil preservatives.
- The results of the treatments are to conform with Tables 7-1 and 7-2 and AWPA Standards U1 and T1. The retentions are to be determined by analysis methods.
- Handling of the product after treatment is to be in accordance with AWPA Standard M4 and the individual pieces are to be marked with the appropriate identification brand, stamp, or tag.
- All inspection certifications and test reports for each shipment are to be provided according to Iowa DOT specification Material I.M. 462.
- Only Douglas-Fir (costal region), Northern Pine, and Southern Pine are allowed to be treated. The structural members must also be pre bored and cut prior to treatment whenever possible.

Division 24 of the specifications describes construction practices and in-place treatment of cut timber members. The cut surfaces of pile heads must be treated with copper naphthenate. Division 24 also states all newly exposed surfaces (e.g., in-field framing and boring) shall be coated with two coats of copper naphthenate.

The Materials Instructional Memorandum states that treated timber products used in timber structures must be supplied by approved suppliers and treatment plants. If any timber material is furnished by an unapproved source, the material shall not be accepted. The steps for becoming an approved supplier and treatment plant are listed within the memorandum. Included in the memorandum is information pertaining to plant treatment quality control, material handling, and criteria for material identification. The appendices for the memorandum contain pre approved treatment plants and suppliers.

7.2. American Wood Protection Association Standards (AWPA)

The American Wood Protection Association (AWPA) is the primary standard-setting body for preservative treatment in the United States. The AWPA Standard-07 contain standards for Use Category System (UCS) Standards, Nonpressure Standards, Preservative Standards, Analysis Method Standards, Miscellaneous Standards, and Evaluation Standards. The UCS standards and Miscellaneous standards are the most applicable to timber bridge preservatives. UCS standards also identify proper preservative retention and penetration for various timber materials. The Miscellaneous Standards have sections pertaining to the care of preservative treated wood and guidelines for pole maintenance programs. These programs may possibly be adapted to bridges.

To guide selection of the types of preservatives and loadings appropriate to a specific end-use, the AWPA recently developed the UCS standards (AWPA 2007). The UCS standards simplify the process of finding appropriate preservatives for specific end-uses. AWPA groups treated wood applications by the service environment and the timber usage. The service environment is divided further by use category designations. The AWPA has five use categories with the lowest category, UC1, for wood that is used in interior construction and kept dry; while the highest, UC5, includes applications that place treated wood in contact with seawater and marine borers. The use category designations also integrate the structural importance of members. Most applications for highway construction fall into categories UC4B and UC4C.

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. The Commodity Specifications have nine classifications (Section A through I) for relating appropriate preservative retentions and the member usage. The Processing Standard, Sections 8.1 through 8.9, provide penetration requirements appropriate to species and use categories. To use the UCS standards the intended use category and the commodity classification must be known. Table 7-3 shows the use category, Commodity Specifications, and Processing Standard for most timber bridge elements.

Table 7-3. AWPA Use Category and Commodity Specifications for timber bridge elements

Bridge Element	Commodity	Use	Exposure	Use Category	Commodity Specification (U1)		Processing Standards (T1)
					Section	Special Reqs	
Piling	Piles, round	Highway construction	Ground contact or fresh water	4C	E	-	8.5
Backwall	Lumber & timbers	Highway construction	Ground contact or fresh water	4B	A	4.3	8.1
Cap beam	Lumber & timbers	Highway construction	Ground contact or fresh water	4B	A	4.3	8.1
Stringer	Lumber & timbers	Highway construction	Ground contact or fresh water	4B	A	4.3	8.1
Decking	Decking	Highway bridge structural	Above ground	4B	A	4.3	8.1
Glue-laminated beams and panels	Glue-laminated beams	Highway important structural	Ground contact or fresh water	4B	F	-	8.6
Glue-laminated beams and panels	Glue-laminated beams	Highway critical structural	Ground contact or fresh water	4C	F	-	8.6
Handrails & guardrails	Handrails & guardrails	Highway construction	Above ground, exterior	3B	A	4.3	8.1
Guide, Sign, & Site Post	Post round	Highway construction including guide, sign and sight	Ground contact or fresh water	4A	B	-	8.2
Guardrail post & spacer block	Post round	Highway construction including guardrail posts, spacer blocks	Ground contact or fresh water, moderate decay	4B	B	-	8.2
Guardrail post & sign post	Post (sawn 4 sides)	Highway construction, general	Ground contact or fresh water	4A	A	4.3	8.1

The AWPA 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. The standard state that all boring, framing, chamfering, etc. should be done prior to treatment whenever practical. If fabrication must be done in the field, however, surface treatment shall be applied to areas where the preservative barrier has been broken. Copper naphthenate is recommended in the standards for most field applications; however, coal tar roofing cement can also be used for patching nail holes, bolt holes and other damaged areas. Timber piles, in addition to surface treatments, are required to have galvanized metal or aluminum sheets securely fastened to their tops for end grain protection. In addition to in-place treatment of members, reuse, burning, and disposal practices are outlined within the standard.

The AWPA also has guidelines for a pole maintenance program. Although the information is presented for utility and pole owners the same maintenance principals may be able to be applied to bridges. The guidelines discuss various components for an effective maintenance program. The first requirement is to have properly trained personnel and a quality control process to insure that trained personnel, whether in-house or a consultant, perform the work as specified. The next major requirement is to perform routine inspections. The inspection methods described in Chapter 6 are the same inspection tools presented in the guidelines. However, partial and full excavation techniques are additional steps outline that help to ensure decay is not forming below the surface. After inspections have taken place, evaluation of the structural integrity must be determined as well as the in-place maintenance or remaining service life. In-place treatments, discussed in Chapter 5, are suggested for remedial treatment. Lastly, bridge marking, record keeping, and data management are indicated to be vital for a successful maintenance program. Good records can help identify changes to new or in-place details.

7.3. American Institute of Timber Construction (AITC)

The American Institute of Timber Construction (AITC) has a Standard for Preservative Treatment of Structural Glued-Laminated Timber (AITC 109-2007). AITC 109-2007 incorporates the AWPA Use Category System for the treatment of glued-laminated timber members. AITC suggests, however, that exterior bridge structural members not in direct contact be classified as use category UC3; AWPA suggests that important highway structural elements in high decay locations have use category UC4.

The AITC standard also has design considerations that should be considered when selecting the proper preservative treatment. One design consideration is whether glued-laminated timber should be manufactured with lumber treated prior to 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. However, the standards do not recommend waterborne treatments pre-or post-lamination due to dimensional changes, warping, checking and splitting that can occur with waterborne treatments. The treating facility limitations must also be considered when designing large glued-laminated members.

As with the Iowa DOT specifications and the AWPA standards, the AITC also suggests that all fabrication and machining should take place prior to treatment. AITC references the AWPA standards M4 for care after treatment and field treatments of glued-laminated timber members.

7.4. 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, the Best Management Practices (BMP) have been developed as a guideline to reduce their impact on the environment. Much of the BMP are dedicated to the plant-applied treating process of timber. Through proper treatment selection, good housekeeping practices, and appropriate post treatment practices, the risk of biological impact on the environment is greatly reduced before the timber elements arrive on site. However, the BMP also include guidelines for the construction and maintenance of these structures in order to reduce biological risk

BMP 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. During the design process, details should be developed to reduce field cutting; which allows for better preservative treatment and reduces the amount of breaks in the protective treatment barrier. Making the contactor aware of BMP during the bidding process is also important and allows the contractor to plan and budget properly (WWPI 2006).

To ensure minimal contamination of the aquatic environment, all materials should be inspected upon delivery. The surfaces of the members should be free of loose debris and excess surface chemicals. If members are found to have areas of concern they should be placed in areas of low susceptibility to debris transfer or rejected altogether. After the elements have been inspected they should be stored off the ground in a well drained area away from standing water. If the material is to be stored for an extended period of time the members should be protected from precipitation (WWPI 2006).

Field cutting and fabrication should be done away from water and sensitive areas to eliminate direct infiltration of saw dust and shavings. The timber waste, including sawdust and shavings, should be collected and properly disposed of. The easiest way to do this is to create a cutting station were members can be carried for fabrication and field treatment. At the cutting station tarps can be place on the ground to facilitate easy debris collection. If the members to be cut are already incorporated into the structure and cannot be removed, tarps may be spread under that part of the structure before cutting. The use of tarps to contain sawdust becomes more difficult in windy or rainy conditions. Shavings from drilling holes are generally easier to contain in a small area than is sawdust. Plastic tubs are useful collection devices when drilling holes on-site. The importance of this collection work 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 (WWPI 2006).

Even wood properly treated with oil-type preservatives may create an oily sheen when it initially contacts standing water. This sheen is generally aesthetic and will dissipate and breakdown in a short time. However, the excess oil can be contained and collected by floating an absorbent boom around or downstream from the structure. An absorbent boom will also help to contain any accidental spillage of field-treatment preservative during construction. Having absorbent pads on hand at the construction site is also a good practice in case members were not adequately conditioned and begin to bleed preservative. Any absorbent materials that have been used for collection of preservative must be disposed of using appropriate procedures (WWPI 2006).

Any untreated wood that is exposed during field fabrication should be treated to prevent decay. However, like the treated wood itself, these field treatment preservatives contain ingredients that could be toxic to aquatic organisms. Field treatment preservatives should be applied sparingly and with care to avoid spillage. Whenever possible, the field treatment should be applied to the member before it is placed in a structure over water. Excess preservative should be wiped from the wood. If the preservative must be applied to wood above water, a tray, bucket, pan or other collection device should be used to contain spills and drips. Field treatments should not be applied in the rain to wood that is above water (WWPI 2006).

A free down load of BMP for the use of treated wood in aquatic and other sensitive environments can be found at www.wwpinstitute.org or a modified version for the state of Michigan can be found at www.fs.fed.us/na/wit (WWPI 2006; Pilon 2002).

7.5. Specification Summary

If state or federal funding is used for any bridge element made of timber, the Iowa DOT specifications are the governing body for preservative treatment. Even if no state or federal funding is used, the Iowa DOT specification and Instructional Memorandum are still recommended for retention, penetration, and certifications for timber treatments. The current Iowa DOT specifications are based on AWPA 2006 standards; however, some differences and clarifications are noted as follows:

- Iowa DOT specifies that lumber and timber shall be treated to current AWPA U1 and T1 standards for retention and penetrations, respectively. By specifying AWPA treatment standards, all lumber and timber uses can be encompassed by the use category system. Table 7-3 can be used for specifying proper use category, commodity specifications, and processing standards for lumber and timber.
- Although not specifically stated, the Iowa DOT classifies glued-laminated beams and panels as lumber and timber. Hence, Table 7-3 can be used to determine the proper treatment categories for glued-laminated materials.
- Iowa DOT allows piles to be treated with only creosote or copper naphthenate and has certified treatment plants and suppliers for piles treated with only these two treatments.
- Penetration standards differ slightly between current Iowa DOT specification and AWPA standards. Both standards list values for foundation piles, however only AWPA lists values for land and freshwater piles. The pile penetration levels required by AWPA and Iowa DOT are shown in Table 7-4. The higher penetration values provide by AWPA for land and fresh water piles are recommended for timber piles used for bridges.
- Iowa DOT does not allow creosote for post, guardrail elements, and spacer blocks. The restricted use of creosote for these elements is due to the higher probability of human contact.

- As shown in Table 7-5, the Iowa DOT has higher retentions than required by AWPA for guardrail post and spacer blocks. The higher retention levels are based on past specified requirements and good performance of in-place guardrail members.
- Round guardrail posts are not allowed by the Iowa DOT specifications, therefore, no treatment values are listed.
- Although the Iowa DOT has ACZA retention and penetration levels listed within their specification there are currently no approved certified treatment plants for ACZA. If ACZA is to be used, an ACZA plant will have to be certified by the Iowa DOT.

Table 7-4. AWPA and Iowa DOT specification preservative penetration requirements

Material and Usage	Penetration (in and/or % of sapwood penetration)		
	Southern Pine	**Douglas Fir**	**AWPA Material Standard Section**
Piles for Foundation:			
Foundation Piles (entirely embedded in ground)	2.5 in. or 85%*	0.75 in. or 85% up to 1.6 in. and 85%*	T1-8.5*
	2.5 in. or 85%**	0.75 in. and 85% up to 1.6 in. and 85%**	T1-8.5**
Land and Fresh Water Piles (entirely or partially embedded in soil or water)	NS*	NS*	NS*
	3.0 in. or 90%**	0.75 in. and 85% up to 1.6 in. and 85%**	T1-8.5**

Note: NS = Not Specified
* = Iowa DOT Specification Requirements
** = AWPA Standards 2007 Requirements

Table 7-5. AWPA and Iowa DOT specifications preservative retention requirements

Material and Usage	Retention (lb/ft^3)					
	Creosote	**Pentachlor-ophenal**	**Copper Naphthenate**	**ACZA**	**CCA**	**AWPA UC-Section-Special Req.**
Piles for Foundation:						
Douglas Fir	17* 17**	NR* 0.85**	0.14* 0.14**	NR* 1**	NR* NR**	UC4C-E* UC4C-E**
Southern Pine	12* 12**	NR* 0.6**	0.1* 0.1**	NR* 0.8**	NR* 0.8**	
Guardrail Post, and Spacer Blocks:						
Sawed Four Sides	NR* 10**	0.6* 0.5**	0.075* 0.060**	0.5* 0.4**	0.5* 0.4**	-* UC4A-A**

Note: NR = Not Recommended
* = Iowa DOT Specification Requirements
** = AWPA Standards 2007 Requirements

8. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to evaluate the performance of different wood preservatives in the field and to review specifications and testing procedures to provide an adequate level of timber treatment. To complete these objectives, the BEC in conjunction with the FPL evaluated various types of preservatives available and reviewed current preservative specifications.

In order to obtain comprehensive conclusions regarding both plant-applied and in-place treatments, several variables were evaluated including preservative type, age, exposure condition bridge element location, engineering properties, and environmental issues. The evaluation also included field investigations of 47 bridges located in various counties in Iowa. The investigations involved visual inspections of all available bridge elements for decay, physical defects, and damage.

Decay severity, preservative penetration, and retentions levels can be evaluated using the inspections tools and testing procedures outlined in this study. The tools and procedures included destructive, nondestructive, and chemical analysis techniques.

The specifications reviewed included Iowa DOT, AWPA, and AITC. In general, the AWPA was found to be the primary standard-setting body for preservative treatments and is the basis for the other specifications reviewed.

Based on the evaluated preservative information, field observations, and review of specifications and testing procedures the conclusions related to timber bridge preservative performance are:

1. Copper naphthenate is recommended as the plant-applied preservative treatment for timber bridge elements. Copper naphthenate 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 copper naphthenate include good handling characteristics, clean surfaces, comparable availability to other preservatives, and the potential for less environmental impacts.
2. During the construction of timber bridges, the Best Management Practices 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 the best management practices, bridge owners need to insure pile tops and cap beams are protected from moisture by use of metal covers and all field cuts are treated with in-place treatments.
3. The AWPA standards are the basis for the Iowa DOT specifications that are the regulating standards for bridges being constructed with state or federal funding in the state of Iowa. If the bridges are being constructed without state or federal the Iowa DOT specifications and plant certifications are still recommended.
4. Treated Southern Pine piles are recommended to have penetration of 3.0 in. or 90% of sapwood penetration. The penetration is in accordance with AWPA standards and is currently stricter than Iowa DOT specifications.

5. Timber bridge maintenance programs need to be developed and implemented. A maintenance program that utilizes combinations of inspection tools and various in-place treatments can easily extend a bridge’s service life. Future work could entail development of a timber bridge maintenance program for bridge owners. An effective maintenance program contains many components that need developed including the following:

    a. Personnel training and education: This would include quality control procedures workers must follow in order to insure work is performed properly.
    b. Inspection procedures: This would include a step-by-step illustrated guide for inspections
    c. Evaluation of structure and restoration: This includes procedures for evaluating structural condition and developing systems to strengthen deteriorated areas similar to techniques presented in Vol. 2 of White et al. 2007.
    d. In-place treatment: Similar to inspection procedures this would include a step-by-step guide for various in-place treatments
    e. Records and data management: This includes development of a searchable database to allow owners to query records for determining inspections frequency and problem elements.

6. Future workshops and/or short courses presenting biodeterioration and preservative concepts to timber bridge owners, designers, and inspectors are recommended in order to implement the information, procedures, etc. presented in this study.

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APPENDIX A

IOWA COUNTY PRESERVATIVE QUESTIONNAIRE

To: Iowa County Engineers

A new research project – *Field Evaluation of Timber Preservative Treatments for Iowa Highway Applications TR-552* has been funded by the Iowa Highway Research Board and the Iowa DOT. The primary objective of this project is to collect and document various timber preservative treatments and develop an evaluation process that will permit bridge owners to make sound decisions regarding their timber bridge treatment options.

The attached questionnaire is intended to assist the research team in collecting information regarding current timber bridge preservation practices in Iowa. As appropriate, the collected information will be used to supplement the recommendations and guidelines developed in this project.

We recognize that you receive numerous surveys and questionnaires requesting various types of information which all take a portion of your valuable time. With that in mind, we have designed the questionnaire to be relatively simple and easy to complete. If you have any questions or would prefer to provide input in another format, please contact either one of us.

In order to keep the project progressing on schedule, please complete the questionnaire and return it to us by **October 6, 2006** if at all possible. However, we would rather have your response a few days late than not at all.

Thank you in advance for your assistance with this project. It is with your help that we hope to produce a practical document that will assist county engineers, consultants, etc. with their timber bridge preservative concerns.

Sincerely,

F. Wayne Klaiber
Professor of Civil Engineering
(515) 294-8763
klaiber@iastate.edu

Michael LaViolette
Bridge Engineering Specialist
(515) 294-6838
mlaviol@iastate.edu

IOWA HIGHWAY RESEARCH BOARD
RESEARCH PROJECT TR-552

Field Evaluation of Timber Preservative Treatments for Iowa Highway Applications

Questionnaire Completed by: ______________________

Organization: ____________________________________

Address: ____

____

____

Email: ____

Responses can be mailed, faxed or emailed to Wayne Klaiber or Mike LaViolette:

Wayne Klaiber
422 Town Engineering
Iowa State University
Ames, IA 50011
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We would appreciate a copy of any additional information you would be willing to share, such as current specifications or timber bridge preservative information.

Section 1 – Timber Bridge Utilization

1.1. Does your county utilize timber in bridges, bridge components or other transportation elements?

Yes_________ No _________

If you answered no, please skip to Section 3 of this questionnaire.

a. If yes, how many timber bridges do you currently have in inventory? _________

b. Would your county have any reservations with constructing a new timber bridge?

Yes_________ No _________

1.2. Regarding timber bridge **backwalls/wingwalls:**

a. Does your county have existing bridges with this feature?

Yes_________ No _________

b. Does your county construct new bridges with this feature?

Yes_________ No _________

c. If no, is there a particular reason? ___________________________________

d. If yes, are you willing to share particularly successful details?

1.3. Regarding timber bridge **piling/substructure:**

a. Does your county have existing bridges with this feature?

Yes_________ No _________

b. Does your county construct new bridges with this feature?

Yes_________ No _________

c. If no, is there a particular reason? ___________________________________

d. If yes, are you willing to share particularly successful details?

1.4. Regarding timber bridge **superstructures:**

a. Does your county have existing bridges with this feature?

Yes_________ No _________

b. Does your county construct new bridges with this feature?

Yes_________ No _________

c. If no, is there a particular reason? ___________________________________

d. If yes, are you willing to share particularly successful details?

1.5. Regarding timber bridge **guardrail systems or sign posts**:

a. Does your county have existing bridges with this feature?

Yes_________ No _________

b. Does your county construct new bridges with this feature?

Yes_________ No _________

c. If no, is there a particular reason? ___________________________________

d. If yes, are you willing to share particularly successful details?

Section 2 – Timber Bridge Preservatives

2.1. What types of shop-applied timber preservative treatment does your county currently specify for timber bridges? (check all that apply)

ACZA	____________	Copper HDO	____________
ACC	____________	Copper Naphthenate	____________
ACQ	____________	Creosote	____________
CA-B	____________	Oxine copper	____________
CCA	____________	Pentachlorophenol	____________

a. Others not listed (possibly including trade names) ? ______________________

2.2. What type of preservative treatment does your county currently specify for field applications for in-service structures?

2.2.1. Surface treatment:

Spray ____________
Brush ____________
Estimated Cost ____________
Reapplication Schedule ____________

2.2.2. Diffusible chemicals:

Boron rods ____________
Flouride rods ____________
Copper boron rods ____________
Estimated cost ____________
Reapplication Schedule ____________

2.2.3. Fumigants:

Liquid ____________
Granules ____________
Restricted use ____________

2.2.4. Others not listed (possibly including trade names)? ______________________

____

2.3. What method of application does your county currently specify for field treatment of cuts, drilled holes, etc.?

____

____

____

____

2.4. Does your county currently specify a scheduled reapplication of preservative treatment?

Yes __________ No __________ If yes, how often? _______________

2.5. What specifications does your county use for specifying preservative treatment?

State specifications ___________

County has own specifications	___________
AASHTO standards	___________
AWPA standards	___________
Other:	___________

Section 3 – Timber Bridge Decision Making

3.1. What are the most important factors in your county's decision not to use timber in bridge components? Please rate these possible reasons in order of importance, with one being the most important factor:

Cost	___________
Durability concerns	___________
Difficulty in specifying preservative treatment	___________
Appearance	___________
Odor or surface cleanliness (handling concerns)	___________
Maintenance concerns	___________
Material Availability	___________
Just not accustomed to using timber	___________
Ease of Installation	___________
Strength properties	___________
Concerns about corrosion of connectors	___________
Other:	___________
Other:	___________

3.2. What do you see as the primary advantage(s) of or reasons your county might utilize timber in bridge components? Please rate these possible advantages in order of importance, with one being the most important factor.

Cost	___________
Durability	___________
Appearance	___________
Maintenance	___________
Material availability	___________
Ease of installation	___________
Strength properties	___________
Other:	___________
Other:	___________

3.3. What are the primary factors that you consider when choosing a wood species for a timber bridge components? ____

____

3.4. What are the primary factors that you consider when choosing a preservative treatment for timber bridge components? ____

____

Section 4 – Timber Bridge Components Life Expectancy

For the questions in this section, please indicate an expected service life for timber bridge components based on your experience. In addition, please indicate the most common form(s) of deterioration observed that necessitate the replacement of these bridge components.

4.1. Timber Deck

1-5 years	____________	21-25 years	____________
6-10 years	____________	26-30 years	____________
11-15 years	____________	31-50 years	____________
16-20 years	____________	Over 50 years	____________

Most common form(s) of deterioration: ____

____

____

4.2. Timber Stringers

1-5 years	____________	21-25 years	____________
6-10 years	____________	26-30 years	____________
11-15 years	____________	31-50 years	____________
16-20 years	____________	Over 50 years	____________

Most common form(s) of deterioration: ____

____

____

4.3. Timber Piling

1-5 years	____________	21-25 years	____________
6-10 years	____________	26-30 years	____________
11-15 years	____________	31-50 years	____________

	___________		___________
16-20 years	___________	Over 50 years	___________

Most common form(s) of deterioration: ______________________________________

____

____

4.4. Timber Backwall

1-5 years	___________	21-25 years	___________
6-10 years	___________	26-30 years	___________
11-15 years	___________	31-50 years	___________
16-20 years	___________	Over 50 years	___________

Most common form(s) of deterioration: ______________________________________

____

____

Section 5 – Timber Bridge Details

5.1. Does your county have timber bridges which feature details that have been especially **problematic**?

Yes_________ No _________

5.2. Does your county have timber bridges which feature details that have been especially **successful**?

Yes_________ No _________

5.3. If the answer to either of the above questions is "YES", would you be willing to submit detailed drawings or photos?

Yes_________ No _________

5.4. If the answer to either of the above questions is "YES", would you be willing to permit the bridge in question to be visited and reviewed by members of the research team?

Yes_________ No _________

Section 6 – Timber Bridge Inspection

6.1. Does your county (or a consultant hired by your county) perform scheduled inspection of its timber bridges?

Yes _________ No _________

Consultants are hired to perform inspections ____________

6.2. Does your county use any specific methods for detecting deterioration of timber components?

External Deterioration		Internal Deterioration	
Visual inspection	____________	Sounding	____________
Probing	____________	Moisture meter	____________
Pick test	____________	Shigometer	____________
Other	____________	Drilling/Coring	____________
		Shell depth indicator	____________
		Sonic evaluation	____________
		X-ray tomography	____________
		Other	____________