Timber Abutment Piling and Back Wall Rehabilitation and Repair

BRIDGE ENGINEERING CENTER

Final Report
September 2012

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16. Abstract

Based on previous National Bridge Inventory data, the state of Iowa has nearly 20,000 bridges on low-volume roads (LVRs). Thus, these bridges are the responsibility of the county engineers. Of the bridges on the county roads, 24 percent are structurally deficient and 5 percent are functionally obsolete. A large number of the older bridges on the LVRs are built on timber piling with timber back walls. In many cases, as timber abutments and piers age, the piling and back wall planks deteriorate at a rate faster than the bridge superstructure. As a result, a large percentage of the structurally deficient bridges on LVRs are classified as such because of the condition of the timber substructure elements.

As funds for replacing bridges decline and construction costs increase, effective rehabilitation and strengthening techniques for extending the life of the timber substructures in bridges with structurally sound superstructures has become even more important. Several counties have implemented various techniques to strengthen/repair damaged piling, however, there is minimal data documenting the effectiveness of these techniques. There are numerous instances where cracked and failed pilings have been repaired. However, there are no experimental data on the effectiveness of the repairs or on the percentage of load transferred from the superstructure to the sound pile below.

To address the research needs, a review and evaluation of current maintenance and rehabilitation methods was completed. Additionally, a nationwide survey was conducted to learn the methods used beyond Iowa. Field investigation and live-load testing of bridges with certain Iowa methods was completed. Lastly, laboratory testing of new strengthening and rehabilitation methods was performed.

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TIMBER ABUTMENT PILING AND BACK WALL REHABILITATION AND REPAIR

Final Report
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The authors would like to thank the county engineers in Iowa who helped identify and locate bridges for field investigation and testing. Thanks to Doug Wood, Iowa State University Structures Laboratory manager, for assisting with laboratory testing.

EXECUTIVE SUMMARY

Based on previous National Bridge Inventory data, the state of Iowa has nearly 20,000 bridges on low-volume roads (LVRs. Thus, these bridges are the responsibility of the county engineers. Of the bridges on the county roads, 24 percent are structurally deficient and 5 percent are functionally obsolete. A large number of the older bridges on the LVRs are built on timber piling with timber back walls. In many cases, as timber abutments and piers age, the piling and back wall planks deteriorate at a rate faster than the bridge superstructure. As a result, a large percentage of the structurally deficient bridges on LVRs are classified as such because of the condition of the timber substructure elements.

As funds for replacing bridges decline and construction costs increase, effective rehabilitation and strengthening techniques for extending the life of the timber substructures in bridges with structurally sound superstructures has become even more important. Several counties have implemented various techniques to strengthen/repair damaged piling, however, there is minimal data documenting the effectiveness of these techniques. There are numerous instances where cracked and failed pilings have been repaired. However, there are no experimental data on the effectiveness of the repairs or on the percentage of load transferred from the superstructure to the sound pile below.

To address the research needs, a review and evaluation of current maintenance and rehabilitation methods was completed. Additionally, a nationwide survey was conducted to learn the methods used beyond Iowa. Field investigation and live-load testing of bridges with certain Iowa methods was completed. Lastly, laboratory testing of new strengthening and rehabilitation methods was performed.

Deterioration of timber substructure elements, attributed to biological or physical deterioration mechanisms, and the methods and tools used to assess their condition is presented. Furthermore, preservative treatments are discussed with respect to bridge applications. Copper naphthenate is the preservative most commonly used among the respondents of a nationwide survey.

Results from Iowa field investigations and live-load testing of currently used repair and rehabilitation methods are presented. Most of the evaluated techniques exhibited their effectiveness by restoring the desired stiffness. The additional methods of repair and strengthening evaluated in the Iowa State University structures laboratory showed promise of improving techniques currently used in Iowa counties.

1 GENERAL

1.1 Introduction

Based on previous National Bridge Inventory data, the state of Iowa has nearly 25,000 bridges, which rank it fifth in the nation, behind Texas, Ohio, Illinois, and Kansas. In Iowa, close to 80 percent of these bridges are on low-volume roads (LVRs) and, thus, are the responsibility of the county engineers. Of the bridges on the county roads, 24 percent are structurally deficient and 5 percent are functionally obsolete. A large number of the older bridges on the LVRs are built on timber piling with timber back walls. In many cases, as timber abutments and piers age, the piling and back wall planks deteriorate at a rate faster than the bridge superstructure. As a result, a large percentage of the structurally deficient bridges on LVRs are classified as such because of the condition of the timber substructure elements. This situation is especially common for bridges constructed in the period 1950-1970 that have reinforced concrete stringers and decks or reinforced concrete decks with steel stringers and timber substructure elements. The soil/water/air interface area of the piling is particularly prone to severe cracking and rot. Because there have been instances where bridges with legal rated superstructures and no load posting have failed under traffic loading due to pile failure, this represents a critical infrastructure situation.

As funds for replacing bridges decline and construction costs increase, effective rehabilitation and strengthening techniques for extending the life of the timber substructures in bridges with structurally sound superstructures has become even more important. Several counties have implemented various techniques to strengthen/repair damaged piling, however, there is minimal data documenting the effectiveness of these techniques. There are numerous instances where cracked and failed pilings have been repaired. However, there are no experimental data on the effectiveness of the repairs or on the percentage of load transferred from the superstructure to the sound pile below.

1.2 Research Objectives and Scope

The objectives of this investigation are to:

- Review existing products for timber preservation and repair and to document their effectiveness in extending the life expectancy of various bridge components.
- Determine techniques used by county engineers and other engineers to repair and restore load carrying capacity of piling damaged by deterioration and cracking.
- Review methods used to repair failed piling.
- Determine/develop effective methods for transferring bridge loads through the failed portion of the pile.
- Determine that safe load capacity is restored by the repair methods (existing or new) determined to be structurally efficient.

1.3 Report Content

This report is divided into nine chapters. A brief review of deterioration mechanisms in timber bridges is presented in Chapter 2. Methods for pile condition assessment are presented in Chapter 3. Chapter 4 presents preservative treatment options for timber bridge elements. The state of practice of pile maintenance is reported in Chapter 5. Chapter 6 presents the results of a survey administered throughout the United States regarding timber pile and abutment back wall repair and rehabilitation methods. Results from four live-load field tests are presented in Chapter 7. Methods developed and modifications of existing methods to strengthen timber piles are presented in Chapter 8. Lastly, conclusions and recommendations are presented in Chapter 9.

2 DETERIORATION MECHANISMS IN TIMBER BRIDGES

In Iowa, low-volume bridge foundation problems are often associated with timber substructures (White et al. 2007). Timber piles are subjected to deterioration, which, at initial stages, can be difficult to detect. Furthermore, information regarding the soil profile and pile length at a given bridge site is often unavailable. There are currently no reliable means to estimate the residual capacity of an in-service deteriorated pile; and thus, the overall safety of the bridge cannot be determined with confidence. Although the majority of inadequate substructures have timber piling, there are numerous cases in which the steel substructures are inadequate (problems with corrosion, misalignment, damage due to impact, etc.). If procedures can be developed to assess the integrity of existing timber substructures and rehabilitate/strengthen inadequate substructures components, it will be possible to extend the life of those bridges and have increased confidence in predicting their performance.

2.1 Biological Deterioration

In most timber bridge applications, decay fungi are the most destructive organisms (Bigelow et al. 2007). 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 rank second to fungi with respect to damage to wood structures in the US (Bigelow et al. 2007). 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 the decay caused by 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 hazards 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 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 percent to sustain any growth, and higher moisture contents (over 29 percent) are required for initial reproduction (Highley 1999). Most brown and white rot decay fungi prefer wood in the moisture content range of 40 to 80 percent. 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, void spaces in the wood are increasingly filled with water as the moisture content exceeds 80 percent. The lack of oxygen and build-up of carbon dioxide in the water limits fungal growth (Bigelow et al. 2007).

2.2 Physical Deterioration

There are several forms of physical deterioration that occur in timber bridge piling and back walls, as shown in Figure 2-1. In almost all cases, the physical deterioration causes exterior damage that breaks down the protective preservative barrier and allows entry of biological decay mechanisms into the untreated wood. One of the most common types of physical deterioration is abrasion or debris damage. This generally occurs by the impact of floating debris and/or ice in a channel (White et al. 2007). The velocity of water moving past the pile and the quantity, shape, size, and hardness of particles being transported have been linked to the rate of abrasion (U.S. Army Corps of Engineers et al. 2001).

(a) Mechanical Damage **(b) Debris Damage** **(c) Fire Damage** **(d) Weathering/UV Damage**

Figure 2-1 Breaks in preservative barriers by exterior damage leads to premature decay (Bigelow et al. 2007)

Overloading of piles can result from continuous heavy loads, infrequent severe loads, loss of the pile structural capacity, or more frequently, complete loss of adjacent supports (White et al. 2003). Failure of one pile requires the adjacent piles to carry additional load. Overloading can be caused by vertical and/or horizontal loads. Continuous overloading results in several modes of compression failure including splitting of the top portion and misalignment or “mushrooming” at a hollow portion after breakage (USDA 1999). These stages include development of initial entry

holes, active deterioration of the inner core with a significant increase in the size of the hollow space, compression failure of the shell, and finally separation of the hanging top portion of the pile from the pile cap (Buslov and Scola 1991). In addition, overloading can occur from the mechanical fasteners used to connect bridge elements. Many times fasteners are over tightened causing bulging around the head, nut, or washer. The bulge generally leads to entry holes for deterioration of the inner portions of the timber to occur.

Fire is a threat to all timber bridge elements and has the potential to destroy an entire bridge in a matter of hours. However, thermal degradation of wood occurs in stages. The degradation process and the exact products of thermal degradation depend upon the rate of heating as well as the temperature (White et al. 2007). A timber pile has a generally uniform strength throughout its cross section. Thus, the unburned section of the timber pile retains its strength, and its load carrying capacity is reduced in proportion to the loss of cross section. When exposed to high temperatures, wood will decompose providing an insulating layer of char that retards further degradation. Therefore, the amount of charring of a cross section controls the fire endurance of a timber pile (USDA 1999).

Other noteworthy physical agents that damage timber piles are connection failure, which exposes untreated wood allowing entry for fungi or insects, ultraviolet (UV) degradation, chemical degradation, and foundation settlement (Manuel 1984).

3 TIMBER CONDITION ASSESSMENT

A number of tools exist to assist the inspector with the diagnosis of deterioration and preventive maintenance (Bigelow et al. 2007). 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 consistency between inspectors.

3.1 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 (Bigelow et al. 2007). 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 and degradation or may suggest areas of future concern (Bigelow et al. 2007).

- **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
- **Staining:** 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

3.2 Probing and Pick Test

Use of an awl or other sharp pointed tool can be used to detect soft spots created by decay fungi or insect damage (Bigelow et al. 2007). 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, and 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 interpret the results reliably.

3.3 Moisture Measurement

Moisture measurements are taken with an electronic hand-held moisture meter (Bigelow et al. 2007). The moisture meter consists of two metal pins that are driven into the wood. The meter displays a measurement of electrical resistance (moisture content) between the pins. Moisture content greater than 20 percent 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.

3.4 Sounding

In this method, a hammer is used to strike the wood surface (Bigelow et al. 2007). Based on the tone, the inspector might 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 is best used in conjunction with other inspection methods (Ross et al. 1999).

3.5 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 defects. 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).

A single stress wave measurement can only detect internal decay that is above 20 percent of the total cross section of a timber pile (White et al. 2007). Therefore, multiple tests are often

conducted to increase the test reliability. In the field, however, it is not always feasible to access the complete circumference of the pile due to the presence of a backwall behind the timber pile. The impulse response (Ir) is determined by coupling the sensors with the timber surface. Most piles exhibit splits and cracks, which results in poor acoustic coupling between the transducer and the timber surface leading to unstable reading (Emerson et al. 1998). Furthermore, in severe internal pile deterioration, and due to high stress wave attenuation in void spaces, a stress wave travel time measurement may not be obtained.

3.6 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).

3.7 Core Boring

Increment core borings of representative areas should be taken perpendicular to the face of the member being sampled (Bigelow et al. 2007). 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.

3.8 Preservative Retention Analysis

In most cases, the pressure-treated shell in bridge members contains more than enough preservative to protect the wood (Bigelow et al. 2007). 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.

3.8.1 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.

3.8.2 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).

3.8.3 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).

3.8.4 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, and 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.

4 TIMBER PRESERVATIVE TREATMENTS

Both plant-applied and in-place applied preservative treatments are expected to protect timber members from attack by a broad range of organisms without posing significant risks to people or the environment (Bigelow et al. 2007). 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 a 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.

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 and/or environment. When the application is structurally critical, such as a primary support member in a bridge, increased retentions are often specified to help ensure durability. Overtreatment, however, may provide little additional durability while increasing the risk of environmental concerns.

4.1 Plant-Applied Preservative Treatments

A summary of 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, 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 taken into account in the design process.

Table 4-1 Properties and uses of plant-applied preservatives for timber bridges (Bigelow et al. 2007)

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	Ammonia cal 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)	Pentachlorop henol 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	Pentachlorop henol 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 understand these factors better for long term performance, the USDA Forest Service Forest Product Laboratory has conducted various field tests since the 1930s. The FPLs comparison of treated posts is expected to be 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 a sufficient number of posts had failed to allow calculation of expected service life as shown in Table 4-2. The posts were treated to retentions below those currently specified in AWPA standards; however, the preservative treatments are performing surprisingly well.

Table 4-2 Estimated service life of treated round fence post in southern Mississippi (Bigelow et al. 2007)

Preservative	Average Retention (lb/ft^3)	Estimated Service Life (years)	90 percent Confidence Limits for Service Life (years)	
			Lower	Upper
Copper Naphthenate	0.03	65	55	78
Creosote	5.60	54	47	62
Pentachlorophenol	0.32	74	60	91
ACA	0.34	60	51	69
Untreated	0	2.4	2.1	2.7

Bigelow et al. (2007) conducted field investigations of several timber bridges in the state of Iowa to determine the life expectancy of various bridge components. The life expectancy, however, was difficult to determine 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 with 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 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. Bridges treated with pentachlorophenol and copper naphthenate were too few and too new to determine any longevity trends from field inspections.

Field investigations (Bigelow et al. 2007) 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 did. 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 compared 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 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 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. Both metal and building felt caps were used for protection, however, metal caps were found to have better longevity and durability.

4.1.1 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 (Bigelow et al. 2007). The AWPA Standard-07 contains standards for Use Category System (UCS) Standards, Non-pressure 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 4-3 shows the use category, Commodity Specifications, and Processing Standard for most timber bridge elements.

Table 4-3 AWPA use category and commodity specifications for timber bridge elements (Bigelow et al. 2007)

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 states 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. Various components for an effective maintenance program are presented in the guidelines. 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 herein are the same inspection tools presented in the guidelines. However, partial and full excavation techniques are additional steps outlined that help to ensure decay is not occurring below the surface. After inspections have taken place, evaluation of the structural integrity must be completed as well as the in-place maintenance or remaining service life. In-place treatments 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.

4.2 In-Place Preservative Treatments

On-site fabrication of timber bridge components (Bigelow et al. 2007) typically results in breaks in the protective plant-applied preservative barrier. Pile tops, which are typically cut to length after installation, specifically need reapplication of an in-place 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 a 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 a 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.

A summary of the in-place preservatives discussed herein is presented in Table 4-4. For comparison, the table includes information on application locations, leaching and diffusing characteristics, bridge applications, and handling.

Table 4-4 Properties and uses of in-place preservatives for timber bridges (Bigelow et al. 2007)

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-Hydroxide, borates	Oil or 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

4.2.1 Surface Treatments

The simplest method for applying a supplemental preservative treatment during fabrication (Bigelow et al. 2007) or routine maintenance involves brushing or spraying the 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 is 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.

4.2.1.1 CuNap

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

4.2.1.2 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.

4.2.2 Pastes

Another type of surface treatment are the water soluble pastes containing combinations of copper naphthenate, sodium fluoride, copper hydroxide, or borates (Bigelow et al. 2007). 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, the pole is covered with a wrap to hold the paste against the pole and to prevent loss into the soil. In bridge piles, this type of paste application should be limited to terrestrial piles that will not be exposed continually or frequently 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.

4.2.3 Diffusible Chemicals

Surface-applied treatments often do not penetrate deeply enough to protect the inner portions of large bridge members (Bigelow et al. 2007). 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 using 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 when 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 percent, little chemical movement occurs, but growth of decay fungi is also substantially arrested below 30 percent 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 RUPs 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.

4.2.4 Fumigants

Like diffusible chemicals, fumigants are applied in liquid or solid form in predrilled holes (Bigelow et al. 2007). However, they then volatilize into a gas that moves through the wood. One type of fumigant has been shown to move in poles more than 8 ft from the point of application (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 size of timber being treated.

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.

4.2.4.1 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 retreatment 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 that are inhabited permanently 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 to workers if chloropicrin leaks out of checks and splits in the wood. The tubes further allow for applications above ground where liquid material would typically flow out (Morrell et al. 1996).

4.2.4.2 Methylisothiocyanate (MITC)

Methylisothiocyanate (MITC) is the active ingredient in several fumigants, but is also available in a solid-melt form that is 97 percent 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 hole. This formulation provides ease of handling and application to drilled treatment holes that slope upward.

4.2.4.3 Metham Sodium (Vapam)

Metham sodium (sodium N-methldithiocarbamate) is a most widely used fumigant. However, metham sodium must decompose in the presence of wood 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).

4.2.4.4 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 percent. 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 speed up the breakdown process.

5 PILE MAINTENANCE STATE OF PRACTICES

Ritter (1992) divided pile maintenance activities into three categories. The first category is preventive maintenance, in which the repair involves keeping the structure in a “good state”. At this stage, deterioration has not started, but the conditions or potential are present. The second category is early remedial maintenance. At this stage, deterioration is present; however, the capacity or performance of the structure is not affected. More severe damage is imminent unless corrective action is taken. The last category is major maintenance, which involves immediate corrective measures to restore the structure to its original condition (White et al. 2007).

5.1 Preventive Maintenance

5.1.1 Moisture Control

The simplest preventive maintenance for timber piles is moisture control (White et al. 2007). Moisture control can be used as an effective technique to extend the service life of many timber piles. When exposure to moisture is reduced, timber piles will dry to moisture contents below that required for fungus and insect growth (Ritter 1992 and Seavey and Larson 2002). Timber abutments placed up and away from stream banks will have an extended service life compared to elements near the stream that are repeatedly going through wet and dry cycles.

5.1.2 In-Place Treatments

In-place treatments, as described previously, are another common preventive maintenance technique applied to timber piles. Surface treatments, paste, and fumigants are three types of in-place treatment that are frequently used.

5.1.3 Repair Small to Medium Cracks

Small to medium cracks and splits caused by weathering or shrinkage create pathways for decay fungi to enter the untreated wood at the core of the timber pile (White et al. 2007). Therefore, cracks and splits must be repaired regularly. Epoxy grout can be injected under pressure for filling checks and splits. The epoxy seals the affected area preventing water and other debris from entering. It can also restore the bond between separated sections, increase shear capacity, and reduce further splitting. Low viscosity epoxy is injected to fill the void, which is then sealed using a sealing epoxy (U.S. Army Corps. of Engineers et al. 2001 and Ritter 1992).

5.2 Remedial Maintenance

Once wood decay has begun, it tends to grow exponentially. Often the damage caused by decay is localized around the wet-dry area near the water level, which can cause strength reduction. Restoring strength of the pile elements by repairing the damaged portion can be achieved by many techniques (Purvis 1994).

5.2.1 Posting/Splicing

This method is used for repairing timber piles that are deteriorated at or above the ground level. The method involves cutting out the deteriorated section and replacing it with a new timber treated section. No more than half the piles in a bent should be repaired using this method.

In general, the posting technique uses a timber strut to support the hydraulic equipment needed to lift the pile cap. The old section is cut below the damaged, rotted, or insect infested area. The new pile section is then placed at the same location as the original pile (White et al. 2007) Connecting the new section to the original pile can be done using concrete jackets or fishplates as shown in Figure 5-1.

If the concrete jacket is used, there should be a minimum cover of 6 inches around the pile. Using concrete jackets as a splicing method greatly enlarges the pile diameter, which could cause flow restrictions on the waterway (Wipf et al. 2003).

If fishplates are used, they must be treated and bolted to the pile using galvanized bolts. All ends and cuts must be treated (Wipf et al. 2003 and U.S. Army Corps of Engineers et al. 2001). There is difficulty in providing full load transfer using mechanical connectors in wood. Furthermore, the flexural stiffness of the pile is usually greatly reduced, and the mechanical connections are subject to corrosion (Avent 1989).

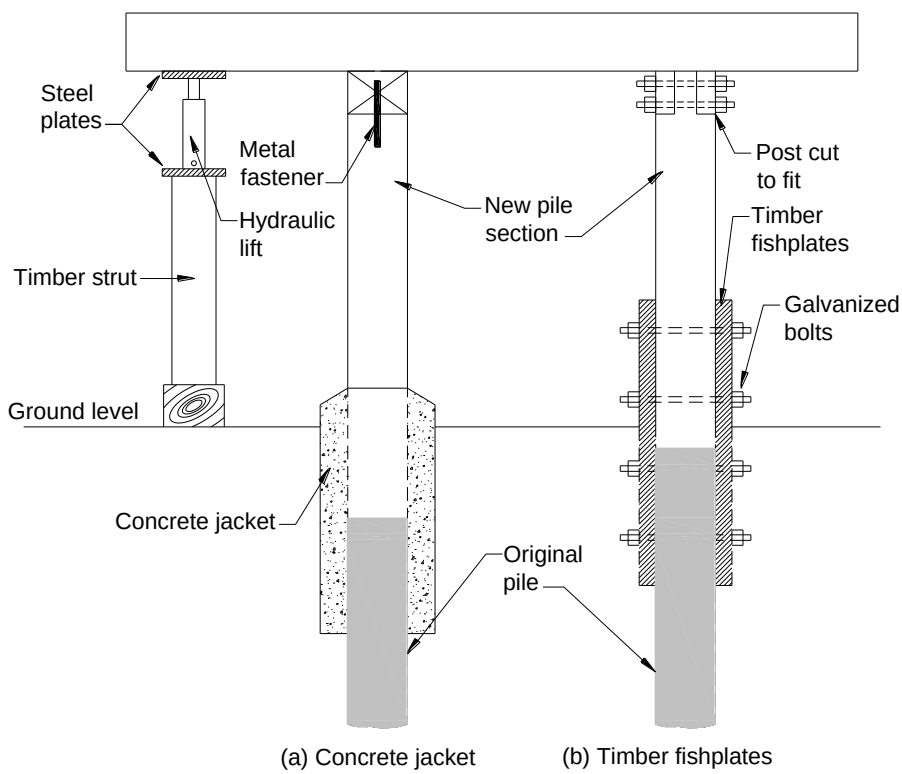


Figure 5-1 Splicing timber piles using concrete jacket or timber fishplate (White et al. 2007)

Avent (1989) developed an economical pile repair procedure that consisted of posting and epoxy grouting timber piles. The repair method consists of cutting the deteriorated section out of the pile. A replacement section of similar diameter should be cut approximately 1/4 to 1/2 in. less than the length of the void. Approximately 9 in. above and below where the new section is to be placed a 1/4 in. wide by 1 in. deep trench is circumferentially placed in order to prevent longitudinal migration of the injection epoxy. The replacement section should then be placed in position and wedged tight in-place while maintaining a 1/8 to 1/4 in. gap at top and bottom. After the new section is in place, 4 -14 in. pilot holes are drilled at a 60 degree angle from horizontal from the existing pile into the new pile section. The tie pins are 3/8 in. square bars twisted to form a spiral with one revolution for each 6 in. of length. The injection and venting ports are placed at the two joints and at the opening of each pin. Then the epoxy trenches and outside surface of the section are filled completely with an epoxy gel, such as Sika Dur Hi-Mod Gel, to form an air tight seal around the joints. A low viscosity epoxy, such as Sika Dur Hi-Mod LV is pressure injected into the injection ports. When epoxy leaks from the vents, a plug is inserted. When all vents are plugged and the joint holds 20 psi for 5 seconds, the injection port is plugged and the procedure is complete; this repair method is illustrated in Figure 5-2.

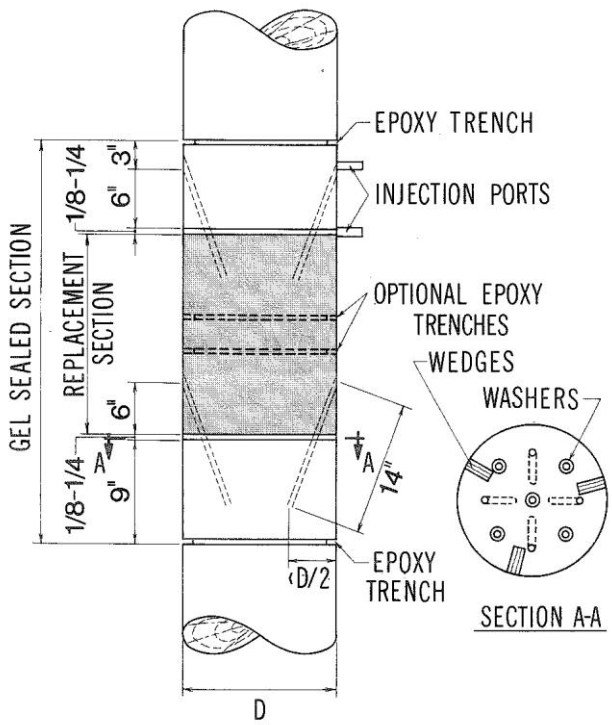


Figure 5-2 Schematic layout of posting and epoxy grouting repair (Avent 1989)

Laboratory testing was conducted (Avent 1989) on the post/epoxy technique. Axial compression load tests showed the pile's original ultimate strength and axial stiffness was restored after the repair. The flexural ultimate strength, however, was found to be reduced by 50 percent to 75 percent. Even so, the test revealed very little change in the modulus of elasticity. The durability of the technique was also evaluated at a repaired bridge in Alexandria, Louisiana; the bridge was monitored for four years and no signs of deterioration were found.

White et al. (2007) investigated two posting type repair methods. For each method, two new timber pile sections, each 4 ft long, were tested to failure in axial and/or bending. The piles were then repaired using the selected repair method and the percent restoration of compressive strength and bending capacity was measured. Two control pile sections, where the cross sectional area was reduced by about 50 percent to simulate pile deterioration, were also tested. The repair methods investigated were as follows:

Repair Method A: Mechanical Splicing

The mechanical splice utilized lap splices at each end of the stub section that were connected to the original pile section with metal screws that were 0.5 in. in diameter and 12 in. long. The repair section, shown in Figure 5-3, was tested in axial compression and in bending. The results of the axial compression tests show that Repair Method A restored about 70 percent of the axial capacity of the original pile. When compared to the control sections that were tested, the repair exceeded the full axial load carrying capacity by 2 percent. The bending test showed the mechanical splice restored only 20 percent of the ultimate flexural load. The repair had just over 2 in. of deflection at failure.

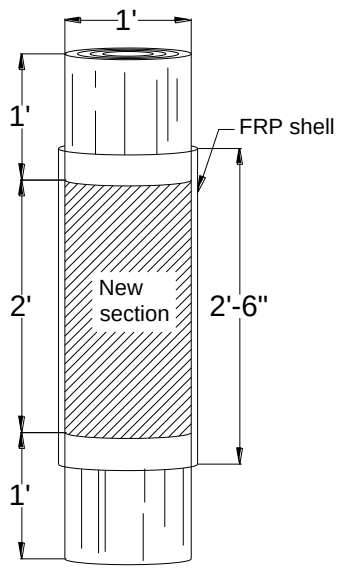
(a) Schematic diagram of the repair method **(b) Connecting the pile sections using metal screws**

Figure 5-3 Repair Method A (White et al. 2007)

Repair Method B: Replacing the damaged section with a new section and a FRP wrap

Repair Method B consisted of removing a 2 ft long damaged section and replacing the damaged piece with a new pile section. The new and old pile sections were connected together by wrapping the timber pile with five unidirectional glass fabric sheets. Each sheet had an overlap of approximately 7 in. and each overlap was staggered to avoid lines of weakness. Prior to wrapping the FRP sheets, a special epoxy, used typically for bonding applications, was prepared and applied to the FRP sheets; the repair can be seen in Figure 5-4.

The results of the axial compression test showed that the repair restored nearly 100 percent of the axial capacity; however, the deflection was approximately 10 percent higher. When compared to the control section, the repair exceeded the axial capacity by 20 percent. The repair restored approximately 50 percent of the ultimate bending load in the original pile, while the repair achieved 80 percent of the ultimate bending capacity of the tested control section.



(a) Schematic diagram of the repair method

(b) Actual repaired section

Figure 5-4 Repair Method B (White et al. 2007)

The Army and Air Force (1994) also developed a quick and simple posting technique for repairing piles. If only a single pile in a bent needs repaired, the Army and Air Force recommend cutting the pile 2 ft below the mud line, then placing a stub pile in for the defective portion. A 3/4 in. diameter center drift pin and three angle sections 2 ft long attached around the outside third points with lag screws are used to connect the piles. If multiple piles need to be replaced, the Army and Air Force recommend cutting the piles 2 ft below the mud line and placing a mudsill on the portion of the piles remaining. The stub piles are then set on top of the mudsill and connected to the mudsill with drift pins and angles.

5.2.2 Concrete Jacketing

According to NCHRP Report No. 222, concrete jacketing may be used for repairing timber, steel, or concrete piles. Concrete jacketing can be used when approximately 10 to 50 percent of the cross sectional area of the pile has been lost by deterioration (Purvis 1994 and Wipf et al. 2003).

A jacket form is wrapped around the length of the damaged area (White et al. 2007). The forms could either be flexible forms or split fiberboard forms. For the flexible form, the zipper should be closed, and the form is secured to the pile top and bottom, while for split fiberboard form, straps are installed and secured every 1 ft (Wipf et al. 2003). A reinforcing cage is installed

around the pile using spacers to keep the reinforcement in place (Figure 5-5). The forming jacket is then placed around the pile and sealed at the bottom against the pile surface. Concrete is then pumped into the form through the top; the top surface of the pile jacket should be sloped to allow runoff (U.S. Army Corps of Engineers et al. 2001 and University of Virginia Civil Engineering Department et al. 1980). The Army and Air Force (1994) also recommend a minimum of 6 in. cover is needed around the pile and that a reinforcing cage made of #3 bars is placed within the concrete.

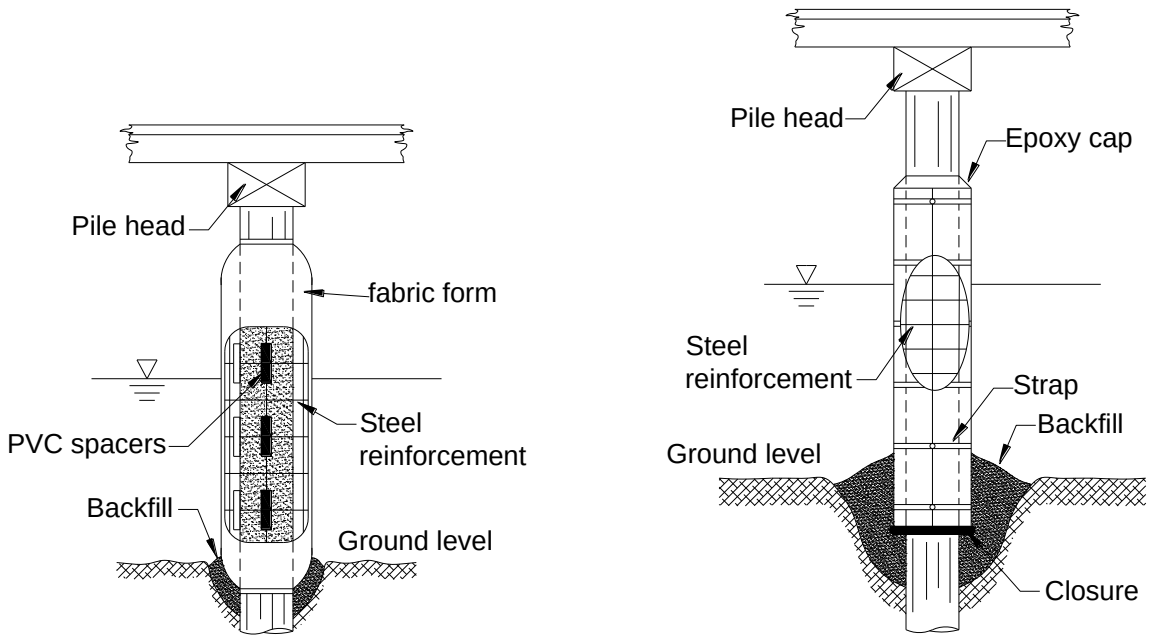


Figure 5-5 Concrete encasement repairs to timber, steel, or concrete piles (White et al. 2007)

Existing wood pile repair methods at the Portland Harbor in Maine were investigated by Lopez-Anido (2005). Three basic concrete jacket repairs were found at the harbor. The first consisted of a corrugated high-density polyethylene (HDPE) pipe encasing split into two halves and placed around the wood pile; the pipe was held together with circumferential metal straps. The space between the wood pile and the pipe was grouted with unreinforced concrete. During later observations, the circumferential straps were damaged and the pipe halves were opened. The concrete fill was deteriorated, spalling, and exposing the interior of the wood pile at the open joints. The second pile repair treatment, shown in Figure 5-6, used the same HDPE pipe; however, the pipe was installed as a continuous section, which eliminated the problem described previously. The third type of repair utilized a lap joint splice where the top portion of the old damage pile was removed and a new wood pile portion was spliced onto the existing using steel bolts, also shown in Figure 5-6.

5.2.3 Polyvinyl Chloride (PVC) Wrap

This repair method comprises of a flexible plastic wrap tightly drawn and attached to the timber pile. This method is useful for pile regions subjected to wet-dry cycles since those regions are

most vulnerable to biological deterioration (Webber and Yao 2001). The PVC wrap prevents the exchange of water behind the pile wrap and the surrounding environment essentially creating an environment toxic to wood parasites. PVC wraps can extend the life of infested piles by 35 years (U.S. Army Corps. of Engineers et al. 2001).

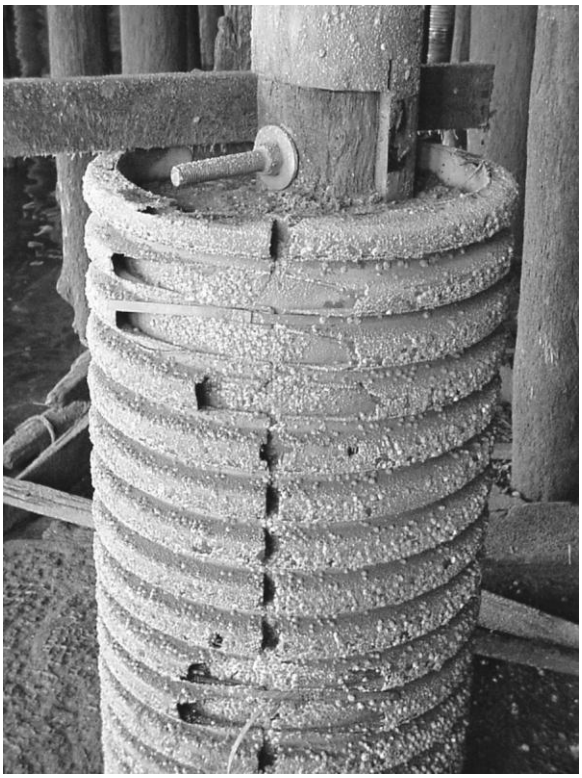
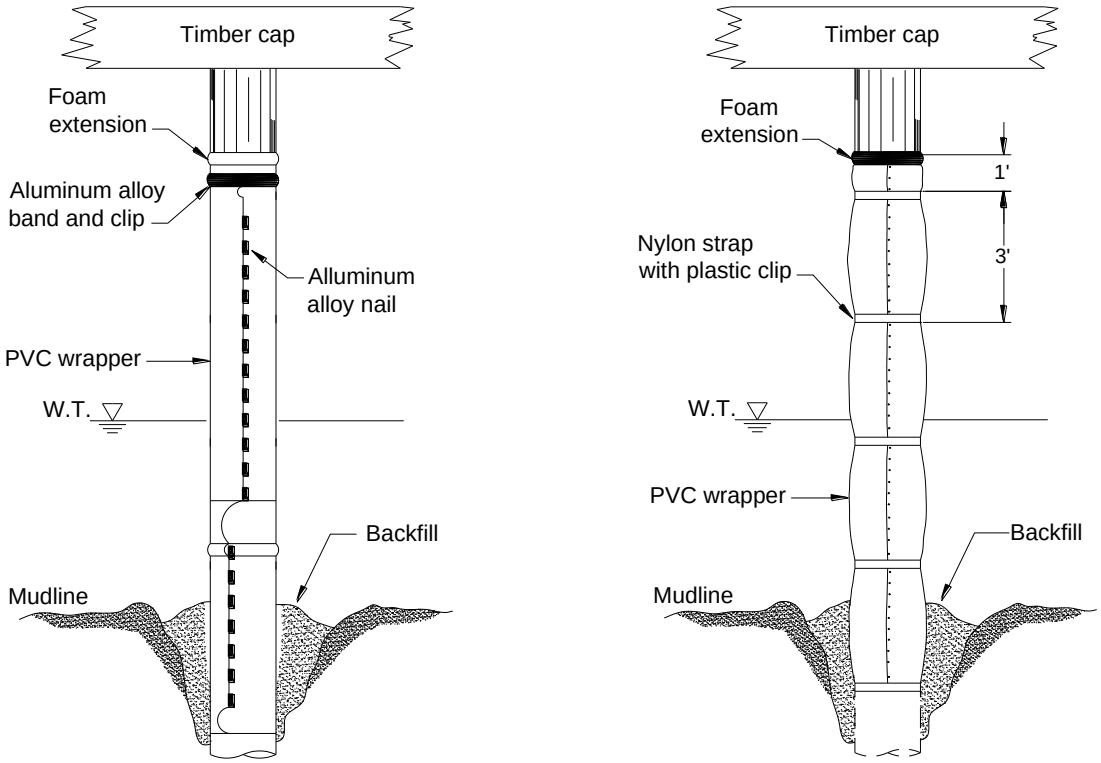


Figure 5-6 Repair method using HDPE pipe with a lap splice (Lopez-Anido et al. 2005)

The PVC wrap consists of an upper unit, which extends above the water level by at least 1 ft, and a lower unit, which overlaps the upper unit and extends below the ground level (White et al. 2003). The PVC wrap is tightened using wood poles and fastened using aluminum alloy bands around the top and bottom with aluminum nails placed along the vertical joints (Figure 5-7). This method is less expensive than concrete jacketing. In addition, the PVC wraps provide protection against abrasion (U.S. Army Corps. of Engineers et al. 2001). This method is used when deterioration is discovered and prevention of further damage is required; however, this method can only be used with wood piles that have adequate structural capacity, since the method does not provide structural restoration (Lopez-Anido et al. 2005).



(a) **Two-unit wrap** **(b) Single-unit wrap**

Figure 5-7 Wrapping timber piles with polyvinyl chloride (White et al. 2007)

5.2.4 Fiber Reinforced Polymer (FRP)

This method is used when pile deterioration has occurred, or when an increase in strength (retrofitting) of intact piles is desired. In either case, deterioration cannot be so extensive as to require replacement. This system provides shear transfer capability between the timber pile and the FRP composite shells, which strengthen the damaged portion. The FRP composite shells also act as a barrier between the wood and wood parasites (Lopez-Anido et al. 2004). The fiber reinforced polymer has both axial fibers, which contribute to both the axial stiffness and strength of the shell, and hoop fibers, which provide integrity to the flexible shell allowing the shear strength and mechanical fastener support to be developed (Lopez-Anido et al. 2005).

Upon review of methods that can be used for structural restoration of wood piles, Lopez-Anido et al. (2005) found two marketed products. One was Hardcore Composites of New Castle, Delaware, which developed the “Hardshell System.” The Hardshell System utilizes E-glass/vinyl ester composite shells that are constructed around the pile in two halves and are joined together by using bonded H connectors. Lopez-Anido et al. indicates the structural continuity in the circumferential direction is lacking due to the bonded area of the H connector being relatively small. Another company with a system that can be used to rehabilitate wood piles is Fibrwrap Construction, LP. The repair uses a fabric reinforcement that is wrapped around the pile and then impregnated with epoxy resin. Lopez-Anido et al. questions if the resin can cure properly in the presence of water.

In lieu of the limited applicability of the repair methods investigated, Lopez-Anido et al. (2005) proposed a new system utilizing FRP composite encasement that encapsulates and splices the deteriorated portion of the pile. The system can both increase the strength and replace deteriorated portions; however, the deterioration cannot be so extensive as to require replacement. The system provides shear transfer capability between the timber pile and the FRP composite shells.

The damaged portion of the pile is encased in a FRP shield made of bonded thin flexible FRP composite prefabricated cylindrical shells. The cylindrical shells have a slit that enables them to be opened and placed around the deteriorated timber pile. It is advantageous to encase the pile with a series of overlapping FRP shells. A minimum of two shells is recommended; even so, the number of shells used depends on the structural restoration required. The slits in each shell are staggered to avoid lines of weakness through the entire shield as shown in Figure 5-8.

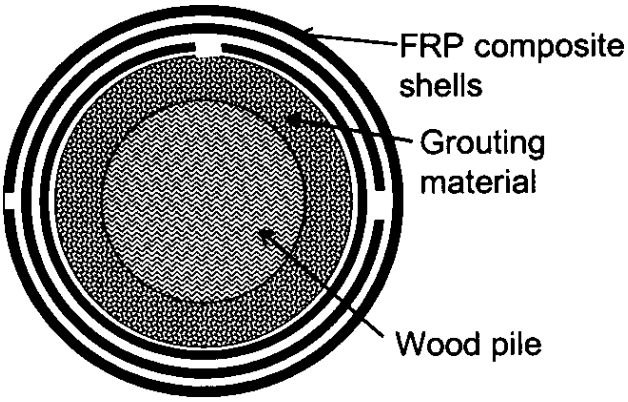
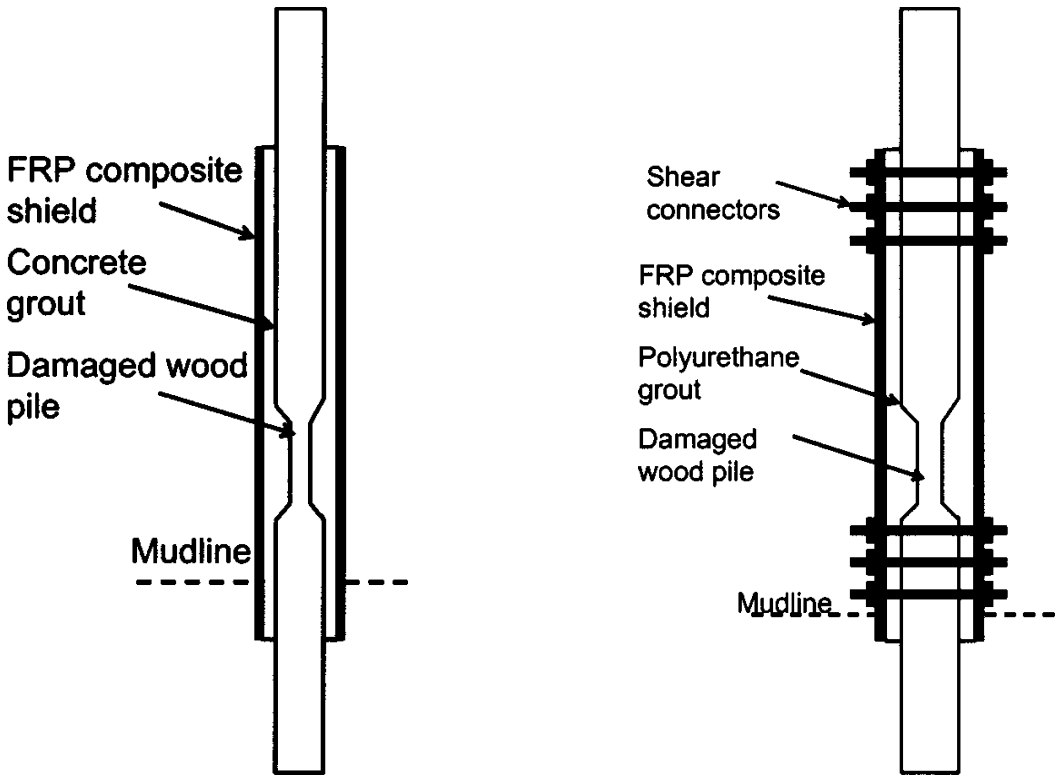


Figure 5-8 Cross-section of timber pile with FRP composite shells (Lopez-Anido et al. 2005)

As shown in Figure 5-9, there are two types of load transfer mechanisms between the timber pile and the FRP composite shield. The first is a cement-based structural grout, and the second is composed of steel shear connectors with an expanded polyurethane chemical grout. Installation of the systems is very similar. After the pile is cleaned, shear connectors, such as lag screws, are placed at the wood-grout interface. The shear connectors can also serve as spacers. The first FRP shell is opened and placed around the wood pile after which adhesive is applied on the interior of the second surface shell and the exterior of the first shell. The second shell is slid around the first with longitudinal gaps staggered to avoid lines of weakness. Note, the previous two steps are repeated if additional shells are needed. The shells are strapped together circumferentially until the adhesive cures; then the FRP shield is driven to the required depth. At this point, if shear connectors are used, holes need to be drilled and the shear connectors installed. Lastly, the grout is pumped into place from the bottom of the wrap in order to avoid segregation.



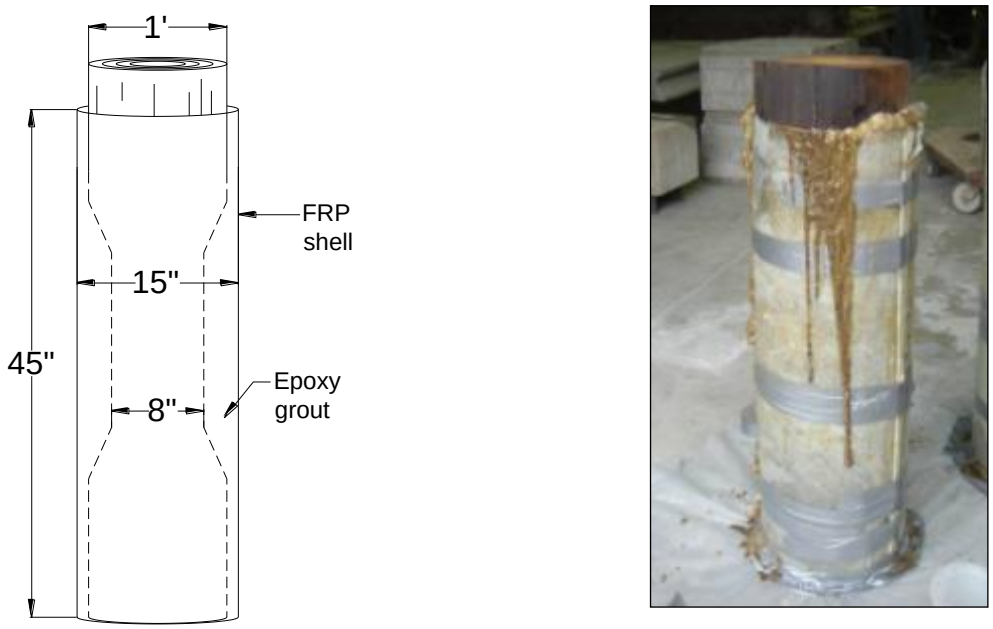
(a) Concrete grout **(b) Shear connectors and polyurethane grout**

Figure 5-9 FRP repair system (Lopez-Anido et al. 2005)

According to a study by Lopez-Anido et al. (2003), two pre-damaged timber piles with 60 percent reduction in cross section were rehabilitated using the two load transfer mechanisms. The pile repaired using FRP with cement-based structural grout had a bending capacity which exceeded an intact referenced wood pile. In addition, this load transfer mechanism resulted in three times the normalized peak load capacity of the intact reference wood pile. Only two thirds and 90 percent of the bending capacity and the normalized peak load capacity, respectively, were restored for the pile repaired using FRP and shear connectors mechanism. Furthermore, transfer of stresses from the FRP shield to the wood pile is better accomplished using cement-based grout than with steel shear connectors.

White et al. (2007) also investigated a FRP wrap repair method. The method, referred to as Repair Method C, comprised of removing 50 percent of the cross sectional area of the damaged pile similar to the control section mentioned previously. Then wrapping the pile with a FRP shell, and filling the void between the pile and the shell with a wood filler epoxy resin. The diameter of the FRP shell was about 15 in., whereas the diameter of the pile section was about 12 in. The diameter of the reduced pile cross section was a nominal 8 in. A PVC pipe with a 15 in. diameter was used to mold the FRP shell. Three FRP sheets were used to form the FRP shell. The FRP shell was placed around the pile section with approximately 1.5 in. gap to allow for placing the expandable wood filler epoxy. The repair method shown in Figure 5-10 restored approximately 70 percent and 88 percent of the axial capacity and control section capacity, respectively. The bending capacity of the repair section was restored to 70 percent and 175

percent of the ultimate load and control section ultimate load, respectively. Although the repair had the highest bending capacity restoration, one disadvantage of the repair is that is requires being slid over the top of the pile.



(a) Schematic diagram of repair method **(b) Actual repaired section**

Figure 5-10 Repair Method C (White et al. 2007)

Wood boring marine worms deteriorated and eroded the New York City Passenger Ship Terminal piers (Pile Repair 2006). To restore the piles, a fiber glass reinforced plastic pile encapsulation system was used. The system comprised of a molded fiber glass reinforced plastic jacket, epoxy grout, and aggregate mix. After the piles were abraded and cleaned, the plastic pile sleeves were placed around the piers. The pile sleeves had a single seam and resin bonded finish that eliminated the need to sand-blast for chemical adhesion of the epoxy. Then a two-component epoxy was pumped from the bottom of the sleeve upwards displacing the seawater. The epoxy, Sikadur 35, Hi-Mod LV/LTL, was developed by SIKA, and is lighter than cement filler, is moisture-tolerant, has low viscosity, and has high strength. The epoxy bonded sleeves strengthened the existing timber piles to their original strength.

FRP super laminates (Ehsani 2010), an advance thin flexible FRP that combines unidirectional and/or biaxial fabrics, have the potential to be very effective for pile repair. The super laminates can be wrapped helically around a column or pile in a continuous manner. As the laminate is wrapped around the pile the overlapping seams are coated with resins to create a seamless, solid, cylindrical shell around pile. The top of the laminate is then wrapped with a band of resin saturated fabric to prevent the top from opening due to its elastic memory. The annular space that is located between pile and super laminate can be filled with expansive grout or resin. A pressurized grout can also be pumped into the annular space to create improved confinement of the column and fill any voids on the surface or within the pile. The super laminate can also be

used in submerged locations with the use of moisture-insensitive epoxy putties. Piles being fitted with the FRP super laminates are shown in Figure 5-11.

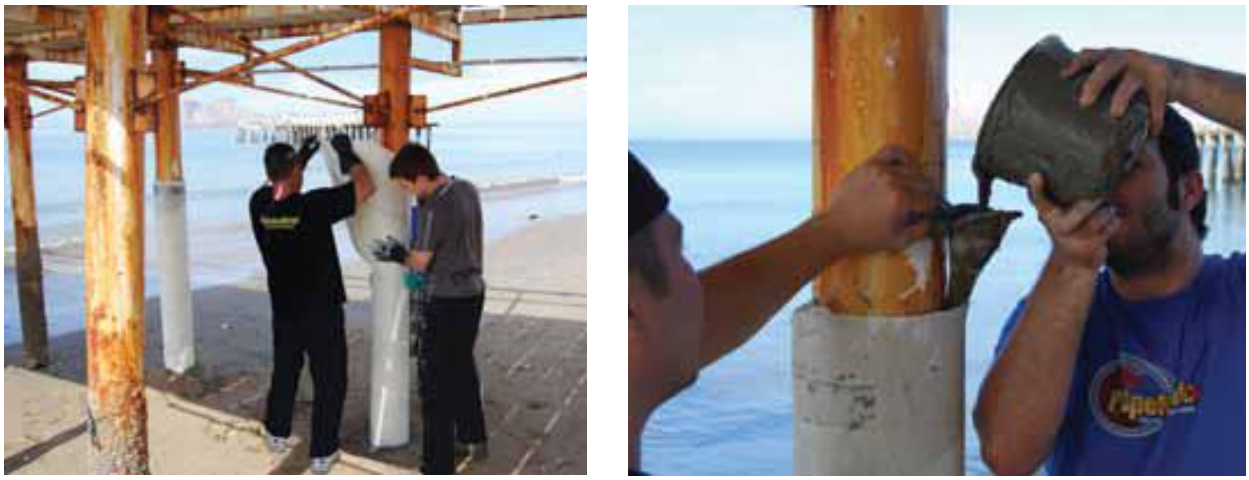


Figure 5-11 FRP super laminates helically wrapped around underwater piles (Ehsani 2010)

5.2.5 Epoxy Injected Piles

This method involves injecting a low-viscosity high pressure epoxy grout into the decayed and voided areas in piles. Prior to injecting the grout, the pile needs to be treated with an in-place treatment and the voids must be cleaned and flushed. In addition, the piles must be wrapped with a fiber material or the exterior cracks must be filled in order to prevent the grout from seeping out and not penetrating the voids.

The Oklahoma Department of Transportation (Emerson 2004) developed an in situ repair technique for decayed timber piles. The repair procedure, which was field tested on the Oklahoma Cotton County Bridge, consisted of first excavating around the pile to expose sound piling. Then holes were drilled through the outer shell and spaced to allow for cleaning and placement of fill material. The exterior and void within the pile was cleaned by vacuuming, flushing, and sawing. The timber was allowed to drain and dry. Next, more holes were drilled above and below the decayed portion and treated with borate rods to prevent any further decay. The treatment holes were plugged with dowels. The void space was then filled with aggregate filler. The pile was transversely wrapped with fiber material and set with resin. Holes were drilled once again in order to inject the epoxy resin mortar. The injection port holes were spaced so the mortar could travel upward filling all the voids. Injection ports were sealed and then an ultraviolet resistant coating was applied to the exposed composite surface. Lastly, the area was backfilled to original grade. Photographs of cross-sections cut from the repaired piles are shown in Figure 5-12.

Figure 5-12 Cross sections of field-repaired timber piles (Emerson 2004)

Four segments of the field repaired piles were tested in the laboratory under compression (Emerson 2004). Two of the segments contained repaired cores with reinforced fiberglass wrapped around the pile. One of the segments was solid wood with fiberglass wrapped around it. The last segment was a pile with a repaired core, but the fiberglass reinforcement was removed prior to testing. Generally, the wrapped piles failed when the fiberglass wrap began to fail. The non-wrapped segment failed at a lower strength when the wood shell separated from the core and the wood shell failed in compression. The results from the compression test found the three repaired and wrapped segments were stronger than required by the 1997 *National Design Specification for Wood Construction* design values and the *Wood Handbook* average compression strengths.

Historically, in 1973 the St. Louis-San Francisco ("Now: Grout-Filled Timber Piles" 1973) developed a method of injecting cement grout under pressure to fill the voids of defective piles. At the time the grout treatment was developed, the cost was one-tenth that of posting and would add 15 to 20 years of life to the piles. The method was tested at Bridge L-173.3 near Miami, Oklahoma. The bridge piling had been treated by the Osmose Wood Preserving Co. several months prior to grouting to allow the preservative time to penetrate the sound wood surrounding the voids. The treatment was needed to halt further decay of the pile. In order to inject the grout, the pile voids were drilled with 1-1/4 in. diameter holes with two or three 3/8 in. diameter holes above them to permit the release of air and show the progress of the grout. Prior to injecting, the voids were flushed with water and blown out with air to remove loose particles. When the pile's shell was less than 3 in. thick, 60d nails with washers were driven at 6 in. on center to provide shear connection between the grout and timber. The grout used consisted of two sacks of standard Portland cement, one sack of fly ash, a small bag of non-shrink ad-mixture, four cu ft of sand and 12 gallons of water. The grout, which tested at 2,100 to 2,400 psi after 28 days, was pumped into the void at approximately 100 psi. When grout was found to escape through cracks, a quick setting grout was rammed into the crack and briefly allowed to set. When the void was

filled, the pump nozzle was removed and all holes plugged. The crew was able to grout five six-pile bents per day, while only being able to cut and post two piles per day.

5.3 Major Maintenance

Major maintenance corrective measures are conducted when deterioration has progressed to the point where major structural components have experienced moderate to severe strength loss and repair or replacement is mandatory to maintain the load carrying capacity (Ritter 1992).

5.3.1 Addition of Supplemental Piles

There are two methods involving replacement of severely deteriorated timber piles (White et al. 2007). The first method involves the addition of supplemental steel or timber piles under a timber deck, while the second method involves adding supplemental steel or concrete piles under a concrete deck. Steel and timber piles can be supplemented by cutting the timber deck adjacent to the damaged pile. The new pile is driven and cut to fit under the pile cap. The pile is pulled laterally into place as shown in Figure 5-13. Shims are then placed as needed between the pile and pile cap. For timber piles, the pile is fixed to the pile cap using a 7/8 inch diameter drift pin, while, for steel piles, the pile is secured to the pile cap using a 1-1/4 inch expansion bolts (U.S. Army Corps. of Engineers et al. 2001).

Using a similar procedure, concrete and steel piles are driven through a concrete deck. The piles are cut below the top of the concrete deck, and a capital is formed under the deck, on top of the new pile. The capital is then cast with the new section of the concrete deck as shown in Figure 5-14 (U.S. Army Corps. of Engineers et al. 2001). Both methods are limited primarily due to cost.

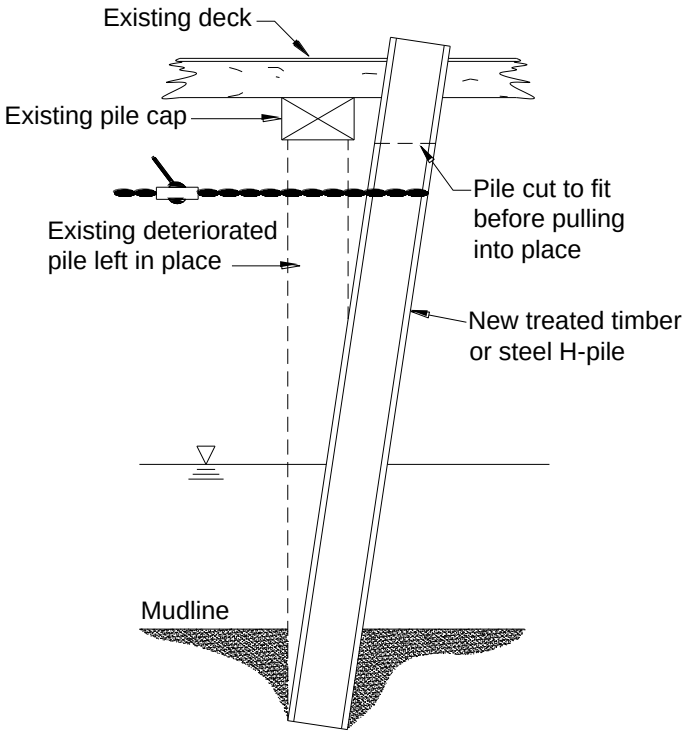


Figure 5-13 Addition of supplemental timber or steel piles (White et al. 2007)

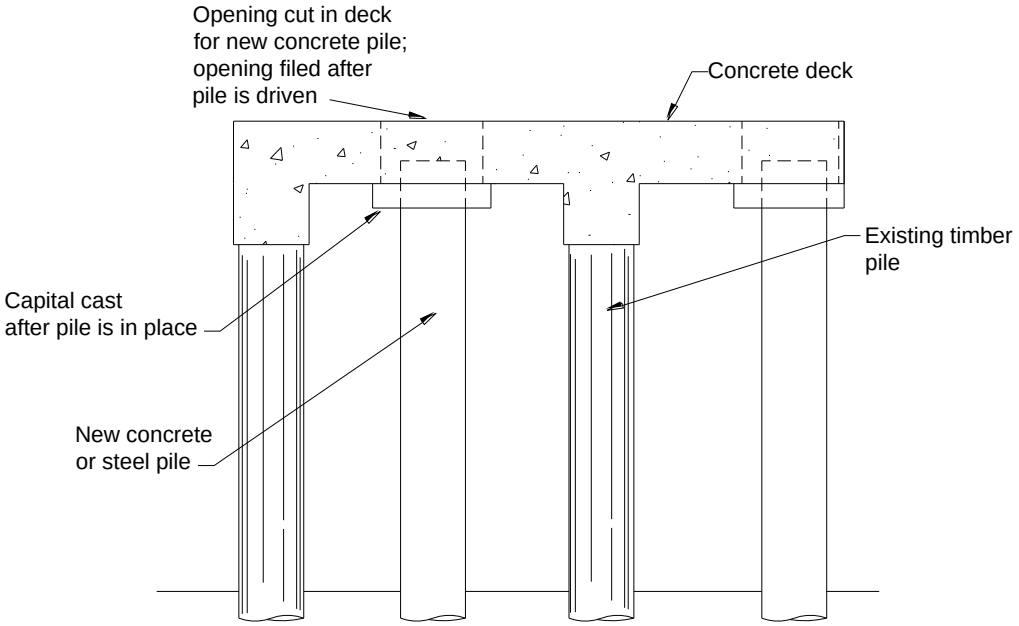


Figure 5-14 Addition of supplemental concrete or steel piles (White et al. 2007)

6 QUESTIONNAIRE STATE OF PRACTICE

To collect information about timber abutment repairs and rehabilitation, a multiple question survey was sent to federal, state, and local bridge owners across the nation. The survey was divided into five sections; 1) current and past usage of timber for bridges, 2) specific usage of timber back walls and wing walls, 3) timber piling and substructure repair, 4) use of timber preservatives, and 5) the potential for destructive and non-destructive testing of bridges within their inventory by the Bridge Engineering Center. The survey can be found in Appendix A

Overall, 93 agencies responded to the survey. Of the 93 respondents, 46 were Iowa county agencies 20 were non-Iowa county agencies, and 27 were state, federal, or Canadian providence agencies.

6.1 Iowa County Timber Repair

Forty-six Iowa counties (46.5 percent) responded in various levels to the questionnaire. Of the 46 counties, several were asked for additional information regarding their respective repairs and four counties were visited so that field investigations could be performed.

6.1.1 General Timber Use

Agencies were first asked if they currently or previously utilize timber in bridge piling or backwall substructures. Figure 6-1 shows the results for Iowa counties. Fourteen agencies stated they currently utilize timber and ten stated they currently and previously utilized timber. Therefore, over 50 percent of the Iowa county respondents currently utilize timber. Twenty-two respondents stated they only previously utilized timber and currently do not. Many of the respondents stated they do not use timber in bridges due to longevity of timber compared to that of steel and concrete. Several also stated that timber requires more frequent and earlier maintenance than other building materials.

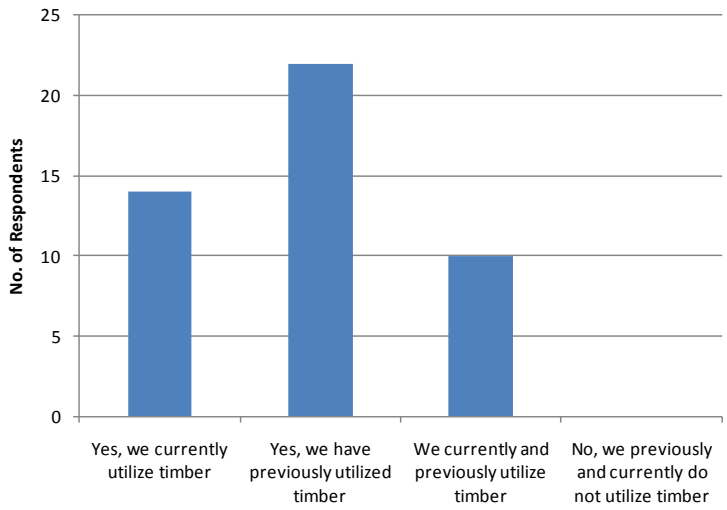


Figure 6-1 Iowa county utilization of timber piling or backwall results

6.1.2 Timber Back Wall/Wing Wall Utilization

Agencies were asked if they have bridges with timber back walls in their current bridge inventory. As seen in Figure 6-2, all the Iowa counties that responded stated they have existing bridges with timber back walls. However, only 13 responded stated they construct new bridges using timber backwall. Many of the same reasons stated for not utilizing timber for bridges were stated for not using timber specifically for the back walls.

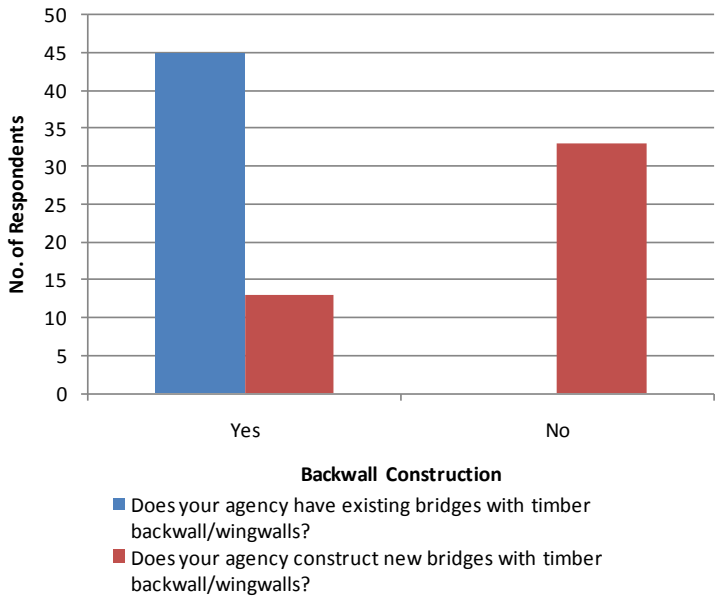
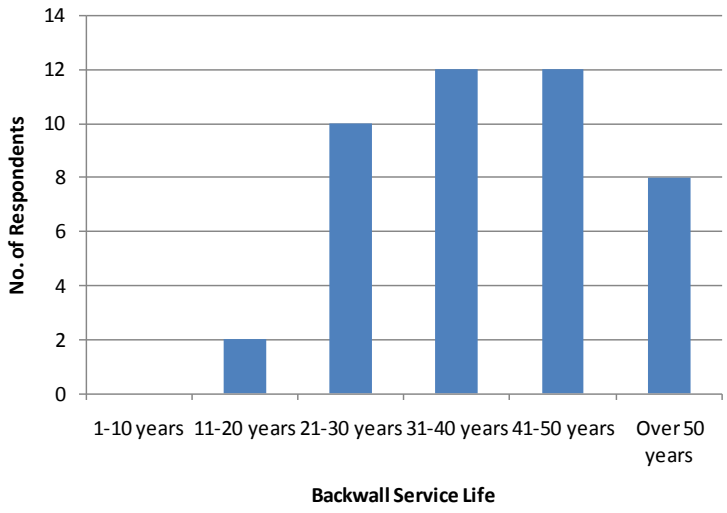
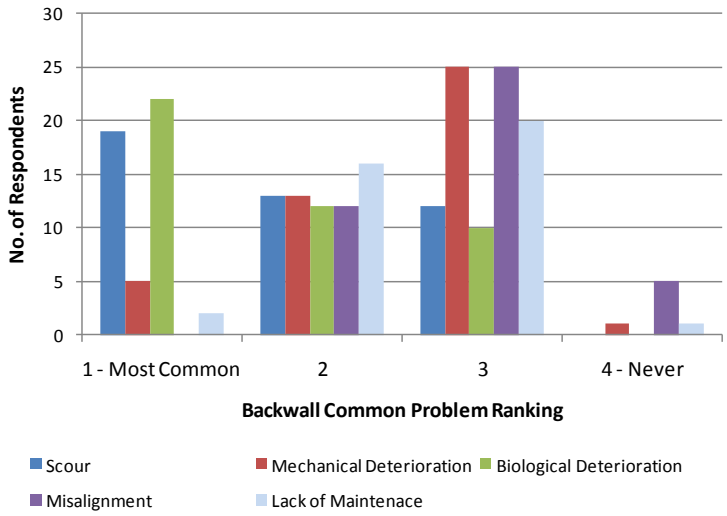


Figure 6-2 Iowa county past and current use of timber back walls or wing walls for bridges

The county engineers were also asked about backwall service life, common problems encountered with back walls, and what testing methods are used to determine if the backwall is deteriorated. Figure 6-3 shows the results from the three questions.

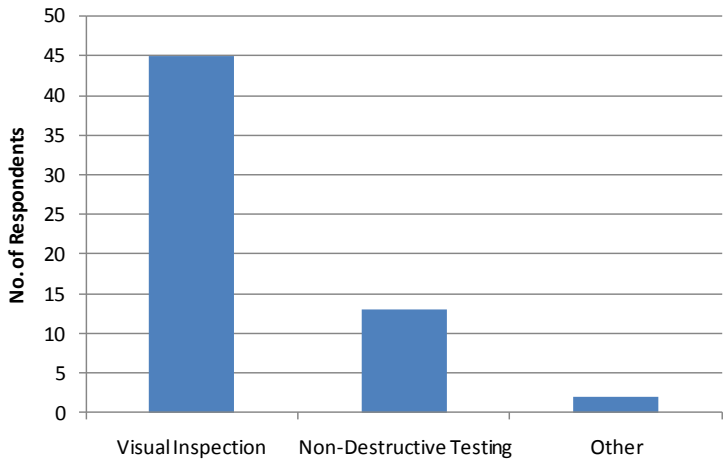


(a) Backwall service life



b) Backwall common problems

Figure 6-3 Iowa county timber backwall metrics



(c) Backwall condition evaluation

Figure 6-3 continued

As seen in Figure 6-3a, the relationship of respondents to service life is nearly parabolic with the curve peaking at approximately 40 years of service. Figure 6-3b shows the ranking counties gave for various problems encountered with timber back walls. The two most common problems are scour and biological deterioration. Although mechanical deterioration, misalignment, and lack of maintenance were not the most common problems encountered, they were still ranked as being a significant problem. In addition to the five listed problems, fire was also noted by several of the counties as being a problem. When asked what methods were used to detect backwall problems all responded that visual inspection was used. In addition, 13 counties also used a form of non-destructive testing which was generally described as sounding with a hammer. Other types of testing methods stated by respondents were boring, probing, and the pick test. Agencies were asked to describe any remedial and/or strengthening measures they have used to repair or restore the load carrying capacity of a backwall. The agencies responded with the following summarized repairs:

- Excavate abutment and remove and replace rotten plank
- Add fabric behind wall to prevent fill loss
- Tie back to deadmans
- Drive sheet pile behind rotten wall
- Use flowable mortar to replace deteriorated wood or to fill scour holes
- Drive additional piling

Of the remedial treatment they listed, the respondents were asked which were considered the most effective. In general, most stated that removal and replacement of the structure was most effective, however, some stated that using fabric behind the wall, adding plank to lower the backwall below the scour line, and driving more piles can be simple and inexpensive methods to obtain more years of service.

6.1.3 Timber Piling Utilization

Agencies were asked if they have bridges with timber piling in their current bridge inventory. Similar results were found for piling as were found for backwall as seen in Figure 6-4. All respondents stated they have existing bridges with timber piling, but only 12 stated they constructed new bridges with timber piling. Reasons for not using timber piling for new structures were timber longevity versus longevity of other materials, length of pile limitations, and, in some cases, inadequate load capacity.

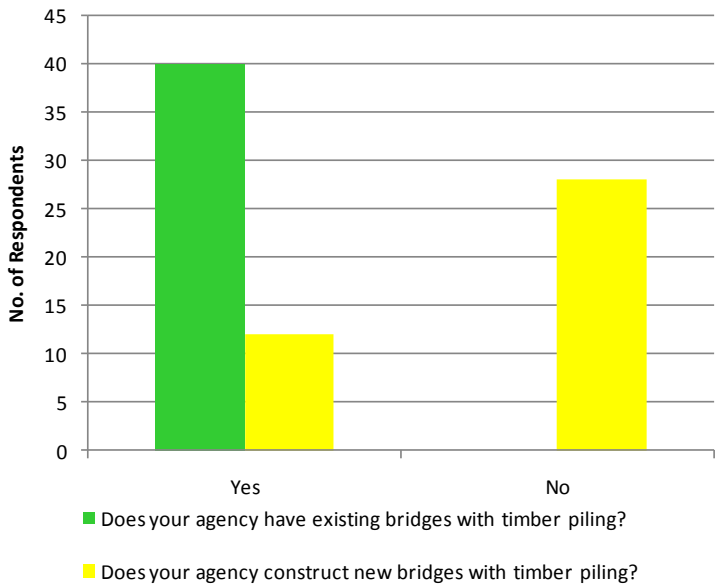
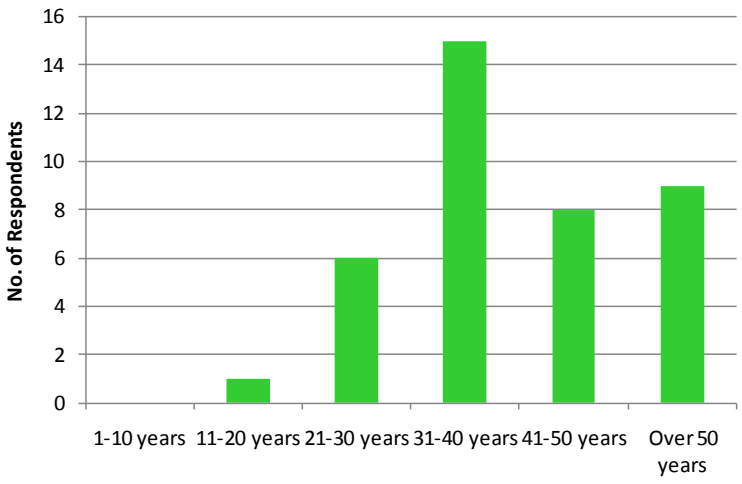


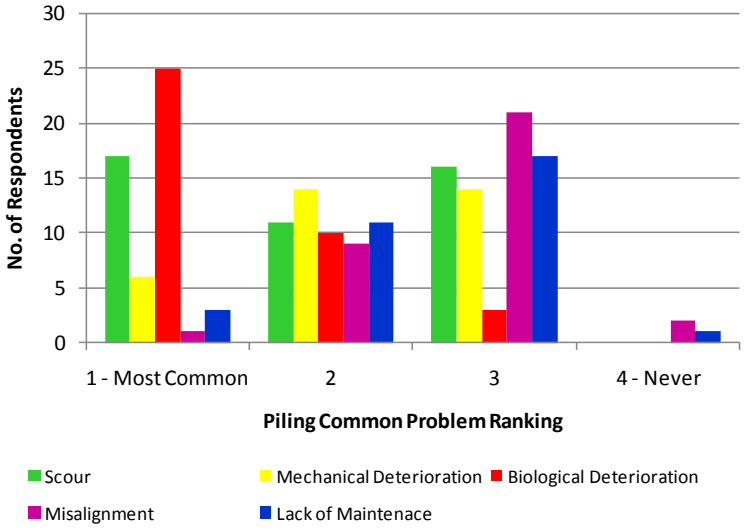
Figure 6-4 Iowa county past and current use of timber piling for bridges

Similar to the back walls the Iowa counties were asked about pile service life, common problems encountered, and testing methods. Figure 6-5 shows the results from the three questions.

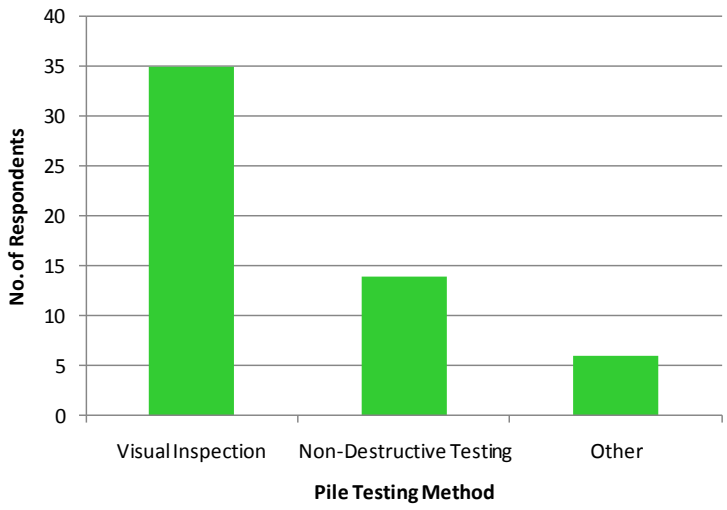
Figure 6-5a shows most respondents chose 31 to 40 years as the service life of piling. Once again similar to the backwall results the most common causes of pile problems is scour and biological deterioration. Figure 6-5b shows the ranking counties gave for various problems encountered with timber piling. Mechanical deterioration, misalignment, and lack of maintenance were also noted as being problems. When asked what methods were used to detect piling problems 35 responded that visual inspection was used. In addition, 14 counties stated they use a form of non-destructive testing which was generally described as sounding with a hammer. Other types of testing methods stated by respondents were boring, probing, and the pick test.



(a) Piling service life



(b) Piling common problem



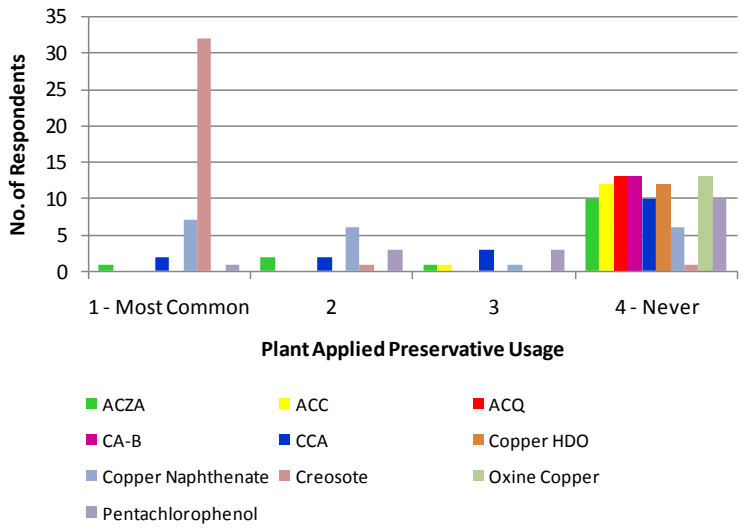
(c) Piling testing methods

Figure 6-5 Iowa county timber piling metrics

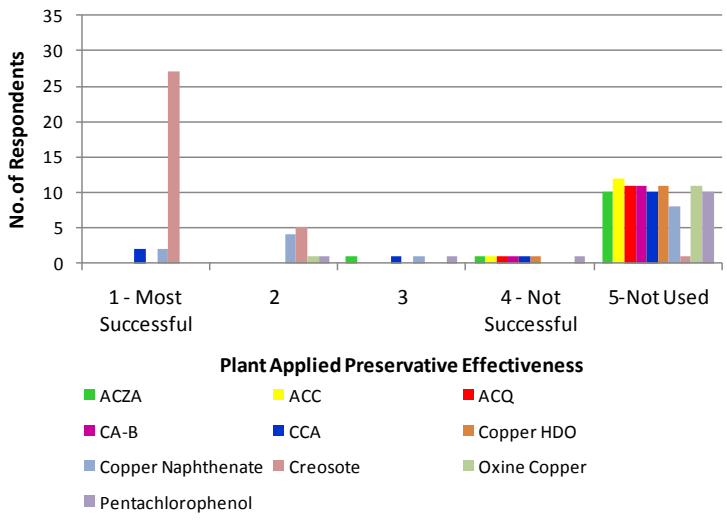
Counties were asked what remedial and/or strengthening measures were used in the past and which of those measures were most effective. The majority of respondents stated that driving new piling next to or near rotten piles was the most common method of bridge strengthening. In addition, posting, concrete encasement, and performing remedial preservative treatment were also mentioned as ways to strengthen piling. In general, the respondents stated driving new pile is the most effective repair treatment if access for driving the pile is available.

6.1.4 Timber Preservative Utilization

Inquiries were made regarding plant-applied and field-applied preservatives to determine the commonality and effectiveness of the preservatives. The most common plant applied preservatives used by the respondents were creosote, copper naphthenate, and CCA as shown in Figure 6-6a. Several preservatives, such as, ACC, ACQ, CA-B, and Oxine Copper were used sparingly or not at all. Creosote, copper naphthenate, and CCA were also selected as the most successful preservative, as shown in Figure 6-6b.



(a) Plant-applied preservative usage



(b) Plant-applied preservative effectiveness

Figure 6-6 Usage and effectiveness of plant-applied preservative treatments in Iowa

The number of Iowa counties that utilize field-applied preservatives was very low with only six responding that they use some type of preservative. The majority of those respondents (five of the six) use a liquid or paste copper naphthenate surface applied treatment. Fumigants and diffusible chemicals were not used. When asked what field-applied preservative is most successful, liquid copper naphthenate had the most respondents; however, this could be due to copper naphthenate being the only treatment used.

6.1.5 Specific County Rehabilitation Methods

6.1.5.1 Polk County, Iowa

Polk County has used steel sheet pile to protect bridge abutments from scour problems. Bridge BR2433 with sheet pile placed to prevent scouring of the foundation is shown in Figure 6-7. Although the abutment in this bridge was reinforced concrete, the same solution can be applied to timber abutments. The sheet pile is placed on the stream side of the abutment. The area between the existing abutment and sheet piling was backfilled and capped with concrete to prevent erosion of the backfill material.

Figure 6-7 Sheet piling at abutment foundation

Polk County has also used timber planks nailed to the front of the existing timber abutments to help protect from scour and deterioration of the existing backwall. Figure 6-8 shows the timber planks on the front of the existing timber abutment. The space created between the existing backwall and new backwall planking was filled with concrete. Additional rip-rap was placed on the stream bank and in front of the abutment to help prevent additional scour.

Figure 6-8 Abutment repair on stream side of existing timber abutment

Polk County has used a combination of splicing and concrete encasement to repair deteriorated timber piles. The repair involves the removal of the decayed portion of the pile up to the pile cap. A new section is placed and is connected to the existing pile with four steel straps. The steel straps, approximately 1/4 in. thick, 1-1/2 in. wide, and 2 ft long, are spaced equally around the pile. The straps are lag screwed with 3 to 4 screws above and below the joints. The splice is then encased with concrete. A corrugated metal pipe (CMP) cut in half and clam shelled around the pile is used for the form. The two halves are connected together using pipe and bolts (Figure 6-9) spaced along the vertical seams of the CMP on approximately 32 in. spacing. The CMP form is extended below the splice straps a minimum of 1 ft and the annular space between the CMP form and the pile is then filled with C-4 concrete. The diameter of the CMP form is approximately 32 in. providing annular space around a 12 in. diameter pile of 10 in. The county did not place reinforcing in the annular space, however, did recommend it for future repairs. One drawback to the repair method stated by the county engineer was the pier bracing had to be reconfigured due the larger diameter of the encased piling. The finished repair is shown in Figure 6-10; this repair was completed in 2000 and is still in good condition.

Figure 6-9 Corrugated metal pipe form connector

Figure 6-10 Corrugated metal pipe pile repairs

6.1.5.2 Buchanan County Iowa

Buchanan County has used steel "W" shapes to splice or post decayed or damaged piles. Figure 6-11 shows two repaired abutment piles. The deteriorated sections are removed and replaced with a "W"-shaped steel section with cap plates welded on each end. The steel section is lag screwed to the remaining pile and to the cap beam with two screws top and bottom. Buchanan County has used this repair on several bridge piles and has seen repairs lasting over 10 years. The one drawback, noted by the county engineer, is a reduction in lateral load capacity and concerns that the abutment could push the wall out. Buchanan County has also used timber sections for repair, however, the longevity of using new timber pile sections was found to be less than that of the steel sections.

Figure 6-11 Posted piles using steel W shapes

Buchanan County has also placed new steel piling at bridge abutments (Figure 6-12). In order to install the new piles, openings were cut into the bridge deck and the piles were driven through

the openings. The new piles, however, did not provide lateral support for the bridge back wall. The backwall was not shimmed against the new piling. After sufficient deterioration of the existing timber piles took place, the back wall buckled. The county engineer suggested the piles be driven as close to the back wall as possible and shims placed between the new piles and existing backwall in order to prevent the backwall movement.

Figure 6-12 Steel piles driven

Buchanan County also uses concrete encasement for repairing deteriorated piles. Figure 6-13, shows the encasements the County has completed on concrete piles, however both systems can be applied to timber piles. The repair seen in Figure 6-13a uses a fabric sock that is placed around the pile and filled with concrete. The cost of using the fabric sock concrete encasement with the exclusion of excavating around the pile was approximately $1800/pile in 1998; the fabric sock encasement was completed in 1998 and is still performing well. Similar to Polk County, Buchanan County also repaired piles using CMP as forms for concrete encasement. Figure 6-13b shows the CMP cut in half, reconnected using an angle welded to the CMP, then bolted together. The CMP encasement was completed circa 1998 and is also still performing well.

(a) Concrete repair sock

(b) CMP repair

Figure 6-13 Pile encasement repairs

6.2 Non-Iowa County Timber Repair

Twenty county agencies not located in Iowa (referred to as non-Iowa counties) responded in various degrees to the questionnaire. Since the geographical location of the respondent can affect the use and effectiveness of timber, the state and number of respondents from that state are shown in Figure 6-14. Of the 20 counties responding, five were asked for more information on their repair methods.

Figure 6-14 State location of non-Iowa county respondents

6.2.1 General Timber Use

Agencies were first asked if they currently or previously utilize timber in bridge piling or backwall substructures. Figure 6-15 shows the results for non-Iowa counties. Eight agencies stated they currently utilize and two stated they currently and previously utilized timber; therefore, 50 percent of the non-Iowa county respondents currently utilize timber. Eight respondents stated they only previously utilized timber and currently do not. Two of the agencies have not used nor currently use timber for bridges. Many of the respondents stated they do not use timber for bridges due to the longevity of timber compared to steel and concrete. Several also stated that timber requires more maintenance.

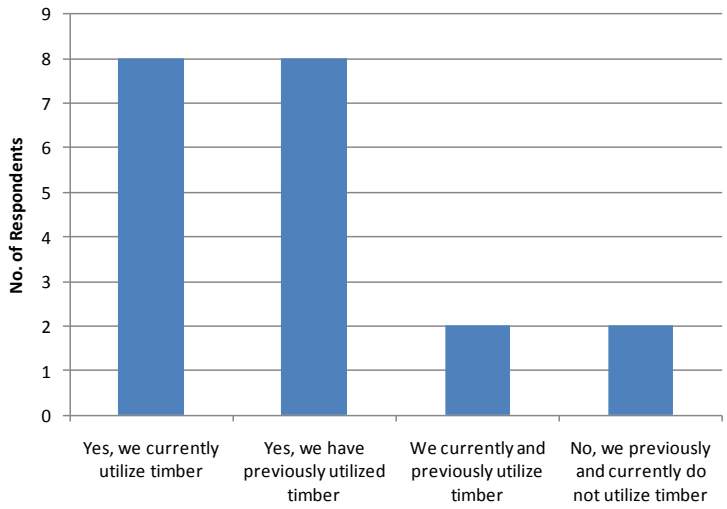


Figure 6-15 Non-Iowa county utilization of timber piling or back walls

6.2.2 Timber Back Wall/Wing Wall Utilization

Agencies were asked if they have bridges with timber back walls in their current bridge inventory. As seen in Figure 6-16, 17 non-Iowa counties responded stating they have existing bridges with timber back walls. However, only seven responded stating they construct new bridges using timber backwall. Many of the same reasons stated for not utilizing timber for bridges were stated for not using timber specifically in the back walls.

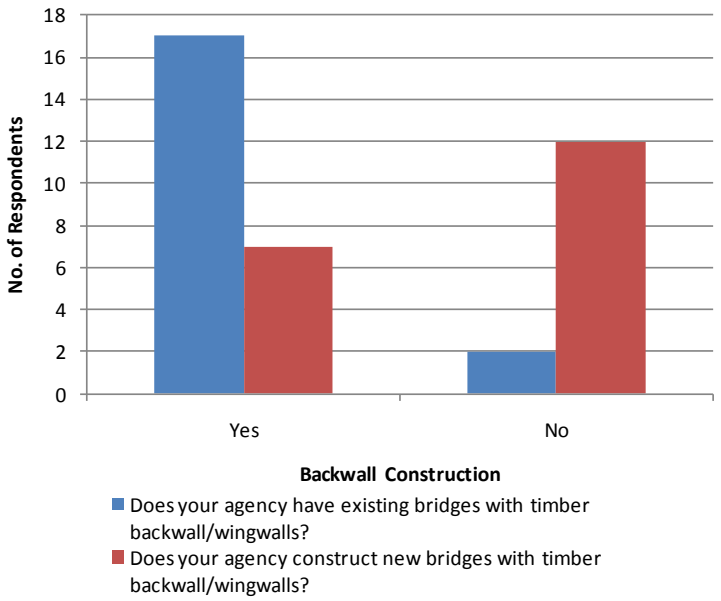
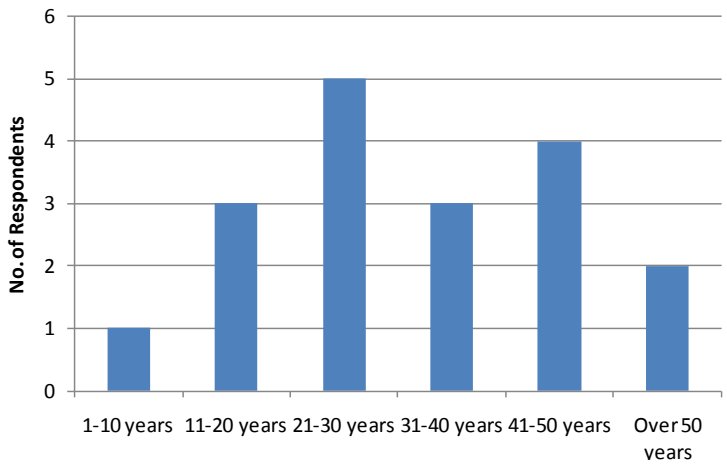
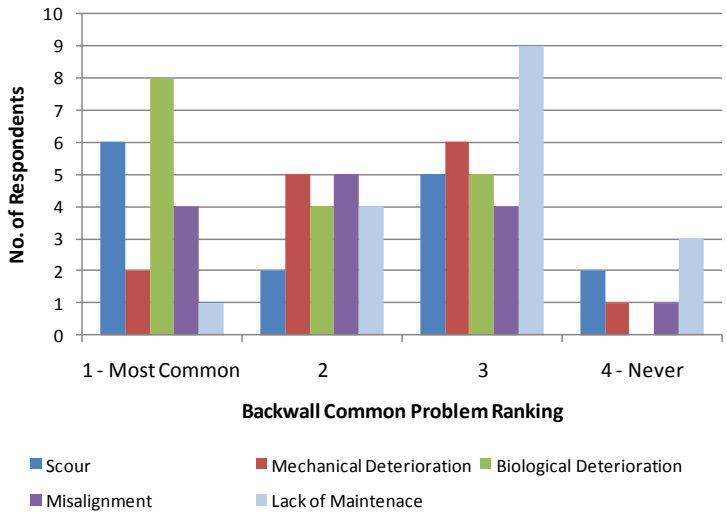


Figure 6-16 Non-Iowa county past and current use of timber back walls or wing walls for bridges

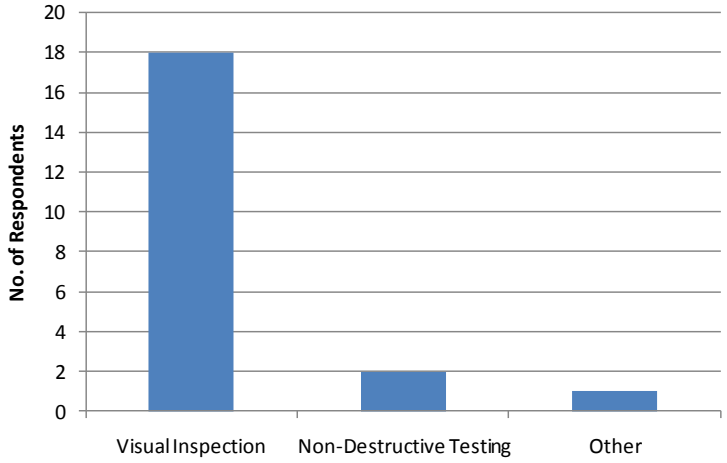
The county engineers were also asked about backwall service life, common problems encountered with back walls, and what testing methods are used to determine if a backwall is deteriorated. Figure 6-17 shows the results from the three questions. As seen in Figure 6-17a the majority of respondents state the backwall service life is approximately 30 years. This is approximately 10 years less than reported by Iowa counties. Figure 6-17b shows the ranking counties gave for various problems encountered with timber back walls. The two most common problems are scour and biological deterioration. Although mechanical deterioration, misalignment, and lack of maintenance were not the most common problems encountered, they were still ranked highly as a problem. When asked what methods were used to detect backwall problems 18 responded that visual inspection was used. Very few of the respondents use non-destructive testing. The three counties that use something other than visual inspection also used sounding with a hammer, coring, acoustic wave analysis, and drilling resistance.



(a) Backwall service life



(b) Backwall common problems



(c) Backwall testing methods

Figure 6-17 Non-Iowa county timber backwall metrics

Agencies were asked to describe any remedial and/or strengthening measure they have used to repair or restore load carrying capacity of back walls. The agencies responded with the following summarized repairs:

- Excavate abutment and remove and replace rotten plank
- Use urethane injection to fill voids
- Install battens
- Drive sheet pile behind rotten wall
- Drive addition piling
- Provide additional scour protection in front of the abutment
- Tie backs

Of the remedial treatment they listed, the respondents were asked which were considered the most effective. In general most stated that removal and replacement of the structure was most effective, however, one stated that urethane seems to be a quick fix that provides easy void filling and strength.

6.2.3 Timber Piling Utilization

Agencies were asked if they have bridges with timber piling in their current bridge inventory. Similar results were found for piling as were found for back walls as seen in Figure 6-18. Seventeen of the non-Iowa counties have existing bridges with timber piling but only five stated they construct new bridges with timber piling. The reasons for not using timber piling for new structures were longevity versus other materials and limitations of pile length.

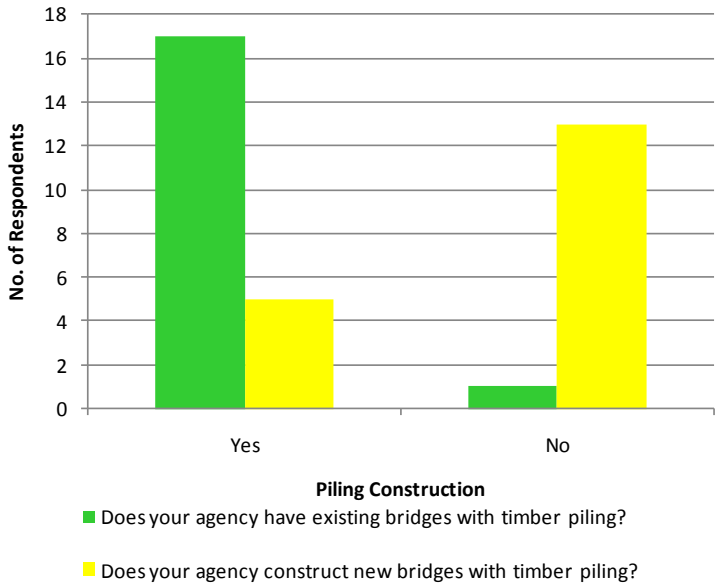
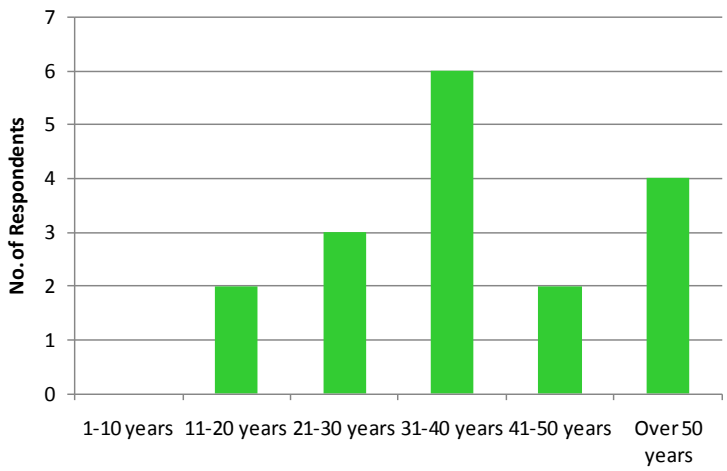
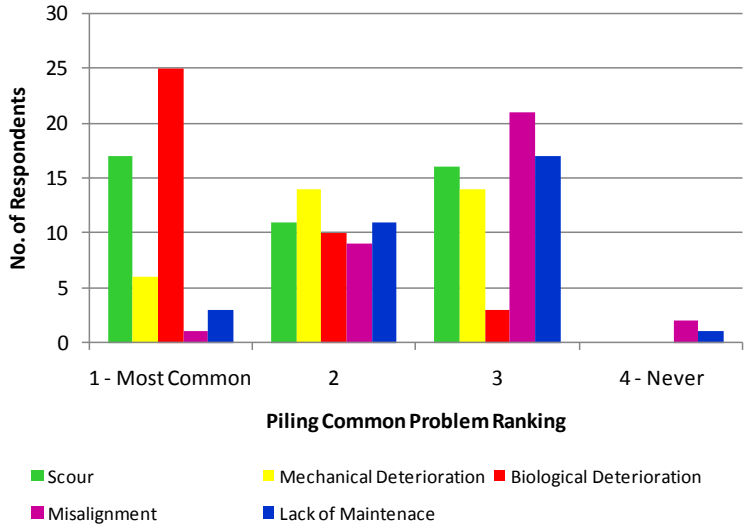


Figure 6-18 Non-Iowa county past and current use of timber back walls or wing walls for bridges

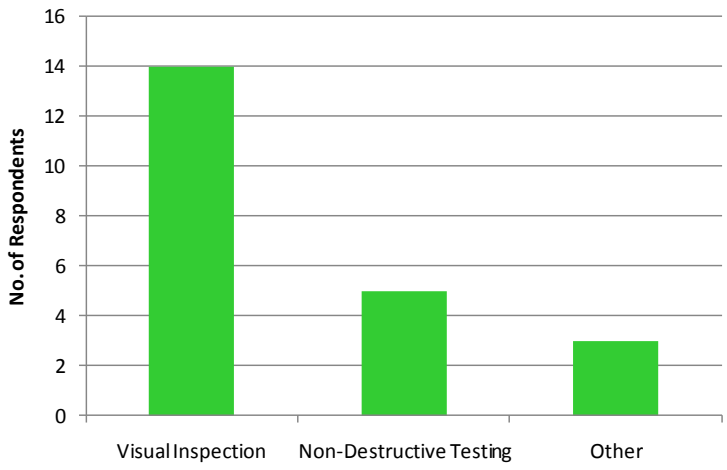
The non-Iowa counties were asked about service life, common problems encountered, and testing methods. Figure 6-19 shows the results of the three questions. Figure 6-19a shows most respondents chose 31 to 40 years as the service life of piling. Once again similar to the backwall results, the most common causes of pile problems is scour and biological deterioration. Figure 6-19b shows the ranking counties gave for various problems encountered with timber piling. Mechanical deterioration, misalignment, and lack of maintenance were also noted as being problems. When asked what methods were used to detect backwall problems 14 responded that visual inspection was used. In addition, five counties stated they use a form of non-destructive testing which was generally described as sounding with a hammer. Other types of testing methods stated by respondents were coring, probing, drill resistance and acoustic wave.



(a) Piling service life



(b) Piling common problems



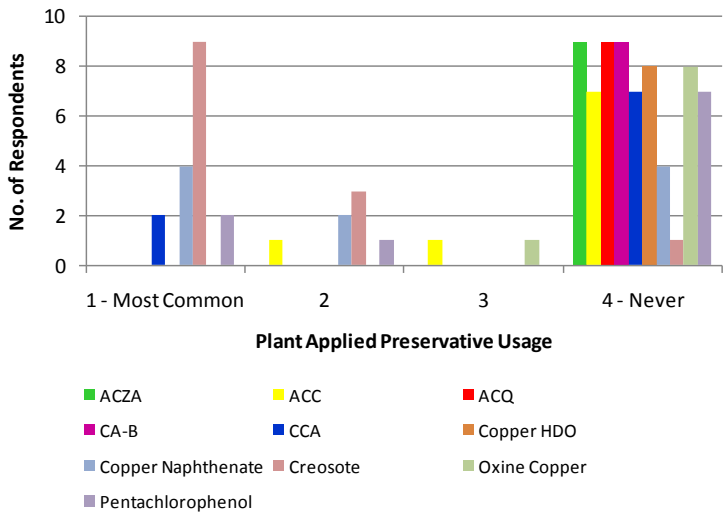
(c) Piling evaluation methods

Figure 6-19 Non-Iowa county timber piling metrics

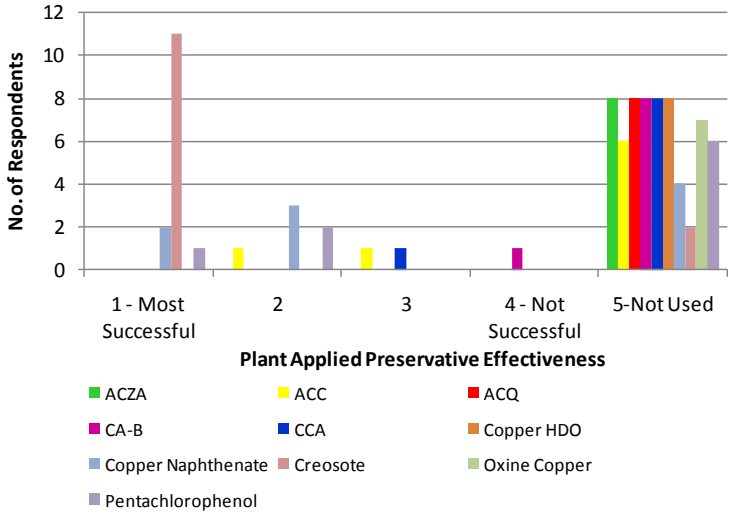
Counties were asked what remedial and/or strengthening measures were used in the past and which of those measures were most effective. The majority of respondents stated that driving new piling or encasing the old pile with concrete was the most effective method of pile strengthening. In addition, posting and mudsills were also used.

6.2.4 Timber Preservative Utilization

Inquiries regarding plant-applied and field-applied preservatives were also made to determine commonality and success of the preservatives. The most common plant applied preservatives used by the respondents were creosote, copper naphthenate, pentachlorophenol, and CCA as shown in Figure 6-20a. Several preservatives, such as, ACC, ACQ, CA-B, and Oxine Copper were used sparingly or not at all. Creosote, copper naphthenate, and pentachlorophenol were also selected as the most successful preservative, as shown in Figure 6-20b.



(a) Plant-applied preservative usage



(b) Plant-applied preservative effectiveness

Figure 6-20 Non-Iowa County expected service life for timber backwall

The number of non-Iowa counties that utilize field-applied preservatives was very low with only four responding that they use some type of preservative. The majority of those respondents used a liquid or paste copper naphthenate surface applied treatment. Fumigants and diffusible chemicals were not used. When asked what field-applied preservative is most successful, liquid copper naphthenate had the most respondents; however, this could be due to copper naphthenate being the only treatment used.

6.2.5 Specific Non-Iowa County Rehabilitation Methods

6.2.5.1 St Louis County, Minnesota

One of the backwall repair methods used by St Louis County, Minnesota is to place "pile stays" on the back side of the backwall. In order to place the pile stays, the embankment is excavated away from the existing backwall, as shown in Figure 6-21a. The deteriorated backwall planks are then replaced and vertical stays (e.g., round timbers) are bolted to the existing piles and cap beam, shown in Figure 6-21b. The wall is then covered with geotextile fabric and backfilled, seen in Figure 6-21c.

St Louis County has also had success preventing wing walls from tipping outward by using a cable that is run between the wing walls to tie them together. Figure 6-22 shows the cable running between the installation of the cable at an existing bridge.

(a) Excavation of embankment

(b) Installation of new planks and pile stays

(c) Backfilling of fabric lined backwall

Figure 6-21 St. Louis County, Minnesota backwall repair by us of vertical pile stays

Figure 6-22 Cable tying wing walls together to prevent tip out

6.2.5.2 Parish of Caddo, Louisiana

The Parish of Caddo in Louisiana has had success with placing new piles on mudsills. The repair technique, shown in Figure 6-23, requires the soil around the existing pile to be removed a suitable distance to expose a firm sound bearing soil layer.

(a) New piles placed on mudsill

(b) New piles backfilled and braced

Figure 6-23 New piles placed on mudsill next to rotted existing columns and braced

A network of thick planking (approximately 6 in. thick) are placed, as shown in Figure 6-23a, to provide a foundation for the new piles. If settlement has occurred, a jack is used to push the

bridge back up to finished grade. New treated timber piles are placed between the top of the mudsill and bottom of the cap beam. Bracing is then attached to the new piles and existing piles to provide stability. Lastly, the bases of the piles were backfilled up to existing grade. The Parish of Caddo has been performing the mudsill repairs for several years; however, improvements were made to the design approximately four years ago that have helped the performance of the repair. The two biggest improvements consisted of digging deeper to allow the mudsill to rest on a firm layer of soil and provide a larger network of planking and thusly a larger foundation below the piles. The new technique has been used on 10 to 15 bridges all showing very little settlement. The Parish of Caddo estimates the repair provides an additional 10 to 15 years of service life to the repaired substructure.

6.3 State and Federal Timber Repair

Twenty-seven state, federal, and Canadian providence agencies (which will all be referred to as state-level agencies) responded in various levels to the questionnaire. One state, Tennessee, had two separate responses providing 28 total responses. Since the geographical location of the respondent can affect the use and effectiveness of timber, the states that responded to the survey are as follows:

- Alaska
- Alberta, Canada
- Arizona
- Florida
- Hawaii
- Illinois
- Iowa
- Kansas
- Maryland
- Michigan
- Missouri
- Minnesota
- Montana
- Nebraska
- New Hampshire
- New York
- Oklahoma
- Oregon
- Pennsylvania
- Saskatchewan, Canada
- South Dakota
- Tennessee- Two Responses
- Texas
- Utah
- Virginia
- Wyoming
- Federal Forest Service

6.3.1 General Timber Use

Agencies were first asked if they currently or previously utilize timber in bridge piling or backwall substructures. Figure 6-24 shows the results for the various state-level responses. Five agencies stated they currently utilize and two stated they currently and previous utilized timber, therefore, 25 percent of the state-level respondents currently utilize timber. Thirteen respondents stated they only previously utilize timber and currently do not. Seven of the agencies have not used nor currently use timber for bridges. The seven agencies that currently and previously do not use timber were not required to complete the remainder of the survey questions.

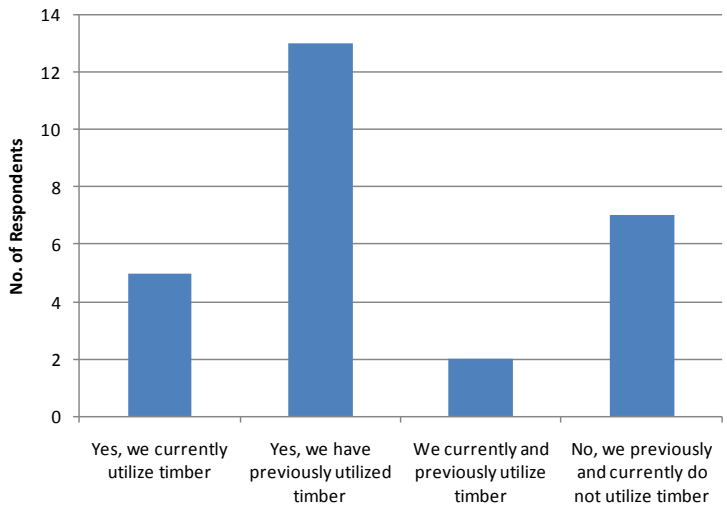


Figure 6-24 State utilization of timber piling or back walls

6.3.2 Timber Back Wall/Wing Wall Utilization

Agencies were asked if they have bridges with timber back walls in their current bridge inventory. As seen in Figure 6-25, 13 state-level agencies that responded stated they have existing bridges with timber back walls. However, only six responded stating they construct new bridges using timber backwall. Reasons many of the respondents stated they do not use timber for bridge back walls include: durability concerns, unreliable, uneconomical, design practices exclude timber from being able to use, and environmental concerns with preservative treatments.

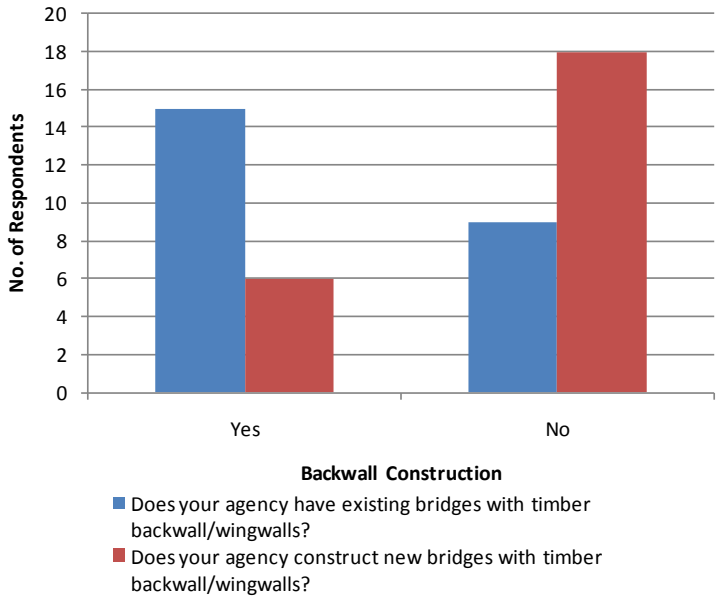
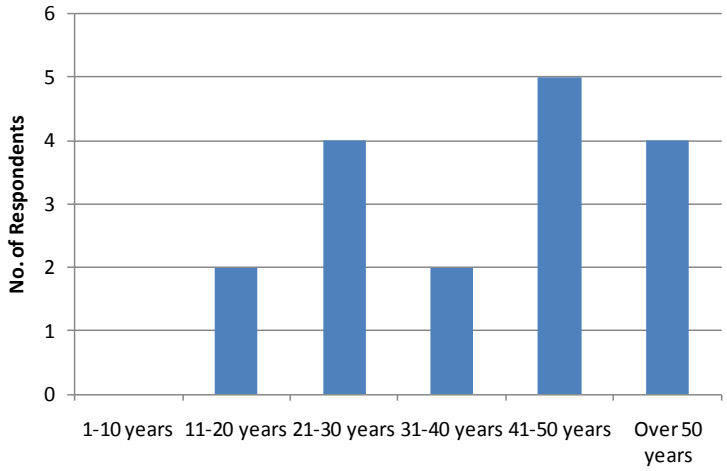
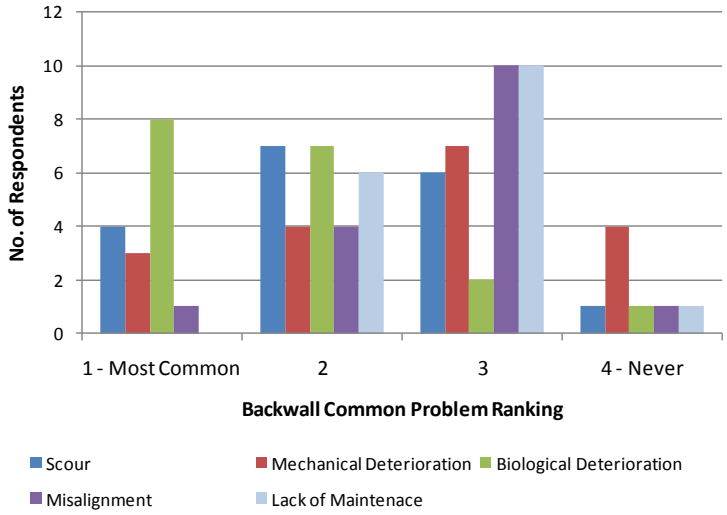


Figure 6-25 State past and current use of timber back walls or wing walls for bridges

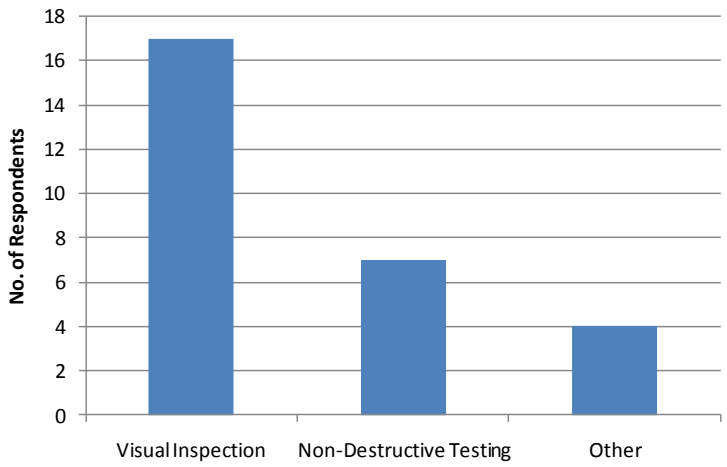
The state-level agencies were also asked about backwall service life, common problems encountered with back walls, and what testing methods are used to determine if the backwall has deteriorated. Results from these three questions are presented in Figure 6-26.



(a) Backwall service life



(b) Backwall common problems



(c) Backwall investigation methods

Figure 6-26 State timber backwall metrics

As seen in Figure 6-26a, four or more respondents chose 21-30 years, 41-50 years, and over 50 years. The large range in the service life of back walls could be attributed to the variation in geographical location of the respondents and their climates. Figure 6-26b shows the ranking states-level respondents gave for various problems encountered with timber back walls. The most common problem encountered was biological deterioration; scour was also listed as a common problem. Although misalignment and lack of maintenance were not the most common problems encountered, they were still ranked as being a problem. Mechanical deterioration had three respondents stating it was the most common problem with back walls, however, four respondents stated the mechanical deterioration was never a problem. When asked what methods were used to detect backwall problems, 17 responded that visual inspection was used. Seven of the respondents reported the use of non-destructing testing. The state-level respondents that use something other than visual inspection stated the use of sounding with a hammer, cores, probing, and resistance testing.

Agencies were asked to describe any remedial and/or strengthening measures they have used to repair or restore load carrying capacity of back walls. The agencies responded with the following summarized repairs:

- Excavate abutment and remove and replace rotten plank
- Total removal and replacement of abutment
- Add treated plywood to front side of abutment to prevent soil loss
- Drive sheet pile behind rotten backwall
- Drive additional piling

Of the remedial treatments they listed, the respondents were asked which were considered the most effective. In general, most stated that removal and replacement of the structure was most effective, however, two stated that installing sheet pile behind the abutment is more cost

effective than new planks for total replacement since it requires no excavating, repair, and re-compaction of the abutment soils.

6.3.3 Timber Piling Utilization

Agencies were asked if they have bridges with timber piling in their current bridge inventory. A similar trend, shown in Figure 6-27, was found for piling as was seen for back walls discussed previously. Twenty of the agencies have bridge with timber piling while only five construct new bridge using timber piling. The reasons for not using timber piling for new structures were stated as follows:

- Durability/Longevity
- Do not meet design requirements
- Restricted by length of timber piles
- Detection of percent defective is difficult

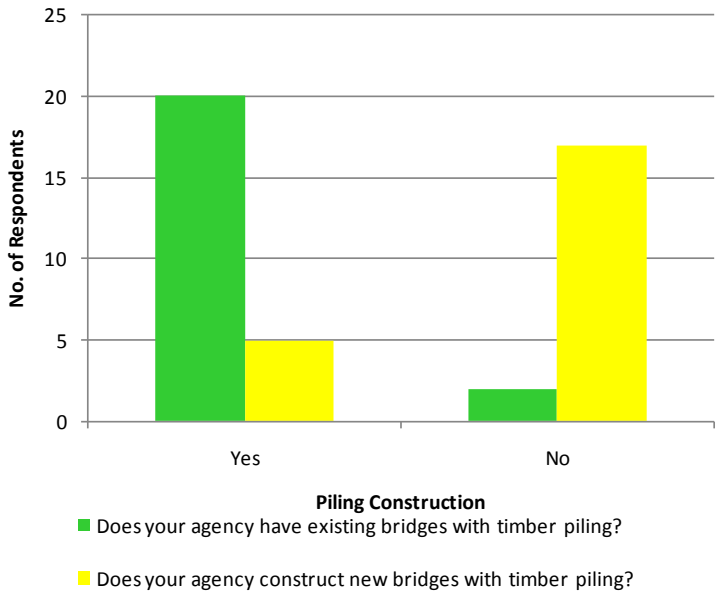
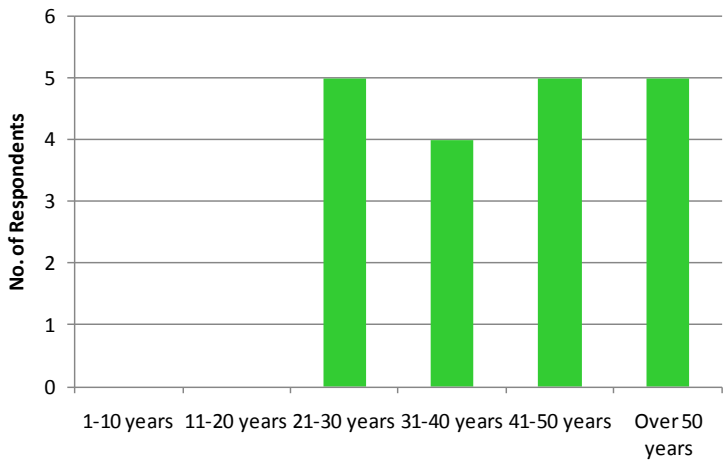
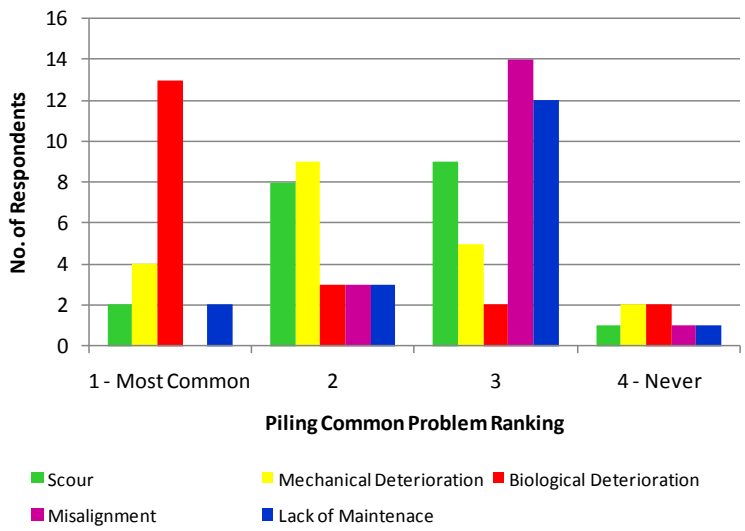


Figure 6-27 State past and current use of timber back walls or wing wall for bridges

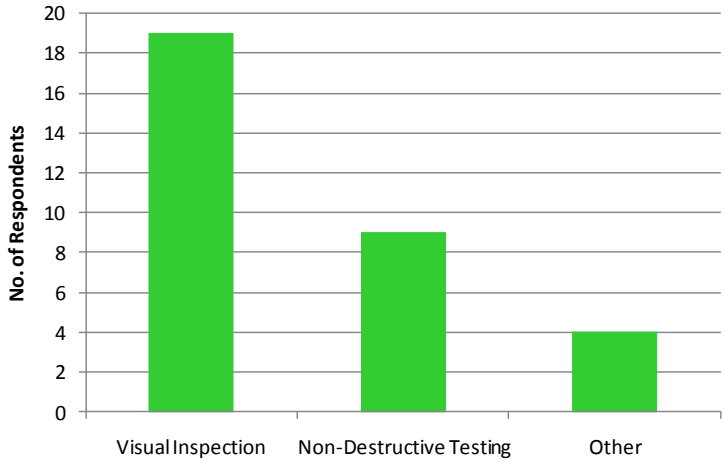
The state-level agencies were asked about service life, common problems encountered, and testing methods for timber piling; results from these three questions are presented in Figure 6-28.



(a) Piling service life



(b) Piling common problems



(c) Piling investigation methods

Figure 6-28 State timber piling metrics

Figure 6-28a shows the service life of piling to range between 21 years to over 50 years. The large range in service life may be attributed to the fact the respondents are located in different climatic regions of North America which can affect the longevity of timber. The most common causes of pile problems are mechanical deterioration and biological deterioration. Figure 6-28b shows the ranking state-level agencies gave for various problems encountered with timber piling. Scour, misalignment, and lack of maintenance were also noted as being problems. When asked what methods were used to detect backwall problems 19 stated visual inspection. Thirteen of the respondents also used non-destructive testing or other types of testing. The non-destructive testing was generally described as sounding with a hammer, coring, probing, drill resistance, and stress wave technologies.

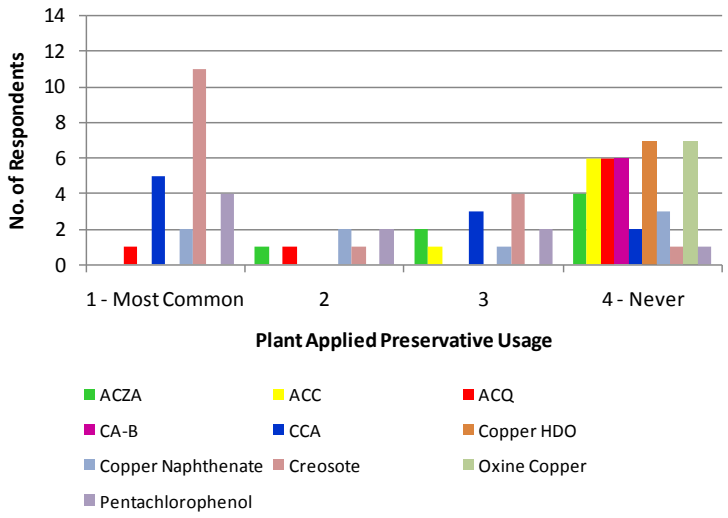
State-level agencies were asked what remedial and/or strengthening measures were used on piling in the past and which of those measures were most effective. The following list summarizes the state-level responses.

- Drive new piles
- Provide steel jackets
- Use straps to splice deteriorated area
- Encase with concrete sleeve
- Posting
- Wrap with FRP
- Add supports on mudsills

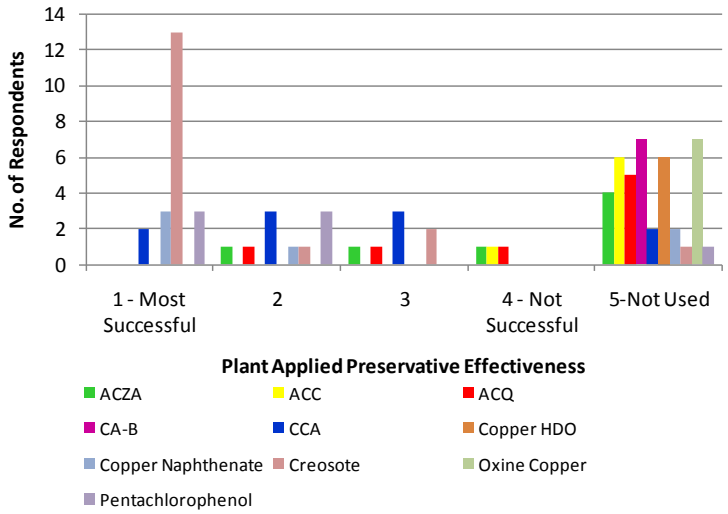
The majority of respondents stated that driving new piling or encasing the old pile with concrete in combination with posting was the most effective method of pile strengthening.

6.3.4 Timber Preservative Utilization

Responders were also questioned about plant-applied and field-applied preservatives to determine commonality and their success with the preservatives. The most common plant applied preservatives used by the respondents were creosote, pentachlorophenol, and CCA as shown in Figure 6-29a. Several preservatives, such as, ACC, CA-B, and Oxine Copper were used sparingly or not at all. Creosote, as shown in Figure 6-29b, was overwhelmingly chosen as the most successful preservative. Copper naphthenate, CCA, and pentachlorophenol were also selected, but not in large numbers, as being successful preservatives.



(a) Plant-applied preservative usage



(b) Plant-applied preservative effectiveness

Figure 6-29 State expected service life for timber backwall

The number of state-level agencies that utilize field-applied preservatives was very low with only four responding that they use some type of preservative. The majority of those respondents used a liquid copper naphthenate surface applied treatment. Fumigants and diffusible chemicals were not used. When asked what field-applied preservative is most successful, liquid copper naphthenate had the most respondents; however, this could be due to copper naphthenate being the only treatment used.

6.3.5 Specific State/Federal Rehabilitation Methods

6.3.5.1 Oklahoma Department of Transportation

The Oklahoma Department of Transportation (2010) has had timber pile repair success with FRP wraps; however, they have only used the repair technique on pile bents and not on abutment piles. The technique was developed by personnel at the Oklahoma DOT and was studied by Emerson (2004) as described previously in this report. The piles are excavated below the ground line to expose a minimum of 2 ft of sound piling. Then, 3 inch-diameter holes are drilled through the outer shell of the hollow or damaged section to clean the interior of the pile. The holes are spaced to allow for cleaning and future placement of fill material in the pile. After both the surface and interior portion of the pile are cleaned, the timber is allowed to drain and dry; the timber is then remedially treated with borate fungicide, which is placed in drilled and then plugged holes above and below the damaged section. The voids in the timber pile are then filled with aggregate to lessen the amount of epoxy required and the heat from the epoxy exothermic. Two wraps of FRP material are then placed around the pile and set with fabric impregnation resin. After the resin has set, the injection port holes are drilled and spaced so that travel of epoxy between ports is assured. After the epoxy resin mortar has cured, the ports are removed. Lastly, an ultra-violet resistant coating is applied to the pile. Two views of FRP repaired piles at an Oklahoma bridge are shown in Figure 6-30.

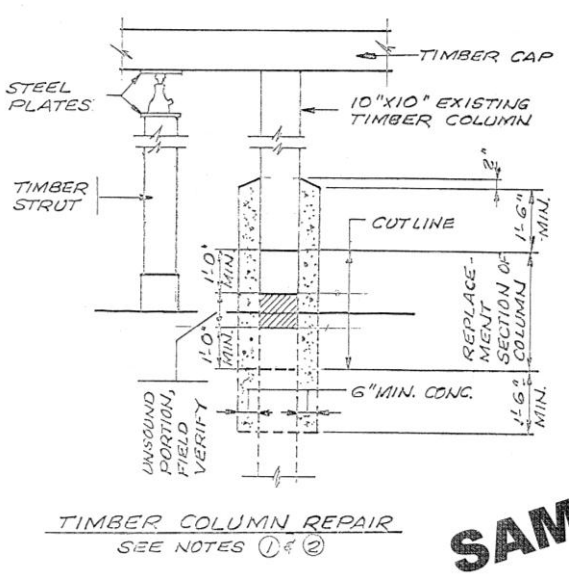
a) Close-up of single pile **b) Completed repairs on entire pier**

Figure 6-30 Completed Oklahoma DOT injected and FRP repaired timber piles

The Oklahoma DOT has used the FRP epoxy injection techniques since 1999. To date approximately 120 piles on 12 bridges have been successfully repaired. The repair technique when used on a need by need basis is estimated to cost $2,000 to $3,000 depending on the length and condition of the pile. The Oklahoma DOT estimates the repair extends the service life of the pile 10 to 15 years.

6.3.5.2 Minnesota Department of Transportation

The Minnesota Department of Transportation has used a combination of posting and concrete encasing to repair deteriorated piling. Shown in Figure 6-31 are example plans for repairing a timber piling and a photo of an existing repair. The repair is completed by excavating 2.5 ft below the unsound portion of the pile or to the base of the pile. Then the cap is jacked up to remove load from the pile. The deteriorated portion of the pile is cut off 1 ft above and below the deteriorated section. A new column section that is 1/4 in. longer than the removed section is placed in the same location as the section removed; after which the temporary jack is removed. The concrete jacket and reinforcing steel is placed; after which concrete is placed with 6 in. of minimum cover around the pile.



a) Example plans **b) Completed repair**

Figure 6-31 Minnesota DOT posting and concrete encasement repair for piles

The Minnesota DOT has installed two concrete encasements and explained that the repair is generally only worthwhile when only one bad pile is found on the bridge. In most cases, there are multiple bad piles in a bridge, which, for the Minnesota DOT, results in replacement of the bridge being a more feasible option. The first concrete encasement repair done by the Minnesota DOT was completed in 1993. According to Minnesota DOT personnel, the 1993 repair, although on dry ground, is in as good of condition as the day is was installed providing an extended service life thus far of 17 years.

The Minnesota DOT also provided information on repair for pilings next to a backwall or brace members. Since the complete circumference of the piling is not exposed, concrete encasement cannot be completed. Therefore, a combination of posting and splicing with channels is used. A similar process as described above is completed except a new section of pile is placed from the cut below the deteriorated location up to the cap beam. The new pile section is sandwiched between two splice channels as shown in Figure 6-32. The channels extend 4 ft above and below the joint between the new and old pile; through bolts are used to clamp the channels to the pile.

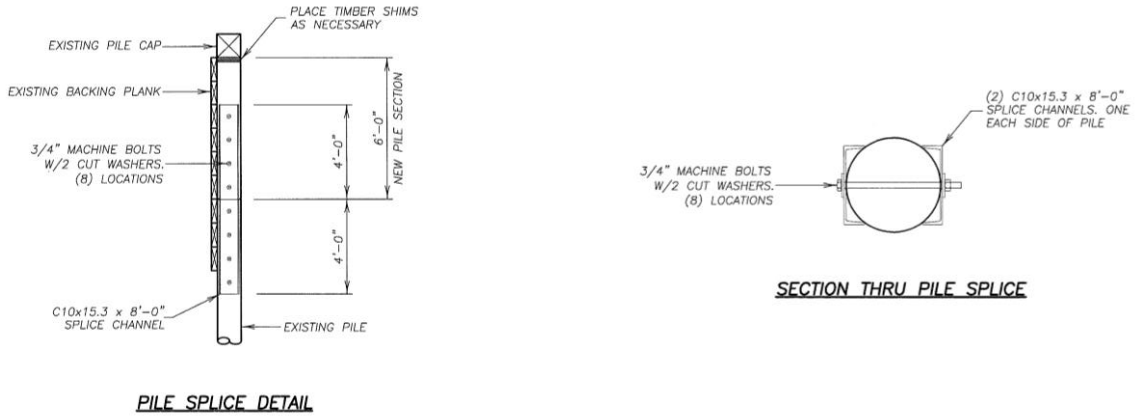


Figure 6-32 Minnesota DOT channel pile splice for piles next to backwall

The channel pile splice repair is a relatively new detail for the Minnesota DOT that was designed by a local consultant. The repair is suited for rotted or damaged pile and can be placed next to a backwall or brace member. To-date the repair technique has not been used, but Minnesota DOT personnel feel that it will last at least as long as the remaining service life of the bridge.

7 FIELD TESTING OF EXISTING TIMBER REPAIR METHODS

Upon review and synthesis of the survey data, five counties in Iowa were selected for field reconnaissance of bridges with timber pile and/or abutment repairs from which several could be selected for live load testing. Within these counties, the methods of repair were both varied and similar, allowing for a broad scope of testing and the ability to compare the performance of like repairs. Figure 7-1 shows several of the repair methods encountered and are described in the following. Images a) - f) show variations of casts created from corrugated metal pipe and concrete infill. Images g) - i) show the addition of supplemental piles; those in image i) are steel rather than timber. Additionally, new concrete sills and pile caps were constructed for those bridges in images h) and i), respectively. Images j) and k) show the addition of an all-steel pier that could effectively replace the timber bents in the event of failure. Images l), m), and n) show steel posting, dough-boy casts, and another variation of corrugated metal pipe casts, respectively.

a) CMP repair 1

b) CMP repair 2

c) CMP repair 3

d) CMP repair 4

Figure 7-1 Example of timber piles and abutment repairs in Iowa

e) CMP repair 5

f) CMP repair 6

g) Additonal pile repair 1

h) Additonal pile repair 2

i) Additonal pile repair 3

j) Added all-steel pier

Figure 7-1 continued

k) Added all-steel pier

l) Steel posting

m) Doughboys

n) CMP repair on concrete

Figure 7-1 continued

Upon completion of the field reconnaissance, the researchers along with the technical committee selected four bridges for live load testing. The goal of the testing was to determine how each repair performed when loaded and how that performance differed from that of a non-repaired pile in good condition. Of all bridges considered, three repair systems were tested; these include 1) encasing the weak pile in concrete, 2) posting, and 3) installing additional piles. Each of the tested bridges included at least one of these repairs; the results are discussed in the following sections.

7.1 Bridge Test 1

Bridge 1 is a 126 ft long bridge with three equal spans. The continuous span superstructure consists of three steel girders and a concrete deck, while the substructure consists of timber piles, five at each abutment and pier. The only timber pile repairs were located at the southernmost pier; two of the five piles were repaired using the concrete encasement method. The

instrumented pier is shown in Figure 7-2. One of the repaired piles was completely encased, while the other was only partly encased (Figure 7-3).

a) Side view

b) Corrugate metal pipe repairs

Figure 7-2 Bridge 1 side view and instrumented pier

Figure 7-3 Repaired piles by concrete encasement

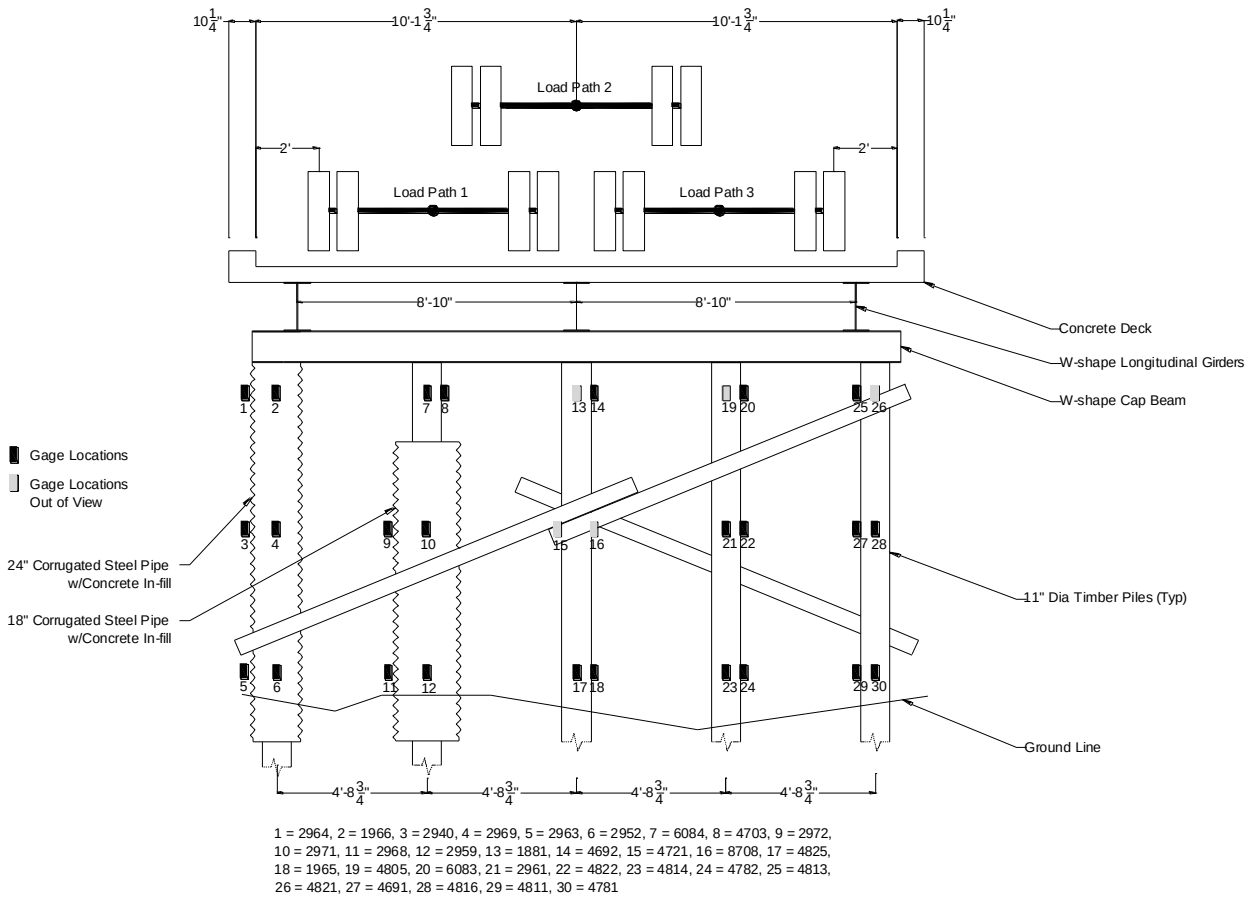
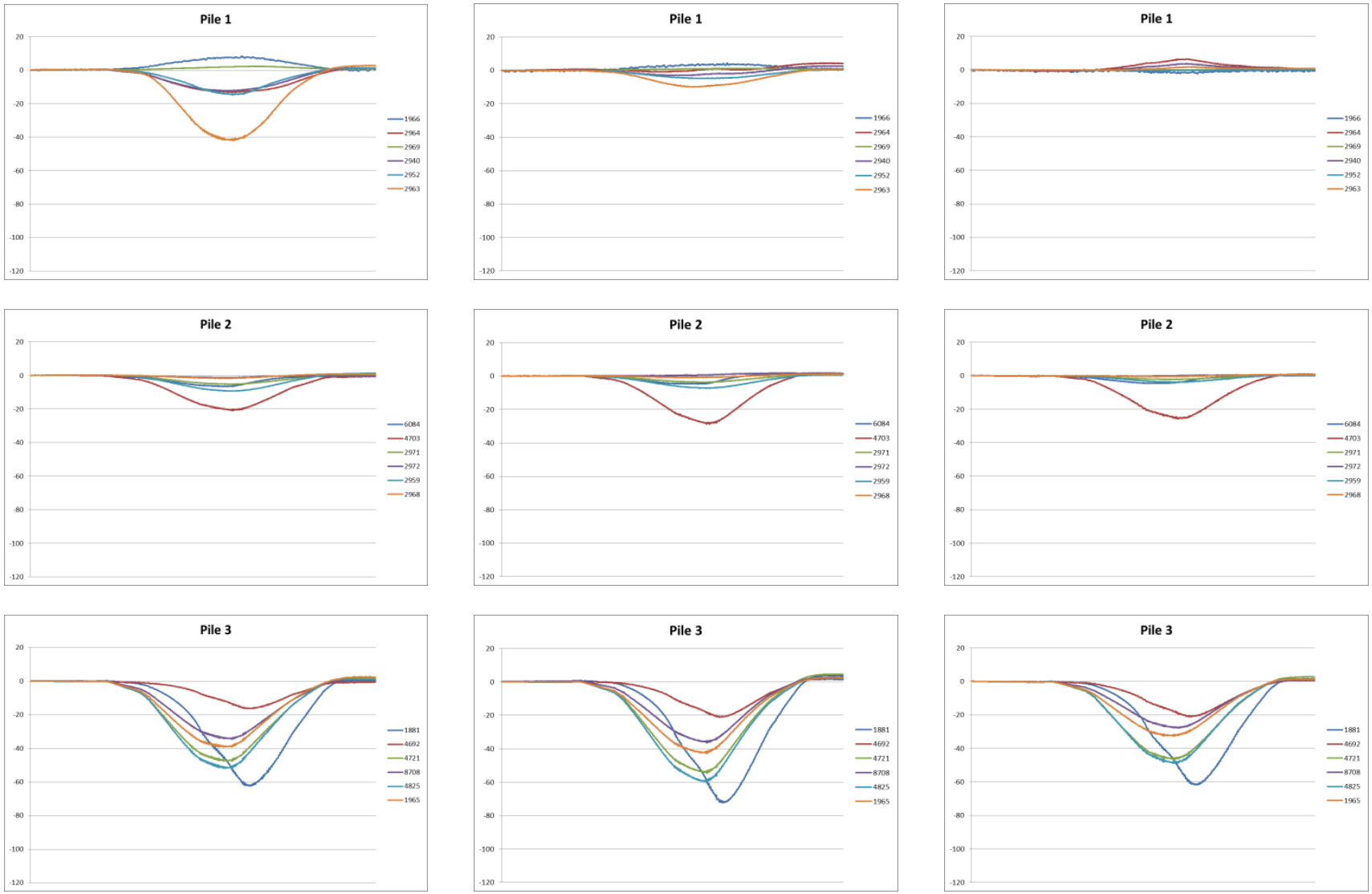


Figure 7-4 Schematic of Bridge 1 instrumented piles and load paths

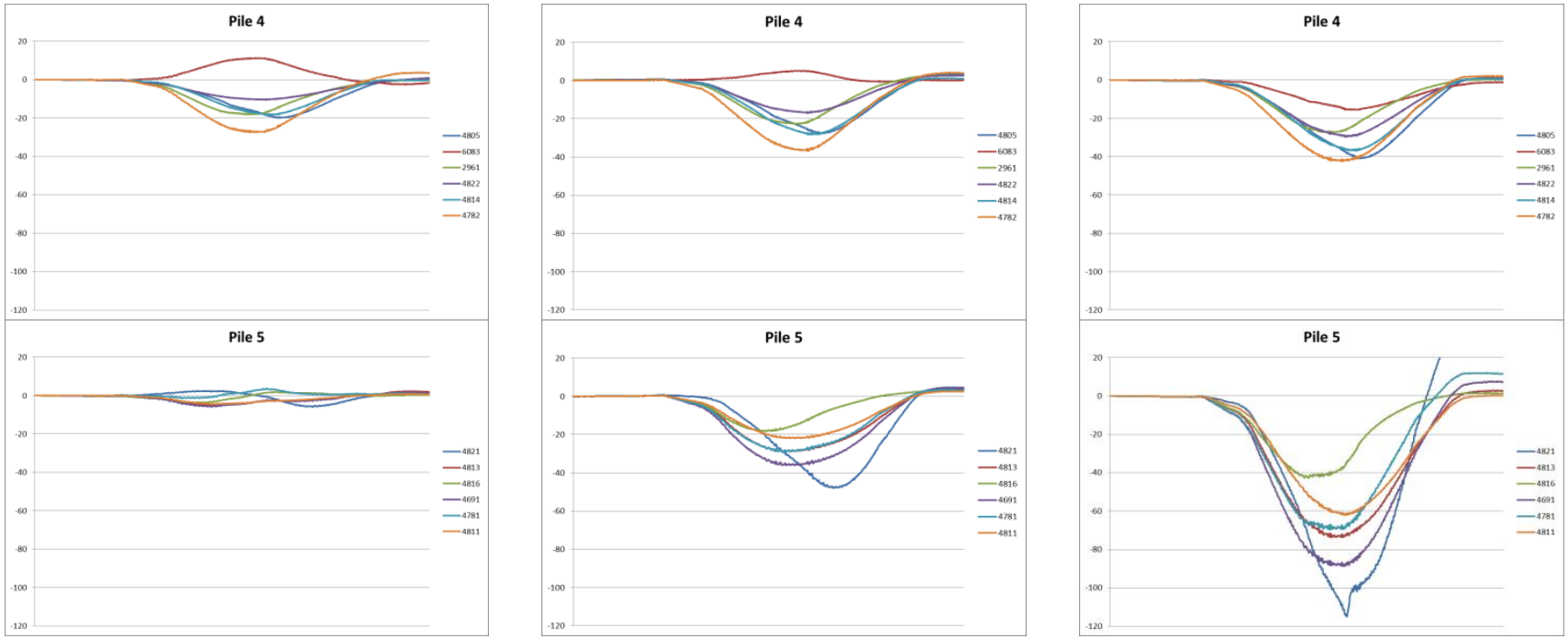
One can assume by visual inspection that the concrete encasement stiffens inadequate piles, yet the need exists to quantify the actual force transferred to the encasement. Each of the five piles within the pier were instrumented with multiple strain gages placed to enable quantification of the force carried by the concrete encasement and, when accessible, the timber piles. It is evident by the strain plots (Figure 7-5) that the concrete encasement did carry part of the total load imposed on the repaired piles. As one might expect, the strain values measured on the encasement were considerably less than those measured on the timber piles alone. This can be attributed to the substantial difference in total cross-sectional area between the timber pile and concrete, along with the greater modulus of elasticity of the concrete. It is assumed that the concrete encasement does not carry the entirety of the load imposed on the pile. This phenomenon would most likely happen only in circumstances where the entire cross-section of the timber has been lost; this method of repair would not have been appropriate if that were the case. The bridge geometry is mirrored on the centerline of the bridge. Likewise, the load paths of the test vehicle were mirrored on the bridge centerline. Subsequently, when comparing the strain values measured in the fully encapsulated pile to the timber pile on the opposite side of the pier, the percentage of total load introduced to the concrete encasement can be derived. After calculating the force induced into the piles given the strains and cross-sectional properties, it was

determined that the concrete encasements carried between 50 and 70 percent of the total load imposed on the respective piles. That is not to say the repaired piles were only capable of carrying 30 to 50 percent of the total load. Rather, it more likely reflects the stiffness of the concrete encasement with respect to the timber and its inherent tendency to carry a greater portion of the load.



Load Path 1 **Load Path 2** **Load Path 3**

Figure 7-5 Comparison of strains between repaired and non-repaired piles



a) Load Path 1 **b) Load Path 2** **c) Load Path 3**

Figure 7-5 continued

Notes:
1 – All gages on pile 1 measured the strain induced in the corrugated metal pipe form.
2 – All gages on pile 2 measured the strain induced in the corrugated metal pipe form except for gages 6084 and 4703, which measured strain induced in the exposed portion of the timber pile.
3 – All gages on piles 3, 4, and 5 measured strain in the timber only.

7.2 Bridge Test 2

Bridge 2 is a single span 16 ft long Greenwood flume bridge. The superstructure consists of timber decking and 21 timber stringers bearing on a timber pile cap, while the substructure at each abutment consists of eight original timber piles and six added timber piles. Additionally, the base of all piles at the waterline was encapsulated in concrete. Bridge 2 can be seen in Figure 7-6 and the instrumented abutment piles and backwall can be seen in Figure 7-7.

a) Side view

b) Abutment with original and new piles

Figure 7-6 Bridge 2 side view and added piles

The added piles were essentially the same size as the existing piles and were placed directly adjacent to them. The bearing conditions appeared to be consistent between all existing and new piles. Presented in Figure 7-8, are the strains in adjacent new and old piles when the first, second, and third axles of the load truck pass over the pile cap, respectively. By visual inspection, one can see the strains in the new and old piles are very nearly the same. Assuming that adjacent piles receive equal load, this gives evidence that the load is approximately split between the two piles, thus reducing the load capacity required by any one pile to half.

The condition of the original piles was unknown prior to the addition of new piles and concrete footing. Nonetheless, the remaining visible portion of the original piles is in good condition. With that said, the strain data also gives evidence to the good condition of the visible portion and the effects of the concrete encasement at the base of all piles. With near equal strain values, the pile stiffness and, therefore, condition must be nearly equal. Additionally, the formed concrete footing that encapsulates the bases of each pile provides a solid base for which the load can be transferred from the piling.

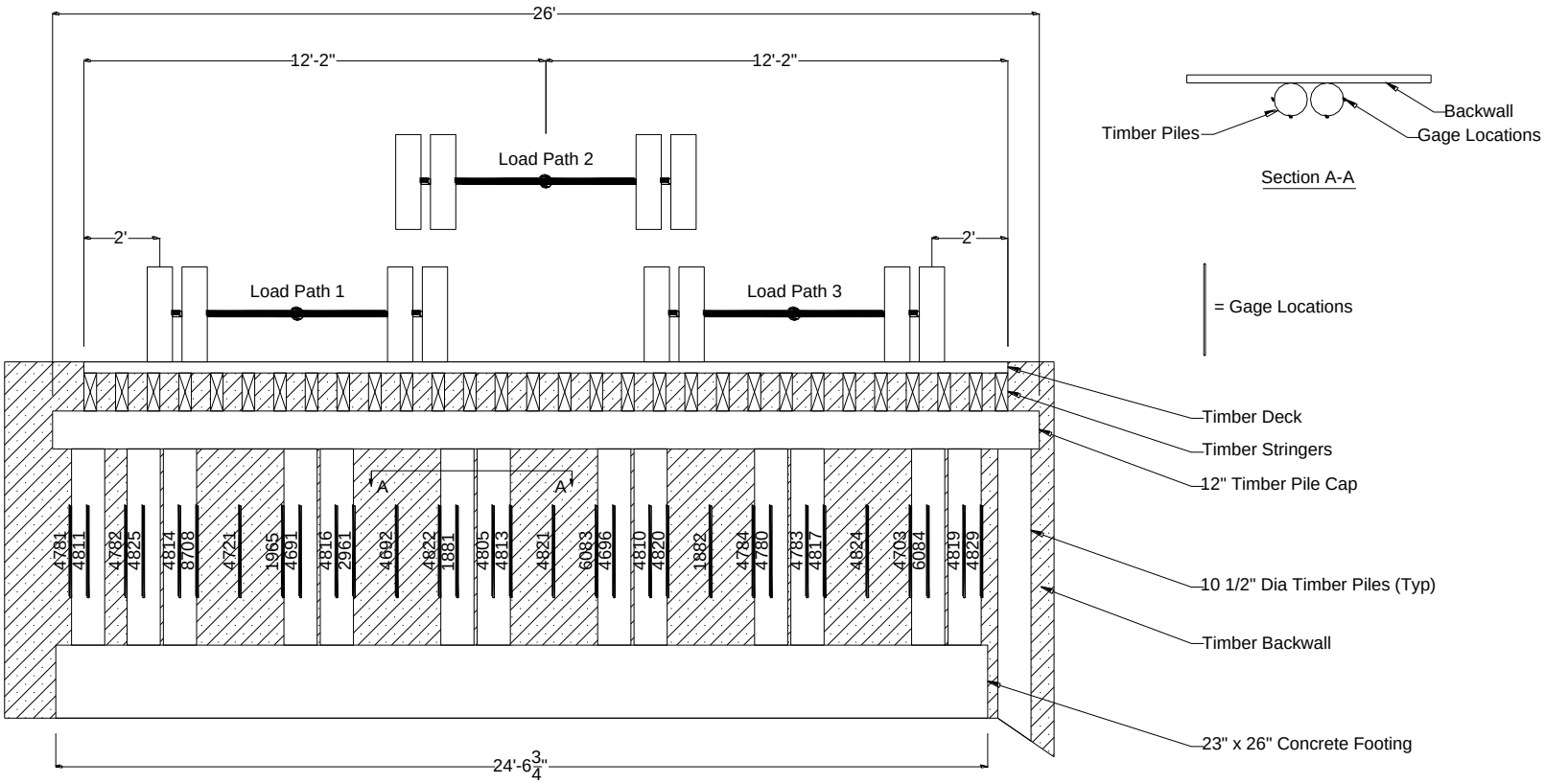
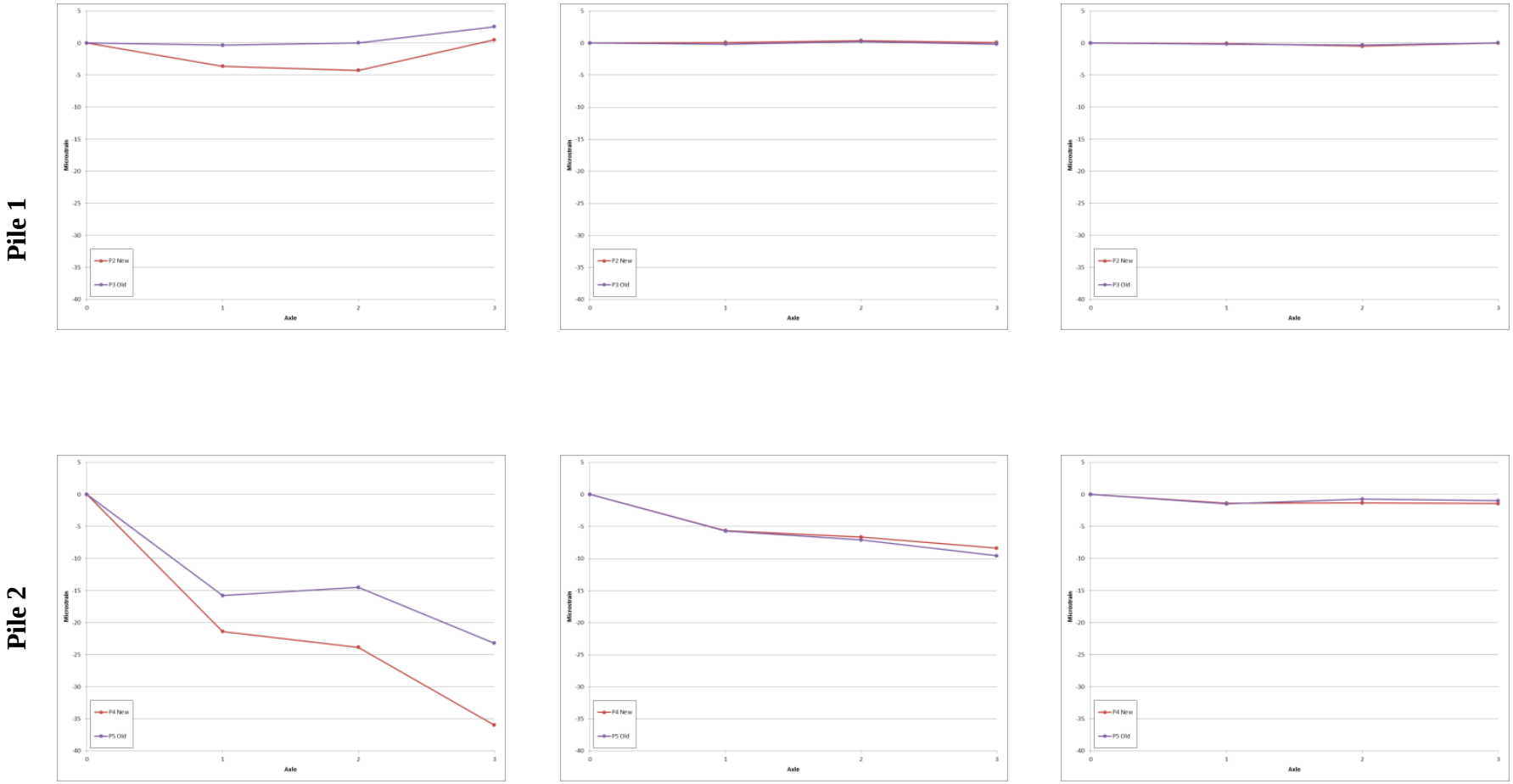


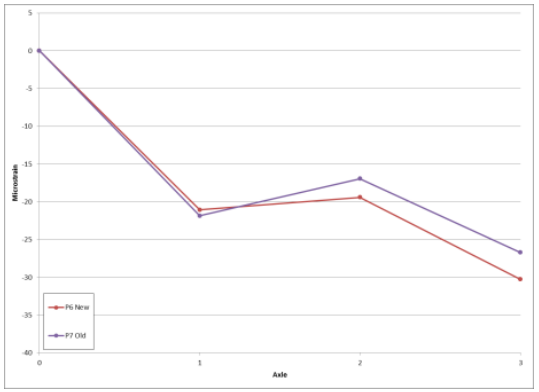
Figure 7-7 Schematic of Bridge 2 instrumented piles and load path positions

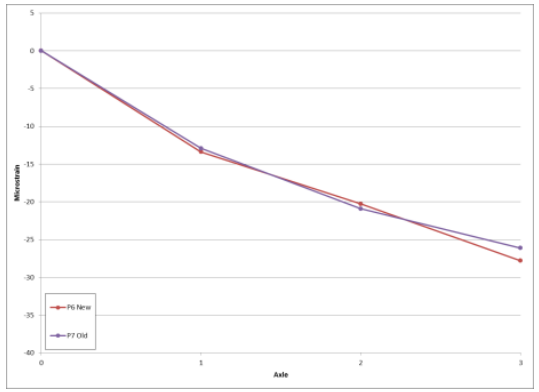


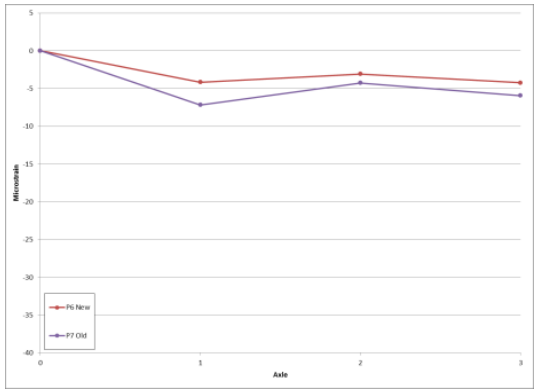
a) Load Path 1 b) Load Path 2 c) Load Path 3

Figure 7-8 Bridge 2 comparison of old and new pile strain under each axle

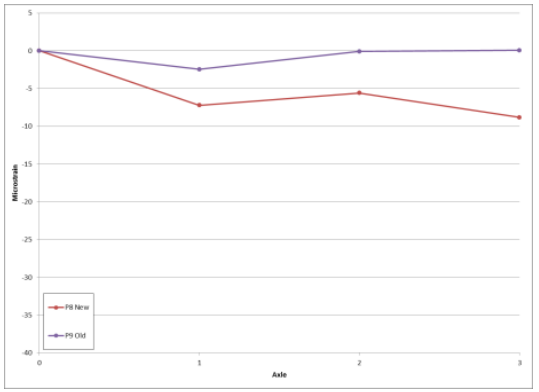
Pile 3

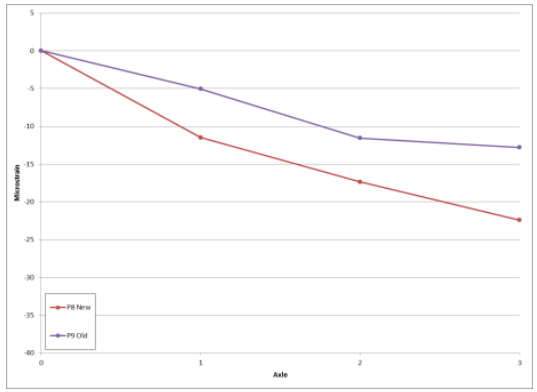


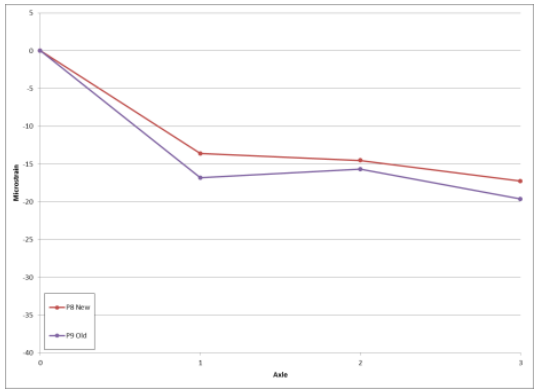




Pile 4



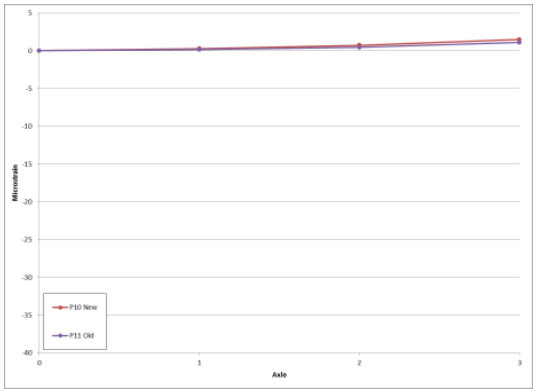


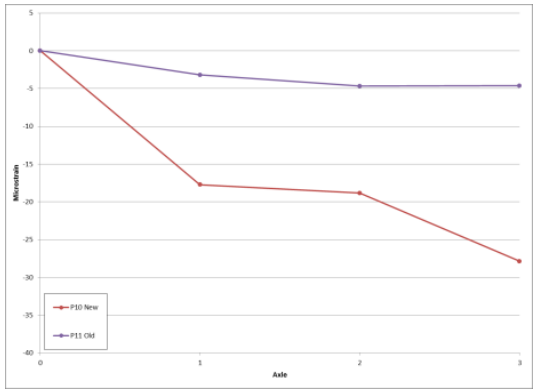


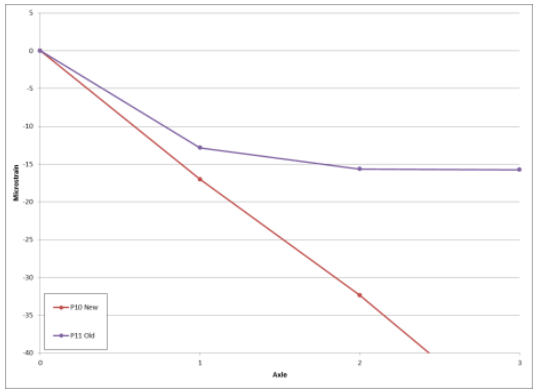
a) Load Path 1 **b) Load Path 2** **c) Load Path 3**

Figure 7-8 continued

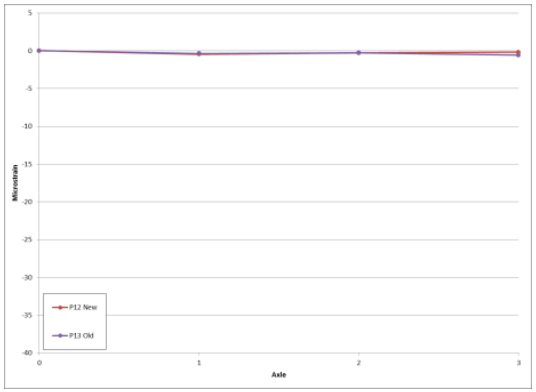
Pile 5

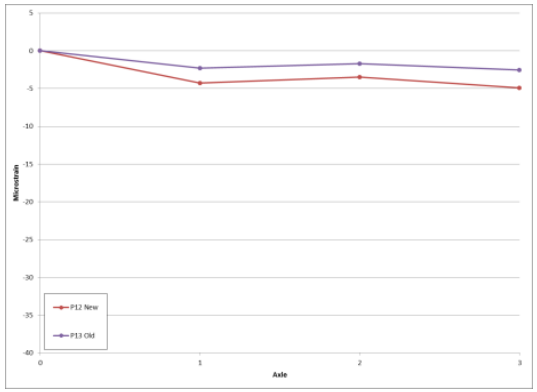


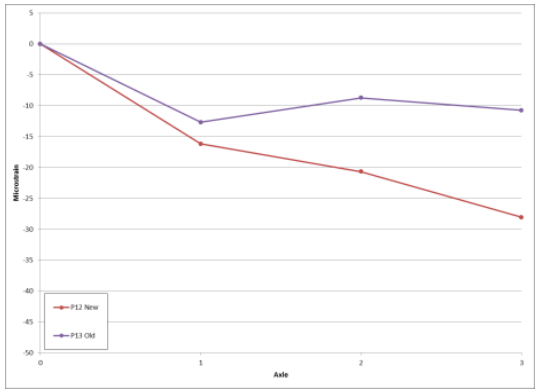




Pile 6



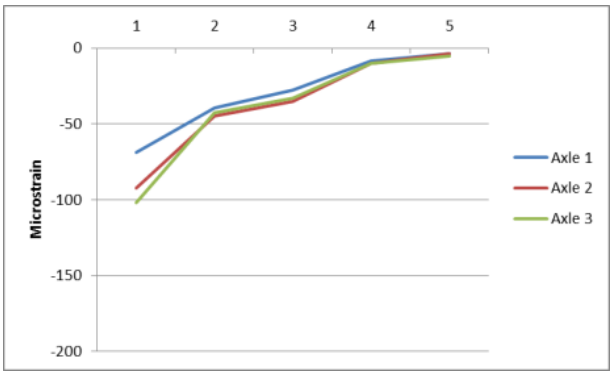




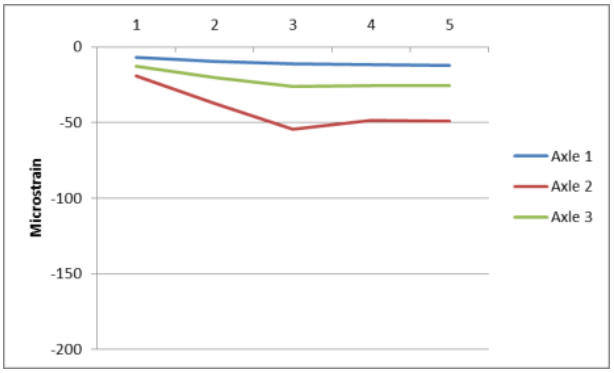
a) Load Path 1 **b) Load Path 2** **c) Load Path 3**

Figure 7-8 continued

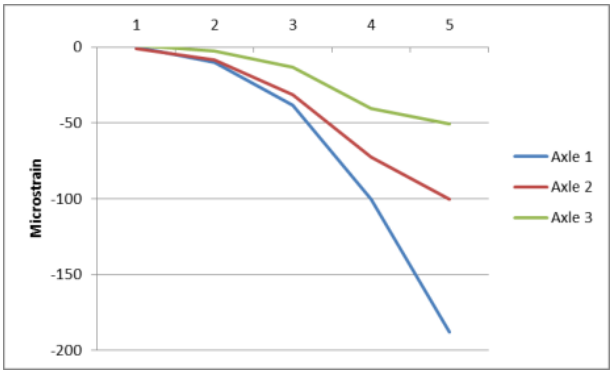
The participation of the backwall in transferring vertical loads is assumed to be negligible when determining the required capacity of piles. Even so, the backwall has shown the ability to transfer some load, thus relieving the piles of the total load. Backwall strains measured under each axle for load paths 1, 2, and 3 are presented in Figure 7-9. The total force carried by the backwall is unknown due to the unknown dimensions of the sawn lumber planks and the partial continuity between individual planks. Nonetheless, the strain patterns are consistent with the load paths and indicate the backwall participates in load resistance.



Load Path 1



Load Path 2



Load Path 3

*1, 2, 3, 4, and 5 correspond to backwall spaces in Figure 7-7 (L-R)

Figure 7-9 Back walls strain under each axle between pile groups

7.3 Bridge Test 3

Bridge 3 (shown in Figure 7-10; constructed in 1950) is a 53 ft long bridge with simple spans of 10 ft, 23ft, and 10 ft for the first, second, and third spans, respectively. The superstructure consists of 20 timber stringers and timber decking bearing on a timber pile cap; the substructure at each abutment consists of four timber piles, a timber back wall, and timber wing walls. Additionally, as shown in Figure 7-9d, the bottom 2 ft of piles above ground have been encapsulated by timber planking and concrete infill. Each of the two piers has six piles. Three piles in the eastern pier (See Figure 7-9a) have been encapsulated in a corrugated metal pipe with concrete infill, whereas in the eastern pier, one pile (See Figure 7-9b) has been encapsulated. Instrumented abutment and pier piles can be seen in Figure 7-11.

As the objective of the load test was to determine how the repaired piles respond to applied load, the researchers decided that strain sensors would be placed on each pier pile and the piles within the eastern abutment. Strain sensors on the pier and abutment piles were placed above and below the encapsulated portions where applicable.

At the piers, the measured strains revealed that part of the applied load was distributed to the formed cast portion around the existing pile. The strain values measured on the cast portion were generally smaller than those measured on the timber-only portion, which should be expected given the difference in total cross-sectional area and combination of materials used at the casted portion. Moreover, where compression and tension strains were measured in the timber-only portions of the pile (top), the strain values in the strengthened portion followed. The total load applied to the piles was calculated assuming the piles were primarily in axial compression. It was also assumed the strains measured at the strengthened portion were uniform throughout each respective cross section. Table 7-1 presents a comparison of the total load calculated in each pile to the calculated load distributed to each component (concrete and timber) within the strengthened portion. Moreover, Figure 7-12 presents the comparison in graphical form. The observable differences in total load between the top of the pile and strengthened portion can be attributed to such unknown attributes as the modulus of elasticity of each material, slight variances in cross-sectional area, or bending behavior. Nonetheless, it is evident that a significant portion of the load is distributed to the concrete within the strengthened portion of the pile.

At pier 2, the only repaired pile carried very little load in all load cases. It is possible the bearing condition between the pile cap and pile has separated enough to inhibit immediate load transfer. It may also be possible that the non-viewable portions of the pile below the ground line have deteriorated to a condition that prevents load transfer to the ground. Given the apparent load transfer within the casted portions of the piles in pier 1, it can be assumed the cast effectively strengthens and restores stiffness to the pile when the pile is in otherwise good condition beyond the casted portions.

The behavior seen in the abutment piles was consistent with the vehicle configuration and load path traveled. Strain data collected at the face of the timber planking mirrored the data collected near the top of the pile, though the strain magnitudes were different. This phenomenon gives evidence for load sharing between the piles and timber planking; it is likely the load is shared

with the concrete infill as well. By visual observation, it is clear the timber planking and concrete infill system shortens the effective length of the pile in the transverse direction, protects the bottom half of the piles from damage due to debris flow, and provides support to the existing backwall.

Table 7-1 Bridge 3 Pier 1 calculated loads at each pile and cast, lbs

		Pile 1	Pile 2	Pile 3	Pile 4	Pile 5	Pile 6
Load Path 1	$P_{p,t}$	-3409	-2372	-4676	-667	-197	-447
	$P_{p,c}$	-	-221	-	-181	-	-27
	$P_{c,c}$	-	-1486	-	-1218	-	-185
Load Path 2	$P_{p,t}$	-312	-916	-5573	-2481	-888	-617
	$P_{p,c}$	-	-25	-	-193	-	-20
	$P_{c,c}$	-	-170	-	-1300	-	-135
Load Path 3	$P_{p,t}$	334	543	-3176	-2020	-1251	-2161
	$P_{p,c}$	-	53	-	-263	-	-255
	$P_{c,c}$	-	358	-	-1770	-	-1719

$P_{p,t}$ = Load at top of pile
$P_{p,c}$ = Load at portion of pile within cast
$P_{c,c}$ = Load within concrete portion of cast

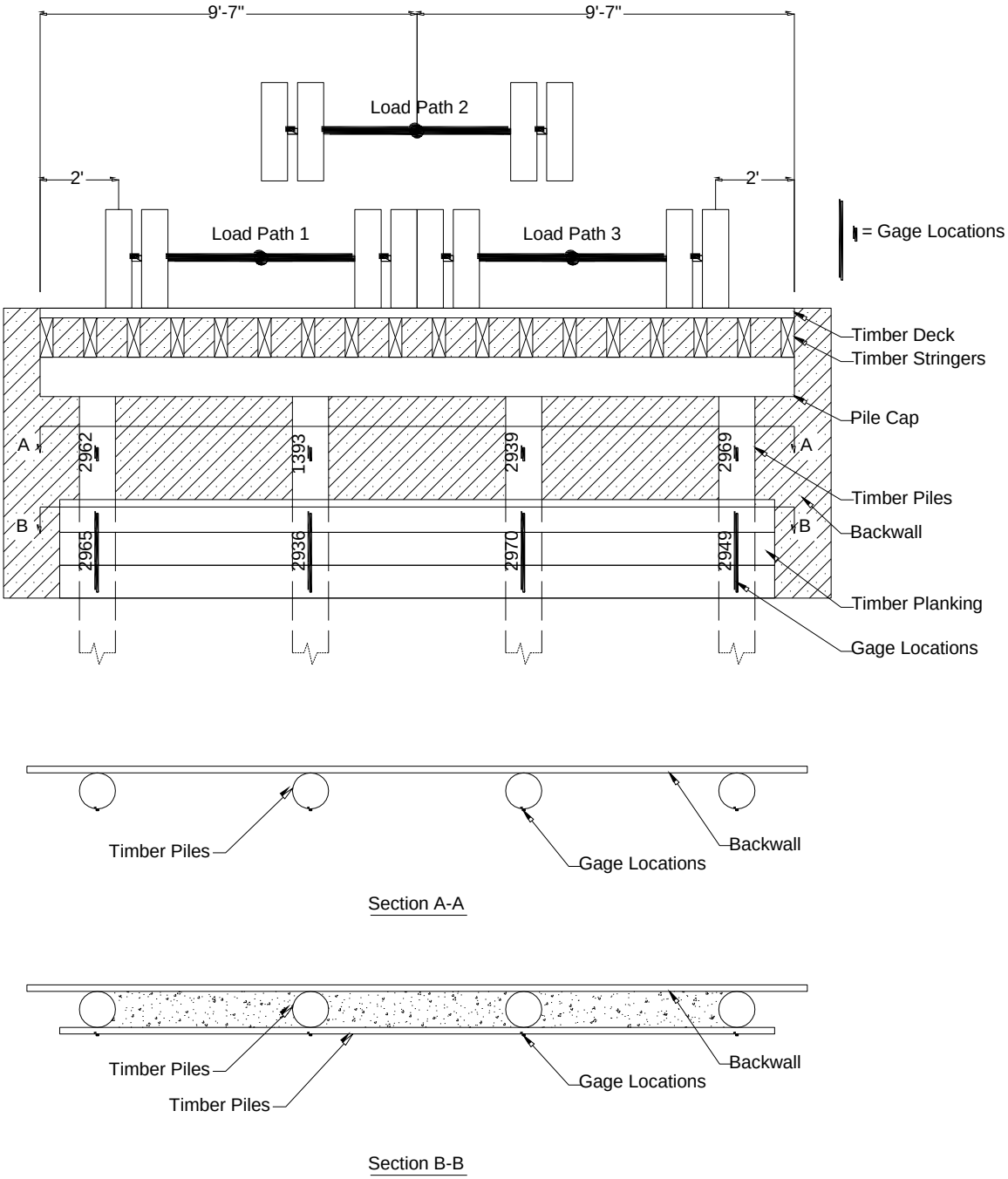
a) Pier 1

b) Pier 2

c) Close-up of repair

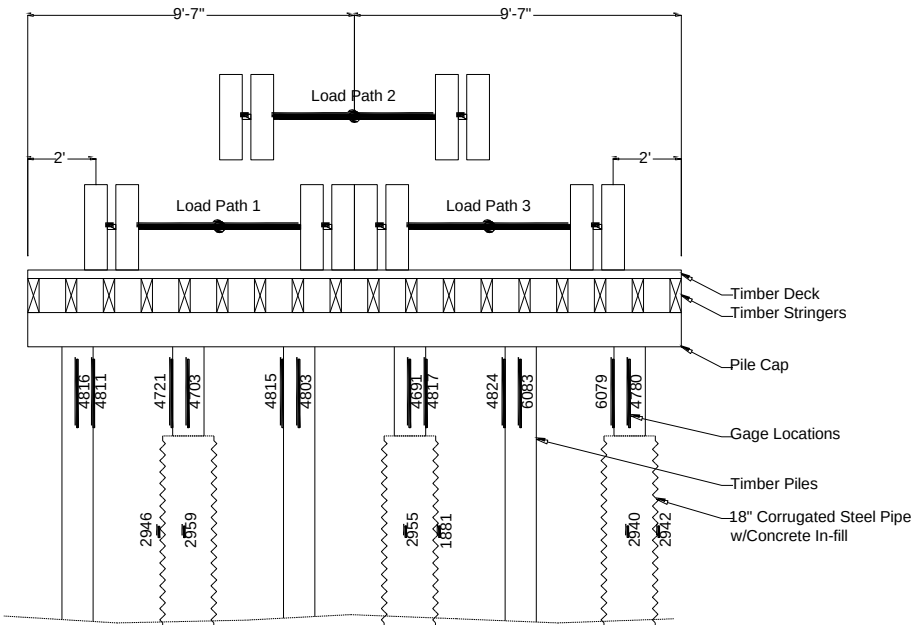
d) Encapsulated abutment piles

Figure 7-10 Bridge 3 repairs and reinforcement

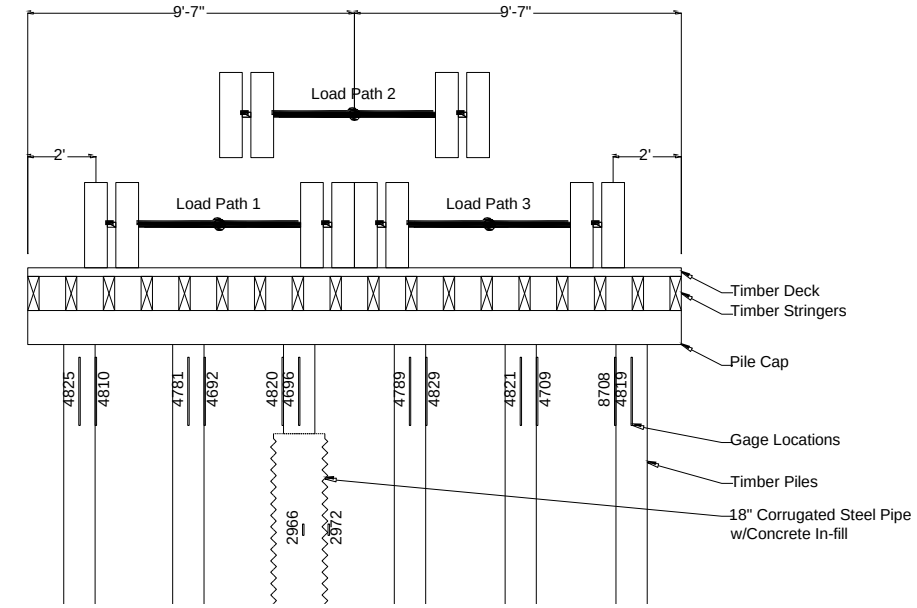


(a) Abutment piles looking east – truck traveling out of page

Figure 7-11 Schematic of Bridge 3 instrumented abutment and pier piles

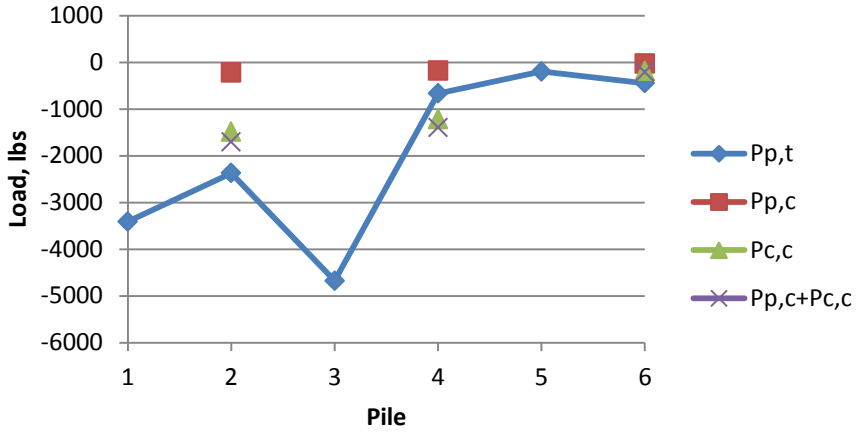


b) Pier 1 piles looking east – truck traveling out of page

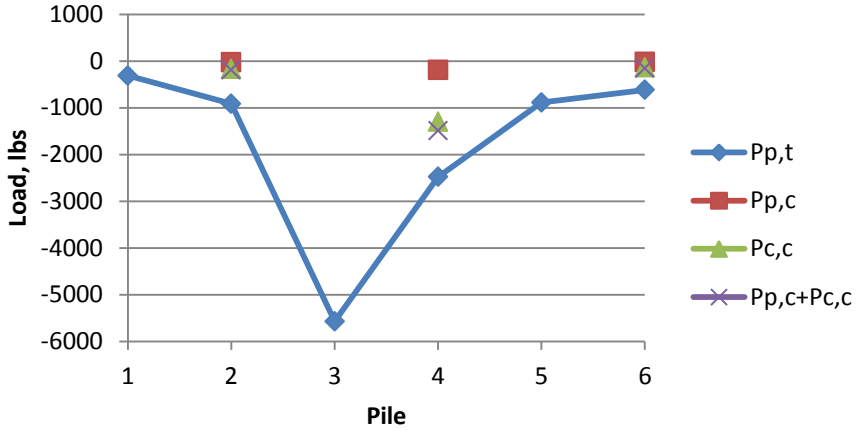


c) Pier 2 piles looking east – truck traveling out of page

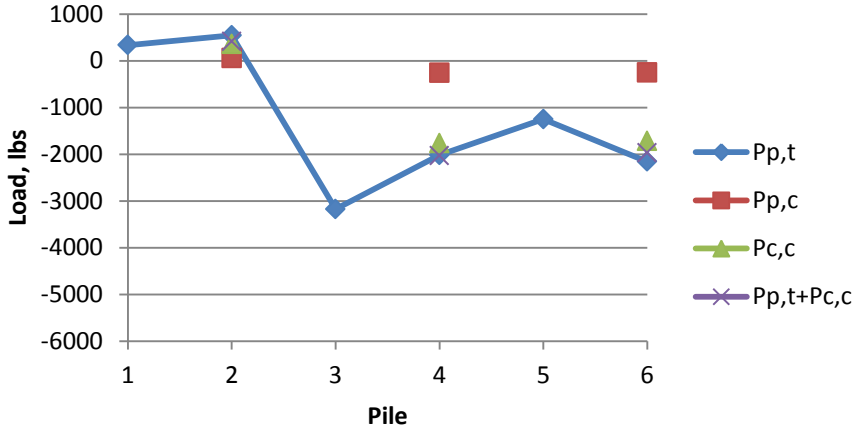
Figure 7-11 continued



a) Load Path 1



b) Load Path 2



c) Load Path 3

Figure 7-12 Bridge 3 load comparison at pile and casted portion of Pier 1

7.4 Bridge Test 4

Bridge 4 (total length of 58 ft) has three spans of equal length. The superstructure consists of 13 timber girders and a timber deck, while the substructure consists of timber pile caps and timber piles, five at each abutment and four at each pier. The only timber pile repair was located at the easternmost pier; one of the four piles was repaired by removing the timber pile from between the ground and the pile cap and replacing it with a steel H-pile; the pier and repair are shown in Figure 7-13.

a) Pier with steel post

b) Steel post connection to pile cap

c) Steel post connection to existing pile

Figure 7-13 Bridge 4 posting repair

Only the pier where the pile repair is located was instrumented with strain gages. Strain gages were placed on each pile and the pile cap. Strain results from three load paths were obtained; two feet from left curb, centerline, and two feet from right curb. The schematic of the instrumented pier and the load path locations are shown in Figure 7-14.

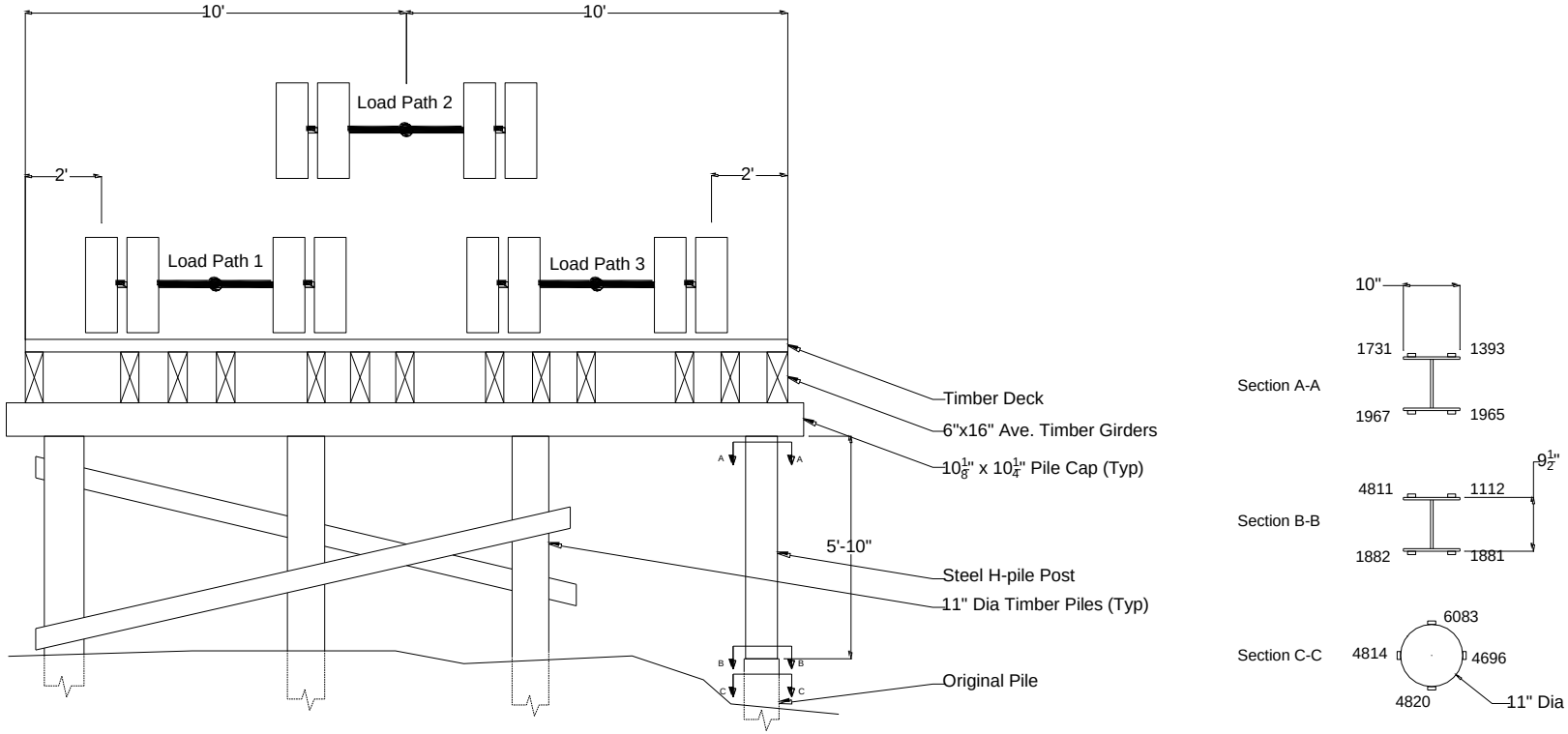
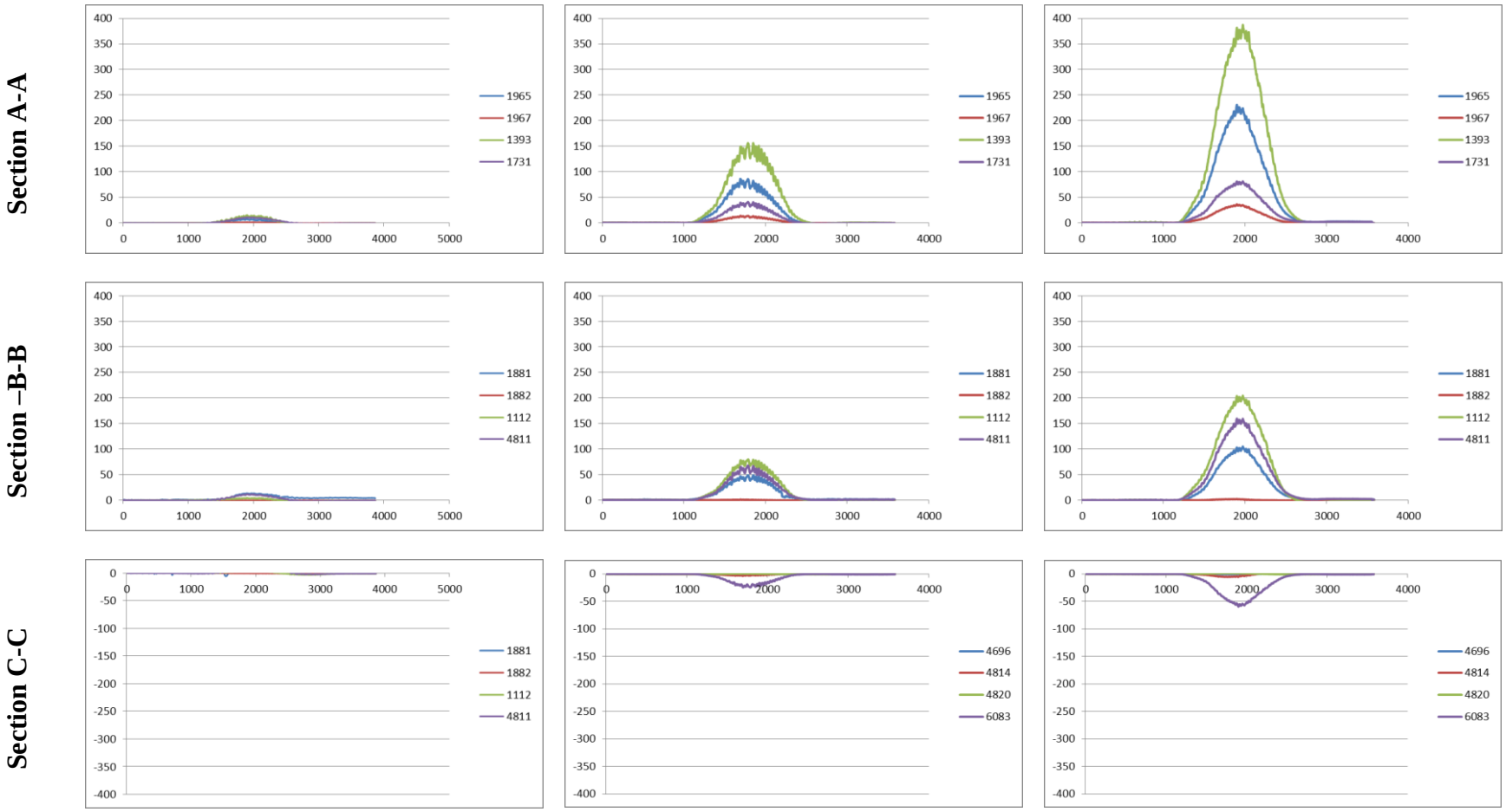


Figure 7-14 Schematic of Bridge 4 instrumented pier and load paths

The strain results obtained from the test on Bridge 4 were typical of those anticipated by the researchers based on the fairly simple overall structure (simple spans and vertical timber piles with diagonal cross-bracing). However, the results obtained from the steel pile, presented in Figure 7-15, were unusual especially given that the only connections to the pile were at the pile cap and at the cut end of the original timber pile, i.e., no diagonal bracing. The researchers anticipated significant compression loading in the steel pile and, at a minimum, compression loading on one side of the pile if bending occurred. Given the position of load path 3 with respect to the position of the steel pile, it would appear very unlikely the pile would be in tension. However, this was the case. Moreover, the strain results in the original timber pile to which the steel pile was connected indicated compression loading. The researchers questioned the validity of the results because of this unusual and seemingly illogical phenomenon; thus, the researchers decided to retest the pile in question. After retesting the pile, the results from the original test were verified to be correct. Without a much greater amount of instrumentation and significant investigation, this puzzling occurrence may be left unsolved.



a) Load Path 1 **b) Load Path 2** **c) Load Path 3**

Figure 7-15 Bridge 4 posted pile strain results

This incident may be attributable, at least in part, to the connections of the steel pile to the original pile and pile cap shown in Figure 7-16. The pile cap did not achieve full bearing on the post. Rather, the pile cap achieved bearing only on one edge of the post. Additionally, lag screws were used to connect each component. It is possible that when a load was introduced to this connection, the localized load path induced tension into the pile. Regardless of the unusual results, and possibly despite little structural assistance of the repaired pile, the bridge has been able to carry vehicular loads.

It is often difficult to achieve full bearing when retrofitting or repairing bridge piles in the field. As such, additional laboratory testing of a method to enable full bearing was completed and is presented in the next chapter.

a) Steel post connection to pile cap – view 1

b) Steel post connection to pile cap – view 2

c) Steel post connection to pile cap – view 3

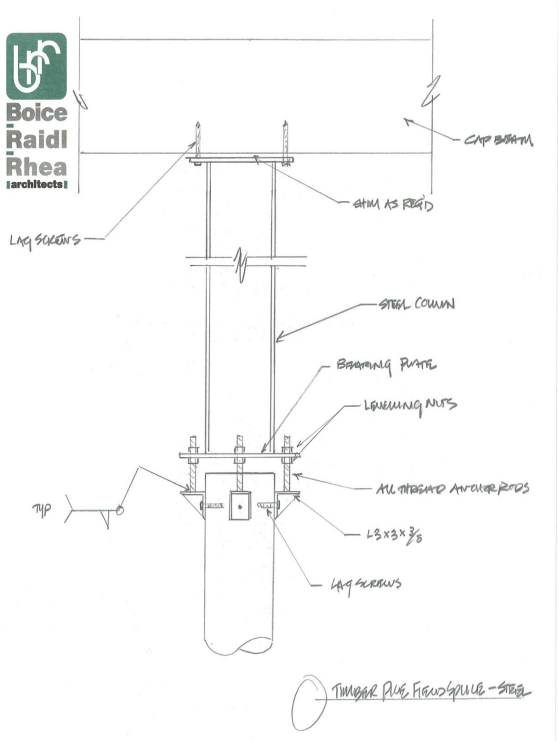
d) Steel post connection to pile cap – view 4

Figure 7-16 Bridge 4 steel pile to pile cap connection

8 DEVELOPMENT OF NEW STRENGTHENING SYSTEM

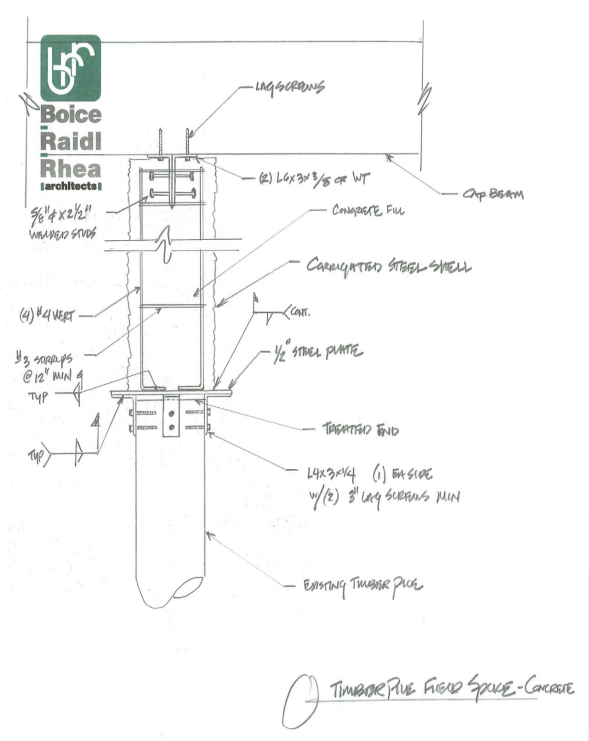
The researchers, after having developed several potential strengthening systems, with the purpose of creating constructible and economical solutions to timber pile strengthening and/or improvement to existing solutions, summarized details for these schemes as shown in Figure 8-1. Subsequently, the TAC was consulted to propose lab testing on a selected few. Three were of particular interest; two of which could be completed in the ISU structures lab, while the third would be a field demonstration. Full page details are provided in Appendix B.

The two options selected for laboratory testing were 1) steel channel attached to opposite sides of the deteriorated portion extending to sound timber above and below (see Figure 8-1d), and 2) revision of steel posting connection to enable field adjustment for full bearing (see Figure 8-1a).

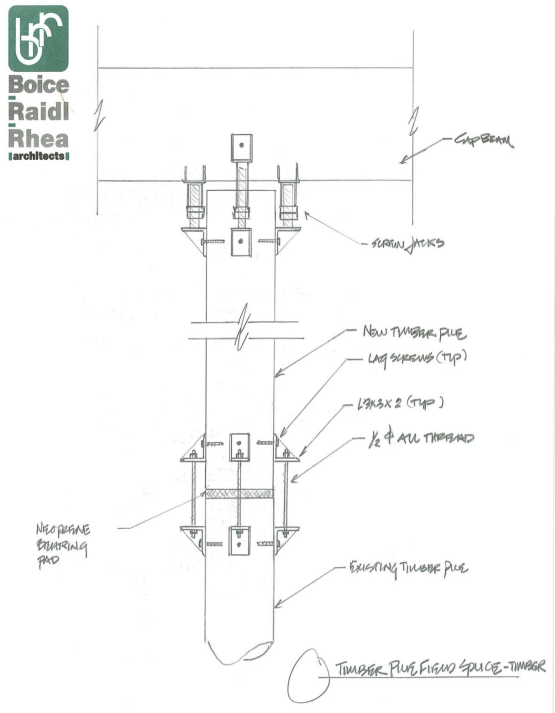


a) Timber pile field splice - steel

Figure 8-1 Details of potential strengthening systems

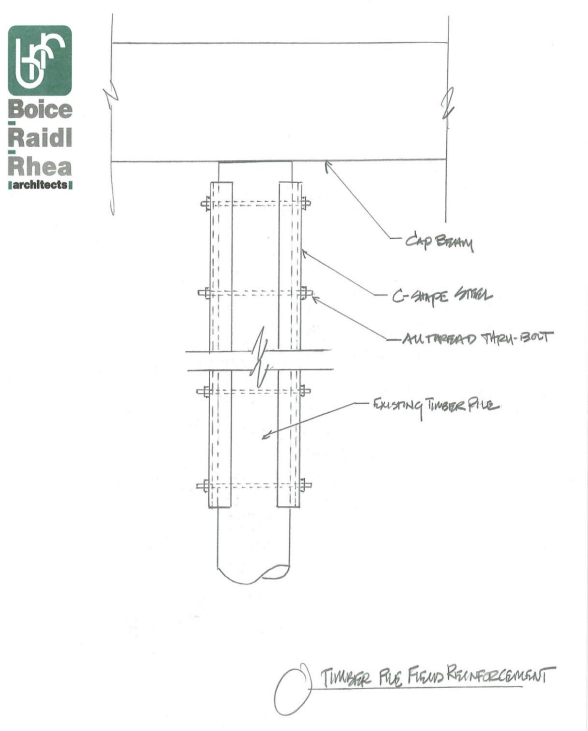


b) Timber pile field splice - concrete

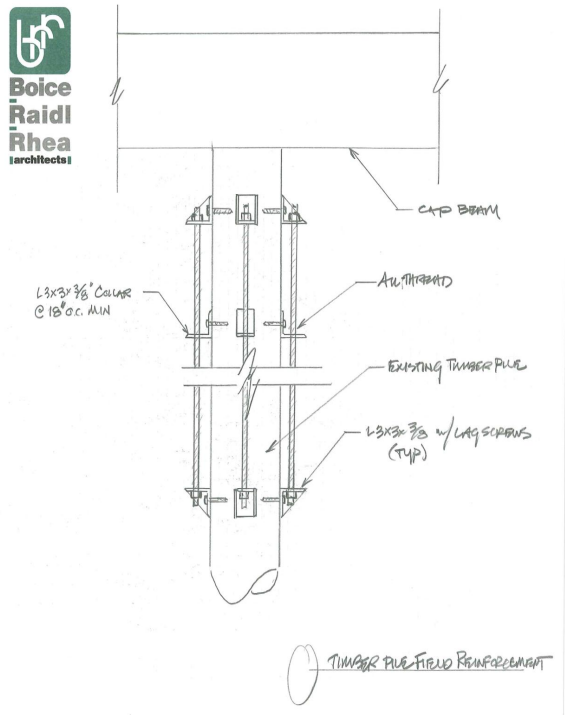


c) Timber pile field splice - timber

Figure 8-1 continued



d) Timber pile field reinforcement - 1



e) Timber pile field reinforcement - 2

Figure 8-1 continued

8.1 Control Specimens

Prior to completing axial load tests on the two selected potential strengthening systems, three control specimens were created using timber piles obtained from former bridge structures. As shown in Figure 8-2, each was cut to simulate 50 percent cross-sectional area loss.

a) Creation of test specimen - 1

b) Creation of test specimen - 2

Figure 8-2 Creating control specimens

The control specimen characteristics including the original and reduced area and diameter and specimen length are presented in Table 8-1.

Table 8-1 Control specimens characteristics

Control Specimen	Original Diameter	Cross-Sectional Area	Reduced Section Diameter	Reduced Section Area	Specimen Length
1	10”	77 in^2	7”	38.5 in^2	48”
2	9 1/2”	71.6 in^2	6 3/4”	35.8 in^2	48”
3	10 1/8”	79.8 in^2	7 1/8”	39.9 in^2	48”

These control specimens were created to compare the results of a strengthened pile load test to that of a non-strengthened pile. Information regarding the material properties and, maybe even more noteworthy, the capacity of a reduced section and failure mechanism is determined from the axial load tests. The specimens undergoing the axial compression test are shown in Figure 8-3.

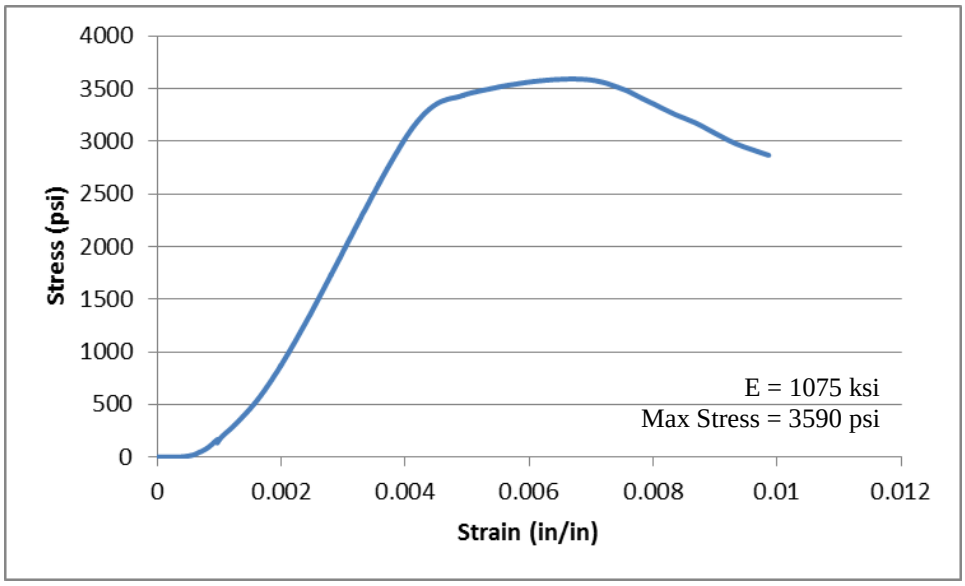
a) Specimen 1 **b) Specimen 2** **c) Specimen 3**

Figure 8-3 Control specimens during load test

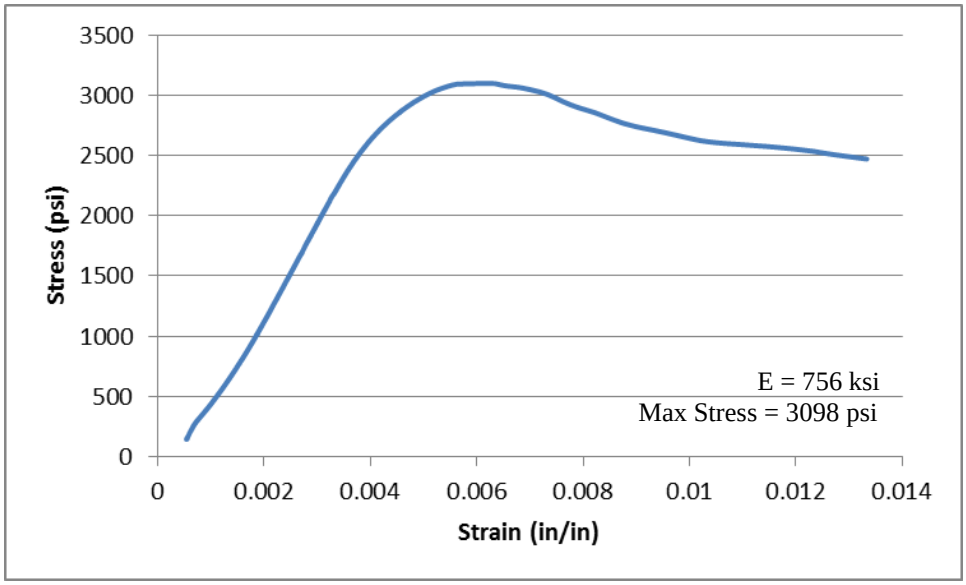
The stress versus strain results of each test are presented in Figure 8-4. These results were obtained using the laboratory's testing machine. The minimum modulus of elasticity was found to be 756 ksi, while the maximum was found to be 1311 ksi. The maximum stress calculated for the three tests varied from 3098 psi to 3590 psi.

As was previously mentioned, the piles used to create the specimens were from former bridges within the state of Iowa. Additionally, the sizes used are typical of those at existing bridges. Subsequently, the total capacity of the specimens in and of itself, even with the simulated 50 percent decay was noteworthy. The smallest failure load measured for any of the specimens was 112 kip – a load significantly greater than that individual pile are currently subjected to at existing bridges. One should not assume that piles even in a decayed state can withstand loads to this magnitude, as the field conditions most likely differ from that of a controlled test, i.e., length and degree of decay, lateral unbraced length, induced bending, etc. Rather, one could assume that a significant amount of reserve capacity exists in piles that have experienced moderate decay.

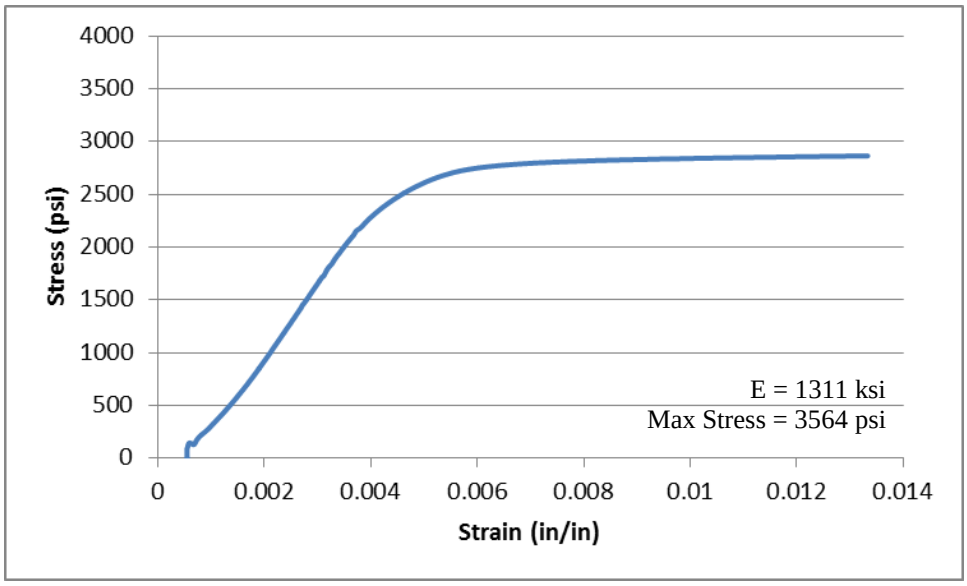
Also noteworthy was the way each of the piles eventually failed. During loading, the reduced section began to balloon in the radial direction until most exterior fibers would splinter and peel away from the specimen. If any checks were present prior to loading, the size of the checks was magnified and propagation often ensued. Representative photographs taken after completion of the load tests are shown in Figure 8-5



a) Specimen 1 load test results



b) Specimen 2 load test results



c) Specimen 3 load test results

Figure 8-4 Control specimens stress versus strain

a) Deep check

b) Splintered outer fibers

Figure 8-5 Specimens after load test

8.2 Steel Posting Connection

The ability to remove deteriorated portions of an existing pile and replace it with a steel pile that fits exactly in a given location can be difficult given the conditions beneath bridges and tools required. That is not to say it is impossible because that task has been successfully completed many times. However, a solution that provides field adjustment capabilities could improve the process and would hopefully achieve full bearing on the replaced pile. In the previous chapter, one of the tested bridges discussed could have potentially benefitted from a repair method with such field adjustability. As previously noted, the pile cap did not entirely bear on the replacement steel pile and therefore could have potentially contributed to the unusual load transfer through the pile observed during testing.

The researchers created a mockup of a connection that exhibits field adjustability. This mockup, shown in Figure 8-6, consisted of a timber pile section, steel H-pile section welded to a base plate, four 1 in. diameter threaded rods, and four 3/8 in. thick steel angles. Each steel angle was bolted to the timber pile using 5/8 in. diameter lag bolts and leveling nuts were placed between the angles and base plate on the threaded rods. The leveling nuts enabled the adjustment of the base plate.

a) Steel posting connection – view 1 **b) Steel posting connection – view 2**

Figure 8-6 Steel posting adjustment connection

The connection was tested in axial compression using the laboratory's universal testing machine. The load versus deflection curve, presented in Figure 8-7, provides evidence the connection has the capacity required in most timber piles. However, the deflection values were higher than desired. This issue could be easily remedied by using a thicker base plate or base plate stiffeners, as a majority of the deflection was a result of base plate bending. The recommended base plate thickness is greater than the 1/4 in. thickness used in the mockup. Near the end of the test, the slope of the load deflection curve significantly increased. This was the result of the base plate coming into contact with the top of the timber pile. This also provides evidence the capacity of the connection would be greater with a thicker base plate as the total load had not yet reached the capacity of the pile.

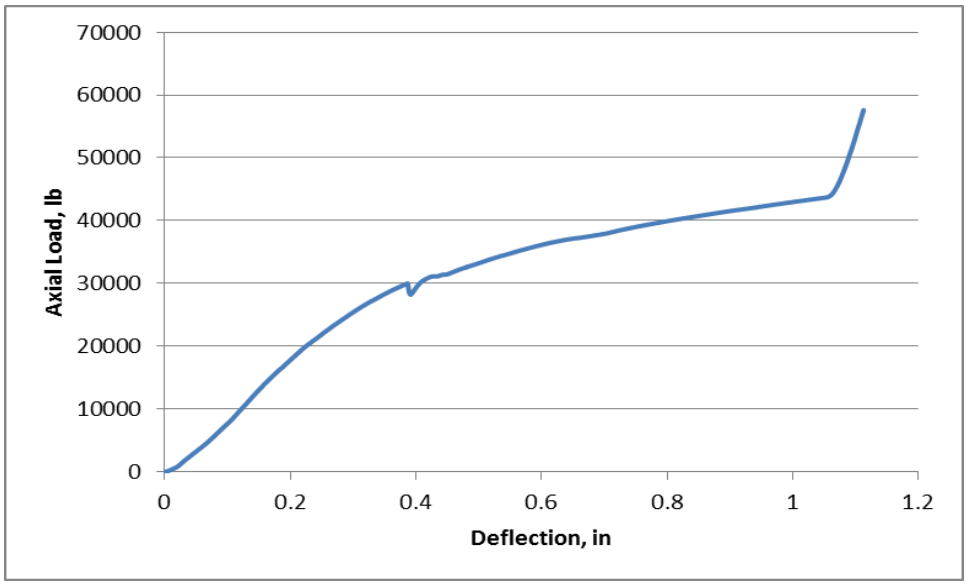


Figure 8-7 Steel posting connection load versus deflection

8.3 Steel Sisters

Commonly, when loss of section is discovered in timber piles and where visual inspection may indicate an inadequate pile, only a short length of the pile has decreased load carrying capacity. A majority of the pile may very well be intact and able to withstand the desired vehicular loading. Where this is the case and localized section loss has advanced to a degree where replacement or reinforcement is desired, a method that could be considered is to sister steel sections to the pile. This method is comprised of spanning and reinforcing the damaged or decayed portion of the pile with steel "sisters" which are anchored above and below within the remaining solid portions of the pile.

The researchers included this method is their laboratory investigation and testing. A pile was modified to simulate a 50 percent cross-sectional area loss over a one foot length. Table 8-2 presents the measurements of the modified pile. Two M6x4.4 (A = 1.29 in^2) steel sections were used to span the section loss and were anchored by four one-inch diameter threaded steel through rods; the specimen is shown in Figure 8-8. Both steel sections were instrumented with strain gages on each flange at the midpoint of simulated decay.

Table 8-2 Characteristics of sistered pile

Sistered Pile	Original Diameter	Cross-Sectional Area	Reduced Section Diameter	Reduced Section Area	Specimen Length
1	9 1/2"	72 in^2	6 3/4"	35.8 in^2	48"

a) Full speciment view **b) Strain gage placment**

Figure 8-8 Timber pile sistered with steel sections

The specimen was axially loaded for purposes of comparison with the control section without the steel sisters. The total combined and individual loads observed in the timber and steel sisters are shown in Figure 8-9. It was found in this test that the steel resisted minimal load until the failure of the pile was imminent and the steel sisters became engaged – the tolerances around the anchor rods were enough that a certain amount of deformation in the pile was required before the rods would bear on the sisters. Even with the simulated 50 percent section loss, the pile performed very well before the sisters were engaged. In fact, the performance was well enough to withstand loads commonly seen by these piles due to vehicular traffic. Nonetheless, with minor changes in how the sisters are attached to the pile, it is likely that one would be able to engage the steel sections almost immediately upon loading.

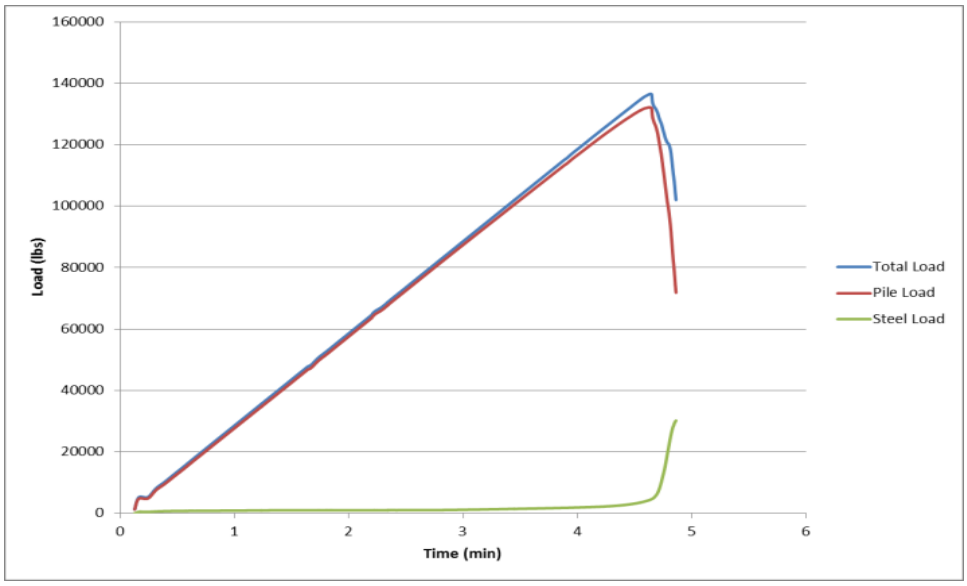


Figure 8-9 Steel sister load test results – Load

The stress values in the timber and steel are shown in Figure 8-10. The observed maximum stress of 3,713 psi in the timber is on the same order as that observed in the control specimens, thus providing assurance that the sistered pile was a representative specimen. Additionally, upon failure of the pile, the maximum stress observed in the steel was only 11,694 psi – well below the yield stress of steel. This would lead one to believe that the overall capacity of the pile would be even greater than the capacity achieved in the load test if the steel were fully engaged earlier in the loading process. Even more, the possibility exists that if the test was not stopped the steel would have become fully engaged and the total load would have reached levels corresponding to the yield stress of the steel.

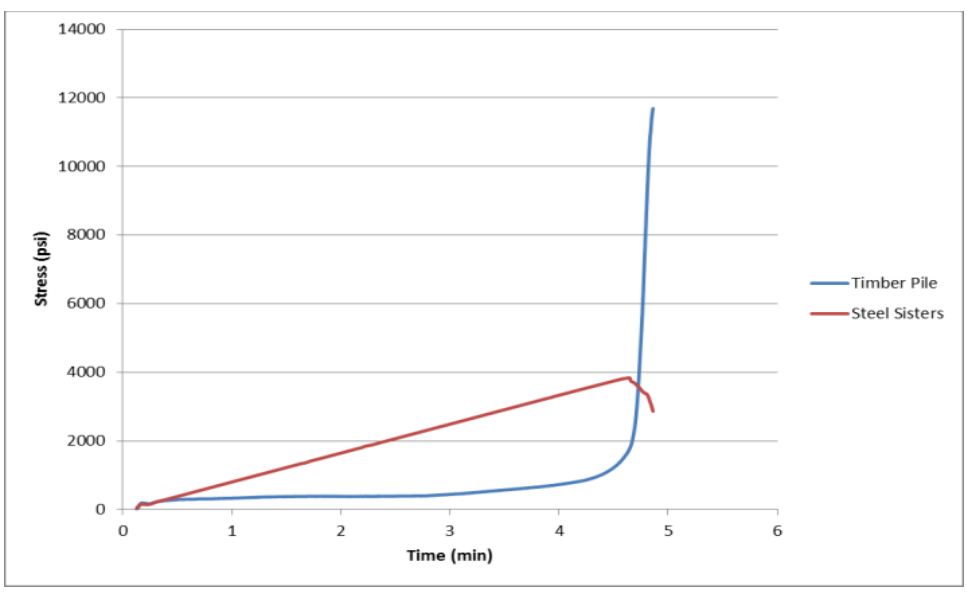


Figure 8-10 Steel sister load test results – Stress

Lastly, the load versus deflection curve for the sistered pile specimen is shown in Figure 8-11. Similar to the curves of the control specimens, the rate of deflection increased significantly only after reaching approximately 0.3 in of total deflection. This gives more evidence that the specimen was representative of other timber piles and the fact that the steel was not becoming fully engaged until the timber began to fail.

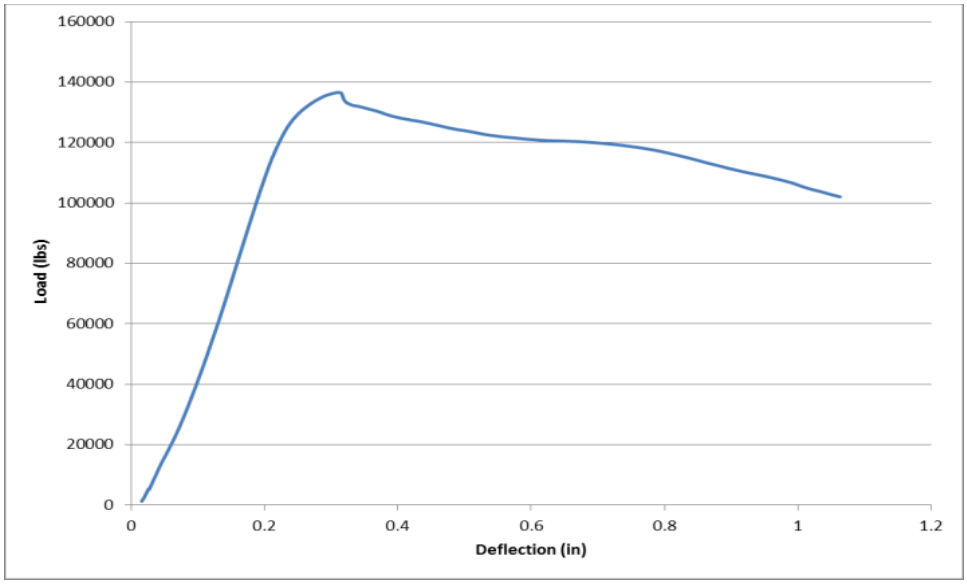


Figure 8-11 Load versus deflection of sistered specimen

8.4 Field Demonstration

The researchers along with the TAC were interested in pursuing a field demonstration at an existing bridge that needed pile repair and/or replacement. A bridge was selected based on the type and degree of decay seen within the piles. In total, five piers, which consisted of 20 total pier piles, were evaluated; 10 of the piles required repairs. Photographs of the bridge and common decay conditions found in the identified piles are shown in Figure 8-12. The pursued method of repair was to fill the decayed portions and other cavities within the pile with an epoxy resin, after which a fiber reinforced polymer wrap would be applied to the pile. The researchers met with a representative from a nationally known company at the bridge site to discuss the process and method of repair. Given the information provided by the representative, the researchers were confident the method could provide a satisfactory repair that would restore the desired load capacity. In the end, however, the repair could not be completed due to the prohibitive cost. Although an effective repair, it may be more suitable for a larger scale project where mobilization and labor costs do not become the greatest percentage of costs. Additionally, this repair may be one that will require independent contractors to complete. The county crews that are able to complete other repairs discussed in this report may not have the expertise or training required.

a) Bridge profile

b) Piers and piles

c) Damage and decay -1

d) Damage and decay - 2

Figure 8-12 Demonstration project candidate bridge

9 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Tens of thousands of bridges within Iowa are maintained at the county level. Of those bridges, a significant percentage is constructed using timber piles, girders, and decks. The superstructures are often sufficient to carry the traffic for which they are required. Even so, the advancing decay of substructure elements, such as timber piles and back walls, pose a problem to the longevity of the overall structure. With such a large number of bridges requiring attention and the fact that available funds are decreasing while maintenance costs are increasing, it becomes important to improve or identify the best currently used maintenance methods for timber substructures.

The objectives of this research were to complete the following:

- Review existing products for timber preservation and repair and to document their effectiveness in extending the service life of various bridge components.
- Determine techniques used by county and other engineers to repair and restore the load carrying capacity of piling damaged by deterioration and cracking.
- Review methods used to repair failed piling.
- Determine/develop effective methods for transferring bridge loads through the failed portion of the pile.
- Determine that safe load capacity is restored by the repair methods (existing or new) determined to be structurally efficient.

To complete these objectives, the BEC employed various tasks including literature searches, field investigation, field testing, lab testing, and online surveys. Following is a brief summary of the results and conclusions discussed within. Additionally, recommendations for future repairs are included.

Deterioration of timber substructure elements can be attributed to either biological or physical deterioration mechanisms. Included in the biological mechanisms are decay fungi, termites, powderpost beetles, and carpenter ants. These mechanisms often have a direct correlation with the temperature and moisture conditions present. Alternatively, physical deterioration mechanisms include abrasion, debris contact, and overloading.

Condition assessment should be conducted using a multitude of tools. These tools include 1) visual assessment, 2) probing and picking, 3) moisture measurement, 4) sounding, 5) stress wave devices, 6) drill resistance devices, 7) core boring, and 8) preservative retention analysis. Any single method may give an incomplete or inaccurate assessment of the given substructure element.

A multitude of preservative treatments exists. Most fall under the categories of oil-borne or water-borne preservatives. Additionally, the preservatives can be applied pre-construction in the manufacturing plant or post-construction while in the field. The longevity or service life of preservative treated wood depends upon a range of factors including type of preservative,

treatment quality, construction practices, type of exposure, and climate. The AWPA has developed standards for treatment and care of timber products to be used in bridge applications.

Maintenance activities depend entirely on the extent of deterioration present within the substructure element. Depending if the deterioration is minor, moderate, or severe, the maintenance activities will be either preventive, remedial, or major, respectively. Preventive maintenance includes moisture control, in-place treatments, and/or epoxy injection of small to medium sized cracks. Remedial maintenance includes posting/splicing by means of mechanical splicing, concrete jacketing, FRP or PVC wraps, and/or injection of epoxy. Major maintenance corrective measures are conducted when deterioration has progressed to the point where major structural components have experienced moderate to severe strength loss and repair or replacement is mandatory to maintain the load carrying capacity. Often the only method that can be employed with this level of decay is to install supplemental piles.

To collect information about timber abutment repairs and rehabilitation, a multiple question survey was sent to federal, state, and local bridge owners across the nation. The survey was divided into five sections; 1) current and past usage of timber for bridges, 2) specific usage of timber back walls and wing walls, 3) timber piling and substructure repair, 4) use of timber preservatives, and 5) BEC destructive and non-destructive testing of bridges within their inventory.

Timber utilization has and continues to warrant the pursuit of maintenance methodologies as all Iowa-county respondents either currently use timber, formerly used timber, or both. Likewise, nearly all non-Iowa county and 75 percent of state/federal level respondents indicated that timber is currently or has formerly been used in substructure elements. Where timber piling is currently not used for new structures, reasons given were the assumed longevity of other materials versus that of timber, durability concerns, lack of reliability, uneconomical, design practices exclude timber from use, and environmental concerns with preservative treatments. Copper naphthenate, either in liquid or paste form, is the most commonly used preservative treatment indicated.

Four Iowa bridges utilizing different methods of repair or strengthening were subjected to live load testing. In each of these tests, the repairs proved to be effective in that the desired stiffness was restored.

At the first of these bridges, corrugated metal pipe was used to create a form around the decayed or damaged portions of the pile, which was filled with concrete, thereby creating a cast and providing additional stiffness. The near term performance of this method appears to be adequate to maintain a functioning bridge. Being as the method of repair has not been observed over the long term, conclusions regarding its indefinite performance cannot be made.

At the second bridge, supplemental piles were placed adjacent to each existing pile. Though seemingly a more expensive option, when installed correctly, this method effectively restores the bridge substructure system to its original condition. Theoretically, the original piles would not require additional maintenance procedures and could progressively lose bearing capacity without any adverse effects on overall bridge performance.

At the third bridge, a cast system similar to that used in the first bridge was used to stiffen the pier piles, whereas at the abutment piles, timber planking was installed across the stream-side face of the piles and the created void between the planking and existing backwall was subsequently filled with concrete. This method, at a minimum, provides much greater protection to the piles from debris flows. Even more, the piles are reinforced in the transverse direction and, as such, may have a greater bearing capacity.

At the fourth bridge, a posting method of repair was used. One pile had been partially removed and replaced with a steel section extending from the sound portion of the existing pile near the ground surface to the pile cap. If installed correctly and proper bearing is achieved at the pile cap and existing pile, the method is quite adequate. One should note that only select piles in any one pile bent should be repaired using this method, as the lateral stiffness in the piles and, therefore, the bridge would be lost at the pile/post connection.

Following the completion of field testing of four Iowa bridges, details of new strengthening systems were developed with the purpose of creating or improving constructible and economical solutions to timber pile strengthening needs. Laboratory testing was completed for two of these solutions.

The first solution involved modifying the existing method of posting with a steel H-pile or the like. Field adjustment of the spliced portion can be necessary when not fabricated to fit the removed portion of pile exactly. A base plate and leveling bolts were implemented to allow for vertical adjustment at the connection between the existing timber pile and new steel post; the connection detail proved to be a promising solution.

The second strengthening system entailed adding steel “sisters” to a decayed or damaged pile. Each sister was bolted to the pile opposite of each other and extended beyond the simulated section loss. In the end, the “sisters” only aided in the strengthening when failure in the remaining portion of the pile was imminent, though it is assumed that modification to the connection details would engage the sisters earlier in the loading process.

The researchers provide the following recommendations regarding the assessment, preservation, repair, and rehabilitation of timber substructure elements.

- Utilize multiple methods to assess the condition of timber substructure elements, including any or all of those previously mentioned in the summary, more accurately.
- Make provisions for physically protecting timber structure elements from environmental conditions (e.g., precipitation), debris, and other damage-causing objects.
- Adhere to the AWPA Standards for the treatment and care of timber bridge elements.
- Be cognizant of applying preservative treatments to cut or fastened portions of timber substructure elements to avoid point of entry for biological decay mechanisms.
- When decay or damage is present, conduct maintenance activities at earliest possible stage to avoid increased cost associated with maintenance postponement.
- The addition of mild-steel reinforcement in the form of angles, channels, W shapes, or

similar has the ability to provide increased load capacity to mild or moderately decayed existing pile.

- Field adjustability can be achieved with few minor and relatively inexpensive parts when completing the posting method of repair.
- The current method of casting a single pile with corrugated steel pipe and concrete effectively restores the desired stiffness within the casted portion of the pile; this method has been used in numerous locations around the state of Iowa.

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APPENDIX A. PILE AND ABUTMENT REPAIR QUESTIONNAIRE

To Transportation Agency,

A new research project –Timber Abutment Piling and Back Wall Rehab and Repair– has been funded by the Iowa Highway Research Board and the Iowa Department of Transportation. The primary objective of this research is to identify several techniques/materials that are effective in rehabilitation/strengthening various timber substructure elements.

The Iowa State University Institute for Transportation has created a brief questionnaire for collecting information regarding techniques/materials for repairing weakened or damaged timber elements that have been used in the past. The online form of the questionnaire can be found at http://www.surveymonkey.com/s/GYW2CC2

If you are not the responsible agency/person for bridge rehabilitation and repair for your area could you please lets us know who is so we can forward the survey to them.

For the research team to complete the work in a timely manner, we ask that you please complete the questionnaire by **August, 15th 2010**

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 rehabilitation and/or strengthening various timber substructure elements. If desired, you may contact me or the project Principal Investigator: Dr. Brent Phares bphares@iastate.edu or (515) 294-5879.

Sincerely,

Jake Bigelow P.E.
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010
(515) 313 5703
jbigelow@iastate.edu

Iowa Highway Research Board

Research Project IHRB-09-04

"Timber Abutment Piling and Back Wall Rehab and Repair"

Questionnaire completed by: _____

Organization: _____

Address: _____

_____

Phone # _____

E-mail address: _____

Written responses can either be E-mailed or faxed to Brent Phares (E-mail address: bphares@iastate.edu; Fax number: 515-294-0467). If you have some procedures, pictures, etc. that you are willing to share, please mail them to:

Dr. Brent Phares, P.E.

2711 South Loop Drive, Suite 4700

Iowa State University

Ames, Iowa 50010-8664

Survey Questions found online at http://www.surveymonkey.com/s/GYW2CC2

Section 1 - General Questions

1.1) Please provide your:

Name:
Agency you are affiliated with:
Phone Number:
Email:

1.2) Does your agency currently utilize or previously utilize timber in bridge piling or backwall substructures? If you answered no, the rest of the questions do not need to be answered.

___Yes, we currently utilize timber
___Yes, we have previously utilized timber
___No, we previously and currently do not utilize timber

Section 2 – Timber Backwall/Wingwalls

2.1) Does your agency have existing bridges with timber backwall/wingwalls?

___Yes ___No

2.2) Does your agency construct new bridges with timber backwall/wingwalls?

___Yes ___No

If no, is there a reason why not?

2.3) What is the expected service life for the timber backwall.

___1-10 years
___11-20 years
___21-30 years
___31-40 years
___41-50 years
___Over 50 years

2.4) What are the most common causes of problems with the timber backwall (Rate with 1= most common to 4 = never)?

___Scour
___Mechanical Deterioration
___Biological Deterioration
___Misalignment
___Lack of Maintenance
___Other (please specify)

2.5) What methods have you or your consultant used to detect backwall problems?

___Visual Inspection
___Non-destructive testing (explain testing)
___Other (please specify)

If NDT is used, what method is used and describe test process. Or specify Other:

2.6) Please describe any remedial and or strengthening measures you have used in the past to repair and restore load carrying capacity of the backwall?

2.7) Of those remedial and strengthening measures, which do you consider to be most effective and beneficial and why?

2.8) May we receive a copy of drawings, pictures, etc. of the remedial and strengthening measures?

___Yes ___No

If yes what is the best way to receive the information?

Section 3 – Timber Piling/Substructure

3.1) Does your agency have existing bridges with timber piling?

___Yes ___No

3.2) Does your agency construct new bridges with timber piling?

___Yes ___No

If no, is there a reason why not?

3.3) What is the expected service life for the timber piling.

___1-10 years
___11-20 years
___21-30 years
___31-40 years
___41-50 years
___Over 50 years

3.4) What are the most common causes of problems with the timber piling/substructure (Rate with 1= most common to 4 = never)?

___Scour
___Mechanical Deterioration
___Biological Deterioration
___Misalignment

___Lack of Maintenance
___Other (please specify)

3.5) What methods have you or your consultant used to detect piling problems?

___Visual Inspection
___Non-destructive testing (explain testing)
___Other (specify)

If NDT is used, what method is used and describe test process. Or specify Other:

3.6) Please describe any remedial and or strengthening measures you have used in the past to repair and restore load carrying capacity of piling?

3.7) Of those remedial and strengthening measures, which do you consider to be most effective and beneficial?

3.8) May we receive a copy of drawings, pictures, etc. of the remedial and strengthening measures?

___Yes ___No

If yes what is the best way to receive the information?

Section 4 – Timber Preservatives

4.1.) What plant-applied preservative treatments have you used in the past (Rate with 1= most common to 4 = never)?

___ACZA ___ACC ___ACQ ___CA-B
___CCA ___Copper HDO ___Copper Naphthenate
___Creosote ___Oxine Copper ___Pentachlorophenol

4.2) What plant-applied preservative was found to be the most successful (Rate with 1= most successful to 4=not successful and 5=not used)?

___ACZA ___ACC ___ACQ ___CA-B
___CCA ___Copper HDO ___Copper Naphthenate
___Creosote ___Oxine Copper ___Pentachlorophenol

4.3) What liquid surface-applied field preservatives are used for in-service structures (Rate with 1= most common to 4 = never)?

___ Copper Naphthenate
___ Borate Solutions
___ Other (please specify)

4.4) What paste surface-applied field preservatives are used for in-service structures (Rate with 1= most common to 4 = never)?

___ Copper Naphthenate
___ Sodium Fluoride
___ Copper Hydroxide
___ Borates
___ Other (please specify)

4.5) What diffusible chemical field preservatives are used for in-service structures (Rate with 1= most common to 4 = never)?

___ Boron Rods
___ Fluoride Rods
___ Copper Boron Rods
___ Other (please specify)

4.6) What fumigant field preservatives are used for in-service structures (Rate with 1= most common to 4 = never)?

___ Chloropicrin
___ Methylisothiocyanate (MITC)
___ Metham Sodium (Vapam)
___ Granular Dazomet
___ Other (please specify)

4.7) What field-applied preservative was found to be the most successful (Rate with 1= most successful to 4=not successful and 5=not used)?

___ Liquid surface treatments
- ___ Copper Naphthenate
- ___ Borate Solutions
- ___ Other (explain)

___ Paste surface treatments
- ___ Copper Naphthenate
- ___ Sodium Fluoride
- ___ Copper Hydroxide
- ___ Borates
- ___ Other (explain)

___ Diffusible Chemicals
- ___ Boron Rods
- ___ Fluoride Rods
- ___ Copper Boron Rods
- ___ Other (explain)

___ Fumigants
- ___ Chloropicrin
- ___ Methylisothiocyanate (MITC)
- ___ Metham Sodium (Vapam)
- ___ Granular Dazomet
- ___ Other (explain)

___ None
Explain Other:

Section 5 – Timber Piling and Backwall Testing

5.1) Are you willing to allow Iowa State University (ISU) to perform non-destructive testing on some of your piles or back walls?

___Yes ___No

If yes, could you send us information on the structure?

(5.2) Do you have any substructures that are placed out of service or close to being removed that ISU can perform *destructive* testing on?

___Yes ___No

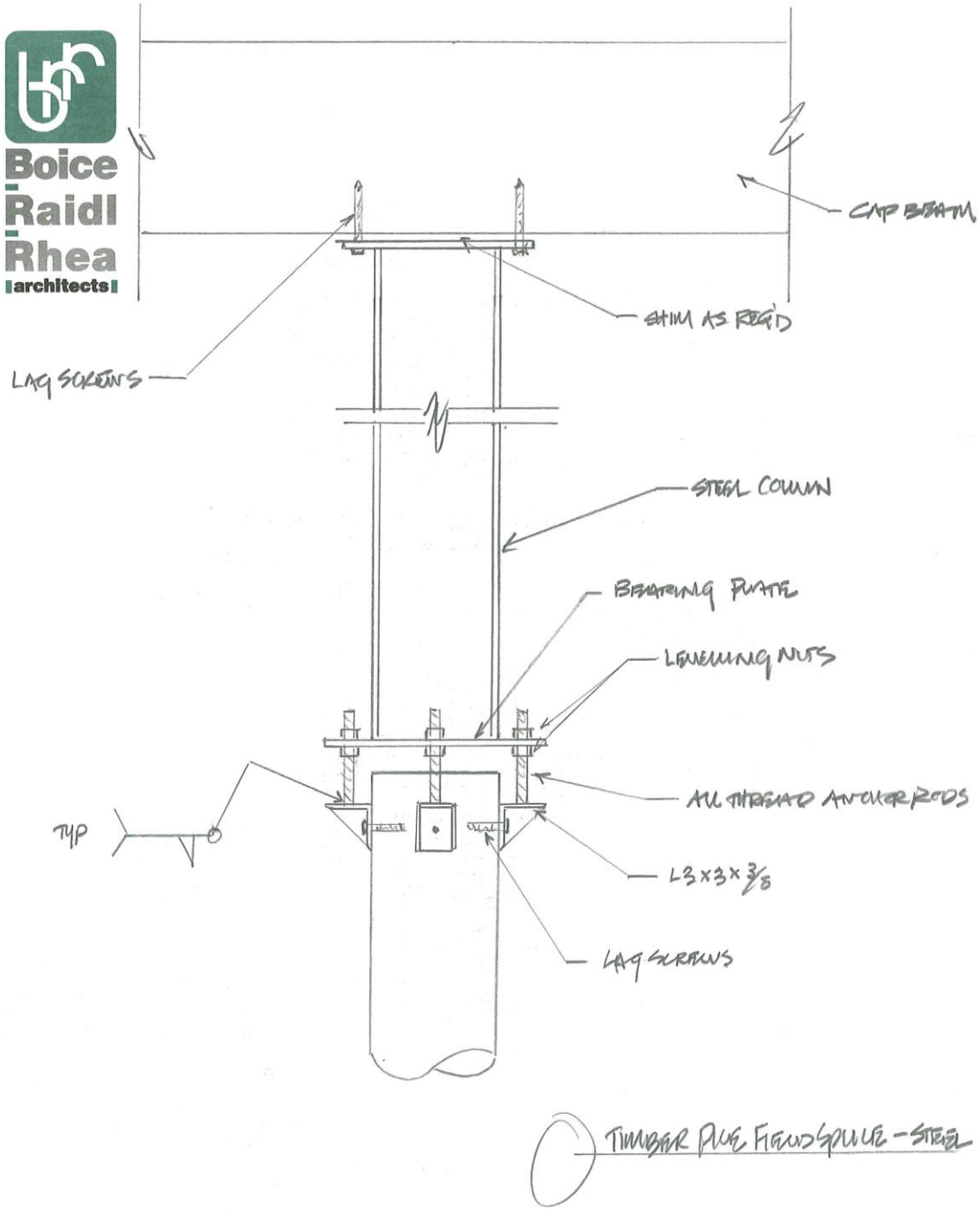
If yes, could you send us information on the structure?

5.3) Do you currently have a functionally or structurally inadequate piling or backwall on which you would allow ISU to perform *destructive* testing?

___Yes ___No

If yes, could you send us information on the structure?

APPENDIX B. PILE STRENGTHENING AND REPAIR DETAILS



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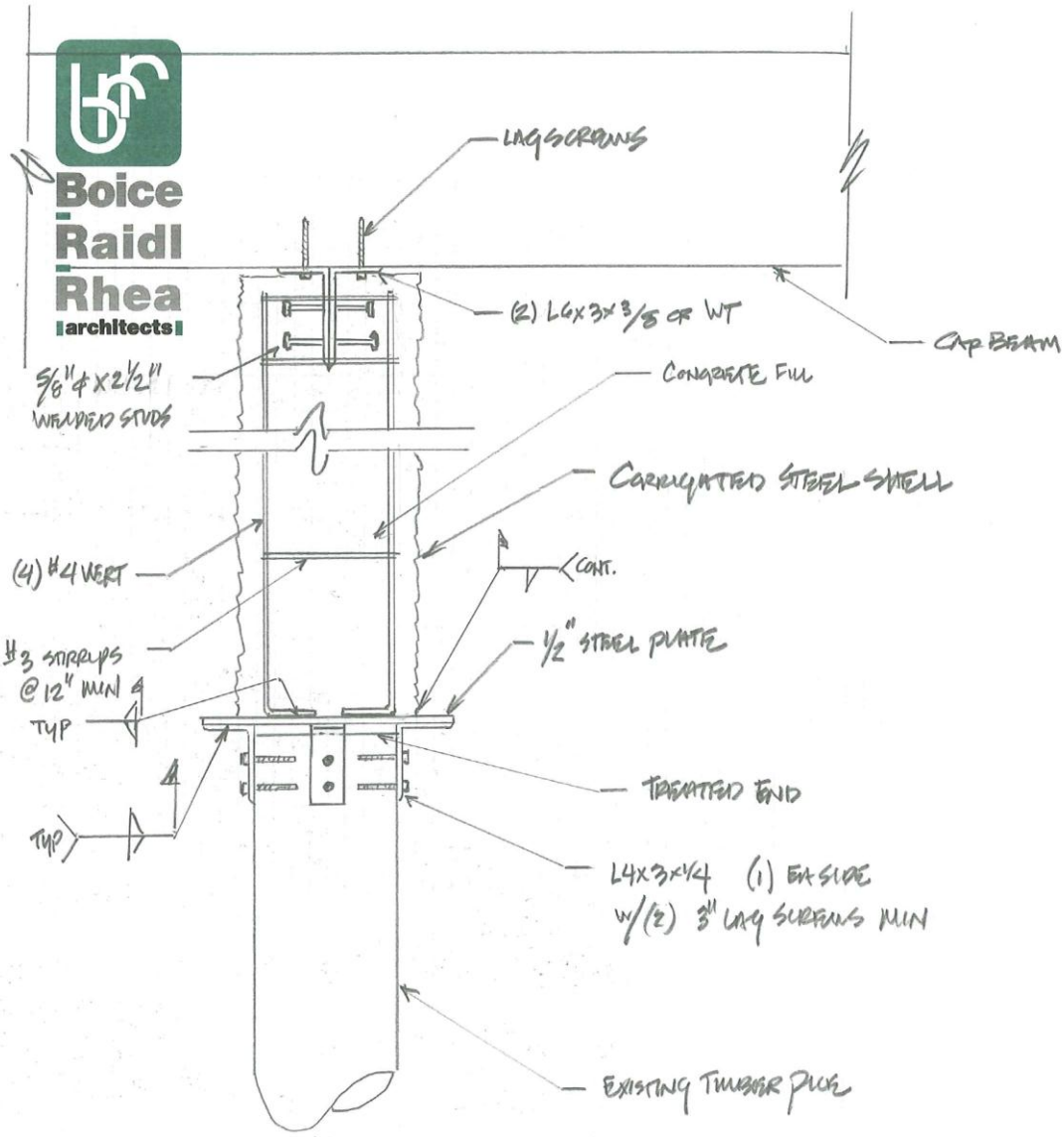

TIMBER PILE FIELD SPLICE - CONCRETE

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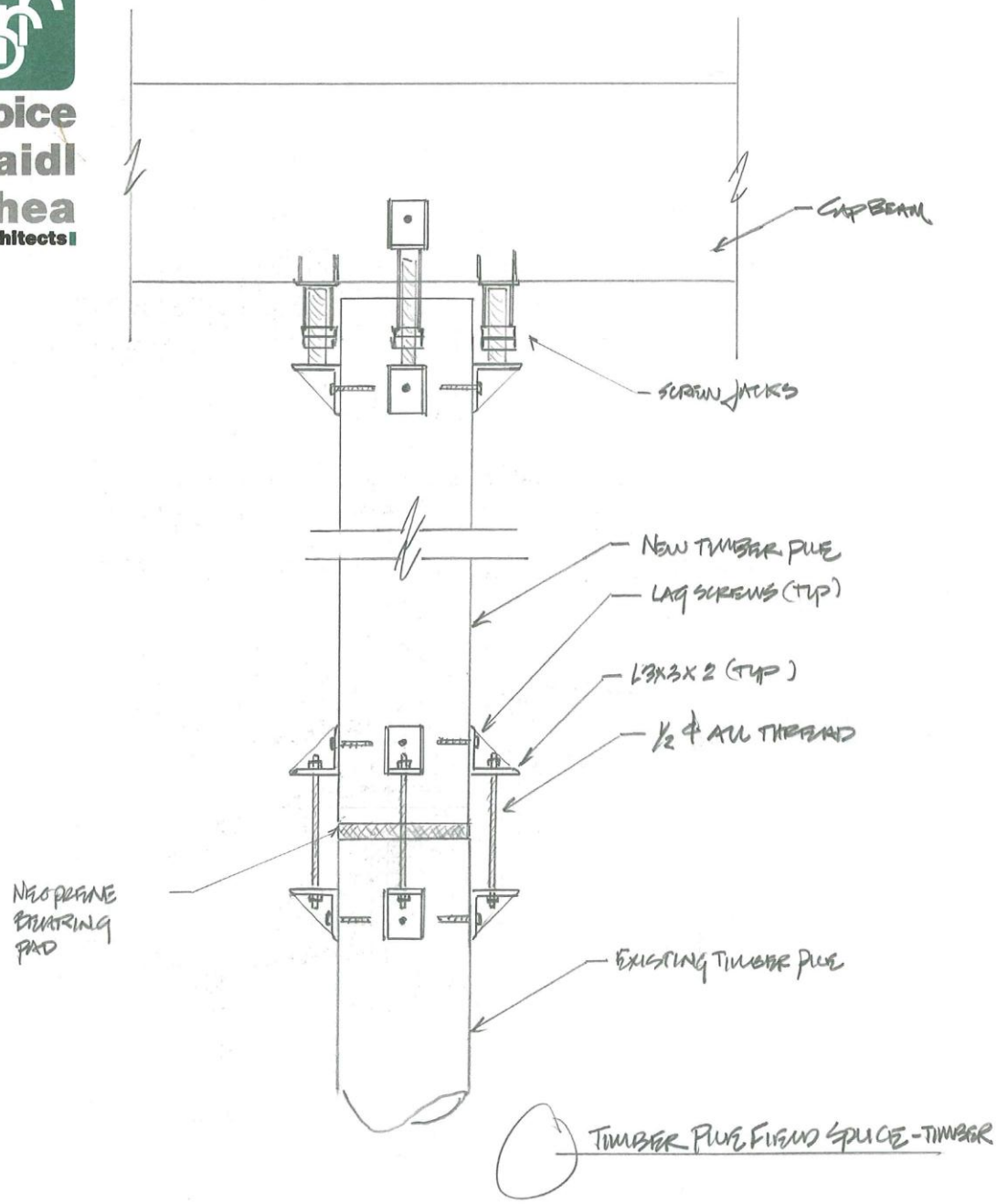

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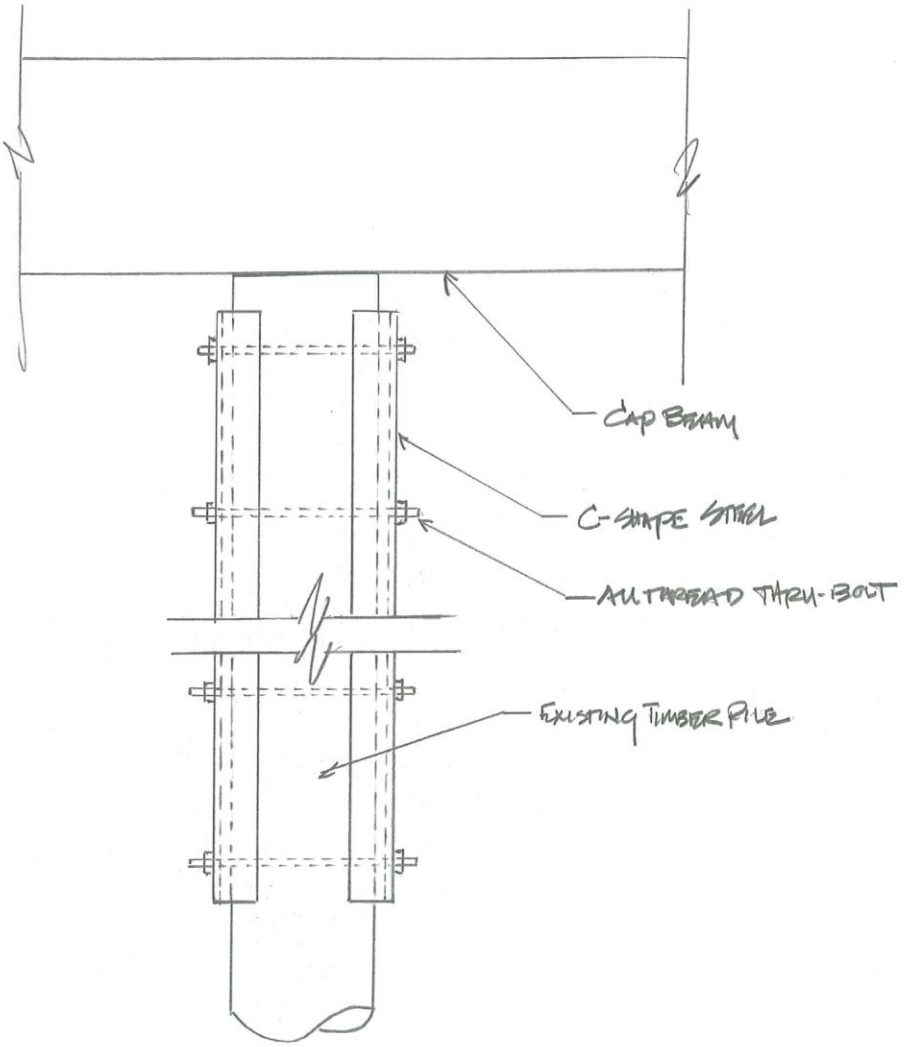

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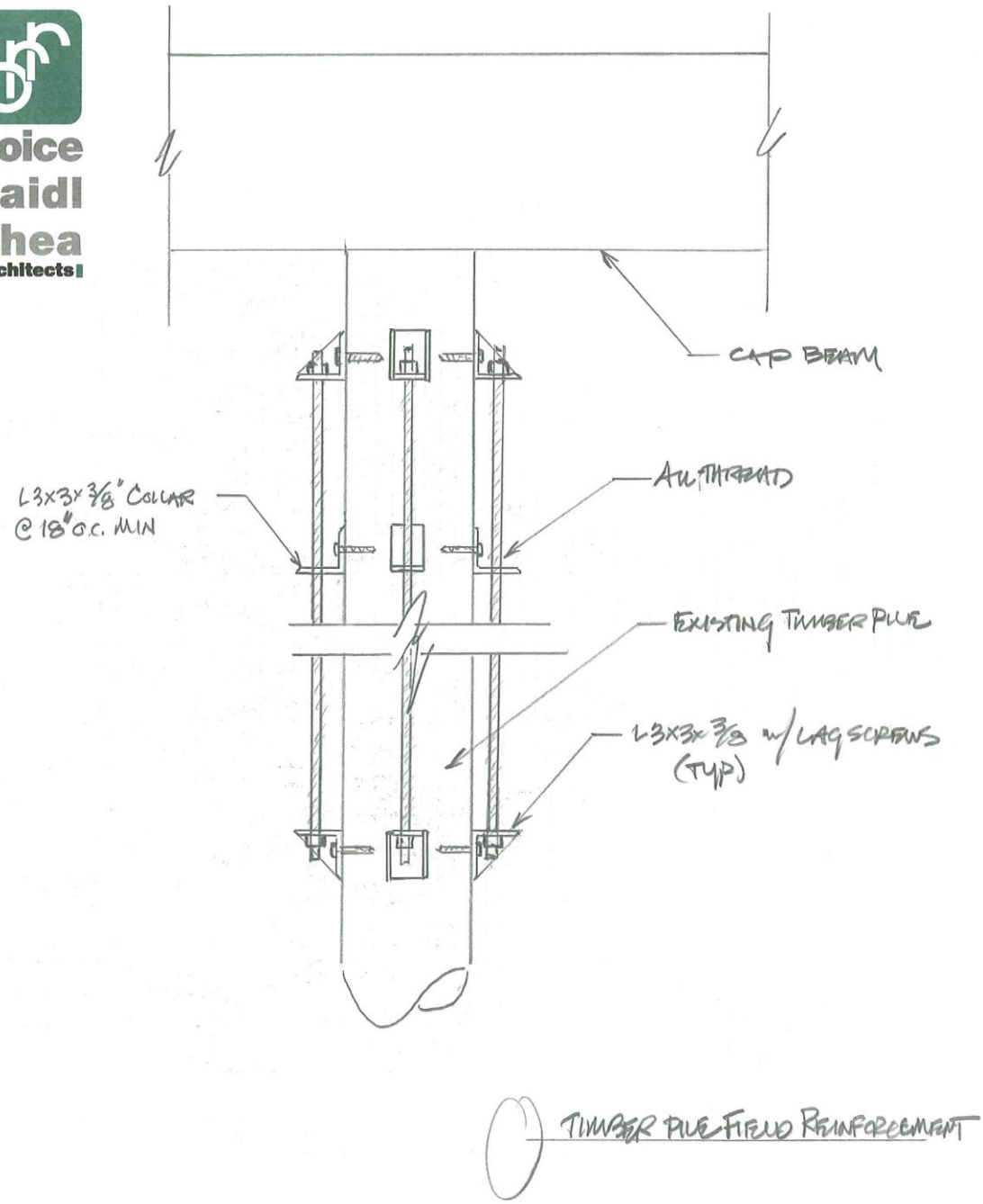

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