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# Cost-Effective Timber Bridge Repairs: Manual for Repairs of Timber Bridges in Minnesota

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Research Project
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# Cost-Effective Timber Bridge Repairs: Manual for Repairs of Timber Bridges in Minnesota

## Manual

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# Executive Summary

Few sources of comprehensive guidance for the repair of timber bridges are available to county engineers and others whose responsibilities include the management of timber bridge inventories. While numerous methods of repair are practiced across the US and other countries and even more research studies have been completed regarding timber repair, few documents exist that summarize the state of the practice and provide a complete document for practicing engineers. This creates a problem and a point of major concern for these individuals, and none more so than county engineers in Minnesota, as many have bridges in their inventories that are in need of repair.

As is often the case, funds required to complete repairs are limited and, as a result, any method used must not only be structurally feasible but also economically feasible. This manual provides bridge owners and caretakers several routine maintenance and repair options aimed to meet the goals of simplicity and affordability.

To achieve the project goal of providing guidance for timber bridge maintenance and repair, the following general tasks were performed:

- Identification of current problems facing Minnesota timber bridge owners
- Identification and development of promising methods of timber bridge repair
- Study of the cost-effectiveness and economics of repair strategies and service life extensions

Several options for timber bridge repair are provided. Many of the repair options are presented at a conceptual level, while others (five total) are more fully developed. These include design and construction procedures, tools and equipment required, and cost estimates.

The five repairs were selected for extended development based on survey responses and on-site interviews, which indicated a need for these specific repairs, especially those that address substructure element repair.

Of the five repairs, each addresses one of the following timber bridge elements:

- Nail/dowel-laminated bridge decks (1)
- Solid sawn or glued-laminated stringers (1)
- Piles (3)

The economic impact of repairing timber bridges was assessed for multiple scenarios: a comparison was made between the net present value of repair at varying repair costs over time and the net present value of varying reconstruction costs over time. Through this exercise, for each scenario, a point in time was identified when repair or reconstruction makes most economic sense.

An additional assessment of overall costs (direct plus indirect), which included the increased user costs due to bridge posting or closure, was completed. This assessment made clear that when indirect costs are included, the benefits of maintaining or repairing a bridge to prevent posting or closure become great.

One of the primary objectives of this project, Development of Cost-Effective Timber Bridge Repair Techniques for Minnesota, was to produce a timber bridge repair manual. This manual is comprised of some of the content from the final report for the project, along with an extended presentation of timber maintenance options. This final manual is a standalone document from which the maintenance and repair options can be implemented.

Efforts to distribute information to those who are most likely to implement the repair options were completed using a three-fold approach including workshops, webinars, and a pre-recorded presentation to be offered as part of annual bridge training. Collectively, these outreach efforts reached numerous people throughout Minnesota from both public and private agencies.

# Chapter 1: Introduction

## 1.1 Background and Problem Statements

There are approximately 1,500 timber bridges in Minnesota that, without proper maintenance and repair, will eventually deteriorate to an unusable state; many of those are on the county or local road system. Currently, little guidance for repair is provided or available to local engineers or others whose responsibilities include the management of timber bridge inventories.

Numerous research studies have been completed addressing timber preservation and repair, yet not one document specifically addressing Minnesota timber bridge repair exists. Furthermore, the expense of many prescribed repairs is great and often outside the bounds of possibility for townships and municipalities with a lack of available bridge funding. Without the necessary guidance, staff are left to devise solutions that could potentially be costly and untested; a manual for cost-effective timber bridge repairs is needed.

## 1.2 Objectives and Benefits

This manual aims to provide cost-effective, easily implemented techniques for timber repair needs that are most commonly found on timber bridges in Minnesota. More specifically, this manual intends to serve as a single formal document for guiding local system engineers in the repair of timber bridge elements.

It is anticipated that the guidance and implementation of repair methods found in this manual will improve the overall condition of the transportation system, thus reducing system failures and improving and ensuring the safety of the traveling public.

## 1.3 Scope of the Investigation

The scope of the investigation from which this manual was put together had four main foci: 1) identification of repair strategies through literature searches and surveys that will be effective for Minnesota’s timber bridge population, 2) performance of on-site interviews with local engineers for additional insight and input, 3) development of effective repair techniques, and 4) study of the cost-effectiveness and economics of repair strategies and extension of service life.

## 1.4 Research Approach

Commensurate with the overall objectives and scope of the investigation, the research approach consisted of a literature review and other information collection methods, identification and development of effective repair techniques, development of cost effective projections for repair strategies based upon typical situations, and preparation of this timber bridge repair manual.

### 1.5 Organization of the Manual

The remainder of this manual is organized as follows: Chapter 2 describes the timber bridge types most commonly found in Minnesota. Chapter 3 briefly addresses methods for timber bridge condition assessment. Chapter 4 highlights recommended maintenance practices, including techniques and recommended time intervals for preventing problems from starting to develop and/or retarding the progression of problems already begun. Chapter 5 presents instructional details and drawings for five bridge strengthening and rehabilitation procedures. Chapter 6 provides cost estimates of those procedures. Several other additional repair options are provided in Chapter 7, albeit in lesser detail and without cost estimates. An overall summary is provided in Chapter 8. The manual is concluded with References.

# Chapter 2: Minnesota Timber Bridges

The variety of timber bridge structure types is extensive at the national level and, as shown in Table 2-1, even within Minnesota, numerous types of timber bridges exist including the following: 1) slab, 2) stringer/multi-beam or girder, 3) girder and floorbeam system, 4) truss – thru, 5) arch – deck, and 6) culverts.

**Table 2-1 Minnesota 2012 county-level timber bridges**

| Type | # |
|---|---|
| Slab | 1,081 |
| Stringer/Multi-Beam or Girder | 395 |
| Girder and Floorbeam System | 2 |
| Truss – Thru | 2 |
| Arch – Deck | 1 |
| Culvert (includes frame culverts) | 22 |

Source: 2012 National Bridge Inventory downloaded from the FHWA May 2013

According to the 2012 National Bridge Inventory (downloaded from the Federal Highway Administration/FHWA May 2013), these bridges make up a total of 1,503 bridges at the county level; a majority of the bridges, 1,476, are slab or stringer/multi-beam (1,081) or girder (395). Given that a significant portion of the population lies within these two types, it is here where much of the focus lies in this manual.

## 2.1 Slab

Slab bridges can be identified by the closely spaced, nail-, spike-, or dowel-laminated dimension or glued-laminated (glulam) lumber placed in the longitudinal direction of the bridge. Figure 2-1 and Figure 2-2 provide examples showing a slab bridge underside and topside, respectively.

**Figure 2-1 Common slab bridge underside**

**Figure 2-2 Common slab bridge topside**

The lumber attached in this manner not only makes up the primary superstructure of the bridge but also the deck. These bridges are most often constructed in panels and then transversely connected using a spreader or distributor beam. Glulam panels can come in various sizes, but generally fall in the range of 6-3/4 to 14-1/4 in. deep and 42 to 54 in. wide. Sawn lumber can also be used in 2 or 4 in. widths and 8 to 16 in. depths nailed or spiked together. Span lengths for slab bridges generally do not exceed 36 ft. Douglas fir lumber treated with creosote is the most common material used for the construction of older slab bridges.

### 2.2 Stringer/Multi-Beam or Girder

Stringer bridges, like those shown in Figure 2-3 and Figure 2-4, can be identified by the full-sawn timber (sometimes glulam) stringers or girders placed in the longitudinal direction of the bridge with a transverse timber deck laid and attached to the top of the stringers.

**Figure 2-3 Timber girder bridge profile**


**Figure 2-4 Timber girder bridge underside**

Stringers/girders are commonly 6 to 8 in. wide and 12 to 18 in. deep and spaced 10 to 16 in. apart. Solid-sawn bridges generally span lengths of 15 to 25 ft with intermediate supports and multiple spans used for longer crossings. Creosote or, more recently, copper naphthenate has been used to treat stringers and girders.

Glulam beams, due to the method by which they are manufactured, have the ability to span much longer crossings (20 to 80 ft) than full-sawn timber. They are are manufactured from 1-1/2 in. thick construction lumber laminations that are face-laminated on their wide dimensions using waterproof structural adhesive. The widths and depths are easily optimized for the span and design loads; the total number of beams is often fewer than that of full-sawn timber construction. Originally, the glulam beams were treated with creosote with more recent use of chromate copper arsenate or copper napthenate.

## 2.3 Substructure

Substructures can take on many forms. However, for timber slab and girder bridges, one of the more common configurations is made up of timber piles, timber pile caps, and timber backwalls and wingwalls. The pilings are typically Douglas fir or southern yellow pine, treated with creosote. Examples are shown in Figure 2-5 and Figure 2-6.


**Figure 2-5 Timber substructure**

**Figure 2-6 Another timber substructure**

# Chapter 3: Condition Assessment

A number of tools exist to assist 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 pinpointing 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.

Following are 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). Several examples are shown in Figure 3-1.

- **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


**Surface check**

**Surface decay**

**End grain split**

**End grain split and check**

**End grain split**

**End grain decay**

**Figure 3-1 Examples of timber deterioration**

### 3.2 Probing and Pick Tests

Use of an awl or other sharp pointed tool like that shown in Figure 3-2 can be used to detect soft spots created by decay fungi or insect damage (Bigelow et al. 2007).

**Figure 3-2 Probing and pick tests**

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 reliably interpret the results.

### 3.3 Moisture Measurement

Moisture measurements are taken with an electronic hand-held moisture meter (Bigelow et al. 2007) like that shown in Figure 3-3.


**Figure 3-3 Moisture measurement**

The moisture meter consists of two metal pins that are driven into the wood. The meter displays the 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

With the sounding method, shown in Figure 3-4, a hammer is used to strike the wood surface (Bigelow et al. 2007).

**Figure 3-4 Hammer sounding**

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 solid wood. Some experience is necessary for reliable interpretation of sounding given that 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 like that shown in Figure 3-5 measure the speed (transmission time) at which stress waves travel through a wood member.


**Figure 3-5 Stress wave timing**

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 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 readings (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 like that shown in Figure 3-6 record the resistance required to drill through a piece of wood.


**Figure 3-6 Drill resistance measurements**

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). The advantage of using drill resistance devices is that the cross-section of the location of drilling can be very accurately defined. Furthermore, the procedure is minimally invasive and non-destructive due to the small size of the drill bits.

### 3.7 Core Boring

Increment core borings are taken using the device shown in Figure 3-7.

**Figure 3-7 Core boring**

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.

This method is used far less frequently than in the past given that it is somewhat destructive in nature and because the technology of drill resistance devices has greatly improved, providing a reliable, non-destructive method of obtaining the same information.

# Chapter 4: Recommended Preventive Maintenance Practices

Relatively minor maintenance practices, when done routinely, can reduce the need for more extensive repair or rehabilitation. The inherent resiliency of timber can be leveraged with these minor procedures. Maintenance generally falls into one of three main categories: routine maintenance, periodic maintenance, or specific works.

**Routine maintenance** primarily consists of minor reactive type works, which are typically expected over the service life (completed annually), but the precise nature and location are not known in advance. Procedures are generally planned and carried out soon after the need is identified.

**Periodic maintenance** generally occurs at regular intervals of longer than one year with the intent of preventing occurrence or progression of deterioration. Unlike routine maintenance, periodic maintenance is most often undertaken on a proactive rather than reactive basis.

**Specific works** include planned and scheduled improvements to the bridge to maintain such things as strength, geometry, and safety. Usually, these maintenance items are scheduled at least two years in advance. The activities of specific works can be similar in scope to repair and rehabilitation activities, which is covered in Chapter 5, and, for that reason, the remainder of this chapter focuses on recommended routine and periodic maintenance.

## 4.1 General Timber Maintenance

### *4.1.1 Moisture Control*

The best preventive maintenance method for timber 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, stringers, or other elements. For example, 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. Given it is highly unlikely that pile locations will be moved on existing bridges, it is paramount to take note of particular piles that are apt to see wet and dry cycling like that shown in Figure 4-1 so special attention may be paid to these piles.

**Figure 4-1 Moisture control**

### *4.1.2 End Grain Treatment*

Without preventive measures, the ends of timber members like that shown in Figure 4-2 are more susceptible to draw in water than other portions of the pile.

**Figure 4-2 End grain treatment**

If the end has been cut, a timber treatment should be brushed on and, where exposed, capped with flashing (tin, aluminum, or similar material) with minimization of water exposure being the goal.

### *4.1.3 In-Place Treatments*

In-place treatments are another common preventive maintenance technique applied to timber piles. Surface treatments, paste (Figure 4-3), and fumigants are three types of in-place treatment that are frequently used.


**Figure 4-3 In-place treatments**

On-site fabrication of timber bridge components typically results in breaks in the protective plant-applied preservative barrier (Bigelow et al. 2007). 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 are more susceptible to moisture absorption, and the immediate area around all fasteners, including drill holes, require supplemental on-site treatment.

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.

### *4.1.4 Fastener Maintenance*

The condition of all structural fasteners, like those shown in Figure 4-4, should be checked for corrosion and tightness.

**Figure 4-4 Fastener maintenance**

Fasteners should be retightened to a snug-tight condition if loose. Where significant corrosion is present, fasteners should be replaced altogether.

## 4.2 Superstructure Elements

### *4.2.1 Maintenance of Outside Timber Stringers*

The outside stringer on a timber bridge is more susceptible to deterioration due to its increased exposure to the elements, including rain, sunlight, and debris flow. An example is shown in Figure 4-5.

**Figure 4-5 Outside stringer maintenance**

All dirt and loose decayed material should be removed and consideration given to adding flashing to prevent excessive wetting and further repairs if checks or splits are present.

### 4.2.2 Maintain Deck Drainage

Proper drainage on timber bridges is often impeded by the collection of road debris, gravel, and sand like that shown in Figure 4-6.

**Figure 4-6 Deck drainage**

The inability for water to quickly exit the bridge deck could promote undue deterioration. It is common for debris to collect at the bridge deck edges; this debris should be removed. Some bridges may have scuppers that become filled. Likewise, the scuppers should be cleared of all debris to allow proper water passage.

### 4.2.3 Removal of Deck Vegetation

Timber decks can be susceptible to vegetation growth given that gaps between deck boards are quite common. These gaps fill with dirt and gravel that, in turn, create an environment in which vegetation can begin to grow. Vegetation growth is a clear indicator that debris has collected and water is being retained within the gaps. As such, the vegetation and debris should be cleared to prevent deterioration of the deck.

## 4.3 Substructure Elements

### *4.3.1 Removal of Debris from Pile Caps*

Commonly, gaps between deck boards on timber bridge decks form and allow at least a nominal amount of debris to pass through. The debris is able to collect on top of pile caps, as shown in Figure 4-7, which can trap water against the pile cap.

**Figure 4-7 Debris removal from pile caps**

Due to the retained moisture, deterioration of the pile cap advances at a quicker rate than would otherwise occur. If left alone, the pile cap could deteriorate to a point where sufficient support of the superstructure is compromised and complete replacement of the pile cap is necessary. Debris should be cleared or washed from the top side of pile caps to reduce chances of water retention.

### *4.3.2 Repair Small to Medium Cracks*

Small to medium cracks and splits caused by weathering or shrinkage similar to those shown in Figure 4-8 create pathways for decay fungi to enter the untreated wood at the core of the timber pile (White et al. 2007).

**Figure 4-8 Crack repair**

Therefore, cracks and splits must be repaired regularly. Epoxy grout can be injected under pressure to fill 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 (US Army Corps of Engineers 2001 and Ritter 1992).

# Chapter 5: Bridge Strengthening and Rehabilitation Procedures

## 5.1 Organization of the Chapter

The material presented in this chapter is intended for use primarily by county engineers and bridge maintenance and rehabilitation personnel working at the secondary road level. The repairs described in this chapter are accompanied by drawings that should sufficiently convey to an engineer overall purpose and applicability; the drawings are not, however, intended to provide detail in entirety given that each bridge is at least minimally unique.

The plans and drawings presented are generalized to be applicable to a wide range of bridges. The written narrative that references these drawings aims to specifically address the deficiencies identified through the preliminary investigation of a particular bridge.

In general, the procedures that follow are conceptual and the responsibility for final design, material specifications, and/or approved products lies with the county engineer and/or a licensed professional engineer.

Specialty tools, if any, are identified for each repair. Common tools such as hammers or wrenches are not explicitly listed as they are presumed readily available and their use is expected.

U.S. customary units are used throughout this chapter.

Bridge elements are commonly described by one of three locations in which they are found: substructure, superstructure, or deck. Accordingly, the repairs that are presented in this chapter are organized in a similar manner.

Superstructure repairs—laminated bridge decks and individual timber stringers—are presented first. In Minnesota, a large part of the timber bridge inventory consists of bridges with panelized dowel laminated decks, which also act as the superstructure. As such, the superstructure repair of laminated bridge decks could also be considered a deck repair.

Substructure repairs—addition of steel channels to piles, addition of reinforced concrete jackets to piles, and encapsulation of pile groups—are presented second.

Additional structural repair solutions are presented in Chapter 7, although at a lesser level of instructional detail than what is provided in this chapter.

The repairs presented in this manual are intended to address the most prevalent problems indicated through the Minnesota county engineer survey that was part of this project.

## 5.2 Strengthening and Rehabilitation of Bridge Superstructure Elements

Two types of superstructures are primarily found in the Minnesota timber bridge inventory: dowel-laminated decks and timber stringers. Deterioration of either can compromise the serviceability or strength of the bridge and a repair could be necessary.

### *5.2.1 Repair of Laminated Bridge Decks*

Application

This method is used to repair a dowel-laminated deck (which is also known as a Wheeler deck), as shown in Figure 5-1, that has an area or areas of deterioration extending to either partial depth or full depth.

**Figure 5-1 Repair of laminated decks**

It is recommended that the area of repair be no longer than 5 ft to minimize the strength required of the patch and no wider than 3 ft to limit the affected transverse members as shown in Figure 5-2.

Repair Method

Remove deteriorated material to existing sound wood and replace with a reinforced patch of concrete or epoxy polymer.

Materials and Tools Required

- Circular saw, awl, drill
- Timber treatment
- Plywood or sheet metal

- Concrete
- Epoxy coated reinforcement bar
- Galvanized lag bolts
- Short, lightweight steel beam designed to span the resulting area of removal
- Epoxy polymer approved by county engineer
- Construction adhesive approved by county engineer

Construction Procedure

1. Identify areas and extent of deterioration using awls and/or drills.
2. Using a circular saw, cut to the depth of deterioration. Deteriorated timber should be removed with hand tools (hammers/chisels) or small power tools to avoid inflicting damage on the remaining sound timber and the exposed timber treated to prevent future deterioration.
3. After deteriorated material is removed, the resulting “hole” should be rectangular in shape with sloped sides as shown in Figure 5-3 and Figure 5-4. Modify if necessary.
4. For partial-depth small repairs, galvanized lag bolts sufficiently sized to hold the repair material need to be installed into pre-drilled holes as shown in Figure 5-3 and a welded wire reinforcement mat (cut to size) placed within the repair area and wire-tied to the lag bolts.
5. For full-depth repairs, holes should be over-drilled in the remaining sound material to accept both ends of the reinforcing steel, which are then adhered in place, as shown in Figure 5-5 and Figure 5-6, with an approved construction adhesive.
6. For lengthier deteriorated areas, in addition to one of the previous repairs, it may be necessary to attach a structural beam (properly sized) along the length of the opening. See Figure 5-7 and Figure 5-8.
7. For full-depth repairs, using common wood screws of proper number and length, affix a piece of plywood or sheet metal to the underside of the laminated deck to use as a form. No formwork is necessary for partial-depth repairs.
8. Complete the repair by filling the hole with a fiber-reinforced concrete mix that is proper for the final bar spacing, clear spacing, durability, etc. Trowel-finish the top surface even with the adjoining timber deck and roughen it (or broom finish) to the appropriate levels to provide sufficient skid resistance.
9. Once cured for the time commensurate with the selected concrete mix and placement conditions, the formwork may be removed from the underside of the laminated deck or simply left in place.

Details

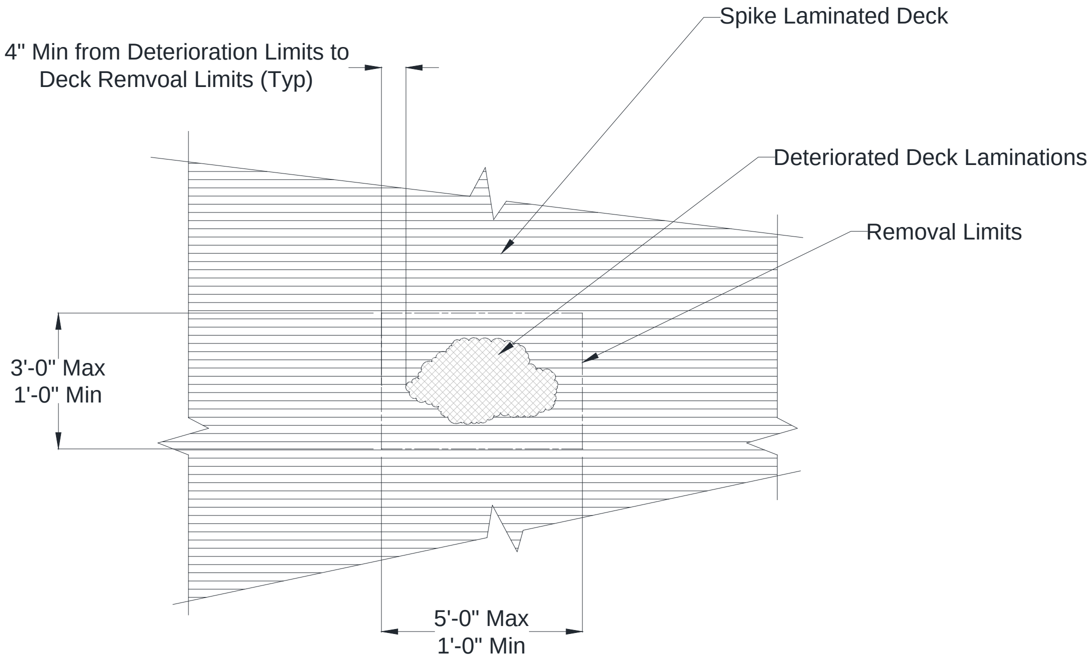



**Figure 5-2 Rehabilitation of laminated bridge decks**

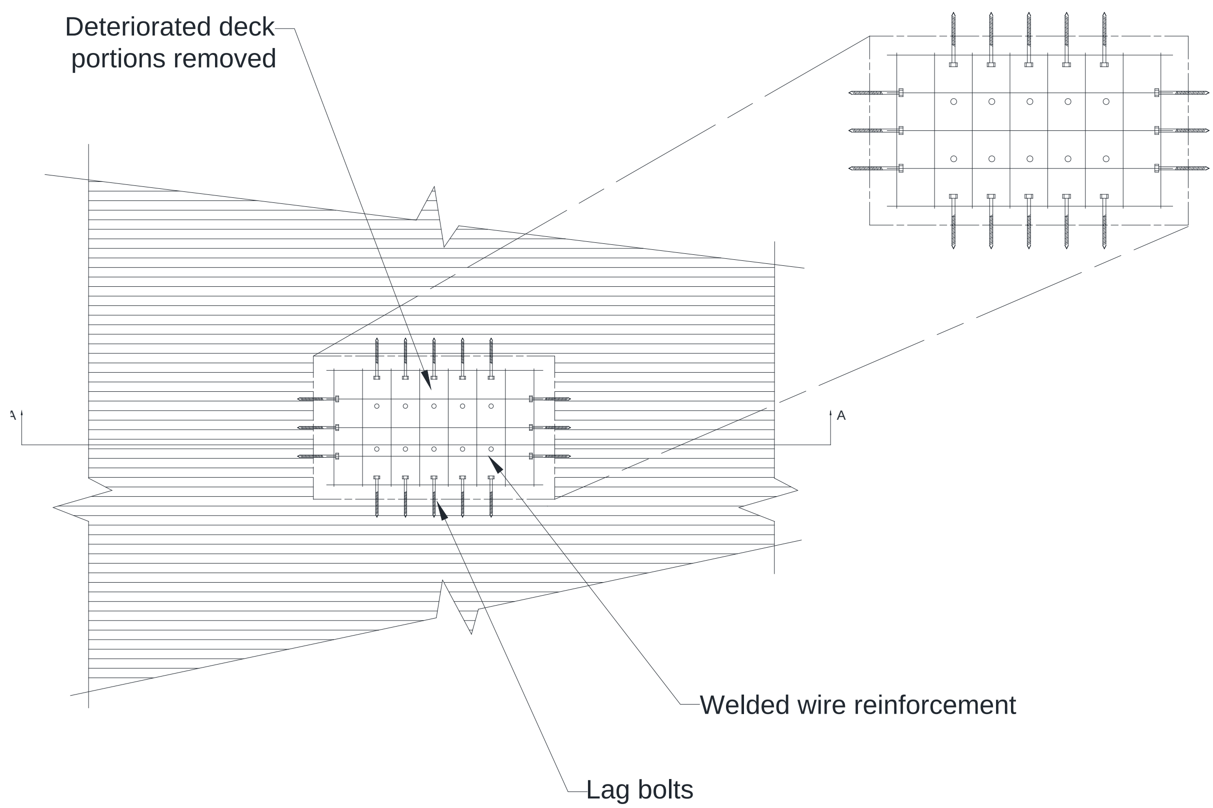



**Figure 5-3 Partial-depth laminated deck repair – plan view**

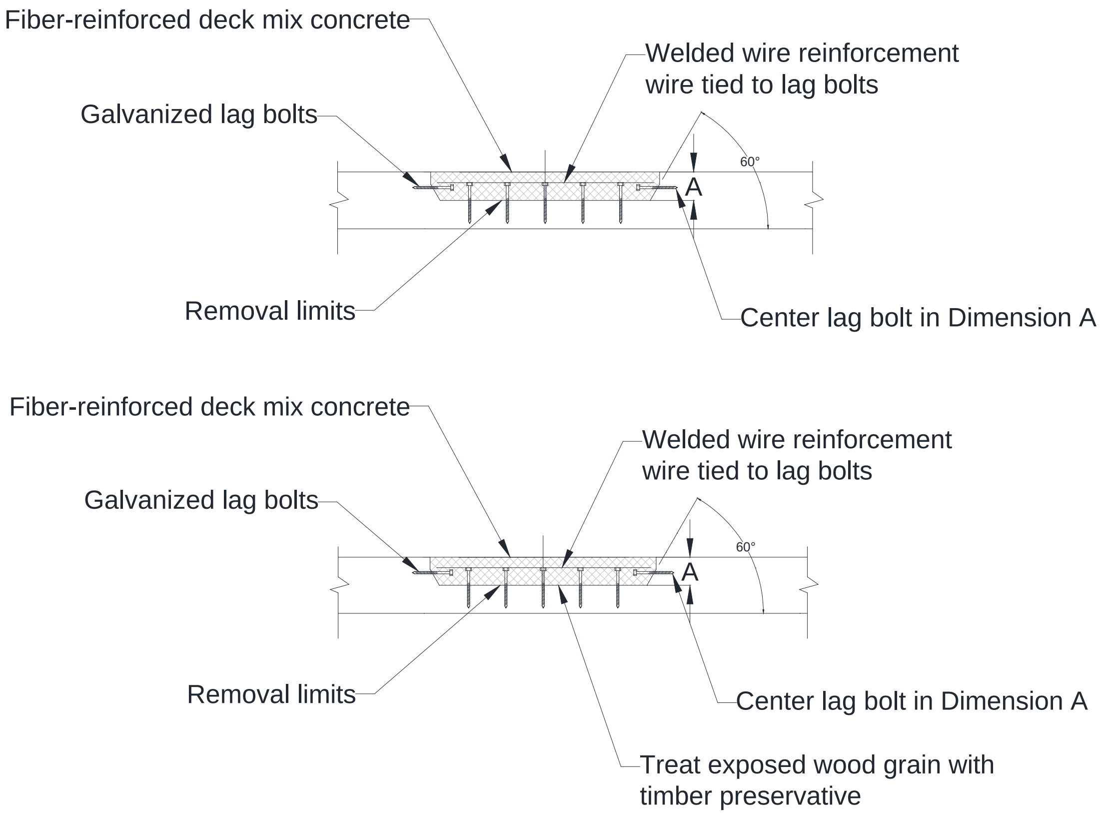



**Figure 5-4 Partial-depth laminated deck repair - detail**

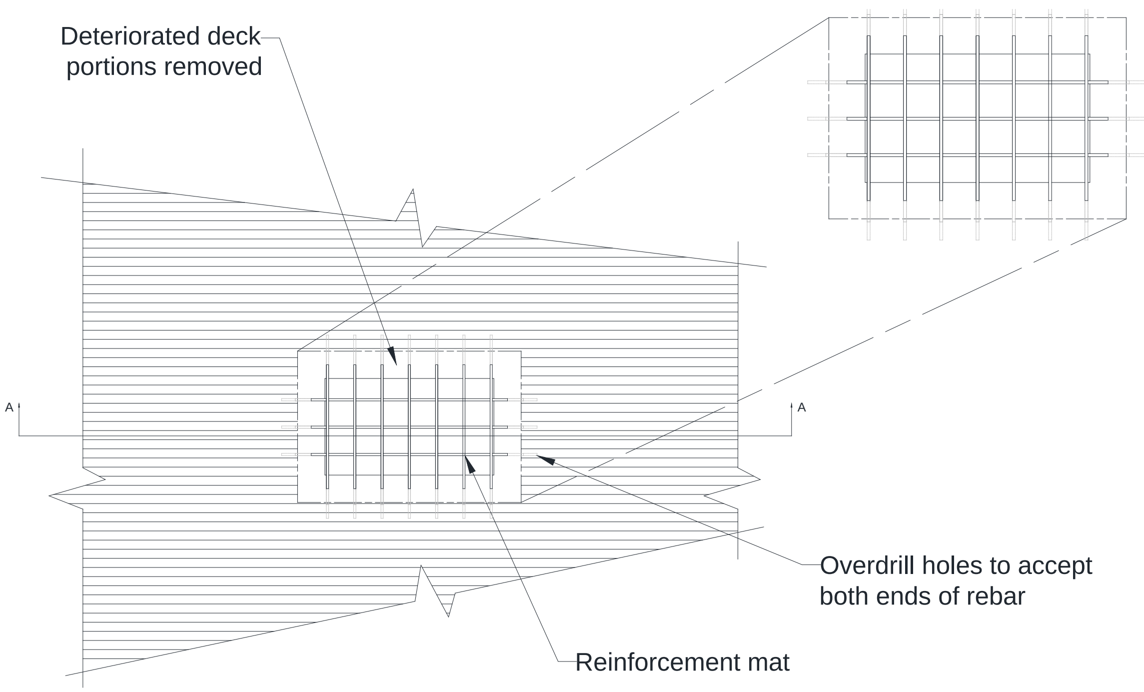



**Figure 5-5 Full-depth laminated deck repair – plan view**

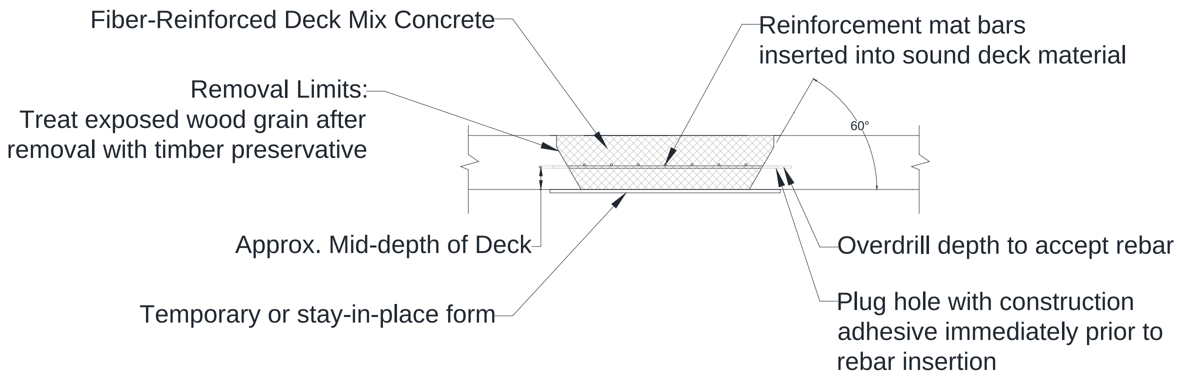



**Figure 5-6 Full-depth laminated deck repair - detail**

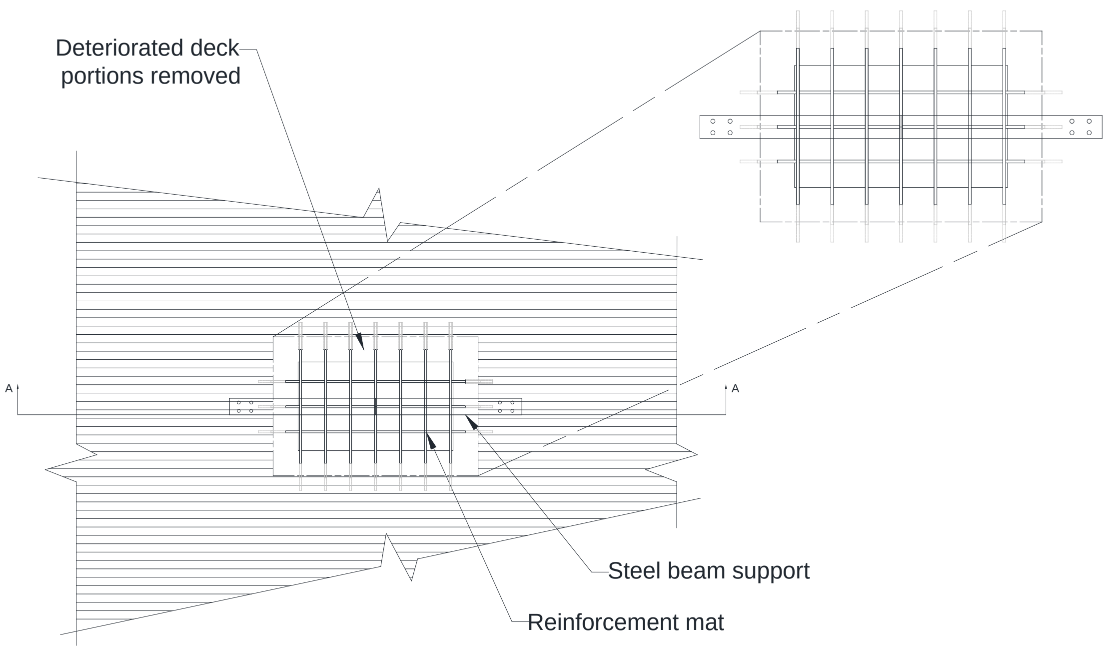



**Figure 5-7 Full-depth laminated deck repair of larger area – plan view**

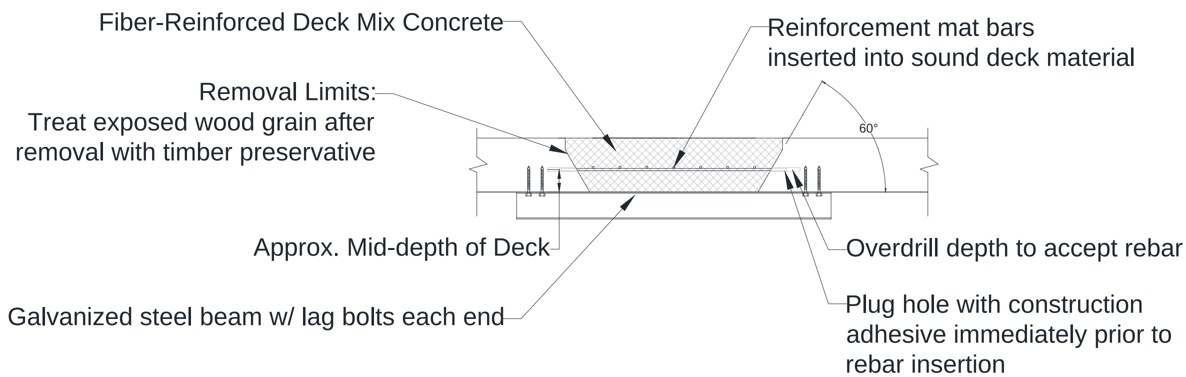



**Figure 5-8 Full-depth laminated deck repair of larger area - detail**

### *5.2.2 Strengthening of Individual Timber Stringers*

Application

This method is used to strengthen timber stringers or girders that have localized minor to moderate deterioration that has weakened the overall strength of the member at the ends or along the span. See Figure 5-9.

Repair Method

Attach steel members to timber stringer or girder using through bolts or lag bolts.

**Figure 5-9 Strengthening of individual timber stringers**

Materials and Tools Required

- Galvanized threaded rods or lag bolts
- Steel channels, plates, or angles

Design Procedure

1. Determine the required capacity of the stringer per codified specifications.
2. Estimate the remaining capacity of the stringer based on the sound portions of the stringer cross-section.
3. Calculate the additional capacity required.
4. To increase the shear capacity at the end of the beam, size timber fish plates, steel plates, or channels to be added to each side of the stringer to increase the shear capacity to what is required. See Figure 5-10.
5. To increase the flexural strength of the positive moment region:
   If only additional tensile strength is required, timber fish plates, steel plates, or angles may be used. See Figure 5-11 and Figure 5-12.

If additional tensile and compressive strength is required, top and bottom angles or channels may be used (see Figure 5-13). It is assumed that the depth of the channel is slightly less than the depth of the stringer.

6. Once the configuration has been selected, size the elements so that the composite member capacity meets or exceeds the required capacity. It is recommended that all added elements extend a minimum of 24 in. to either side of the deteriorated area where possible to ensure that an adequate number of fasteners located away from the deterioration can be installed.
7. Per the National Design Specification (NDS) (from the American Wood Council), size and space the through rods or lag bolts to sufficiently anchor and attach the channels to the stringer to ensure the desired composite action. To simplify construction, lag bolts rather than through rods are recommended.

Construction Procedure

1. Identify the area and extent of deterioration using awls and/or other nondestructive methods.
2. Using the steel elements that have been properly sized for the desired added strength and also for the recommended minimum extension of 24 in. to either side of the deterioration extents, center the elements on the area of deterioration.
3. Attach the pre-drilled elements to the stringer using threaded rods extending through the stringer and elements on each side or individually using lag bolts. Pattern the rods or bolts per the designed layout. Additional holes for drainage in any members fastened to the bottom should be provided.

Details

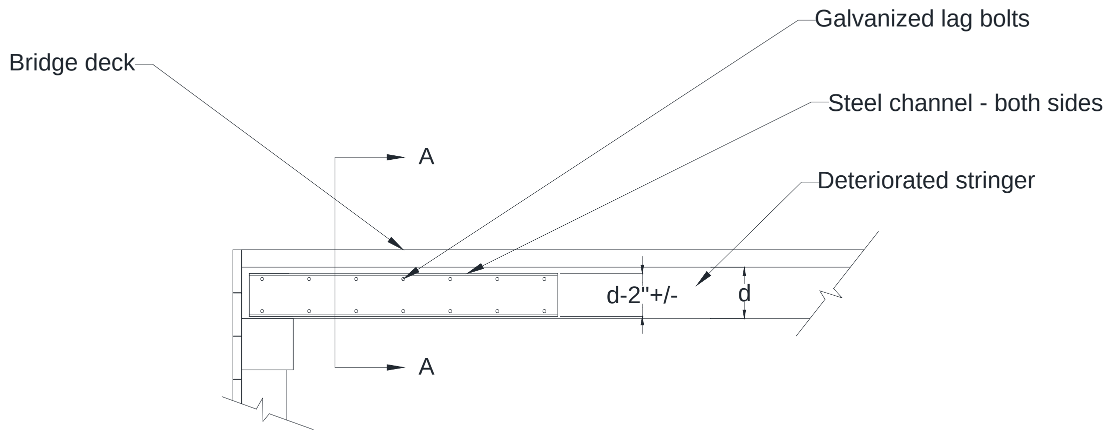



**Figure 5-10 Strengthening of timber girder or stringer – shear reinforcement**

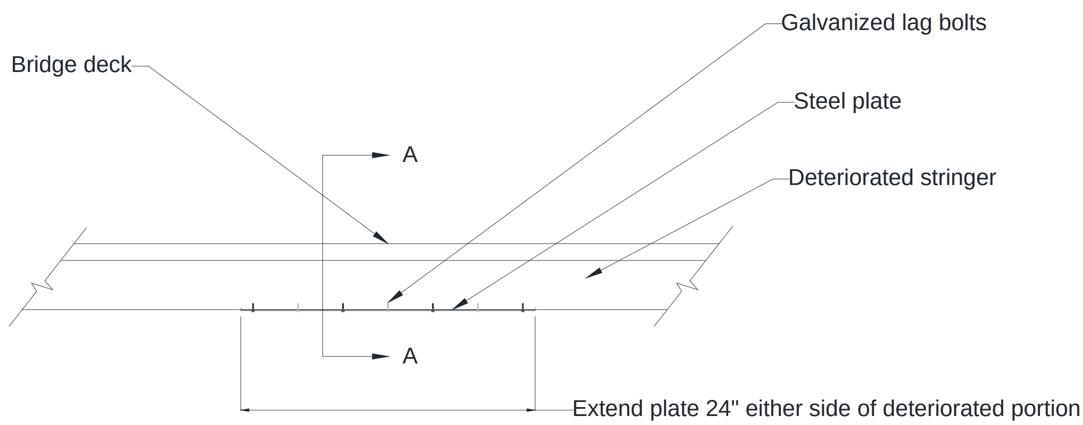



**Figure 5-11 Strengthening of timber girder or stringer – flexural reinforcement, bottom plate**

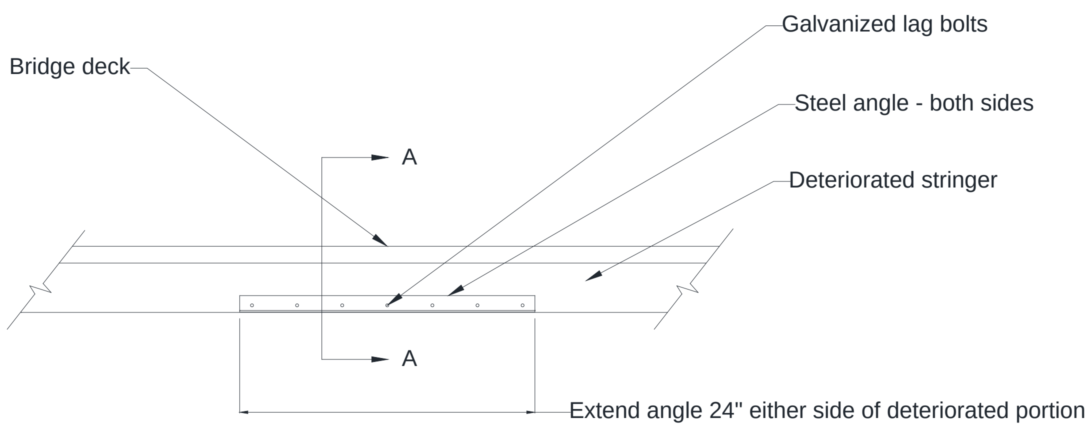



**Figure 5-12 Strengthening of timber girder or stringer – flexural reinforcement, bottom angle**

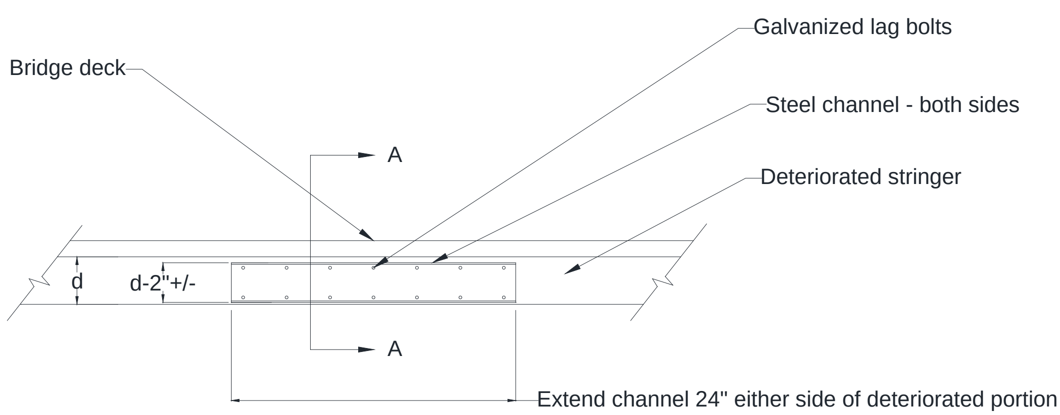



**Figure 5-13 Strengthening of timber girder or stringer – flexural reinforcement, steel channel**

## 5.3 Strengthening and Rehabilitation of Bridge Substructure Elements

### *5.3.1 Addition of Steel Channels to Piles*

Application

This method is used for strengthening timber piles that have localized minor to moderate deterioration or damage no longer than 18 in. that has weakened the overall strength of the member.

Repair Method

Attach steel channels to timber piles using through bolts or lag bolts as shown in Figure 5-14.

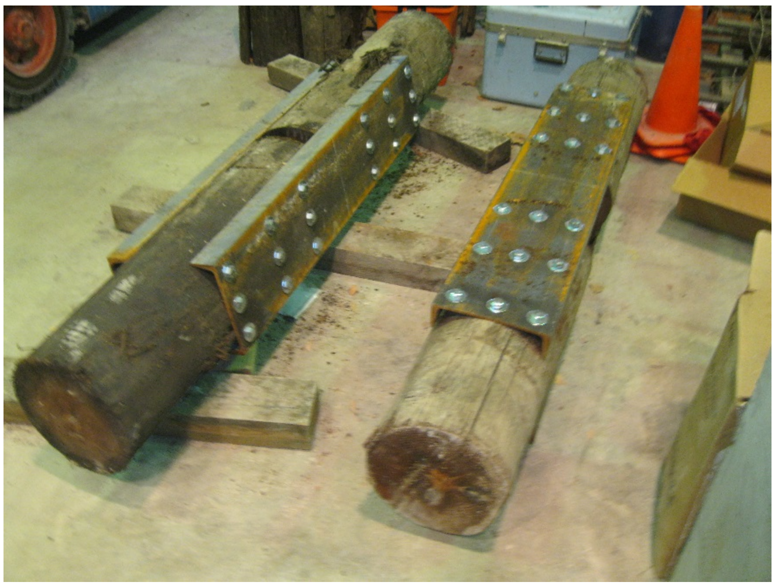


**Figure 5-14 Addition of steel sisters for pile reinforcement**

Materials and Tools Required

- Lag bolts or threaded rods
- Steel channels
- Wood preservative

Design Procedure

1. Determine the required capacity of the pile per codified specifications.
2. Estimate the remaining capacity of the pile based on the sound portions of the pile cross-section.
3. Calculate the additional capacity required.
4. Size steel channels to place on opposite sides of the pile to increase the capacity what is required. It is recommended that the channel extend a minimum of 24 in. beyond the deteriorated section on either side.

5. Per the National Design National Design Specification (NDS) (from the American Wood Council), size and space the lag bolts to sufficiently anchor and attach the channels to the pile to ensure the desired composite action. To simplify construction, lag bolts rather than threaded through rods are recommended.

Construction Procedure

1. Depending on the amount of damage, channels can be added to the area without removing the damaged section, or added to the area after the damaged section is removed and replaced. See Figure 5-15.
2. Weld 1x1x1/8 in. angles to the web of the channel equally spaced between the rows of bolts. The angle acts as a cleat to better engage the pile and channel.
3. Notch the pile to accept the angle.
4. Apply a preservative treatment at trimmed and notched locations.
5. Attach the pre-drilled channels to the pile per the designed lag bolt or threaded rod pattern.

Details

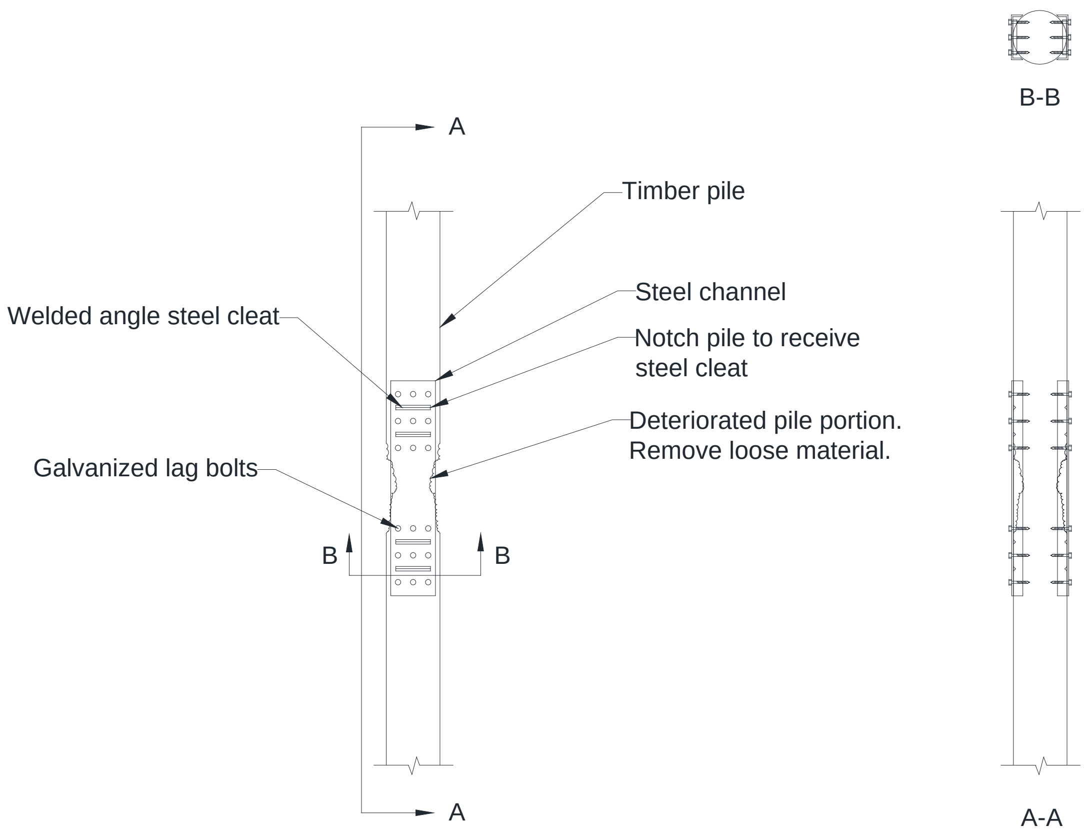



**Figure 5-15 Addition of steel channels**

### *5.3.2 Addition of Reinforced Concrete Jackets to Piles*

Application

This method is used for strengthening timber piles that have localized minor to moderate deterioration or damage that has weakened the overall strength of the member.

Repair Method

Timber piles are partially encased within a concrete-filled steel shell as shown in Figure 5-16.

**Figure 5-16 Addition of pile jackets**

Materials and Tools Required

- Corrugated metal pipe (CMP)
- Concrete
- Steel cable
- L-shaped lag bolts
- Reinforcing bars
- Metal nibbler or saw with metal cutting blade
- Epoxy resin

Design Procedure

1. Determine the required capacity of the pile per codified specifications.
2. Estimate the remaining capacity of the pile based on the sound portions of the pile cross-section. The capacity could be conservatively assumed to be 0 since there will no longer be the ability to inspect the pile once the repair has been completed.
3. Calculate the additional capacity required.
4. Determine the length of the pile cast required.

5. Determine the diameter of CMP required. A 6 in. nominal thickness of encasing concrete is recommended; for example, a 24 in. CMP for a 12 in. diameter pile.

Construction Procedure

1. Identify the area and extent of deterioration/damage using awls and/or other nondestructive methods. See Figure 5-17.
2. If near the ground surface, remove surrounding soil to a depth of 18 in. below the extents of the deterioration.
3. Install L-shaped lag bolts into the pile radially at quarter points using an epoxy resin. Space the bolts longitudinally at 24 in. on-center (o.c.) maximum. The hooks are used as stand-offs for the longitudinal reinforcement bar, which is recommended to be spaced midway between the pile and the CMP with a 2 in. minimum cover.
4. Attach the longitudinal reinforcement bar to the bolts with wire ties.
5. Beginning at one end of the pile cast, spirally wrap the steel cable around the longitudinal reinforcement.
6. Split the CMP into two halves with a metal nibbler or saw it with using a metal cutting blade.
7. Place the two halves around the pile and attach together using steel banding, double angles and bolts, or other means. Depending on the location of the deterioration/damage, the CMP may rest on the ground below, which acts as a form for the bottom of the cast. A means for holding the CMP in place prior to and during filling should be devised.
8. Fill the CMP form with concrete and create a sloped top edge to allow water to shed away from the pile.

Details

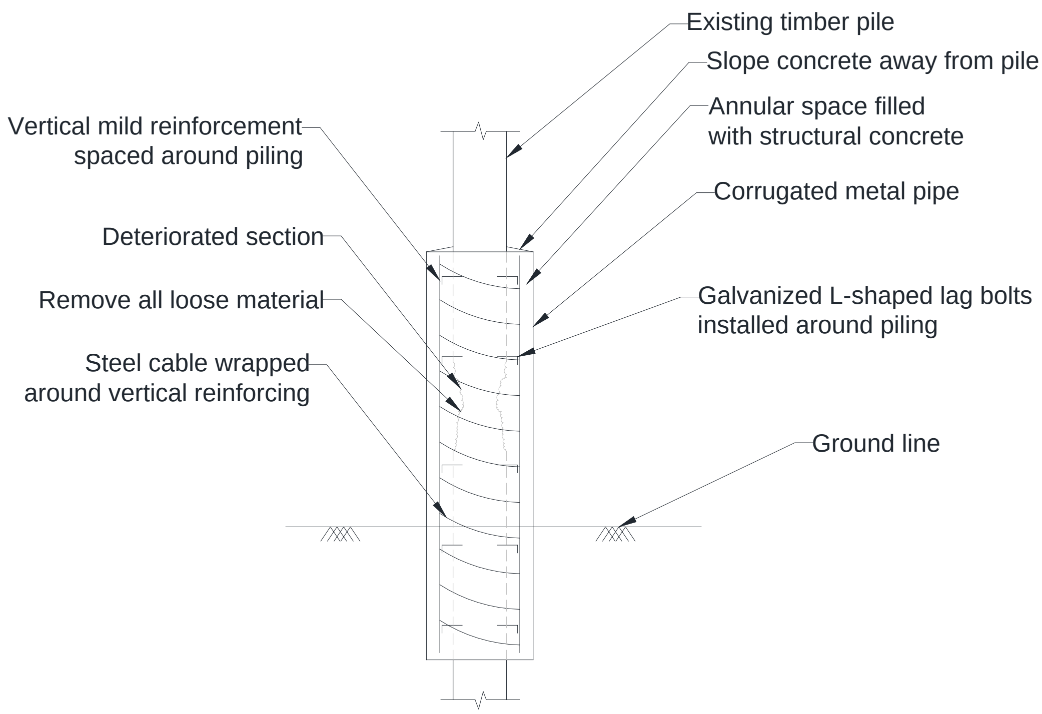



**Figure 5-17 Addition of concrete jacket**

### *5.3.3 Encapsulation of Pile Groups*

Application

This method is used for strengthening a group of timber piles in a single pile bent that have localized minor to moderate deterioration/damage that has weakened the overall strength of the member.

Repair Method

A group of piles, within which deterioration/damage is present on multiple piles, is encapsulated in a reinforced concrete grade beam, tying each pile together and strengthening the overall pile group as shown in Figure 5-18.

**Figure 5-18 Pile encapsulation at abutment**

Materials and Tools Required

- Concrete
- Reinforcing bars
- Formwork

Construction Procedure

1. Excavate a minimum of 12 in. below the area of deterioration/damage or at the ground surface of the pile group, whichever is lower. See Figure 5-19. If piles are submerged, a cofferdam or other means will be required and the site will need to be dewatered.
2. Place reinforcing bars by drilling holes through the pile and threading the horizontal bars through the piles.
3. Place a second set of reinforcing bars beyond the face of the pile using lag bolts attached to the pile face as standoffs.

4. Construct formwork for reinforced concrete encapsulation.
5. Place concrete around all piles ensuring the top slopes away from the piles to properly shed water. See Figure 5-20.

Details

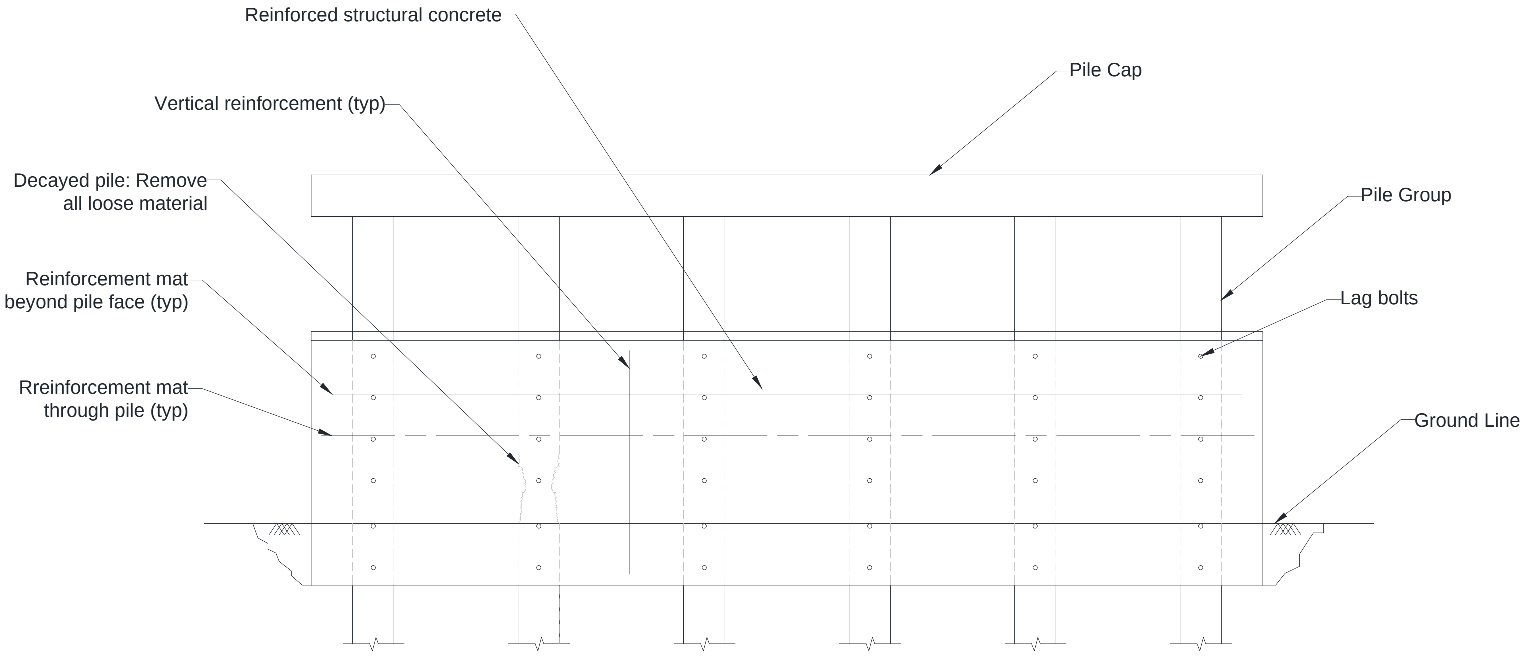



**Figure 5-19 Pile encapsulation – profile view**

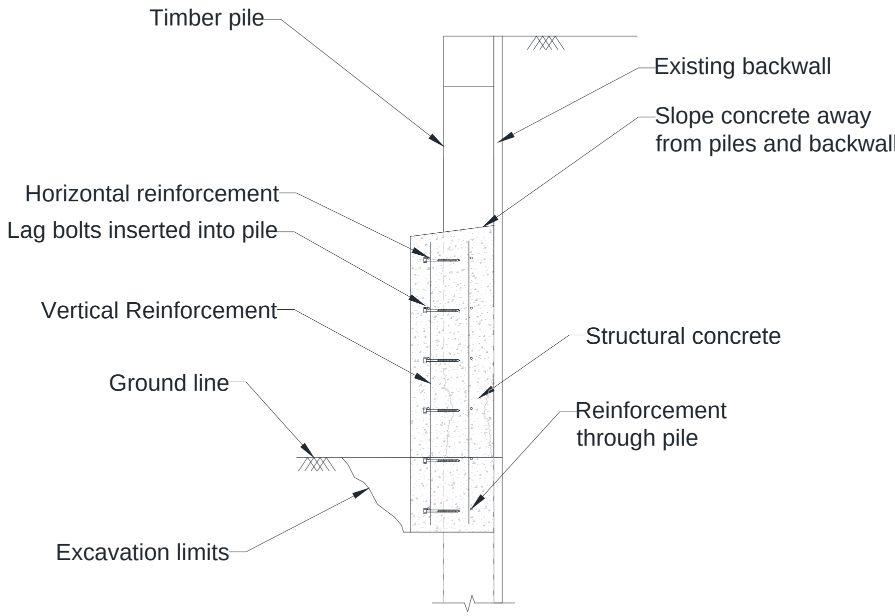



**Figure 5-20 Pile encasement – section view**

# Chapter 6: Cost Estimates

Cost estimates for each of the previously described repairs are provided in Table 6-1.

**Table 6-1 Cost estimates for timber bridge repairs**

| Repair Type | Costs | Notes |
|---|---|---|
| Repair of Laminated Bridge Decks (Partial-Depth) | $263/SF to $329/SF | • Add for traffic control or bridge closure<br>• Add approximately $250 for mobilization each day |
| Repair of Laminated Bridge Decks (Full-Depth) | $420/SF to $449/SF | • Add for traffic control or bridge closure<br>• Add approximately $250 for mobilization each day<br>• Cost of repair will be increased by height of deck and/or water depth dictating equipment required |
| Strengthening of Individual Timber Stringers (Shear) | $1,531 for each stringer | • Add approximately $250 for mobilization each day<br>• Cost of repair will be affected by height and water depth |
| Strengthening of Individual Timber Stringers (Flexural) | $3,016 for each stringer | • Add approximately $250 for mobilization each day<br>• Cost of repair will be affected by height and water depth<br>• Estimate assumes 9 ft length |
| Addition of Steel Channels to Piles | $1,943 per pile | • Add approximately $250 for mobilization each day<br>• Any cofferdam and dewatering costs not included |
| Addition of Reinforced Concrete Jackets to Piles | $5,520 each pile +/- $370/LF variance from 15LF | • Add approximately $250 for mobilization each day<br>• Any cofferdam and dewatering costs not included |
| Encapsulation of Pile Groups | $16,410 per pile group plus $450/LF over 28 ft length | • Add approximately $400 for mobilization each day<br>• Add approximately $6,500 for any necessary cofferdam and dewatering |

Estimates based on experienced Minnesota union labor
Counties self-performing the above work could save up to 25% based on labor experience and availability of equipment and materials

Keep in mind that each bridge repair is unique and that the cost estimates may not always be accurate. Even so, the estimates should give a good approximation of a ballpark figure for each repair. The estimates were completed using general assumptions based on the repair details and experienced Minnesota union labor. Where the work is self-performed, a 25 percent savings is anticipated based on labor experience and availability of equipment and materials.

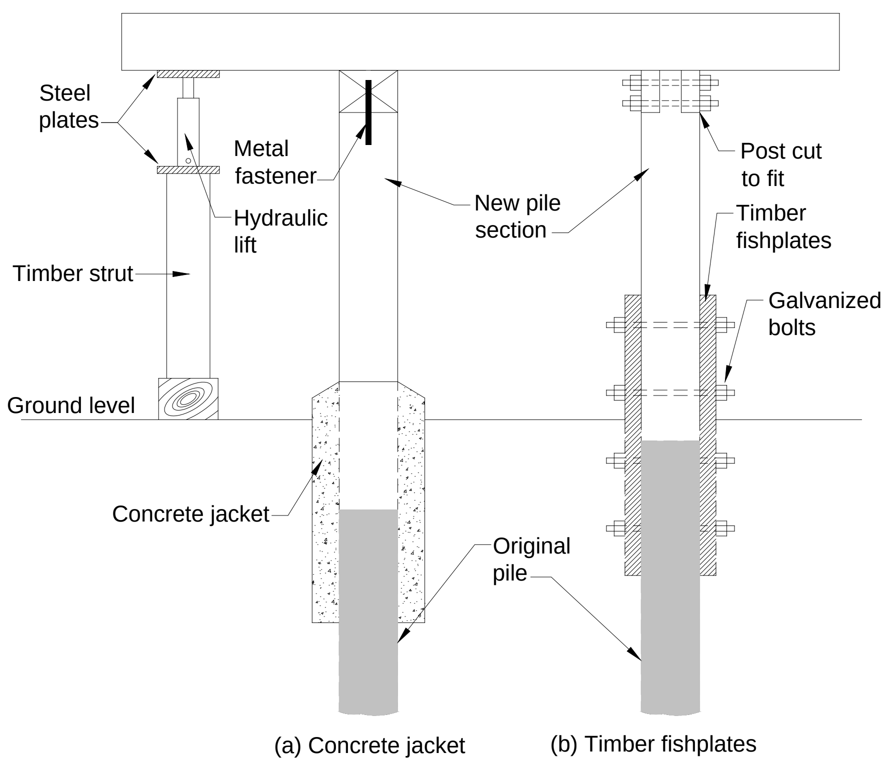
# Chapter 7: Other Potential Repair Methods

## 7.1 Repair of Timber Piles

### *7.1.1 Posting/Splicing*

The method of posting and splicing is most often performed above the ground line where accessibility to the pile is possible without too much difficulty. Be that as it may, the method can be performed below the ground line when the extents of the deteriorated portion warrant doing so.

This method is described in research conducted by White et al. 2007. To complete the repair, after the pile cap is temporarily supported with a strut and jack or other means, the deteriorated portion is cut out of the pile and replaced with a section similar in diameter. Cuts are made above and below the section to be removed. Once removed, the new treated pile portion can be installed. Attachment to the remaining portions of the pile can be achieved through various methods including timber fishplates and concrete jacketing. Figure 7-1 schematically shows examples of both methods. If timber fishplates are used, they must be treated and all fasteners must be galvanized. Additional discussion of the concrete jacketing method is included later in this document.




White et al. 2007

**Figure 7-1 Posting timber piles using concrete jacket or timber fishplates**

A method of posting used in Iowa is shown in Figure 7-2 (Dahlberg et al. 2012).

Dahlberg et al. 2012

**Figure 7-2 Posted piles using steel W shapes**

Here, W shapes take the place of deteriorated portions of the pile. The method requires that the pile be cut below the area of deterioration at a sound, non-deteriorated location. It is at this location where a steel member is placed between the top of the remaining pile and the pile cap above and then lagged into place at both the top and bottom.

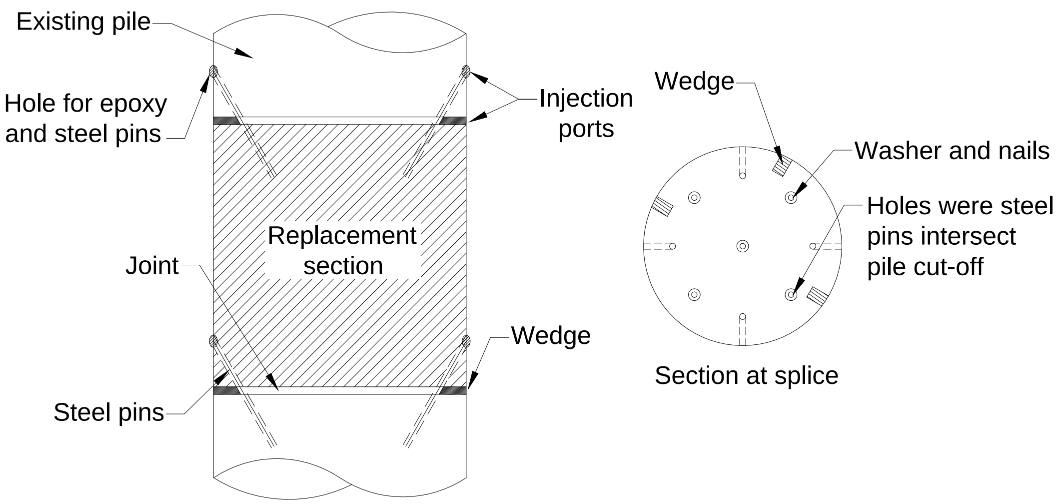
This posting method requires precision that may not always be achievable in the field. The steel must be fabricated to exactly fit the area between the remaining pile portion and pile cap. Moreover, full bearing between the pile and post or post and pile cap is rarely seen. One method to help alleviate the problem of non-fitting steel members was introduced by researchers at Iowa State University (Dahlberg et al. 2012). The method created the ability to vertically adjust the steel member to fit in a desired location using leveling nuts and a threaded rod, which are attached to angles that are lagged to the pile (see Figure 7-3).

Dahlberg et al. 2012

**Figure 7-3 Leveling mechanism for steel post on timber pile**

### *7.1.2 Mechanical Splicing*

Another method of splicing described in White et al. 2007 involves the use of epoxy resin and mechanical fasteners. With this method, the deteriorated portion of the pile is removed as with the methods previously described, above and below the deteriorated portion. A new pile of similar diameter is placed in the area of removal with a 1/8 to 1/4 in. gap between the existing and new pile portions and the splice is wedged tightly into place against the existing pile cutoffs. Holes are then drilled at a steep angle starting from the existing portions to new portions and, within these holes, a steel pin is placed and epoxy is injected. The space between existing and new portions of the pile is also filled with epoxy resin. This method is schematically shown in Figure 7-4.

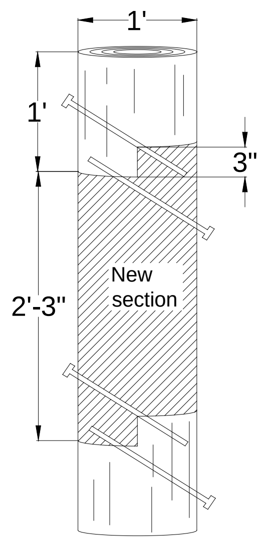



White et al. 2007

**Figure 7-4 Pile splice with steel pins and epoxy**

Laboratory and field testing showed that the original ultimate compressive strength and axial stiffness of deteriorated piles is economically and effectively restored using this method. However, the ultimate flexural strength was reduced by 50 to 75 percent (White et al. 2007). As such, it is recommended that this method be used when only a few piles are in need of repair.

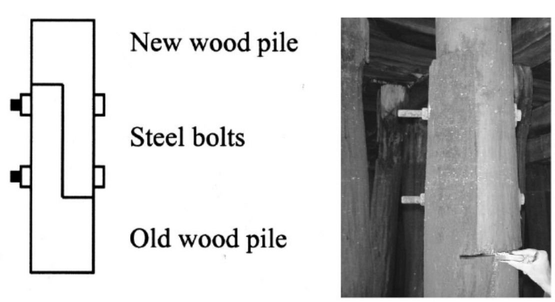
Similarly, a study was conducted at Iowa State University that investigated another splicing type repair method (White et al. 2007). The method utilized lap splices mechanically fastened with long lag screws. Along with control sections, tests were conducted on the posted specimens to measure the ultimate capacity in compression and bending. Both the new and existing portions of the pile were cut so that each could lap the other. The tests revealed that about 70 percent of the axial capacity of the original pile was restored, while only 20 percent of the bending capacity was restored. This method is shown in Figure 7-5.




White et al. 2007

**Figure 7-5 Mechanical splice mechanical fasteners**

Another lap-spliced pile method was observed and investigated by researchers of another study (Lopez-Anido 2005). In this case, each of the piles were fastened together using steel through bolts as shown in Figure 7-6.



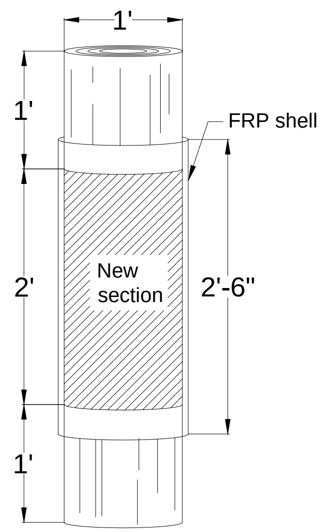

Lopez-Anido 2005

**Figure 7-6 Pile splice using lapped joints and bolts**

Although initially this repair seemingly would provide an effective solution, the researchers expressed concerns with the gap between the old pile and the end of the new pile, which does not allow for proper transfer of vertical forces, and also left the untreated center of the pile exposed. However, both of these concerns could be fairly easily rememdied.

### *7.1.3 Splice with FRP Wrap*

Another study completed by Iowa State University explored the option of splicing a timber pile using fiber-reinforced polymer (FRP) wrapping (White et al. 2007). In this study, the deteriorated portion of the pile was removed and replaced with a sound pile portion of similar size. Afterwards, multiple FRP wraps coated with epoxy resin were used to join the two portions of the pile with the wraps overlapping the sawn joint by approximately 7 in. Axial and bending tests showed that the repair restored nearly 100 percent of the axial capacity, while only approximately 50 percent of the bending capacity was restored. This repair is shown in Figure 7-7.

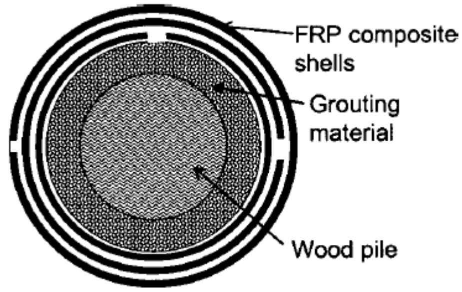



White et al. 2007

**Figure 7-7 Pile splice with FRP wraps**

### *7.1.4 Fiber-Reinforced Polymer*

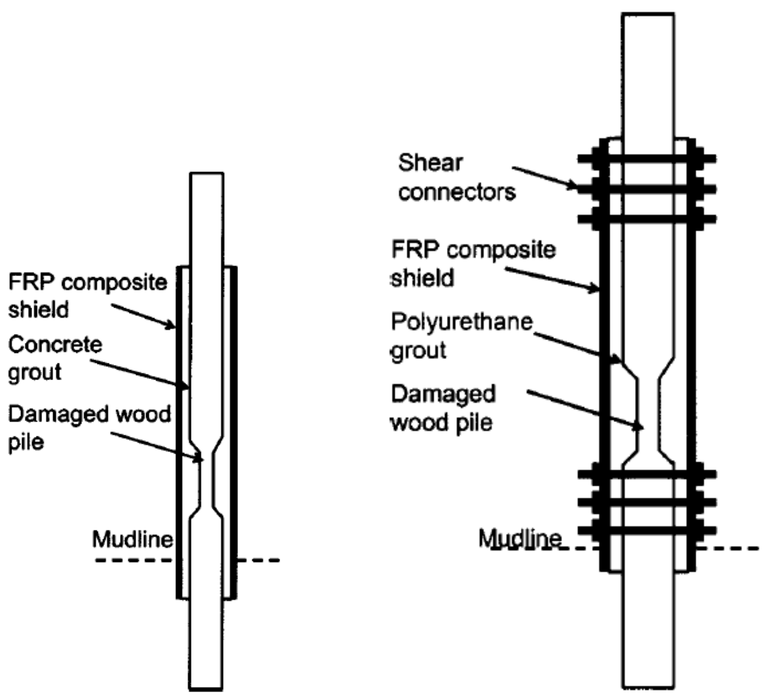
FRP shells are suitable for repairing piles that require an increase in strength but are not so far deteriorated that replacement is required. The benefits of this method are two-fold. First, added strength is provided to the existing pile and, second, the shell acts as a barrier between the wood pile and biological decay mechanisms (Lopez-Anido 2005). To complete the repair, the FRP shells are positioned around the pile, fastened to each other, and then filled with a grout material. To avoid weakness in the shell at butt joints, it is recommended to use multiple shells at staggered positions (see Figure 7-8).




Lopez-Anido et al. 2005

**Figure 7-8 Cross section of wood pile repaired with FRP composite shells**

This system forms a cast around the pile similar to that achieved with the concrete jacketing method. Strength within the FRP is provided from both axial fibers and hoop fibers, contributing to the axial stiffness and mechanical fastener support, respectively. Two methods by which the process can be completed include using cement-based grout without shear connectors and using polyurethane grout, which requires shear connectors between the pile and FRP shell because of its non-structural characteristics (see Figure 7-9). Generally, the cement-based method is considered more cost effective and also more effective in transferring stresses from the pile to the FRP shell.

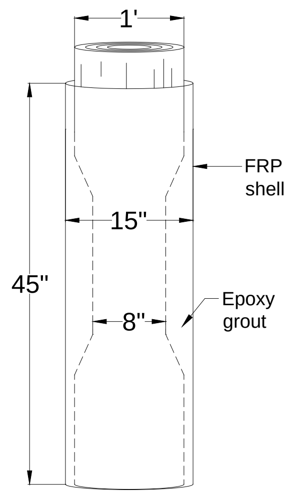



Lopez-Anido et al. 2005

**Figure 7-9 Variations of FRP composite shells**

Variations of the FRP shell method have been produced by at least two companies: Hardcore Composites of New Castle, Delaware, which developed the Hardshell System, and Fibrwrap Construction. The Hardshell System uses composite shells constructed around the pile in two halves and joined with connectors at the seam. The strength of a single point of connection at the seams is of some concern. Fibrwrap uses a fabric reinforcement, which is wrapped around the timber pile and then impregnated with epoxy resin. The curing of the resin is of some concern if the wrap is submerged below the waterline.

An investigation by Iowa State University was conducted with the intent of evaluating another variation of the FRP wrap method (White et al. 2007). FRP shells slightly larger than the diameter of the deteriorated pile were created using polyvinyl chloride (PVC) pipe forms and then placed around the pile (see Figure 7-10). The annular space between the pile and FRP shells was filled with a wood filler epoxy resin. Laboratory tests showed that approximately 70 percent of the pile's axial and bending capacity was restored with this repair.

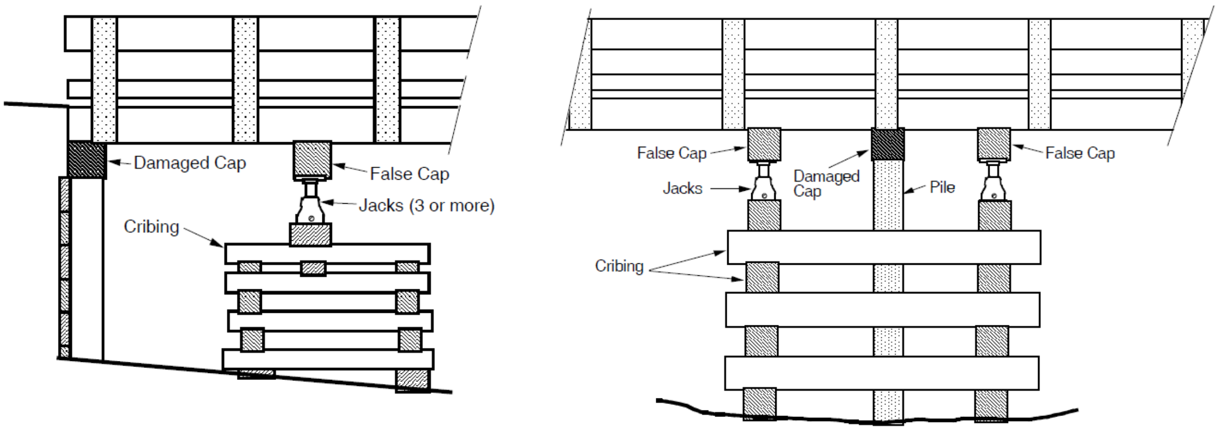



White et al. 2007

**Figure 7-10 FRP wrap filled with wood filler epoxy resin**

### *7.1.5 Timber Cap Replacement*

When timber caps deteriorate to a point that replacement is necessary, the superstructure must be jacked-up so that access to and removal of the old cap can be achieved (Johnson 2002). This method can be accomplished by using timber cribbing as a jack stand and a false cap for the stringers to bear on as shown in Figure 7-11.




Johnson 2002

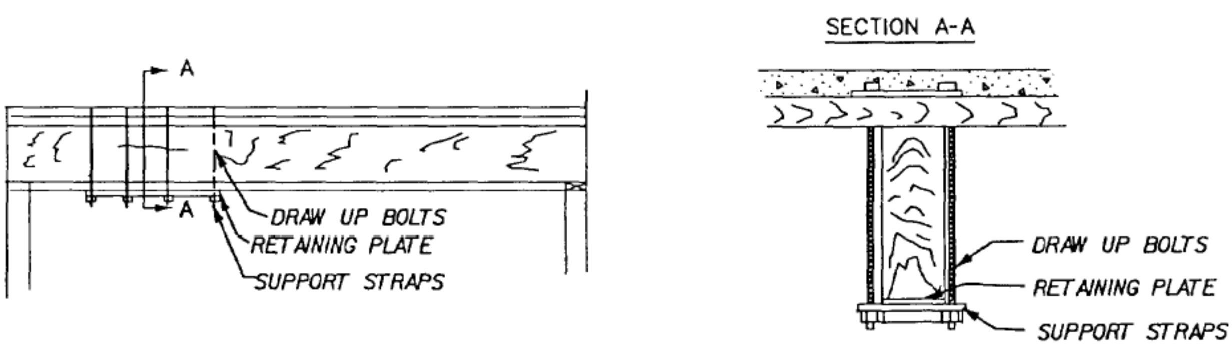
**Figure 7-11 Timber cap replacement at abutment and pier**

Once the superstructure has been raised 1 to 2 in., the old cap can be cut out and removed, and the new cap can be moved into position. Lowering the jacks and then fastening the stringers and existing piling to the new cap with steel straps and drift pins complete the repair.

## 7.2 Repair of Timber Superstructures

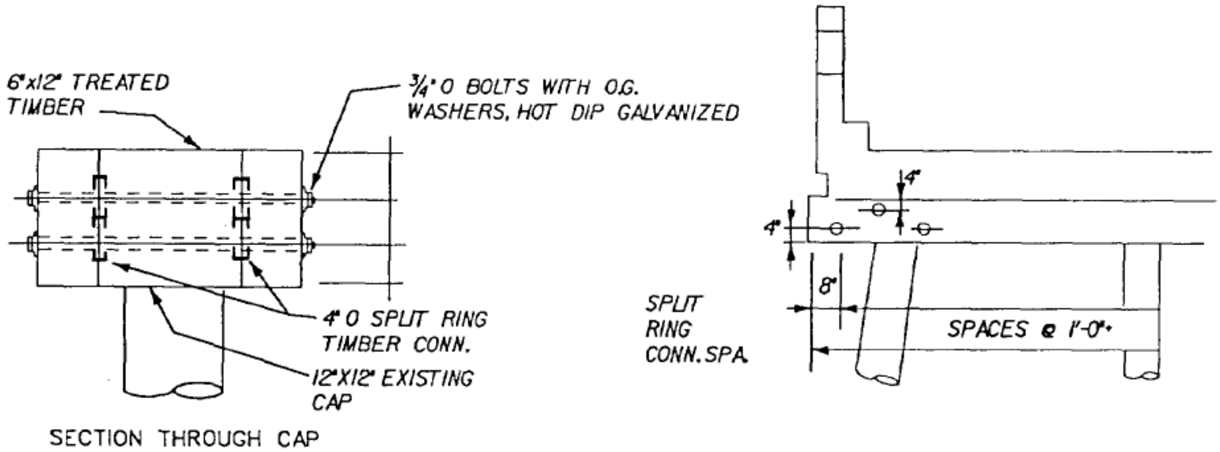
### *7.2.1 Scabbing*

When timber deteriorates to a point that the structural integrity of the member is questionable, one method that can restore the strength of the member is to scab additional lumber or steel plates to the member (US Army and Air Force 1994). This method effectively provides a path for loads to bypass the deteriorated portion. Note that this method is intended only for when a member has deteriorated no further than a moderate level though. This method could be ineffective and another method such as splicing might be more suitable for members with extensive deterioration. Figure 7-12 and Figure 7-13 show examples of two scabbing methods.




US Army and Air Force 1994

**Figure 7-12 Repair of cracked or split stringers**




US Army and Air Force 1994

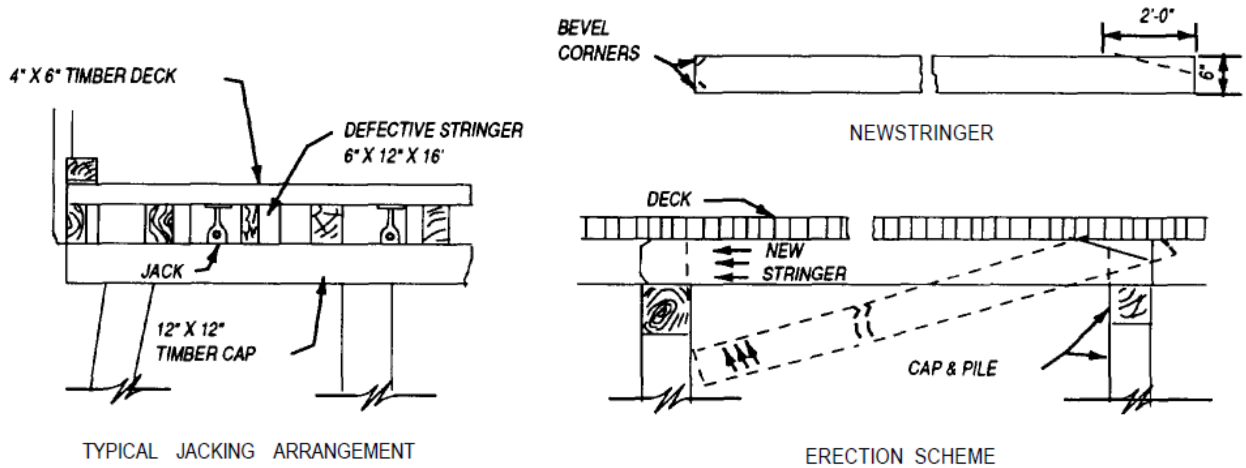
**Figure 7-13 Timber cap scabs**

The first (Figure 7-12) is for the reinforcement of a timber girder or stringer. Steel plates are attached to the stringer and deck system via draw-up bolts, which strengthen the damaged area by closing slits and cracks in the member and by developing composite action between the stringer and the deck.

The second (Figure 7-13) is more commonly used on a timber cap to extend the bearing area of timber stringers and girders where the ends have deteriorated to a point where the bearing capacity has been reduced.

### *7.2.2 Replacement of Flexural Timber Components*

Occasionally, a timber girder or stringer is beyond repair and requires replacement. This can be achieved from below the deck by jacking the deck from the pile cap on each side and at each end of the respective stringer (US Army and Air Force 1994). The original stringer is removed and a new stringer is put in its place after it has been cut as needed to allow for insertion. The jacks are then removed and the ends of the stringer are wedged so that contact with the deck is made along its length. The method is schematically shown in Figure 7-14.




US Army and Air Force 1994

**Figure 7-14 Girder or stringer replacement from below the deck**

# Chapter 8: Summary

This investigation, Development of Cost-Effective Timber Bridge Repair Techniques for Minnesota, consisted of six tasks. One of the tasks resulted in the preparation of this manual, *Cost-Effective Timber Bridge Repairs: Manual for Repairs of Timber Bridges in Minnesota*. This manual consists of seven main chapters.

Chapter 1 presented the background and scope of the investigation. The scope consisted of four main areas:

- Identification of effective repair strategies through literature searches and surveys
- On-site interviews, for additional insight, with local engineers
- Development of effective repair techniques
- Investigation of the cost-effectiveness of the repair strategies and extension of service life

Chapter 2 provided a brief summary of the timber bridge inventory in Minnesota and, specifically, additional information regarding slab and girder bridges.

In Chapter 3, information on the tools that assist with preventive maintenance and the diagnosis of deterioration was presented. Details in this chapter were organized into seven areas:

- **Visual assessment:** A quick qualitative assessment (corroded fasteners, splits, cracks, checks, etc.) can be obtained by a general visual inspection.
- **Probing and pick tests:** An awl or other sharp pointed tools can be used to detect soft spots created by decay fungi or insects.
- **Moisture measurement:** Moisture measurements are taken with a hand held moisture meter. Moisture content greater than 20 percent indicates sufficient moisture is present for decay to initiate.
- **Sounding:** By striking the wood surface with a hammer, based on the tone, the inspector might be able to detect a void or pocket of decay.
- **Stress wave devices:** Stress wave measurements can locate voids caused by insects, decay fungi, or other physical defects.
- **Drill resistance devices:** These devices record the resistance to drilling through a piece of wood, which is related to the density of the wood at that location.
- **Core boring:** Incremental core borings at a particular location can be visually examined for signs of deterioration.

Chapter 4 presented various maintenance practices that generally fall into one of three categories: routine maintenance, periodic maintenance, or specific works.

- **Routine maintenance** primarily consists of minor reactive work that is typically expected over the service life of the bridge (such as moisture control, end grain treatment, pile treatment, fastener maintenance, and so forth).

- **Periodic maintenance** is required for both superstructure and substructure elements. For example, superstructure periodic maintenance can include maintenance of outside stringers, deck drainage, and removal of deck vegetation. Substructure maintenance can include removal of debris from pile caps and repair of small or medium cracks in different elements.
- **Specific works** includes planned and scheduled improvements to various bridge elements to maintain such things as safety, strength, and desired geometry.

Chapter 5 presented five strengthening and rehabilitating procedures. These procedures were developed to address the timber bridge concerns in Minnesota identified through survey questionnaire results and interaction with county engineers. Two of the five procedures developed are for superstructure repairs while the other three are for substructure repairs.

For each of the methods, a list of required materials, tools, procedures, and details are provided. One of the procedures for superstructure repair addresses laminated bridge decks, while the other addresses the strengthening of individual timber stringers. For substructures, one procedure adds steel channels to timber piling for additional strength. Another restores strength by using reinforced concrete jacketing. The third method restores strength by encapsulating a group of timber piles in reinforced concrete, several of which may have minor to moderate damage or deterioration.

Cost estimates for each of the repairs presented in Chapter 5 are included in Chapter 6.

In addition to the five strengthening and repair procedures presented in Chapter 5, several other methods for strengthening superstructure and substructure elements are presented in Chapter 7. These methods are generally described and fewer details are provided compared to those in Chapter 5.

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