

MAINTENANCE AND REHABILITATION OF TIMBER BRIDGES**14.1 INTRODUCTION**

Wood is one of the most durable bridge materials, but over extended periods it may be subject to deterioration from decay, insect attack, or mechanical damage. Timber bridges must be periodically maintained or rehabilitated in order to keep them in a condition that will give optimum performance and service life. Effective bridge maintenance programs improve public safety, extend the service life of the structure, and reduce the frequency and cost of repairs. The objective is not only to repair existing deficiencies, but also to take corrective measures to prevent or reduce future problems. When tied to a competent bridge inspection program, regular maintenance represents the most cost-effective approach for achieving long service life from existing structures. Unfortunately, maintenance is often neglected until critical problems develop that require major restoration or replacement of the structure. In times of declining budgets, the first program reduced as a money-saving measure is often maintenance, when, in fact, reduced maintenance substantially increases long-term costs.

In general terms, bridge maintenance includes those activities necessary to preserve the utility of a bridge and ensure the safety of road users. In practice, all maintenance is either preventative or remedial. Maintenance activities are divided into categories that vary in definition and scope among different agencies. In this chapter, timber bridge maintenance is divided into the three following categories:

1. **Preventative maintenance** involves keeping the structure in a good state of repair to reduce future problems. At this stage, decay or other deterioration has not started, but the conditions or potential are present.
2. **Early remedial maintenance** is performed when decay or other deterioration is present but does not affect the capacity or performance of the bridge in normal service. At this stage, more severe structural damage is imminent unless corrective action is taken.
3. **Major maintenance** involves immediate corrective measures that restore a bridge to its original capacity and condition. 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 load-carrying capacity.

Bridge rehabilitation is another form of restoration performed on bridges that are functionally or structurally obsolete. Rehabilitation is similar to maintenance in some ways because it involves many of the same methods and techniques; however, rehabilitation is performed to improve the geometric or load-carrying capacity of an existing bridge, rather than to restore the original capacity. Rehabilitation is most commonly performed on older bridges that were built to lesser geometric or loading standards than those required for today's modern traffic.

This chapter discusses several maintenance and rehabilitation practices and methods that are commonly used for timber bridges. Because deficiencies develop from a variety of causes, it is impractical to address each type of potential problem. Rather, preventative and remedial methods are discussed that can be adapted to the specific circumstances of the structure. These methods include moisture control, in-place preservative treatment, mechanical repair, epoxy repair, and component replacement. Applications of these techniques to actual projects are given in case histories presented in Chapter 15. For additional guidelines and information related to bridge maintenance in general, consult the references listed at the end of this chapter.^{1,3,28,37}

14.2 MOISTURE CONTROL

Moisture control is the simplest, most economical method of reducing the hazard of decay in timber bridges. It can be used as an effective and practical maintenance technique to extend the service life of many existing bridges. When exposure to wetting is reduced, members can dry to moisture contents below that required to support most fungal and insect growth (approximately 25 percent). Moisture control was the only method used for protecting many covered bridges constructed of untreated timber, some of which have provided service lives of 100 years or more (Figure 14-1). Although modern timber bridges are protected with preservative treatments, decay can still occur in areas where the preservative layer is shallow or broken. This damage is the major cause of deterioration in timber bridges.

Moisture control involves a common sense approach of identifying areas with visible wetting or high moisture contents, locating the source of water, and taking corrective action to eliminate the source. For example, drainage patterns on approach roadways can be rerouted to channel water away from the bridge rather than onto the deck. Cleaning dirt and debris from the deck surface, drains, and other horizontal components also reduces moisture trapping and improves air circulation (Figure 14-2). One of the most effective approaches to moisture control is restricting or preventing water passage through the deck. Decks that are impervious to moisture penetration will protect critical structural members and



Figure 14-1. - Many covered bridges constructed of untreated timber, such as this one in New Hampshire, have lasted more than 100 years because they were protected from moisture.

substantially reduce the potential for decay. Glulam or stress-laminated decks afford the best protection because they can be placed to form a watertight surface. Leaks between glulam panels or at butt joints in stress-laminated decks can be resealed using bituminous roofing cement.

The deck wearing surface also plays an important role in moisture protection. Wearing surfaces constructed of lumber planks or steel plates provide little protection and often trap moisture under the planks or plates. Lumber running planks are a particular problem because they inhibit drainage on watertight decks and often cause water ponding on the deck surface. When ponding occurs, the only practical option for its removal is to install tubes through the deck to drain water down and away from the deck, rather than onto the deck underside and supporting members (Figure 14-3).

On glulam, stress-laminated, and some nail-laminated decks, the addition of an asphalt wearing surface provides a moisture barrier that protects not only supporting members but also the deck. The effectiveness of the surface protection is increased when the asphalt is placed on geotextile



Figure 14-2. - Dirt and debris on the deck surface can trap moisture and lead to premature deterioration. Material such as this should be removed periodically as part of a good preventative maintenance program.

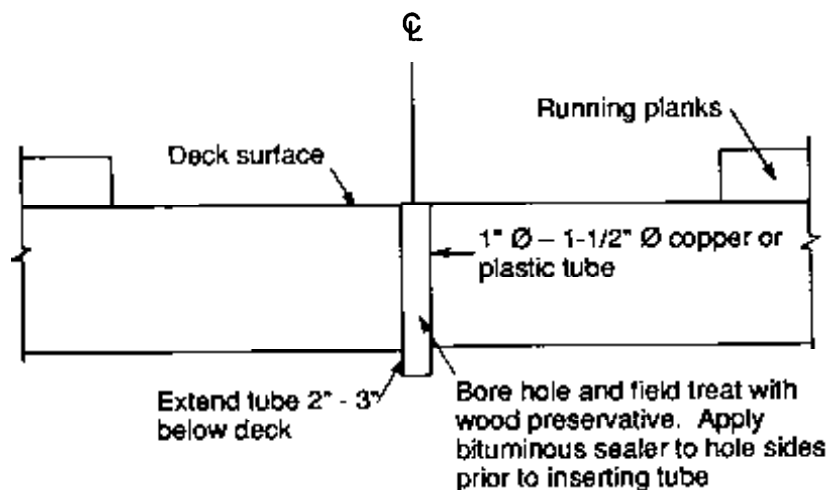


Figure 14-3. - Detail of drain tube for removing trapped water between lumber running planks.

fabric (Chapter 11). All glulam and stress-laminated decks are normally suitable for asphalt surfaces; however, use of asphalt surfaces on nail-laminated decks may be limited by the condition of the deck. Nail-laminated decks commonly show varying degrees of looseness after 5 to 10 years of service under heavy loading. Paving these decks is futile because the separation and movement of laminations will cause the pavement to crack and disintegrate. The best approach to waterproofing a loose nail-laminated deck is to apply stressing to restore deck integrity

(discussed later in this chapter), followed by application of an asphalt wearing surface. When this is not practical, deck replacement is usually the only other option.

On bridges with asphalt surfaces, breaks in the surface may develop in service from deck deflections, improper bonding, or poor construction practices. Deficiencies of this type should be repaired as soon as possible to prevent more serious deterioration. Cracking may result from a number of causes but is typically caused by differential deck deflections at panel joints or at bridge ends. Cracks of this type should be thoroughly cleaned with a stiff brush and compressed air, then filled with emulsion slurry or liquid asphalt mixed with sand (Figure 14-4). If pavement is broken or missing, surrounding pavement must be removed to the point where it is sound and tightly bonded to the deck, and a patch must be applied. For best results, the repair area should be cut in a square or rectangular shape with vertical sides, be thoroughly cleaned, and be patched with a dense grade of asphalt pavement.

14.3 IN-PLACE PRESERVATIVE TREATMENT

In-place treating involves the application of preservative chemicals to prevent or arrest decay in existing structures. Two types of treatment are commonly used: surface treatments and fumigants. Surface treatments are applied to prevent infection of exposed wood, whereas fumigants are used to treat internal decay. In-place treating can provide a safe, effective, and economical method for extending the service life of timber bridges. Most of the techniques and treatments were developed for use on railroads or utility poles, for which they have been used effectively for many years. A large number of timber bridges have been treated in-place, extending service life by as much as 20 years or more (see case histories in Chapter 15).

SURFACE TREATMENTS

Surface treatments are applied to existing bridge members to protect newly exposed, untreated wood from decay or to supplement the initial treatment some years after installation. This type of treatment is most effective when applied before decay begins and is commonly used for treating checks, splits, delaminations, mechanical damage, or areas that were field-fabricated during construction. The ease of application and effectiveness of surface treatments as toxic barriers make them useful in preventive maintenance; however, the shallow penetration limits their effectiveness against established internal decay.

Surface treating uses the same basic procedures discussed for field treatment (Chapter 12). Conventional liquid wood preservatives are applied by



Figure 14-4. - (A) Minor cracking in an asphalt wearing surface from differential deck deflections. (B) Sealing the cracks with an asphalt emulsion slurry.

brushing, squirting, or spray-flooding the wood surface (Figure 14-5). Creosote heated to 150 to 200 °F is probably the most commonly used preservative, but penta and copper naphthenate are also used. The wood surface should be thoroughly saturated with preservative so that all cracks and crevices are treated; however, care must be exercised to prevent excessive amounts from spilling or running off the surface and contaminating water or soil.



Figure 14-5. - Liquid wood preservative is applied to a check in a timber curb by brushing.

In addition to preservative liquids, some preservative compounds are available in semisolid greases or pastes. These preservatives, which generally use sodium fluoride, creosote, or pentachlorophenol as the primary preservative chemical, are useful for treating vertical surfaces or openings. Their primary advantage is that larger quantities of the toxic chemical can be locally applied in heavy coatings that adhere to the wood. Preservative adsorption over an extended period of time can produce deeper penetration than single surface applications of liquid treatments. Semisolid preservatives are commonly used at the groundline of posts, poles, and piling, where they are brushed on the surface from several inches above the groundline to 18 to 24 inches below the groundline (Figure 14-6). After the preservative is applied, the treated portion is wrapped with polyethylene, or other impervious material, to exclude moisture and prevent leaching of the treatment into the surrounding soil.

The effectiveness of surface treatments depends on the thoroughness of application, wood species, size, and moisture content at the time of treatment. Wet wood absorbs less preservative than does dry wood. This factor is significant in timber bridges because many areas requiring treatment are subject to wetting. Tests indicate that improved treatment of wet wood was obtained by using preservatives at double the normal 3- to 5-percent concentration.¹⁷ Although field tests show that surface treatments in aboveground locations can prevent decay infections for up to 20 years or more,³⁵ it is recommended that treatments used for bridge applications be systematically reapplied at intervals of 3 to 5 years to ensure adequate protection from decay.



Figure 14-6. - Paste wood preservative is applied to a timber pile around the groundline. Note the wrapping material at the upper end of the treated section (photo courtesy of Osmose Wood Preserving, Inc.).

FUMIGANTS

Fumigants are specialized preservative chemicals in liquid or solid form that are placed in prebored holes to arrest internal decay. Over a period of time, the fumigants volatilize into toxic gases that move through the wood, eliminating decay fungi and insects. Fumigants can diffuse in the direction of the wood grain for 8 feet or more from the point of application in vertical members, such as poles. In horizontal members, the distance of movement is approximately 2 to 4 feet from the point of application. The three chemicals most commonly used as liquid fumigants are Vapam (33-percent sodium N-methyldithiocarbamate), Vorlex (20-percent methylisothiocyanate, 80-percent chlorinated C₃hydrocarbons), and chloropicrin (trichloro-nitromethane). Solid fumigants are available in capsules of methylisothiocyanate (MIT), which is the active ingredient of Vapam and Vorlex. Solid fumigants provide increased safety, reduce the risk of environmental contamination, and permit fumigant use in previously restricted applications.

To be most effective, fumigants must be applied to sound wood. When applied in very porous wood or close to surfaces, some of the fumigant is lost by diffusion to the atmosphere. Before applying fumigants, the condition of the member should be carefully assessed to identify the optimal boring pattern that avoids fasteners, seasoning checks, badly decayed

wood, and other openings to the atmosphere. In vertical members such as piles, holes should be bored at a steep downward angle toward the center of the member to avoid crossing seasoning checks (Figure 14-7). It is best to begin by boring almost perpendicular to the member, then quickly raising the drill to a 45 to 60-degree angle once the bit catches in the wood. For horizontal members, holes are bored in pairs straight down to within 1-1/2 to 2 inches from the bottom side. If large seasoning checks are present in horizontal members, holes should be bored on each side of the check to more completely protect the timber (Figure 14-8). The amount of chemical and the size and number of treatment holes depends on the member size and orientation. Table 14-1 gives some examples of the number and size of holes and fumigant dosages required to treat vertical piling. For horizontal members, pairs of holes should not be more than 4 feet apart. Additional information and recommended dosages for fumigants may be obtained from the chemical manufacturers.

When solid fumigants are used, they are inserted directly into the prebored holes. Liquid fumigants are applied using commercial equipment but can also be applied from 1-pint polyethylene squeeze bottles (Figure 14-9).²⁷ When using polyethylene, it is helpful to replace the plastic cap with a reusable cap fastened to a 1-foot length of plastic or rubber tubing. After adding the required dosage of fumigant, the original cap is replaced so the remaining liquid stays in the bottle, and the fumigant is returned to its original container (liquid fumigants should not be stored in plastic bottles for long periods because they can cause the plastic to become brittle and crack). If leaks are observed while applying liquid fumigants, it is



Figure 14-7. - Treating holes for fumigants in vertical members are bored at a steep downward angle (photo courtesy of Jeff Morrell, Oregon State University).

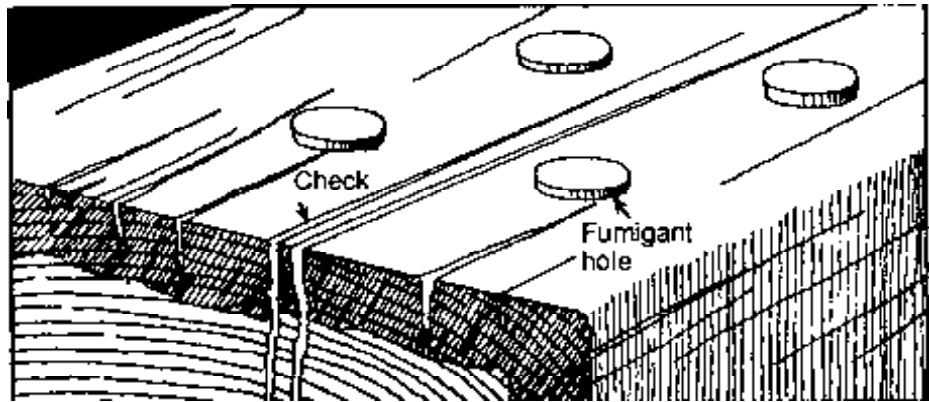


Figure 14-8. - Treating holes for fumigants in horizontal members should be placed on both sides of checks or splits, and be bored to within 1-1/2 to 2 inches of the bottom of the member.



Figure 14-9. - Application of liquid fumigants. (A) Liquid fumigants applied with commercial equipment (photo courtesy of Osmose Wood Preserving, Inc.).

Table 14-1. - Number and size of holes and dosage of fumigant required for piles.

Hole dimensions (In.)		Fumigant dosage (pints per in. of hole)	Numbers of holes for piles of various circumferences (and dosages)		
Diameter	Length ^a		< 32 in. (3/4 pint)	32 – 45 in. (1 pint)	> 45 in. (2 pints)
5/8	15	0.010	6	—	—
	18	0.010	5	—	—
3/4	15	0.015	4	6	—
	18	0.015	—	5	—
	21	0.015	—	4	—
	24	0.015	—	3	6
7/8	21	0.024	—	3	5
	24	0.024	—	—	4

^a Effective length of treating hole is 3 inches less to allow for a 3-inch treated plug. From Morrell and others.²⁷



Figure 14-9. - Application of liquid fumigants (continued). (B) Liquid fumigants applied from a polyethylene squeeze bottle (photo courtesy of Jeff Morrell, Oregon State University).

important to stop filling, to plug the hole, and to bore another hole into sound wood. Immediately after placing the chemicals, the hole is plugged with a tight-fitting, treated-wood dowel driven slowly to avoid splitting the wood. For liquid fumigants, sufficient room (1.5 to 2 inches) must be left in the treating hole so the plug can be driven without squirting the chemical.

Fumigants will eventually diffuse out of the wood, allowing decay fungi to recolonize. In properly treated solid wood, Vorlex and chloropicrin will remain effective for 10 to 15 years, while Vapam is somewhat less effective (Figure 14-10). These periods will be reduced when the wood has many fastener holes, splits, checks, or end grain where the chemical can diffuse to the atmosphere. Retreatment can be made at periodic intervals in the same holes used for the initial treatment. The old plug is drilled or pulled, new fumigant is added, and the hole is replugged with a new, treated dowel. Until retreatment cycles are better defined, it is recommended that a 10-year treatment cycle be used with a regular inspection program at 5-year intervals. When inspections indicate the presence of active decay, the protective effects of the fumigant have declined below a toxic threshold, and retreatment is required. It is important to keep accurate records of all in-place treating, including the date and location of the application, the type of chemical, and the dose (such records are required in some States). It may also be beneficial to place a metal tag on the

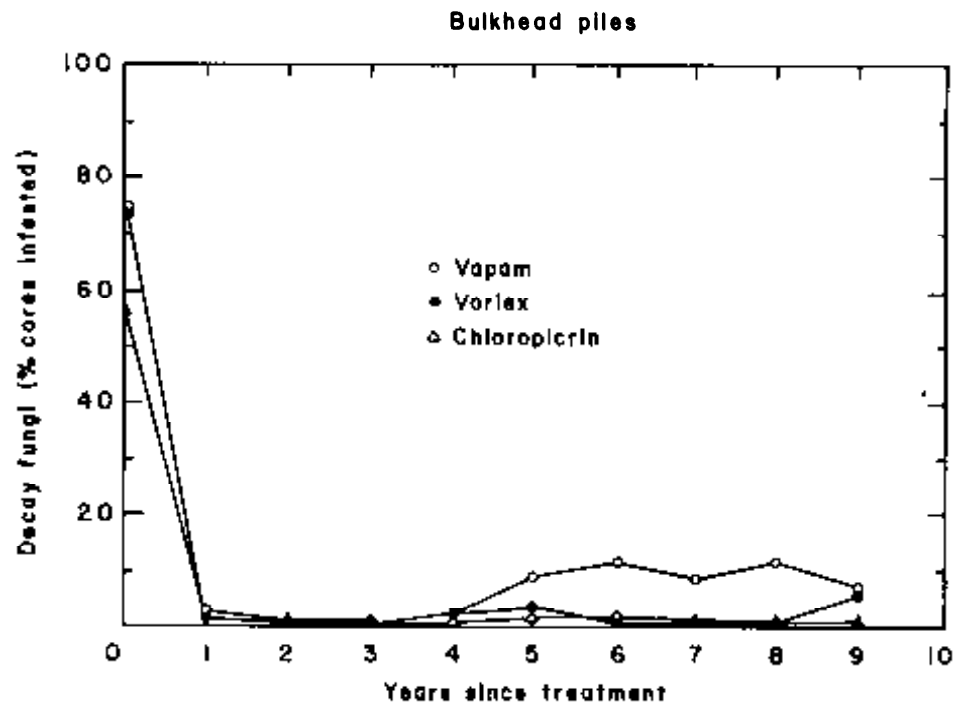


Figure 14-10. - Annual changes in the population of decay fungi isolated from creosoted Douglas-fir piles treated with various fumigants. Each value on the curve represents 60 cores from each of 12 piles. From Morrell and others.²⁷

member noting treatment information; however, these tags may be stolen or vandalized and should not be the sole means of recording treatment information.

PRECAUTIONS FOR IN-PLACE TREATING

As with other preservatives and pesticides, wood preservatives and fumigants for in-place treating are toxic to humans and must be used in accordance with State and Federal laws. When properly applied, the treatments pose no environmental or health hazard; however, the potential for environmental damage can be higher in some field locations because of variable conditions and the proximity to streams and other water sources. In-place treatments must be applied only by trained and licensed personnel who fully understand their use and the required safeguards. In addition to the precautions for wood preservatives discussed in Chapter 12, fumigant applicators should also have a gas mask with the appropriate filter available for emergency use. If fumigant vapors are detected by their strong odor or eye irritation, all personnel should move upwind from the treating area and allow vapors to clear. When any form of in-place treatment is used, the procedures, precautions, and contingency for accidental spillage or injury should be well planned before beginning treatment.

In general, in-place treating by local maintenance crews is limited by the scope of the treatment required. For routine maintenance, the amount of treating required is normally minor, and local crews can be used when properly trained and licensed personnel are available. For larger projects involving many members or an entire structure, it is advisable to contract the project to specialists in the field. There are companies that have provided in-place treating services for many years with excellent safety records and results. When selecting a contractor, previous experience and performance histories should be carefully evaluated to ensure that the contractor is qualified to perform the required treating.

14.4 MECHANICAL REPAIR

Mechanical methods of repair use steel fasteners and additional wood or steel components to strengthen or reinforce members. The three methods of mechanical repair discussed in this section are member augmentation, clamping and stitching, and stress laminating.

MEMBER AUGMENTATION

Member augmentation involves the addition of material to reinforce or strengthen existing members. The additional pieces, commonly wood or steel plates attached with bolts, serve to increase the effective section and thus load capacity. The two most widely used methods of member augmentation are splicing and scabbing. Although the distinction between the two is rather vague, splicing generally applies to a defined

location where load transfer is restored at a break, split, or other defect (Figure 14-11 A). Scabbing is more frequently associated with strengthening members where existing capacity is insufficient and may involve adding reinforcing pieces over a substantial portion or even over the entire member length (Figure 14-11 B). In both cases, a thorough structural analysis is required to ensure the capacity of the repair and to verify stress distribution in the members. Situations that introduce eccentric loads or tension perpendicular to grain must be avoided. When using splices, it is recommended that the defective member be cut entirely through to more equally distribute loads to splice plates.³

In addition to wood or steel augmentation methods, reinforced concrete can be used to strengthen deteriorated timber piling sections (Figure 14-12). Using this procedure, the pile is wrapped with a jacket-type form of fiber-reinforced plastic or fabric that fits the pile like a sleeve. Reinforcing steel is placed around the pile, and the sleeve is filled with concrete. The reinforced concrete increases pile strength and prevents further deterioration, but the pile size is increased and specialized equipment is required for construction.^{15,16,20}

CLAMPING AND STITCHING

A typical problem associated with timber members is the development of longitudinal splits. These splits commonly develop in sawn lumber as the member seasons and checks in place. To a lesser degree, splits may also develop in glulam if delamination occurs at the glue lines, although this problem has become very rare with the introduction of waterproof adhesives. In both sawn and glulam members, splits can also develop from overloads or poor design details that introduce tension perpendicular to grain at connections. When splitting is detected it must be determined whether the splits are the result of normal seasoning or the result of a more serious structural problem. Several references are available that provide a good overview of the potential structural effects of splitting in timber members.^{3,25}

Clamping and stitching are maintenance operations that use fasteners and steel assemblies to arrest cracks, splits, or delaminations in timber members. These methods are most commonly used for buildings, but also apply to some bridge components, particularly trusses or other structures with a high number of small members or fastened connections. The objective is not to close the split or check, but rather to prevent its further development by drawing the two parts together. Clamping uses bolts with steel-plate assemblies, while stitching uses bolts or lag screws through the member (Figure 14-13). Although both methods have been used effectively, clamping with bolts and steel plates is generally preferable because the section of the member is not reduced. Aside from fastener design requirements discussed in Chapter 5, there are no specific design criteria for clamping and stitching, and the configuration, number, and size of fasteners must be

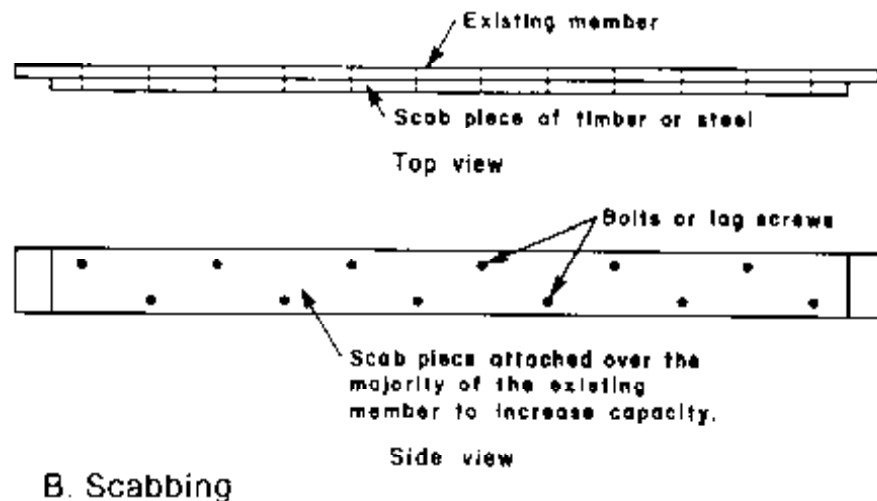
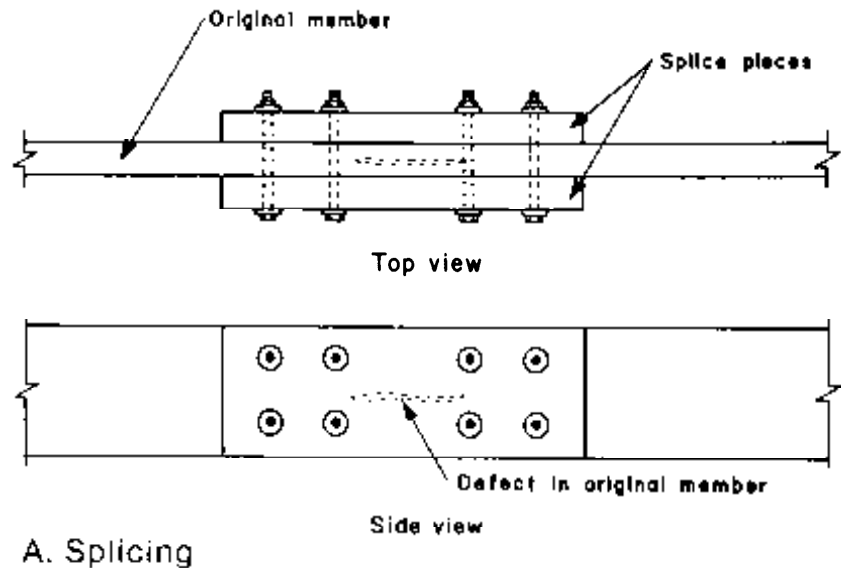


Figure 14-11. - Splicing and scabbing methods of member augmentation.

based on designer judgment on a case by case basis. The following guidelines for stitching are recommended by Ketchum, May, and Hanrahan:²⁵

When used at the end of a piece, stitch bolts should be placed between 2 inches and 3 inches from the end. Small 3/8 or 1/2 inch diameter bolts are suggested. Ordinarily, when bored at a critical stress section of a member, the area of the cross-section removed by the hole for the stitch bolt should not exceed the cross-sectional area occupied by the maximum knot permitted in the structural grade. In drawing up the stitch bolts they should be tightened only to the point where the bolts begin to take tension. No attempt should be made to close a split or check as this may extend the split on the other side of the joint. In servicing structures, stitch bolts should be tightened as well as other bolts.

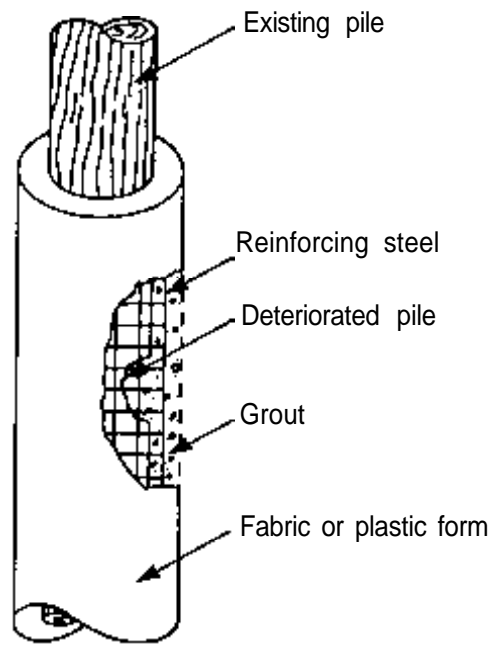


Figure 14-12. - Reinforced concrete jacket for pile augmentation.

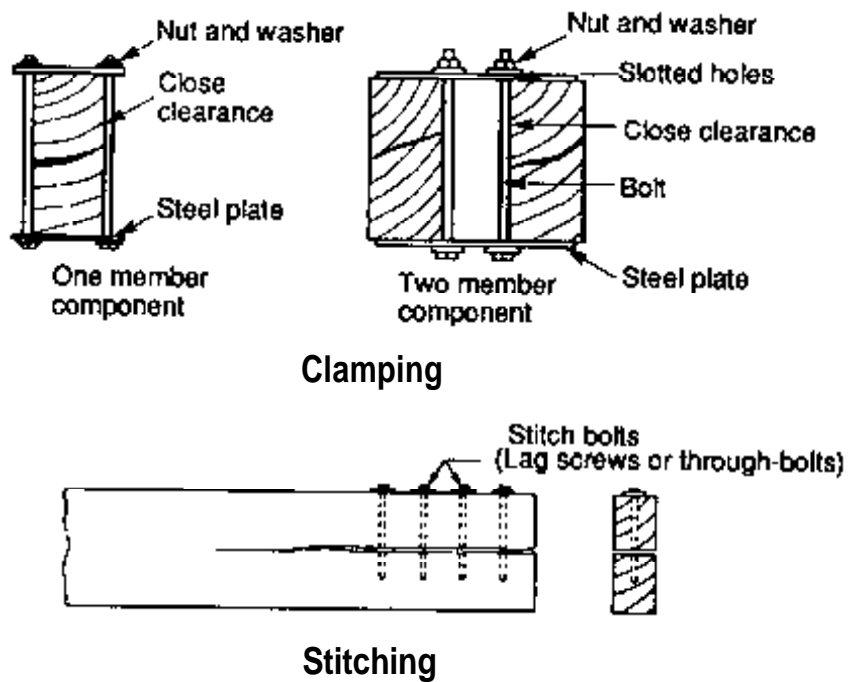


Figure 14-13. - Typical configurations for clamping and stitching timber members.

STRESS LAMINATING

Stress laminating is probably the most effective method for the mechanical repair of existing nail-laminated decks. Such decks frequently separate and delaminate from repeated loading, causing breakup of asphalt wearing surfaces, water penetration through the deck, and a loss in live load distribution width. In these cases, the static strength and condition of the deck is generally maintained, but its serviceability and ability to distribute loads between individual laminations is greatly reduced. In this situation, the laminations no longer act together to distribute loads, and local failures occur. This condition also increases the rate of deterioration, eventually leading to failures that require complete deck replacement.

The system for stress laminating existing nail-laminated decks was originally developed in 1976 by the Ministry of Transportation and Communications in Ontario, Canada. Since that time, it has been successfully used on a number of bridges to restore the integrity of the existing decks.^{3,18,36} Using this approach, which uses the same design criteria discussed in Chapter 9, the laminations are stressed with a series of high-strength steel rods applied transverse to the length of the laminations. The stress squeezes the laminations together and greatly increases the load distribution characteristics of the deck. Additionally, the stress seals the deck as the laminations are pressed together, providing a watertight surface.

Stress laminating for existing decks differs in configuration from new construction in that stressing rods are positioned on the outside of the laminations, rather than in holes through the laminations (Figure 14-14). This allows the stressing operation to take place without removing the deck and without costly fabrication operations, while traffic is still using the bridge. It is usually necessary to add laminations to the deck before stressing because the rod force squeezes laminations together, reducing the deck width 10 inches or more, depending on the original width. Stress laminating provides a good long-term solution for repairing existing nail-laminated decks to increase load capacity and substantially extend the service life of the structure. More specific information on stress laminating existing nail-laminated decks is presented in a case history in Chapter 15.

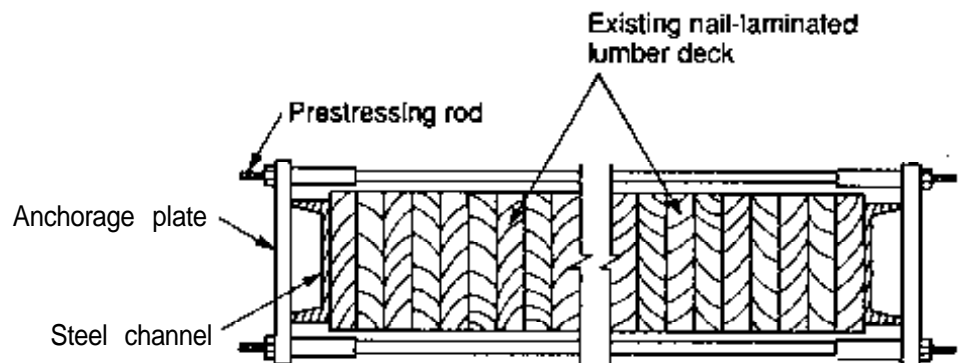


Figure 14-14. - Typical rod and anchorage configuration for stressing existing nail-laminated lumber decks.

14.5 EPOXY REPAIR

Epoxies consist of basic resins and resin-hardening agents that are blended together in a liquid or gel (putty) form. When mixed, the epoxy compounds harden to form a solid, durable material that provides a high degree of adhesion to most clean surfaces. Epoxies were originally developed by the paint and aircraft industries in the 1950's and have been used extensively to repair cracks in concrete since the 1960's. The first reported study on epoxy use for timber repair was presented by Avent⁸ in 1976. Since that time there has been a considerable research effort to develop design criteria and to evaluate the effectiveness of epoxy repairs in timber members. Although there are currently no codes or specifications with design criteria or allowable stresses, epoxy repair techniques have been successfully used on timber bridges (some since the early 1960's). The information presented in this section is based on referenced research publications and successful field applications.

TYPES OF EPOXY REPAIRS

Epoxy is used for timber repair as a bonding agent (adhesive) and/or grout (filler) in both structural and semistructural repairs. It is commonly injected under pressure but is also manually applied as a gel or putty. Epoxy is most effective when used as a bonding agent to provide shear resistance between members for structural repairs in dry locations. For semistructural repairs, it is used to fill voids or repair bearing surfaces. Avent⁶ describes six basic types of epoxy repairs for structural (Type A) and semistructural (Type B) repairs, as follows:

Type A- 1. Epoxy injection of cracked and split members at truss joints.

Type A-2. Epoxy injection and reinforcement of decayed wood.

Type A-3. Splicing and epoxy injection of broken members.

Type A-4. Epoxy injection of delaminated beams.

Type B-1. Epoxy injection of longitudinal cracks and splits in truss members away from joints.

Type B-2. Repair of bearing surfaces using epoxy gel.

For bridge applications, epoxy repairs can be categorized as grouting, splicing, and pile rehabilitation.

Grouting

As a grouting material, epoxy is used for filling checks, splits, delaminations, insect damage, and decay voids. 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. In building applications, epoxy has been successfully used in structural repairs to fill splits in truss connections.^{2,3,8,9} It has also been used in conjunction with reinforcing rods to replace severely decayed portions of existing members.³ In bridge applications, its use as a grout has been limited primarily to semistructural or cosmetic repairs involving surface damage or internal insect damage. For surface repairs, voids or other defects are filled with epoxy gel (Figure 14-15). For internal repairs involving splits or insect damage, liquid epoxy must be injected to the inside of the member to fill the void.



Figure 14-15. - Epoxy gel surface repair of a timber pile (photo courtesy of Osrose Wood Preserving, Inc.).

Splicing

Splicing repairs involve the addition of splice pieces that are lapped over the split or deteriorated members and are epoxied in place. In this type of repair, epoxy is used as an adhesive to bond the splices in place. While other types of adhesives are available for wood, epoxies are preferable for field repairs because of their high strength and rapid cure rate. Epoxy splicing has been used mostly in buildings and is not a common type of repair in bridge applications at this time. However, one method of splicing that has been used to a limited degree involves the reconstruction of glulam. In this method, damaged or decayed laminations are cut from the

glulam member and replaced with new laminations that are epoxied in place. The laminations in the replacement section are lapped over existing laminations a sufficient distance to develop the required shear strength at the epoxied joint. There is evidence that variations in the moisture content of timber members can in time cause a significant reduction in the bonding strength of epoxy. Therefore, splicing repairs in members exposed to weathering or significant fluctuations in moisture content are not recommended. Also, epoxy splicing should not be used on material treated with oil-type preservatives because of poor bonding between the wood and the epoxy.

Pile Rehabilitation

Pile rehabilitation employs epoxy (using grouting and splicing) for the repair of timber piles loaded primarily in axial compression. The two methods of pile rehabilitation most commonly used are pile posting and pile restoration. In pile posting, the damaged section of pile is completely removed and a new section of similar cross section is installed in its place (Figure 14-16). The new section is positioned with a 1/8- to 1/4-inch gap at the top and bottom and is wedged tightly against the existing pile cutoffs. Following placement of the new section, holes are bored at a steep downward angle above each joint, spaced approximately 90 degrees apart. Steel pins are then driven through the holes to mechanically join the two sections. The sides of the joints are next sealed with epoxy gel, plastic film, or tape, and epoxy is injected into the joints, filling the voids and

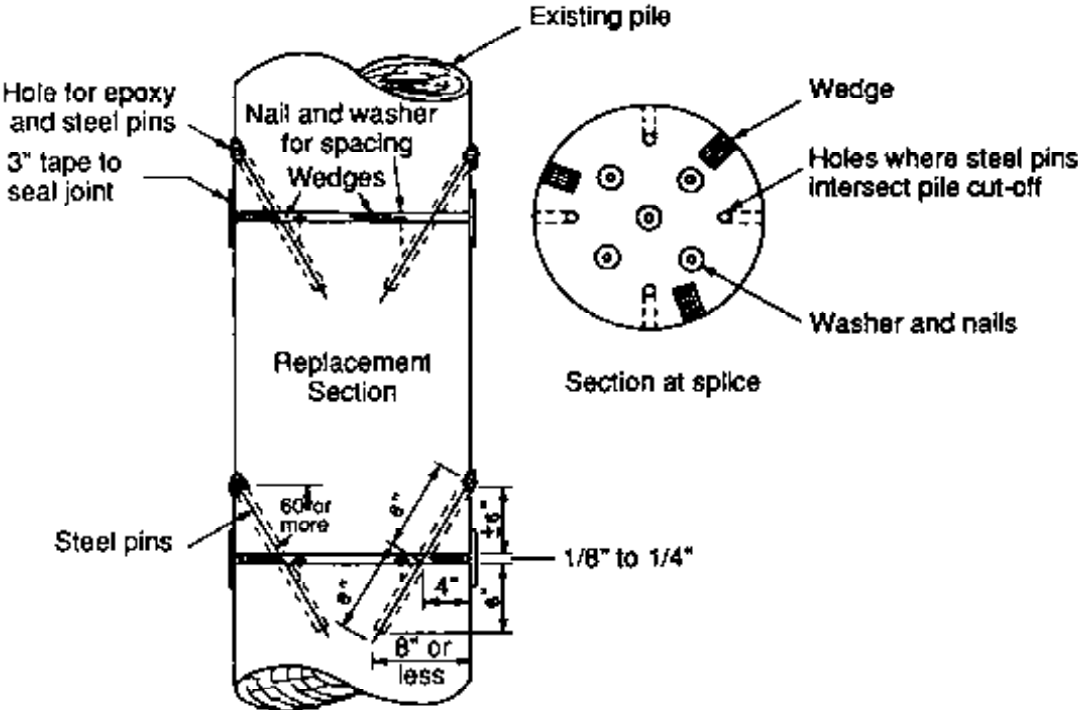


Figure 14-16. - Schematic diagram of pile posting.

bonding the old and new pile sections. This type of repair has proven to be an economical method of substructure repair that effectively restores the compressive strength of deteriorated members. Additional information on pile posting can be found in case histories presented in Chapter 15.

Pile restoration involves the removal and replacement of a vertical wedge-shaped section of piling rather than the entire cross section. This type of repair has been successfully used on piling where localized deterioration occurs in an otherwise sound section. Using this method, a wedge-shaped section is removed from the existing pile by cutting and chiseling (Figure 14-17). A matching replacement section is fabricated from new treated material. The replacement section is fitted to match the removed section, but is slightly smaller in size. After the replacement is fabricated, the contact surfaces of both old and new sections are covered with epoxy gel applied with a putty knife. The new section is placed in position, and metal bands are installed around the section to hold it in place while the epoxy cures. Pile restoration is more expensive than posting and is normally used only when posting is impractical because of limited access.



Figure 14-17. - Pile repair using pile restoration techniques. (A) The deteriorated pile area is removed as a wedge-shaped section. (photos courtesy of Osmose Wood Preserving, Inc.).



Figure 14-17. - Pile repair using pile restoration techniques (continued). (B) A replacement section is cut, and epoxy gel is applied to the contact surfaces. (C) The replacement section is placed and banded to the existing pile (photos courtesy of Osmose Wood Preserving, Inc.).

GENERAL PROCEDURES FOR EPOXY REPAIR

The procedures for the use of epoxy vary with the type and extent of repair. The basic procedures for epoxy injection can be summarized in four steps: member preparation, port setting and joint sealing, epoxy injection, and finishing.⁶ For manual, nonpressure application, port setting and joint sealing are not required. As with all types of repairs, a structural evaluation and analysis of existing components must be made to determine load capacity before and after repair. The cause of the problem should also be identified and corrective measures taken to prevent its recurrence.

Member Preparation

The degree of member preparation required for epoxy repair varies with the type of repair and the wood condition. When the defect or weakness in the original member is the result of decay, actions must be taken to remove the damaged wood, arrest the infections, and prevent renewed damage. If areas to be repaired show early signs of decay, in-place treatment may be sufficient to arrest decay, provided sufficient strength remains in the member. When visible decay is present, the most thorough approach is to remove the infected section. For such cases, the following guidelines are given by Clark and Eslyn:¹⁷

The undetectable extensions of the infecting fungi may reach 6 to 12 inches in the grain direction beyond the apparent limits of the decay. A safe rule in removing decayed parts of members is to include the visible decay plus an additional 2 feet of the adjacent wood in the grain direction.

In addition to removing or treating decay areas, the moisture source to the infected member should be identified and eliminated, if possible. When moist wood (greater than 20 percent moisture content) is found, the member should be dried before repairs are made. Although there are epoxies that will bond to moist wood, the presence of moisture levels greater than 20 percent may provide suitable conditions for continued fungal growth and continued deterioration.

As a final preparation step for all epoxy repairs, surfaces must be thoroughly cleaned of all dirt and debris so that a good bond can be achieved between the wood and the epoxy. Areas should be free of excess oil preservatives, which may affect the bond. Although there have been no studies on the bonding strength of epoxies to wood treated with oil-type preservatives, successful piling repairs (compressive loading) have been made on existing members treated with creosote that have been in place for a number of years. Splicing or shear-type repairs are not recommended on surfaces treated with oil-type preservatives because of the questionable bonding to the member surfaces.

Port Setting and Joint Sealing

When epoxy is applied by pressure injection, the repair area must be provided with injection ports and completely sealed before epoxy placement. The injection ports are holes bored into the joint area that permit epoxy injection into interior portions of the repair, vent displaced air as epoxy fills the void, and provide a visual means of observing epoxy distribution. These ports are generally 1/4 to 3/8 inch in diameter and are topped with a small copper or plastic tube that projects from the wood surface. The number and location of ports varies depending on the size and configuration of the repair area. The minimum number of ports is two, one for the injection and one as an escape for displaced air. For most types of repairs, additional ports are added to ensure epoxy penetration to all areas of the joint.

After injection ports are set, areas of the joint must be completely sealed (with the exception of injection port openings). Incomplete sealing allows epoxy to seep from the repair area, wasting material and creating voids in the epoxy that reduce its effectiveness. Methods of joint sealage vary depending on the configuration of the members being repaired. For most repairs, openings can be sealed with an epoxy gel, provided the gel viscosity is sufficiently low to span the distance of the opening. Another common method for sealing piling and other exposed, smooth locations is to staple plastic wraps or tape to the outside of the member (Figure 14-18). With porous wood, it may be beneficial to seal the outside surface with thick epoxy paint to fill hairline cracks and other small openings. These



Figure 14-18. - A joint for a post-injection epoxy repair is sealed with plastic wrap stapled to the members. Small wood strips are then nailed across the plastic to provide an additional seal (photo courtesy of Osmose Wood Preserving Inc.).

openings will allow epoxy to escape even though they may not be evident during visual inspection.

Epoxy Application

Epoxy is applied using manual nonpressure methods or pressure injection, depending on the type of repair. Nonpressure methods are usually limited to exposed surface applications. The two epoxy components are thoroughly mixed in a bowl or other container and are applied with a knife or brush. Surface repairs on angled or vertical surfaces may require a plastic wrap or special tape to keep the epoxy in position as it cures. For pressure injection, the epoxy is applied through one injection port at each joint. As the epoxy fills the voids in the joint, venting ports begin to leak an even flow of epoxy and are progressively sealed. Injection is accomplished using either a caulking gun and tubes of epoxy that are mixed manually before application (Figure 14-19) or an automatic injection gun that mixes the epoxy components in the nozzle. For both techniques, the injection pressure must be sufficient to completely fill the void without breaking joint seals. A maximum injection pressure of 40 lb/in² is recommended.⁶

Finishing

The time required for epoxy to cure to its full strength varies among brands of epoxy and the curing temperature. Most epoxies set in a few hours, but complete curing can take several days. After final curing, the epoxy surface can be finished to meet aesthetic requirements of the site, including removal of projecting injection ports, sanding, and painting of the epoxy surface.

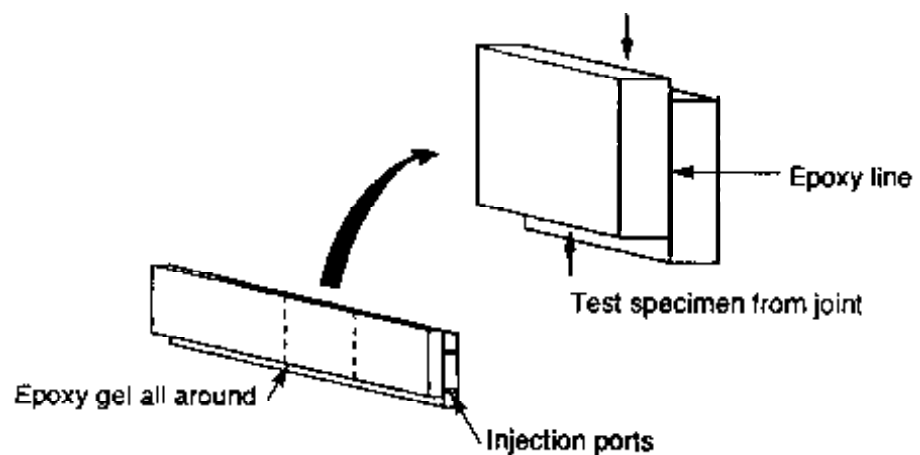


Figure 14-19. - Epoxy is manually injected between a timber pile and cap using a caulking gun (photo courtesy of Osmose Wood Preserving, Inc.).

QUALITY CONTROL FOR EPOXY REPAIRS

A key factor in epoxy effectiveness is the level of quality control provided during the repair process. Although little has been published on this subject, the following guidelines on quality control are given by Avent:⁴

In many cases laboratory testing is not possible for wood repair in contrast to concrete repair where test cylinders can be taken. For example, lack of quality control can result in serious problems for epoxy repaired members. Many epoxies are very sensitive to mix proportions. The standard injection equipment consists of two positive-displacement pumps driven by a single motor geared to obtain the proper mix. The two epoxy components are mixed at the nozzle; thus a fairly continuous flow prevents hardening of the epoxy in the nozzle. However, crimped lines, malfunctioning pumps, or line blockages can sometimes occur. In severe cases the epoxy will not harden at all, but in other cases the problem may result in soft spots within the joints. Frequent collecting of small samples in containers will verify if the epoxy is hardening as expected, and this is routinely done by contractors on an hourly basis. The detection of weak but hardened material is much more difficult. One method is to inject shear block specimens at the beginning of operations and after the repair of every fifth member. A shear specimen [see Figure 14-20] is cut into four shear blocks after curing and each is tested in single shear. The failure stress level should be approximately equal to the ultimate shear strength of the *wood*. This level of shear strength indicates a high-quality bond.



Joint for quality control tests

Figure 14-20. - Typical shear block specimen for evaluating the strength of an epoxied joint.

Another quality control problem is that of determining epoxy penetration into voids. Special sampling techniques are currently in the development process, but none have proven completely satisfactory as yet. This problem is often heightened because there are two types of repair: structural and non-structural. Non-structural repairs are associated with sealing in applications such as water-proofing, crack sealing to prevent contamination, and cosmetic repairs. Many contractors are familiar only with this type. The approach to non-structural repairs is to inject from port to port without undue concern for complete penetration. Often air voids become trapped by such an approach. The key to successful structural repair is to fill all voids. To ensure complete penetration, it is best to inject from only one port while letting others serve as vents. The successive bleeding and capping of these ports gives a high degree of confidence in the amount of penetration. An average repair often involves at least 12 ports and many have considerably more. However, without close supervision of the injection operation, a contractor may revert to his usual approach for non-structural repairs, especially since the different goals of these types of repair are usually not appreciated. Close supervision thus becomes the primary method of quality control.

14.6 COMPONENT REPLACEMENT

There are situations where a lack of maintenance or other causes leads to deterioration so severe that replacement of the member is the only economically viable alternative. In these cases, the structure must be temporarily supported (when required), the old member removed, and a new one installed in its place. Before replacing members, the cause of deterioration in the original member must be determined and corrected. If the problem is structural, an increased capacity for the replacement may be warranted. If decay is the source of deterioration, corrective measures should be taken to exclude moisture from newly installed members. Whenever a member is replaced, it is advisable to thoroughly inspect all adjacent and contacting components for decay that may not have been apparent when the member was in place. Confirmed or suspected areas of decay should be treated in place before the new member is installed. Remember that failure of the original member resulted from a specific cause that could also cause premature failure or high maintenance costs for the replacement.

On some structures it may be impractical to replace a member because of difficulties with removing the old member or positioning a new member in its place. An alternative solution is to add a sister member that is structurally capable of resisting the loads previously applied to the original member. The use of sister members is most applicable when damage occurs

from overloads or other mechanical damage (Figure 14-21). When existing members are decayed, appropriate steps must be taken to eradicate the infection and prevent its spread to the new component. The decayed portions of the member should be removed and the remaining portions treated in place. Again, the source of moisture that provided the suitable decay conditions must also be eliminated.



Figure 14-21. - A sister member in a glulam beam superstructure. The outside beam, which was damaged by a vehicle overload, could not be easily replaced. The sister member was added along the outside of the beam to restore the capacity to the structure.

14.7 SELECTED REFERENCES

1. American Association of State Highway and Transportation Officials. 1976. AASHTO manual for bridge maintenance. Washington, DC: American Association of State Highway and Transportation Officials. 251 p.
2. American Society of Civil Engineers. 1986. Evaluation and upgrading of wood structures: case studies. New York: American Society of Civil Engineers. 111 p.
3. American Society of Civil Engineers. 1982. Evaluation, maintenance, and upgrading of wood structures. Freas, A., ed. New York: American Society of Civil Engineers. 428 p.
4. Avent, R.R. 1985. Decay, weathering and epoxy repair of timber. *Journal of the Structural Division, ASCE* 111(2): 328-342.
5. Avent, R.R. 1986. Design criteria for epoxy repair of timber structures. *Journal of Structural Engineering* 112(2): 222-240.

6. Avent, R.R. 1985. Factors affecting strength of epoxy-repaired timber. *Journal of the Structural Division, ASCE* 112(2): 207-221.
7. Avent, R.R. 1986. Repair of timber bridge piling by posting and epoxy grouting. In: *Trans. Res. Rec. 1053*. Washington, DC: National Academy of Sciences, National Research Council, Transportation Research Board: 70-79.
8. Avent, R.R.; Emkin, L.Z.; Howard, R.H.; Chapman, C.L. 1976. Epoxy-repaired bolted timber connections. *Journal of the Structural Division, ASCE* 102(4): 821-838.
9. Avent, R.R.; Emkin, L.Z.; Sanders, P.H. 1978. Behavior of epoxy-repaired full-scale timber trusses. *Journal of the Structural Division, ASCE* 104(6): 933-951.
10. Avent, R.R.; Sanders, P.H.; Chapman, C.L. 1982. Space-age adhesives. *The Military Engineer* 74(477): 20-22.
11. Avent, R.R.; Sanders, P.H.; Emkin, L.Z. 1978. Epoxy repair of timber structures comes of age. *Construction [Adhesive Engineering Co.]* 13(2): 6.
12. Avent, R.R.; Sanders, P.H.; Emkin, L.Z. 1979. Structural repair of heavy timber with epoxy. *Forest Products Journal* 29(3): 15-18.
13. Avent, R.R.; Issa, R.R.A.; Baylot, J.T. 1982. Weathering effects of epoxy-repaired timber structures. In: *Structural Uses of wood in adverse environments*. New York: Van Nostrand Reinhold Co.: 208-218.
14. Better Roads. 1980. Bridge pilings can be protected; FPR jackets stop deterioration. *Better Roads* May: 20-25.
15. Better Roads. 1973. For these timber piles, life begins at 58 years. *Railway Track and Structures* September: 27-29.
16. Better Roads. 1980. Gribbles' attack collapses bridge...but polyester sleeves thwart them. *Better Roads* April: 10-14.
17. Clark, J.W.; Eslyn, W.E. 1977. Decay in wood bridges: inspection and preventive & remedial maintenance. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 51 p.
18. Csagoly, P.F.; Taylor, R.J. 1979. A development program for wood highway bridges. 79-SRR-7. Downsview, ON, Can.: Ministry of Transportation and Communications. 57 p.
19. Eslyn, W.E.; Highley, T.L. 1985. Efficacy of various fumigants in the eradication of decay fungi implanted in Douglas-fir timbers. *Phytopathology* 75(5): 588-592.
20. Gerke, R.C. 1969. New process restores timber piles. *Ocean Industry* May: 92-93.
21. Heising, G.D. 1979. Controlling wood deterioration in waterfront structures. *Sea Technology* 20(6): 20-21.
22. Highley, T.L. 1980. In-place treatment for control of decay in waterfront structures. *Forest Products Journal* 30(9): 49-50.
23. Highley, T.L.; Eslyn, W.E. 1982. Using fumigants to control interior decay in waterfront timbers. *Forest Products Journal* 32(2): 32-34.

24. Hurlbut, B.B. 1978. Basic evaluation of the structural adequacy of existing timber bridges. Washington, DC: National Academy of Sciences, National Research Council, Transportation Research Board: 6-9.
25. Ketchum, V.T.; May, T.K.; Hanrahan, F.J. 1944. Are timber checks and cracks serious? *Engineering News Record* July 27: 90-93.
26. McCutcheon, W.J.; Gutkowski, R.M.; Moody, R.C. Performance and rehabilitation of timber bridges. *Trans. Res. Rec.* 1053. Washington, DC: National Academy of Sciences, National Research Council, Transportation Research Board: 65-69.
27. Morrell, J. J.; Helsing, G.G.; Graham, R.D. 1984. Marine wood maintenance manual: a guide for proper use of Douglas fir in marine exposure. *Res. Bull.* 48. Corvallis, OR: Oregon State University, Forest Research Laboratory. 62 p.
28. Muchmore, F.W. 1983. Timber bridge maintenance, rehabilitation, and replacement. GPO 693-015. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 31 p.
29. *Railway Track and Structures.* 1973. Grout-filled timber piles. *Railway Track and Structures* February: 28-29.
30. *Railway Track and Structures.* 1980. In-place decay treatment "supports" timber trestle. *Railway Track and Structures* June: 38.
31. *Railway Track and Structures.* 1977. Second-generation in-place treatment for these ICG timber trestles. *Railway Track and Structures* January: 28-30.
32. *Railway Track and Structures.* 1971. Wood piles wrapped to keep out marine borers. *Railway Track and Structures.* April: 1.
33. Sanders, P.H.; Emkin, L.Z.; Avent, R.R. 1978. Epoxy repair of timber roof trusses. *Journal of the Construction Division, ASCE* 104(3): 309-321.
34. Scales, M. 1964. Epoxy based structural adhesives. *Adhesives Age* 7 (November): 22-24.
35. Scheffer, T.C.; Eslyn, W.E. 1982. Twenty-year test of on-site preservative treatments to control decay in exterior wood of buildings. *Material u. Organismen* 17(3): 181-198.
36. Taylor, R.J.; Csagoly, P.F. 1979. Transverse post-tensioning of longitudinally laminated timber bridge decks. Downsview, ON, Can.: Ministry of Transportation and Communications. 16 p.
37. White, K.R.; Minor, J.; Derocher, K.N.; Heins, C.P., Jr. 198 1. Bridge maintenance inspection and evaluation. New York: Marcel Dekker, Inc. 257 p.
38. Williams, J.R. 1965. Redrive timber piling or treat in place-why not a program that utilizes both? *Progressive Railroading* July: 3.
39. Williams, J.R.; Norton, K.J. 1976. Decay in timber trestles: what is its rate of growth? *Railway Track and Structures* April: 26-29.