United States
Department of
Agriculture

Forest Service

**Technology &
Development
Program**

7100 Engineering
November 2003
0371-2809-MTDC
WIT-12-0004

In cooperation with

United States
Department of
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**Federal Highway
Administration**

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Merv Eriksson
Pacific Northwest Region

Homer Wheeler (retired)
Strategic Highway Research Program

Sharon Kosmalski
Payette National Forest

**USDA Forest Service
Technology and Development Program
Missoula, MT**

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Introduction

An asphalt paving system protects the structural elements of timber bridge decks from tire wear; reduces the penetration of moisture to other superstructure members, such as beams, stringers, diaphragms, and their associated hardware; and provides a skid-resistant roadway surface.

This report, which was prepared in response to concerns expressed to the U.S. Department of Agriculture (USDA) Forest Service, Forest Products Laboratory, Wood In Transportation program, and the San Dimas and Missoula Technology Development Centers, discusses problems with recently constructed timber bridges that were paved with asphalt. Numerous publications and articles were reviewed; agency and industry professionals were consulted, and asphalt adhesion and paving membrane solubility were tested. Information was collected at treated timber bridges in Alaska, Montana, Oregon, Washington, Michigan, and Wisconsin. Many of the bridges were performing very well—others exhibited one or more problems.

Ensuring long-term pavement performance and minimizing environmental problems for bridges with treated timber decks (figure 1) is the goal of this project. Some effects of waterborne preservatives are covered, but the focus is primarily on timber treated with oilborne preservatives.

Asphalt paving failures on the decks of treated timber bridges are caused by one or more of the following deficiencies:

- Bridge deck design and construction

- Type and quantity of the wood's preservative treatment

- Design and installation of the asphalt paving system.

- Deck deflection and movement (the primary causes of pavement cracking)

Preservative treatment and asphalt paving system problems are often related. The treatment's interaction with asphalt cement (asphalt) is the main cause of pavement delamination and asphalt bleeding and leakage. Improper treatment practices compound improper paving system design, and vice versa.

Timber Bridge Deck Design

The four most common timber bridge decks in the United States (Wacker and Smith 2001) are:

- Timber plank
- Glued-laminated timber panel
- Stress-laminated timber
- Nail-laminated timber

Figure 1—Paved timber bridge in Oregon.

Timber Plank Decks—Timber plank decks generally are used on low-volume, rural, unpaved roads. Because timber plank decks are too flexible to provide a durable sublayer for asphalt pavement, they are rarely paved.

Glued-Laminated Timber Panel Decks—Glued-laminated panels usually are placed across (transverse to) beams or stringers to create the bridge deck and connected to timber beams mechanically with lag bolts or deformed shank nails. The panels usually are bolted onto steel beams.

Glued-laminated timber panel decks also can be placed longitudinally over transverse floor beams of an arch or suspension bridge. However, short-span bridges may span from abutment to abutment.

Most asphalt pavement cracking problems with glued-laminated timber panel decks result from a bridge's structural design. Unless deck panels are mechanically interconnected, wheel loads cause the glued-laminated panels to move independently of each other, especially with the more common transverse glued-laminated timber panel decks. This relative displacement causes reflective cracking (cracking that migrates up from the timber deck) of the asphalt pavement above the panel joints. The extent and size of the reflective cracking is proportionate to the deck panel displacement.

Asphalt pavement cracks when panels move independently, either vertically or horizontally. Horizontal movement occurs when glued-laminated panels shrink as they dry. This shrinkage opens gaps at the deck panel interfaces, cracking the pavement if the movement is large.

Stress-Laminated Timber Decks—Stress-laminated timber decks are multiple timber laminations (usually longitudinal) that are stressed into monolithic slabs by high-strength steel reinforcing rods. These laminations can be timber planks, or glued-laminated beams for longer spans.

A stress-laminated deck often is self supporting. Beams or stringers are not needed. Because the deck behaves as a single unit, differential deflection does not occur. Volume change, caused by moisture, is spread across the width of the entire deck, minimizing pavement cracking as the deck shrinks.

Nail-Laminated Timber Decks—Nail-laminated timber decks are timber planks, usually placed across (transverse to) longitudinal beams or stringers. The laminations are nailed to the longitudinal beams. When new, these decks perform much like stress-laminated timber decks. With age, nail-laminated decks become more flexible and frequently show random reflective asphalt pavement cracking. Glued-laminated timber decks often replace nail-laminated in new construction.

Wood Preservatives

Wood preservatives protect wood by inhibiting decay fungi and insects that feed on wood fiber. Preservatives in properly treated wood are stable. Only minimal amounts leave the wood. Preservatives do not penetrate the entire cross section of large structural members—they usually penetrate less than 1 inch. To be effective, the treatment must penetrate deeply enough and supply enough preservatives to create a preservative "envelope" that prevents decay fungi or insects from reaching untreated wood. Applying the appropriate amount of preservatives is critical. Too little will leave the wood vulnerable to decay. Too much will result in preservatives and solvents leaching to the surface of the wood and into the environment. When treated timber decks are paved, leached preservatives and solvents interact with paving membranes and asphalt, potentially causing pavement failure.

Wood preservatives are broadly classified as oilborne or waterborne. Oilborne preservatives generally consist of a pesticide chemical carried in an oil solvent. They are the most commonly used treatment for bridge construction. Because oilborne preservatives leave an oil solvent film on the surface of the wood, they generally are not recommended for applications that allow repeated human contact.

Waterborne wood-treatment chemicals that fixate with the wood tend to be more appropriate for human contact. However, because such chemicals do not produce a water-resistant, oily surface, the wood member can lose or gain moisture rapidly. The change in water volume can split and crack large structural members, exposing untreated wood. Wood treated with waterborne preservatives is rarely recommended for highway bridge construction.

In 1995, the San Dimas Technology and Development Center published *Selection and Use of Preservative Treated Wood in Forest Service Recreational Structures* (9523–1203–SDTDC). This document provides background on the various preservatives, with recommendations for appropriate use.

Asphalt Pavement

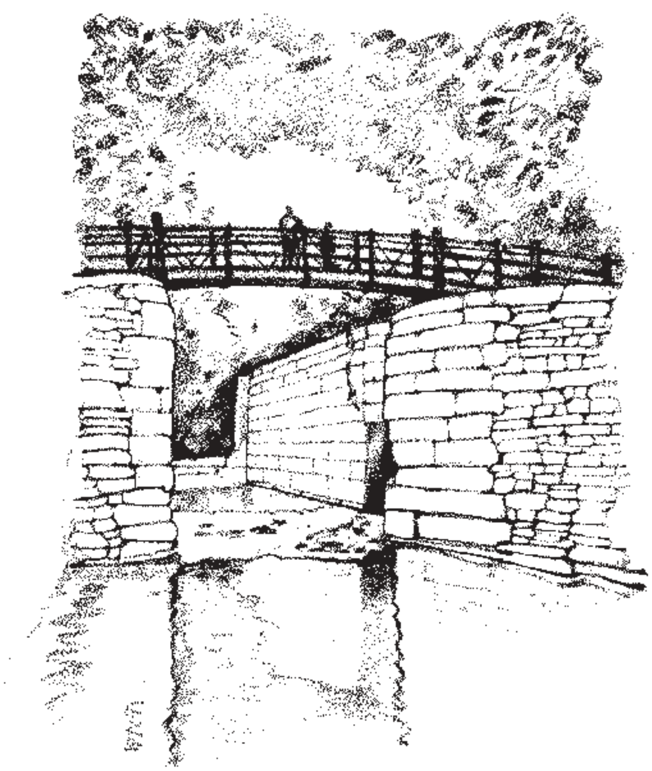
Asphalt pavement can be constructed with hot materials (hot mix) or cold materials (cold mix). In this report, asphalt pavement refers to hot-mix pavement. Asphalt pavement is about 95-percent aggregate and 5-percent asphalt cement.

Asphalt cement is referred to as asphalt. The aggregate provides structural carrying capacity through point-to-point contact, while asphalt holds the aggregate in place under traffic loads and prevents dust. Adding asphalt to aggregate reduces porosity, but asphalt pavement is still permeable.

Modern asphalt includes numerous additives to best fit the local environment and improve the performance of asphalt pavement. Asphalt itself is the end result of the oil refining process. John Norton, Jr., described asphalt as “the bottom of the refinery barrel” (Norton 2002).

Since the 1990s, asphalt specifications have used the performance graded (PG) system under the national Superpave asphalt pavement program. The PG grading system uses two numbers, such as PG 64–22, to reference a grade. In this example, 64 and –22 represent the temperature extremes in degrees Celsius that the pavement is designed to withstand.

Additives are used to create polymer-modified asphalt. Polymers are the most common asphalt additive and have the greatest effect on the performance of asphalt pavement, particularly in the Northern States. Elastomers made from styrene-butadiene-styrene (SBS) or styrene-butadiene-rubber (SBR) are the most common polymer additives. Elastomer polymers add considerable elasticity, ductility, and cracking resistance. In cold weather, polymers significantly increase the asphalt pavement’s adhesion to the treated timber deck (see the *Asphalt Adhesion to Treated Timber* section). Industry testing also has shown that SBS significantly reduces cold weather cracking. Polymers are often added to high asphalt content mixes to stiffen the mix and reduce rutting.



Asphalt Pavement Systems

Paving systems are composed primarily of the asphalt pavement, but can include primers and paving membranes, tack coats, and paving fabrics. Primers should not be confused with prime coats. Prime coats are low-viscosity asphalts that are applied to prepare an aggregate base. They penetrate the base, seal the aggregate, and harden the surface. A prime coat would not be used on bridge decks. Primers are specialty products designed to improve adhesion of paving membranes to a surface—usually concrete bridge decks.

A paving membrane is a fabric, often a nonwoven paving cloth, with polymer-modified (or rubberized) asphalt on one or both sides. This asphalt melts when hot asphalt is applied over it. The melted paving membrane provides a waterproof layer between the pavement overlay and the underlying structure.

A tack coat is a thin layer of liquid asphalt sprayed over the prime coat or base course, or directly onto a bridge deck. A tack coat helps bond the asphalt course to the underlying surface. Paving fabric is usually a nonwoven geotextile placed beneath or between paving layers. Paving fabrics are always placed over a light application of asphalt cement to provide a moisture-resistant barrier in the pavement structure (American Association of State Highway and Transportation Officials 2001).

Response to Concerns

Potholes or cracks may form when asphalt pavement fails on timber bridge decks. Asphalt pavement may dissolve and decompose, or the asphalt and preservative chemicals or solvents may bleed to the pavement surface and to the underside of the bridge. When asphalt pavement contains too much asphalt, the asphalt will migrate to the top pavement surface and bleed, or to the bottom of the pavement and drip. Asphalt from the paving membrane can also bleed and drip if it is dissolved by excess preservative chemicals and solvents. Asphalt bleeding can lead to rutting and stripping, which can be accelerated by heavy loads, hot weather, or improper pavement design. Asphalt and preservatives can drip from the underside of a bridge and be released into the environment.

The quality and durability of asphalt pavement on treated timber bridge decks is determined by four main factors:

- **Structural (serviceability) characteristics—**The design of the bridge superstructure affects deck movement and deflection. Deck deflections and shrinkage of timber deck members can cause severe pavement cracking.

- **Type and amount of preservative treatment chemicals and solvents—**Residual treatment chemicals and solvents can be found on the surface of improperly treated wood. These chemicals and solvents will dissolve asphalt from the paving membranes and the asphalt pavement. This dissolved asphalt, along with the preservative, will soften the pavement and bleed to the pavement surface, or leak around or through the deck. Having these products drip into streams and rivers is unsightly and environmentally unacceptable.

- **Asphalt paving systems—**Paving membranes or excessive primers or tack coats, combined with treatment chemicals, often cause improper bonding and excessive concentrations of asphalt in the pavement mix.

- **Construction and application methods—**Variations in construction can cause excessively thick tack coats, affecting asphalt pavement's adhesion to the deck. Inappropriate use of paving membranes can cause a membrane to slip, allowing pavements to bunch and fold. Weather also affects the curing and adhesion of asphalt.

Timber Bridge Deck Structural Behavior

Timber plank decks are seldom paved, so they will not be discussed further. Stress-laminated timber decks perform as monolithic slabs and pavement cracking is minimal. Most pavement cracking occurs with the most common type of treated timber bridge deck—the glued-laminated panel deck.

Figure 3—Cracking over panel joints on the Watchtower Creek Bridge at the Bitterroot National Forest, MT, in 2000.

Differential Deflection of Deck Panels

Asphalt pavement seldom cracks because of normal, longitudinal deflection of the bridge's superstructure. The most common cause of pavement cracking on glued-laminated panel deck systems is differential deflection between adjoining deck panels. This is particularly true of transverse glued-laminated deck panel systems. The panels are installed with the laminations perpendicular to traffic flow. Wheel loads moving from panel to panel cause rapid, repetitive, and sometimes significant panel movement at the panel interface. When these wheel load deflections are more than 0.05 inches, the pavement tends to crack. When deflections exceed 0.10 inches, the cracks often ravel (crumble), causing bumps that increase impact to the bridge and lead to moisture problems.

Example 1—The Watchtower Creek Bridge (figures 2 and 3) and West Fork Creek Bridge were constructed on the Bitterroot National Forest in Montana during the summer of 1989. These two-lane, single-span bridges were constructed with transverse glued-laminated deck panels on seven glued-laminated timber beams spaced 48 inches apart. The beams supporting the deck of the Watchtower Creek Bridge are 27 feet long, 8¾ inches wide, and 22½ inches deep. The beams supporting the West Fork Creek Bridge are 35 feet long, 8¾ inches wide, and 28½ inches deep. Deck panels on both bridges are nailed to the beams and were not mechanically interconnected. The decks were paved shortly after being installed. Within days, the asphalt paving showed reflective cracking (cracking that is reflected up from the deck) directly over all the deck panel joints. The deck panels were treated with pentachlorophenol carried in a heavy oil solvent. The asphalt pavement cracked as soon as the bridges were put in use. The cracking resulted from differential movement of the deck panels, not from panel shrinkage.

Figure 2—Cracking over panel joints on the Watchtower Creek Bridge at the Bitterroot National Forest, MT, in 1989.

The cracks have opened and raveled somewhat over the 14-year life of the bridges. However, the bridges are functional. No timber deterioration was detected in the deck or superstructure members.

Deflection of longitudinal deck panels can also cause asphalt pavement cracking, although the problem is usually less severe because the wheel loads are not crossing the panel joints. Because longitudinal deck panels usually have a long span, the panels are connected to load distribution beams that help distribute wheel loads.

Example 2—The Satsop River Bridge (figures 4 and 5) near Shelton, WA, was constructed in 1996. It is a double-lane, glued-laminated arch bridge with longitudinal glued-laminated deck panels across transverse floor beams. The asphalt pavement cracked within days of installation. The bridge carried a large number of logging trucks. Significant deck movement was observed as loaded trucks crossed the bridge. The longitudinal deck panels were not interconnected with dowels. The deck panels span 10 feet between floor joists and are stiffened with intermediate load distribution beams. The decks are connected to the floor beams and distribution beams with aluminum fasteners.

Figure 4—Longitudinal cracks over the deck panel joint on the Satsop River Bridge near Shelton, WA.

Figure 5—Distribution beam installed under the Satsop River Bridge.

Reducing Differential Deflection

Traditionally, timber bridges were built with flexible beams and stiff decks. The solid beams were closely spaced and the nail-laminated decks were usually oversized. Glued-laminated timber allows fabrication of deeper, stiffer beams and uses thin, flexible glued-laminated deck panels.

Example 3—Seven bridges (figure 6) on the Wolf Creek Road in Lincoln County, MT, were constructed in 1969. The bridge superstructures are solid beams spaced 25 inches apart. The decks are nail-laminated two by sixes for a deck thickness of 5¾ inches. The beams are relatively flexible and the decks are very stiff. The bridges were paved with a cold-mix asphalt shortly after construction. The timber decks have occasional deteriorated laminations that would be logical slip planes for differential deflection, yet the 32-year-old bridges exhibit only random reflective cracking, which would be expected in pavement this old.

Figure 6—Bridge across Wolf Creek near Libby, MT, showing minimal cracking.

Spacing beams closer together or using thicker decks can stiffen glued-laminated panel decks, preventing deflection-induced pavement cracking. However, such design changes increase the cost of a timber bridge.

A more effective solution is to mechanically interconnect the glued-laminated deck panels. The most common method, developed by the Forest Products Laboratory in 1971, uses steel dowels. This system is described in *Timber Bridges: Design, Construction, Inspection, and Maintenance* (Ritter 1990). A series of dowels are placed in predrilled holes at middepth of the sides of the glued-laminated panels. Design specifications are included in the *Standard Specifications for Highway Bridges* (American Association of State Highway and Transportation Officials 1996). This system can be complicated to construct because deck panels can be difficult to align and pull tightly together. The dowels must fit tightly enough to prevent movement. The predrilled holes in the timber deck panels should not be oversized by more than $\frac{1}{16}$ inch.

Example 4—The Mill Creek Bridge near Medford, OR, was constructed in 1956. It is a three-span bridge initially designed with a transverse nail-laminated timber deck nailed to three glued-laminated timber beams spaced 5 feet 5 inches apart. In 1978, the nail-laminated timber deck was replaced with transverse glued-laminated timber deck panels lag-bolted to the beams. The deck panels were interconnected with steel dowels (figure 7). The deck was paved with asphalt pavement shortly after the deck panels were installed. The 22-year-old paving shows some reflective cracking over the deck panel joints. However, the cracks are intermittent and small and appeared gradually. The cracking may be caused, at least partially, by shrinkage of the individual deck panels. The deck is functioning well and shows no signs of further deterioration.

Figure 7—Dowel-interconnected, transverse glued-laminated deck panels on the Mill Creek Bridge near Medford, OR.

Another interconnection system—which may be easier to install and more economical—is a longitudinal stiffener beam (load distributor beam) attached to the underside of the deck midway between the longitudinal load-carrying beams. This stiffener beam should extend the length of the bridge and be continuous across at least three deck panels. The stiffener beams must have a minimum stiffness of EI = 80,000 square kip-inches (a measure of stiffness). They should be bolted through the deck near the edges of all glued-laminated panels (Weyerhauser, Inc. 1980).

Example 5—The Lighthouse Bridge across Upper Salt Creek in the northern end of the Olympic Peninsula in Clallum County, WA, was constructed in 1994. The 103-feet-long by 34-feet-wide double-lane bridge was constructed with full-length stiffener beams (figures 8 and 9) between the glued-laminated timber beams. The $6\frac{3}{4}$-inch glued-laminated timber deck is supported by glued-laminated beams spaced 5 feet apart. The asphalt pavement was laid down shortly after the glued-laminated timber deck panels were installed. No cracking (figure 10) had occurred when the bridge was inspected in October 1999. The deck panels are attached to the beams with steel 5- by 5- by $\frac{5}{16}$-inch angle irons that also help stiffen the deck.

Figure 8—Deck stiffener beams installed under transverse glued-laminated deck panels on the Lighthouse Bridge near Port Angeles, WA.

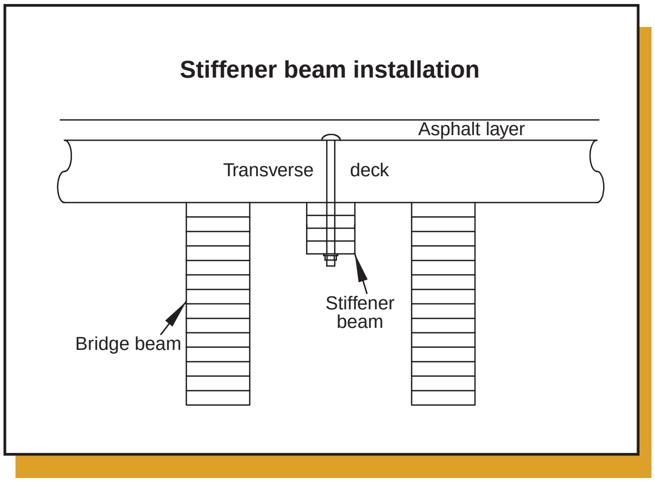


Figure 9—Stiffener beam between bridge beams.

Figure 10—Crack-free deck on the Lighthouse Bridge near Port Angeles, WA.

Deck Panel Shrinkage

The dimensions of timber fluctuate almost exclusively because of changes in moisture content. Thermal expansion of wood is minimal. Most moisture-induced dimensional change occurs perpendicular to the grain. Dimensional change perpendicular to the grain is about nine times more than the dimensional change parallel to the grain (Forest Products Laboratory).

Glued-laminated timber is fabricated at a maximum moisture content of 16 percent (American Institute of Timber Construction 1994). Studies have shown that moisture contents in glued-laminated timber decks average between 15 and 23 percent (Gutkowski and McCutcheon 1987). In most environments, moisture levels in glued-laminated timber decks treated with oilborne preservatives remain relatively constant. However, if deck panels are improperly stored, the wood's moisture content could increase, resulting in significant shrinkage after installation.

Glued-laminated deck panels for bridges are normally treated with oilborne preservatives that minimize moisture penetration, moisture loss, and the associated volume changes. Waterborne treatments, or in some locations, light oil solvent treatments, do not provide the same level of protection against moisture change. Another potential problem of the waterborne treatment is that the moisture content of the wood increases significantly. If the treated wood is not redried before installation, drying can cause significant deck shrinkage and asphalt pavement cracking at the panel joints. Horizontal movement of an $\frac{1}{8}$ inch per panel joint causes asphalt pavement to crack. The loss of 1-percent moisture content in a 48-inch-wide glued-laminated deck panel can cause $\frac{1}{8}$ inch of shrinkage.

Example 6—The Standish Avenue Bridge in Petoskey, MI, was constructed in the fall of 1999. The 80-feet-long, two-lane bridge was constructed with transversely placed, glued-laminated timber panels treated with chromated copper arsenate, a water-borne treatment. The panels were attached to glued-laminated timber beams spaced every 52 inches with aluminum clips. The deck panels were not mechanically interconnected.

The deck panels fit tightly against each adjoining deck panel when installed. The asphalt pavement was laid down immediately after the deck panels. The pavement showed reflective cracking (figure 11) within days after the bridge was opened to traffic. The cracks continued to grow during the first year of operation. When the bridge was inspected during the summer of 2000, gaps up to $^1/_4$ inch (figure 12) were observed between deck panels. The early cracking of the asphalt paving on this bridge may have been caused by differential deflection of the deck panels. Shrinkage of the deck panels enlarged the cracks and contributed to the failure of the pavement.

Figure 11—The pavement cracked about 1 year after construction of the Standish Avenue Bridge in Petoskey, MI.

Figure 12—Shrinkage of deck panels contributed to pavement cracking on the Standish Avenue Bridge.

Expansion of glued-laminated deck panels because of increased moisture content is unlikely to cause pavement damage, because the deck-to-beam connections restrict expansion. In extreme situations, glued-laminated deck panels have expanded on timber bridges in Alaska, buckling and damaging backwalls.

Preservative Treatment

Oilborne Preservatives

Oilborne preservatives commonly used in bridge construction include: creosote, pentachlorophenol (penta), and copper naphthenate (American Wood Preservers' Association 1997). Creosote is a naturally occurring coal tar product. Penta and copper naphthenate are pesticide chemicals that are dissolved in a type A (heavy oil), or a type C (light oil) solvent. The heavy oil solvent is diesel oil. Light oil solvent is as viscous as mineral spirits. The oil carrier, particularly a type A heavy oil, protects the wood from rapid moisture change and minimizes wood shrinkage, checking, and splitting. Excessive checking and splitting allow fungi and insects to penetrate the interior of the wood, causing the wood to deteriorate and eventually leading to the loss of structural integrity.

Waterborne Preservatives

Waterborne preservatives commonly used in bridge construction include; chromated copper arsenate (CCA), ammoniacal copper/zinc arsenate (ACZA), and similar products. Waterborne treatments chemically bond with the wood. Because these treatments do not use an oil medium, timber treated with waterborne preservatives expands and contracts more quickly with moisture change, and is susceptible to heavy checking and splitting over time.

The pressure-treatment process for waterborne preservatives significantly increases the moisture content of freshly treated wood. If waterborne-treated wood is not redried after treating, the wood will shrink after installation. The redrying—or curing—process lowers the moisture content gradually, minimizing cracking and splitting. Waterborne preservatives are not recommended for large structural members, particularly glued-laminated timber.

Proper Treatment Practices

In consultation with the Forest Service in 1996, the Western Wood Preservers' Institute (WWPI) and the Canadian Institute of Treated Wood (CITW) published a set of specifications for timber treatment, *Best Management Practices for the Use of Treated Wood in Aquatic Environments* (BMPs).

In 2002, the Michigan Timber Bridge Initiative published *Best Management Practices (BMPs) for the Use of Preservative-Treated Wood in Aquatic Environments in Michigan*. This document contains much of the same information as the 1996 WWPI publication, but includes a discussion of the U.S. Department of Labor, Environmental Protection Agency's consumer information sheets and the environmental risks associated with the use of most common wood preservatives.

Both sets of BMPs seek to minimize the amount of treatment chemicals dispersed into the environment by controlling treatment procedures, mandating cleaning procedures after treatment, limiting chemical loading, and requiring visual inspection before installation of structures using preservative-treated wood. These BMPs were prepared to protect water quality and the diversity of life forms found in lakes, streams, estuaries, bays, and wetlands. A secondary result of complying with these specifications has been the improved performance of asphalt pavements on timber bridge decks treated in compliance with the BMPs.

Benefits of Cleaning Procedures After Treatment—In 2000, the Forest Service's Forest Products Laboratory inspected and measured preservative retention levels in six creosote-treated bridges in rural Michigan (Wacker, Crawford, and Eriksson 2002). Two of these bridges were in the same county and had the same type of superstructure. One bridge had undergone cleaning procedures after treatment, as required by the BMPs—the other bridge had not. Core samples revealed similar creosote retentions in both bridges. The bridge that was not cleaned after treatment exhibited excessive underside leakage of creosote, bleeding of asphalt and creosote on the roadway surface, and pavement rutting. The bridge that was cleaned after treatment had none of these problems.

Recommended cleaning procedures after treatment with creosote are:

- Expansion bath—Following the pressure period, heat the creosote 10 to 20 °F above press temperatures for a minimum of 1 hour. Pump the creosote back to storage and apply a minimum vacuum of 24 inches of mercury for at least 2 hours.

- Steaming—After the pressure period, once the creosote has been pumped back to the storage tank, a vacuum shall be applied for a minimum of 2 hours at a vacuum of not less than 22 inches of mercury to recover excess preservative. Release the vacuum back to atmospheric pressure and steam for a 2-hour period. Maximum temperature during this process shall not exceed 240 °F. Apply a second vacuum for no less than 4 hours at a pressure of 22 inches of mercury.

The long-term benefits of complying with this requirement can be seen in the performance of the asphalt pavement and the reduction of excess creosote on the visible surfaces of treated wood.

Example 7—The Barlow and Cruzen bridges in Alcona County, MI, are two-lane, single-span, stress-laminated, creosote-treated timber deck bridges. The bridges are similar in design. Both were part of the creosote retention study in Michigan. Timber materials of the Barlow Bridge were cleaned after treatment and show almost no bleeding of creosote (figures 13a and 13b) on exposed treated timber surfaces or through the asphalt pavement. The timber materials of the Cruzen Bridge were not cleaned after treatment and show excessive amounts of creosote (figures 14a and 14b) on timber surfaces and through the asphalt pavement. The American Wood Preservers' Association's (AWPA) minimum creosote retention levels for these bridges is 12 pounds per cubic foot. The average measured retention levels were 46.2 pounds per cubic foot for the Barlow Bridge and 52.2 pounds per cubic foot for the Cruzen Bridge. Creosote retention levels were excessive for both bridges. However, the Barlow Bridge shows no significant bleeding. The difference appears to be that the Barlow Bridge received the BMP-recommended cleaning procedures after treatment.

Figure 14a—The Cruzen Bridge in Alcona County, MI, was made from timbers that had not been cleaned properly after being treated with preservative.

Figure 13a—The Barlow Bridge in Alcona County, MI, was made from timbers that were cleaned properly after being treated with preservative.

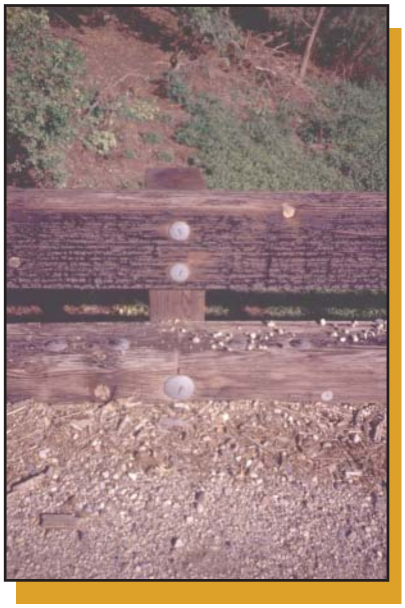


Figure 14b—Creosote-treated timbers on the Cruzen Bridge were not cleaned after treatment. Creosote is leaching from the timbers.

Figure 13b—Proper cleaning prevented creosote-treated timbers from bleeding through the asphalt pavement on the Barlow Bridge.

Preservative Use

Creosote for bridge timbers should be derived entirely from coal tar, as required in AWPA P1/P13. Penta and copper naphthenate treatment chemicals can be carried in a heavy oil solvent (AWPA type A) or a light oil solvent (AWPA type C). The type A solvent provides more protection against moisture intrusion and usually is preferred by bridge engineers. However, type C solvent is often used in more sensitive environments. It provides a cleaner surface with less potential for solvent dripping.

When timber is improperly treated, or if the cleaning procedures are not followed after treatment, chemicals and solvents (treatment residues) will be present at, or may migrate to, timber surfaces. This can occur as a natural process in a treated timber or may be accelerated by heat or compressive stressing forces, as is the case for stress-laminated bridges. Excessive creosote, penta, copper naphthenate, or oil solvents reduce pavement-to-deck adhesion, soften the asphalt in the pavement mix, cause bleeding and pavement rutting, and dissolve paving membranes. In extreme cases, the mixture of asphalt, treatment solvent, and treatment chemicals can leach into the environment.

To minimize problems associated with preservatives:

- Treat the wood using preservatives specified by AWPA for land, freshwater, and marine applications.
- Follow good housekeeping practices to minimize sawdust and other surface residues on the wood before treatment. If necessary, power wash timbers to remove excess surface deposits before shipping them to the worksite.
- Use one of the techniques recommended in Standard C2 in *Lumber, Timbers, Bridge Ties and Mine Ties* or Standard C3 *Piles* of the *American Wood Preservers' Standard* (American Wood Preservers' Association 1997) to condition the wood and reduce the moisture content before preservative treatment.
- Wood should be cleaned after treatment as specified in the *Best Management Practices for the Use of Treated Wood in Aquatic Environments* (Western Wood Preservers' Institute 1996).

AWPA treatment standards provide minimum requirements for preservative penetration and retention. The BMPs strive to meet these standards without using more chemicals than necessary. The average preservative retention of wood treated to BMP standards should not exceed 150 percent of the AWPA required minimum retention.

Setting precise maximum chemical loading levels is difficult because of the inherent variability found in wood, including cell structure and the proportion of sapwood (newly formed outer wood) to heartwood (inactive wood).

Glued-laminated and solid members are sometimes treated in the same batch. Glued-laminated timber has a higher sapwood-to-heartwood ratio than solid material. Because sapwood is more permeable than heartwood, the glued-laminated timber usually retains significantly more preservative than solid timbers from the same batch. Glued laminates are dried to 16-percent moisture content to increase the penetration and retention of treatment chemicals and solvents. Solid materials are dried to 19-percent moisture content.

Example 8—The Cameron Bridge across the Manistee River in Crawford County, MI, was constructed in 1995 as a two-lane, two-span, stress-laminated timber box-beam bridge. The deck is comprised of a laminated box section with southern pine glued-laminated webs spaced every 24 inches. Solid pin oak dimensional wood stressed between the glued-laminated webs forms the box section. This bridge was also part of the Michigan creosote-treated bridge study. The glued-laminated webs had an average creosote retention of about 12.5 pounds per cubic foot. The solid wood had an average creosote retention of about 5.1 pounds per cubic foot. Although these are not exceptionally high retention levels, excess creosote dissolved the asphalt-impregnated paving membrane between the deck and the asphalt paving over the tops of the glued-laminated members (figure 15). The long stripes of creosote bleeding through the asphalt paving show the locations of the glued-laminated beams.

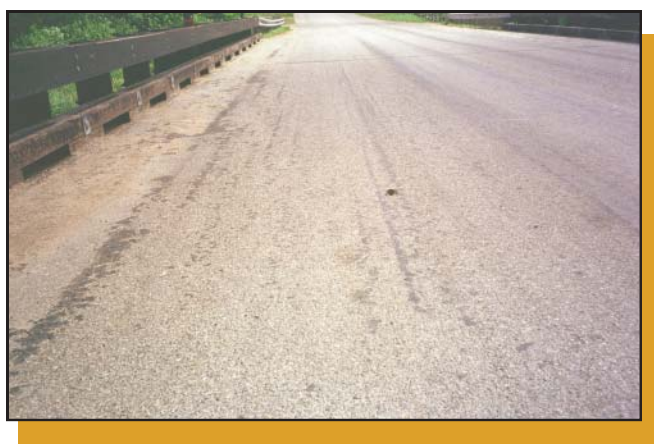


Figure 15—The Cameron Bridge in Crawford County, MI, had asphalt bleeding over glued-laminated webs.

Effects of Preservatives on the Environment

Several publications discuss the environmental effects of treated wood on aquatic environments. The first, *Assessment of the Environmental Effects Associated with Wooden Bridges Preserved with Creosote, Pentachlorophenol, or Chromated Copper Arsenate* (Brooks 2000), involves studies of actual preservative concentrations in the soil and water adjacent to bridges treated with those chemicals.

The second, *Environmental Impact of Preservative-Treated Wood in a Wetland Boardwalk* (Weyers and others 2001), is a study of the effects of four different wood treatment products in sensitive wetland environments.

Both reports indicate minimal risk to the environment from preservatives lost from timber bridges. Any risk can be minimized or eliminated through better treatment, cleaning after treatment, and construction and maintenance practices.

Example 9—The previously discussed Cruzen Bridge in Alcona County, MI, was part of the State's creosote-retention study. The two-lane, single-span, stress-laminated timber-deck bridge was constructed in 1995. The asphalt paving was placed shortly after the deck was stressed. The following summer, bridge users began complaining of excessive bleeding of the asphalt (figure 16). The bridge has creosote bleeding on the underside and sides of the deck. Creosote retention levels in this bridge deck average about 52 pounds per cubic foot. The deck laminations are $6\frac{3}{4}$-inch-wide glued-laminated sections of southern yellow pine and red pine. When laminated decks are stressed, preservatives are squeezed out. A higher concentration of preservatives occurs at the junctions of the deck laminations. At the Cruzen Bridge, these concentrations of creosote bled up through the asphalt pavement. The spacing of the asphalt lines on the surface of the pavement match the width of the glued-laminated beams in the stressed deck. This bridge did not have a paving membrane, so the visible bleeding is pavement asphalt and excess creosote.

As specified in the Western Wood Preservers' Institute's *Best Management Practices for the Use of Treated Wood in Aquatic Environments* (1996), cleaning procedures should be required after treatment. Treatment retentions should be limited to 150 percent of the American Wood Preservers' Association retention minimums.

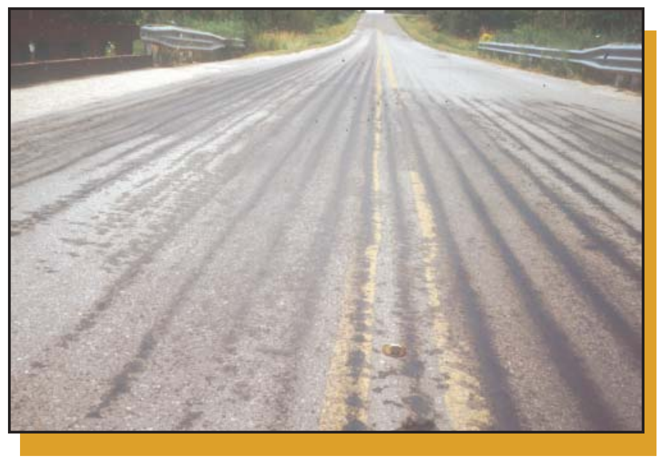


Figure 16—Asphalt bleeding directly over creosote concentrations on the Cruzen Bridge in Alcona County, MI.

Asphalt Pavement Behavior

Asphalt pavement is a flexible system, structurally composed of layers of asphalt and underlying bases—in this case, treated timber bridge decks. Portland cement concrete pavement is a rigid system where the concrete serves as the structural component. Underlying bases do not contribute to the strength of the system as significantly as in an asphalt system. Products and paving systems appropriate for concrete bridge decks may not be appropriate for timber bridge decks.

Because asphalt pavement is flexible and concrete pavement is rigid, they distribute loads differently. The concrete pavement has greater structural strength and stiffness, distributing loads over a wide area. Minor variations in subgrade strength have little influence on the structural capacity of the concrete pavement.

Asphalt pavement distributes loads over a much smaller area. Asphalt roadway pavement consists of a series of layers, with the highest quality materials at or near the surface. The strength of flexible pavement is a result of built-up layers that distribute loads over the subgrade through all layers, rather than the strength of a slab alone. Because the asphalt pavement overlay on a bridge is quite thin (2 to 4 inches), minor deflections in the bridge deck can crack the pavement.

Asphalt pavement depends on the bridge deck to act as a relatively stiff, monolithic sublayer that provides underlying strength and stability. When individual sections of the deck (such as glued-laminated deck panels) move independently, this movement may cause asphalt pavement to crack and fail at the deck panel joints.

The design of asphalt pavement mixtures is complex. Too little asphalt results in a brittle mix where aggregate doesn't bond together or to the underlying surface. Too much asphalt results in a soft mixture susceptible to rutting and bleeding.

Another difference between asphalt pavement and concrete pavement is that asphalt pavement does not "set" or become totally stable as it cures. The asphalt in an asphalt paving system can dissolve, soften, or leach from the pavement mix. Hydrocarbon solvents used to carry treatment chemicals in treated wood readily dilute and dissolve asphalt. The chemical composition of creosote is similar to asphalt, and the chemicals in penta and copper naphthenate will dissolve asphalt as well as styrene and rubber additives (polymers). Heat also softens asphalt and accelerates the damaging effects of preservative chemicals and solvents.

Asphalt Adhesion to Treated Timber

Very little information is available about the adhesion of asphalt to treated timber. Asphalt should readily adhere to dry, clean wood, but the effects of oilborne preservatives are not well known. Project coordinators also were interested in determining whether adhesion would be less for smooth wood surfaces, such as glued-laminated timber, and the effect temperature has on asphalt adhesion.

Adhesion Testing—Coast Douglas-fir is a common structural wood species in the Western United States. It accepts treatment relatively well. Four 12- by- 36- by 2-inch sections of rough, solid coast Douglas-fir were tested. One was treated with creosote, another with penta in heavy oil, a third with copper naphthenate in heavy oil, and a fourth with chromated copper arsenate (a waterborne preservative). Three 12- by 36- by $5\frac{1}{8}$-inch individual sample pieces of glued-laminated coast region Douglas-fir treated with creosote, penta in heavy oil, and copper naphthenate in heavy oil were used for adhesion testing. Chromated copper arsenate is not recommended for use with glued laminates.

Four different asphalt mixes were tested on each of the wood samples. Two of the asphalts were performance-graded asphalts, PG 58-28 and PG 64-28. These liquid asphalt samples are used by transportation agencies in the Northern States. The PG 64-28 asphalt is polymer modified; the PG 58-28 asphalt is not. We also selected AC 85/100, a nonpolymer penetration-grade asphalt, and CRS-2P, a cationic, polymer-modified emulsion (an asphalt cement milled into small particles that can be mixed with water and emulsifying agents). These asphalt mixes are similar to those used in some mountainous climates and Northern States.

The adhesion of these asphalts was tested on the two types of wood (solid and glued laminated) and the four types of treatment (creosote, penta, copper naphthenate, and chromated copper arsenate) at room temperature using a tensile-strength testing machine (figure 17). Templates were attached to the wood samples to keep the asphalt a consistent thickness. Fabricated pullout brackets (figure 18) were embedded in the asphalt. The contact area was $1\frac{1}{2}$ by $3\frac{3}{4}$ inches. The asphalt samples were preheated to 300 °F before being poured into the templates. After the brackets were embedded in the asphalt, the samples were allowed to cure for 48 hours.

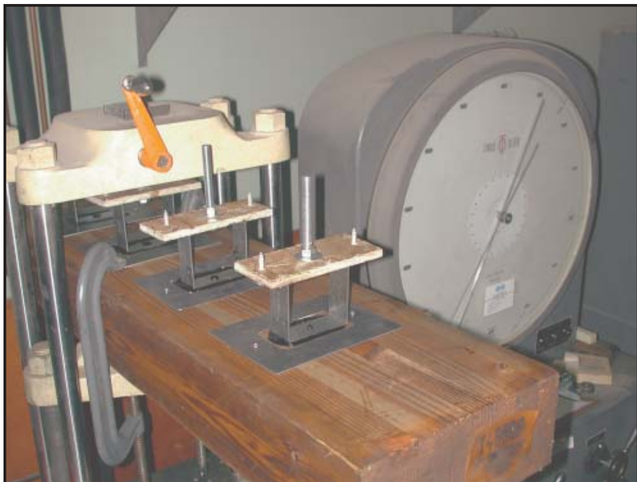


Figure 17—Testing the tensile strength of asphalt adhesion.

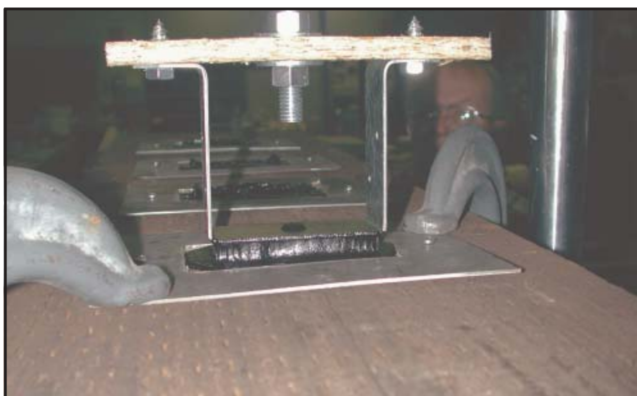


Figure 18—Tension being applied to the pullout brackets.

When tested in tension, all the samples failed gradually by pulling the asphalt apart. The asphalt did not separate from the treated wood or the metal brackets. There was no measurable difference in adhesion between the solid samples and the glued-laminated samples. Surprisingly, the dry chromated copper arsenate (waterborne treatment) sample didn't differ significantly from the other samples. The adhesion strengths for penta were the lowest for both the solid and glued-laminated samples. The adhesion strengths for copper naphthenate were the highest for both wood types. The factor determining adhesion strength seemed to be how much the treatment type softened the asphalt. The asphalt on the penta wood samples seemed to be softer, and when tested, elongated farther (figure 19). This result is not conclusive because the particular penta wood sample may have had a higher retention of treatment material and oil solvent.

The polymer-modified asphalts performed better on both wood types. The performance-graded PG 64-28 performed slightly better than the polymer-modified emulsion.

To evaluate the asphalts during cold temperatures (tables 1, 2, and 3), the four asphalts were retested on the creosote sample at freezing temperatures. The templates were refilled and the brackets set on the creosote-treated glued-laminate panel. The samples were left outside for 24 hours. The surface temperature of the sample was 28 °F at the time of testing. The polymer-modified asphalts failed at a tensile load 54 percent higher than at room temperature. The nonpolymer-modified asphalts failed at much smaller loads. The nonpolymer-modified samples resulted in a brittle failure as soon as the minimum load was applied.

Table 1—Adhesion test of solid timbers.

Tension failure loads (pounds) at 65 °F					
Asphalt type	Creosote	Copper naphthenate	Penta	Chromated copper arsenate	Average
PG 58-28	52	90	62	106	77.5
PG 64-28	134	142	88	114	119.5
AC 85/100	126	110	90	94	105
CRS-2P	126	134	112	112	121
Average	109.5	119	88	106.5	105.8

Table 2—Adhesion test of glued laminates at 65 °F.

Tension failure loads (pounds) at 65 °F				
Asphalt type	Creosote	Copper naphthenate	Penta	Average
PG 58-28	98	76	54	76
PG 64-28	112	142	92	115.3
AC 85/100	112	110	96	106
CRS-2P	136	134	80	116.7
Average	114.5	115.5	80.5	103.5

Table 3—Adhesion test of glued laminates at 28 °F.

Tension failure loads (pounds) at 28 °F	
Asphalt type	Creosote
PG 58-28	28
PG 64-28	190
AC 85/100	28
CRS-2P	192

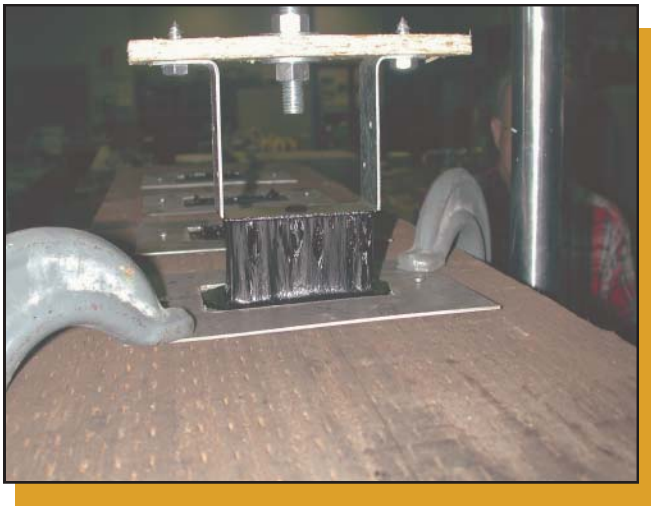


Figure 19—Asphalt adhesion test after the asphalt failed when it had elongated.

These results do not provide a hard and fast measure of asphalt adhesion to treated timber because the tests were conducted quickly and lacked a standardized test methodology. However, they do show asphalt-treated timber adhesion characteristics.

Asphalt Pavement Systems

An asphalt paving system on a bridge deck may include: a geotextile or paving membrane, a tack coat, and one or more layers of asphalt pavement. Improper pavement system design, incompatible products, poor construction practices, or climatic conditions may cause a pavement system to fail on treated timber bridge decks. Asphalt pavement materials must be at the proper temperature when they are placed and compacted. Cold air can affect placement and cause faster curing of the asphalt and lead to cracking and improper bonding between the asphalt, aggregate, and the deck surface. The most common problem seen in field inspections was excess amounts of asphalt and preservative. Another common problem was that paving membranes became unstable and slipped when the hot asphalt pavement was being placed.

Tack Coats

A tack coat is a very light application of asphalt, usually an asphalt emulsion diluted one to one with water, applied to ensure a bond between the surface being paved and the overlying asphalt pavement course. A tack coat should be quite thin, just thick enough to help the dry fabric or asphalt overlay stick to the underlying surface. The application rate for a tack coat varies for different applications. A concrete bridge deck needs a heavier application because the relatively porous concrete surface will absorb the asphalt. A timber bridge deck treated with creosote, penta, or copper naphthenate carried in a heavy oil solvent already has an oily surface. The asphalt emulsion will not penetrate the timbers well. A diluted application rate of 0.25 gallons of asphalt per square yard may be appropriate for a concrete bridge deck. An application rate of 0.05 to 0.10 gallons of asphalt per square yard is more appropriate for a treated timber bridge deck. The rate depends on how quickly the asphalt is absorbed by the material below and above it. During an installation, too much liquid asphalt acts more like a lubricant than a bonding agent and causes pavements, fabrics, or membranes to slip and bunch. Any excess asphalt placed against the treated wood will cause long-term problems.

Paving Membranes

Concern about water penetration causing wood to deteriorate and dissolved roadway salts causing steel components to rust has prompted the widespread use of rubberized asphalt paving membranes in many asphalt paving systems on treated timber bridges. Waterproofing requires a continuous layer of asphalt. Rubberized asphalt works even better than standard asphalt, because it is less likely to crack during cold weather. Paving membranes are paving fabrics or fiber mesh impregnated with polymer-modified or rubberized asphalt. While paving membranes were originally produced to prevent problems, their indiscriminate use on treated timber bridge decks has caused installation, durability, and environmental problems.

One side of some paving membranes is sticky and designed to adhere to the bridge surface. Other paving membranes are designed to adhere to a tack coat or primer. These membranes were developed for concrete bridge decks where the hot asphalt overlay melts the membrane and fills surface voids in the concrete and tightly bonds the asphalt overlay to the bridge deck. Often, a primer or sealer is recommended for the concrete surface to decrease the porosity of the concrete and improve the bond. This continuous layer of asphalt produces a waterproof seal of the concrete bridge deck. Waterproofing concrete decks is important because reinforcing steel can be damaged by water and dissolved roadway salts. In most cases, properly treated timber decks are not nearly as susceptible to damage by moisture and salt.

Treated timber bridge decks present a different installation challenge than concrete decks. Timber decks treated with oilborne preservatives will not absorb the melted paving membrane. Timber decks do not absorb and dissipate the heat of the asphalt overlay as readily as concrete. When 280 to 300 °F asphalt is placed on an asphalt-impregnated paving membrane on a treated timber deck, the membrane immediately melts, forming a pool of liquid asphalt between the deck and the asphalt pavement. As the fabric slips under the asphalt pavement, it may fold and bunch in front of the paving machine. Various attempts have been made to prevent the fabric from folding and bunching, including stapling the membrane to the timber deck, and filling the paving machine's hopper before paving so the paving machine will not have to push a truck in front of it.

Example 10—The LaChance Bridge, constructed in 1998 near Cadillac, MI, was part of the State's creosote retention study. It has creosote-treated, glued-laminated transverse deck panels across timber deck trusses. The average creosote retention in the deck panels was 35.7 pounds per cubic foot. An asphalt-impregnated paving membrane was installed before paving. Construction personnel related difficulties in paving because the membrane slipped. The paving was done on a cool November day. Immediately after paving, long strands of cooled asphalt were visible (figure 20a) at the deck panel joints on the underside of the bridge.

The bridge began dripping a mixture of creosote and asphalt into the Clam River the following spring. A collection system was installed under the bridge (figure 20b). The creosote and rubberized asphalt mixture was still dripping when the bridge was inspected in 2000.

Figure 20a—Cooled asphalt dripping from the underside of the LaChance Bridge in Michigan.

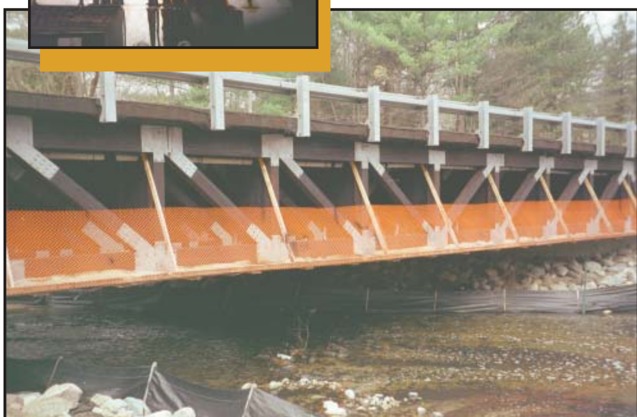


Figure 20b—A collection system catches the creosote and rubberized asphalt dripping from the underside of the bridge.

Figure 21—Alternating longitudinal deck panels treated with penta and copper naphthenate on a bridge in Washington County, OR.

Even if a bridge is successfully paved and the deck is tight enough to prevent melted membrane asphalt from dripping between the deck panels, the layer of asphalt remains at the wood-pavement interface. When combined with preservative residue, this concentration of asphalt will soften asphalt pavement and cause ongoing problems, such as bleeding, overlay deterioration, and rutting, particularly when bleeding treatment chemicals and solvents add additional solvents and oils to the mix.

Rubberized asphalt from the paving membranes does not leak just because it is being melted by the hot asphalt pavement. The LaChance Bridge was still dripping between the deck panels 2 years after installation.

Washington County, OR, workers replaced the decks on a number of treated timber bridges in the summer of 1998 and on four others in 2000. On two of the bridges, the alternating longitudinal deck panels had been treated with either penta or copper naphthenate (figure 21). This approach allowed the performance of glued laminates treated with copper naphthenate to be evaluated. At the time, copper naphthenate was a relatively new treatment for bridges. The third bridge deck was treated entirely with penta. The fourth bridge deck was treated with ammoniacal copper/zinc arsenate (ACZA), a waterborne treatment. The solvent for all the decks treated with oilborne preservatives was type A heavy oil. Rubberized asphalt-impregnated paving membranes were used on all four bridge decks.

All three decks treated with oilborne preservatives showed significant dripping of the rubberized asphalt from the paving membranes. The pavement surfaces of these three bridges were rutted and showed signs of asphalt bleeding. One bridge deck had two large potholes near the center of the bridge. The deck panels treated with penta exhibited more asphalt bleeding than the deck panels treated with copper naphthenate. The extra bleeding may have occurred because the penta panels were in the wheel paths.

The bridge deck treated with waterborne preservatives showed almost no asphalt dripping, and the pavement surface had no obvious signs of asphalt bleeding.

Two Forest Service bridges also exhibited long-term membrane dripping. The deck of the Rogue River Bridge was replaced in 1998. The deck panels were treated with penta in a type A heavy oil solvent. A paving membrane was installed over a bridge deck against a primer and tack coat.

Some difficulty was experienced with membrane slippage. No membrane dripping problems were immediately apparent. Two years later, dissolved rubberized asphalt began dripping from between the deck panels (figure 22). The problem was severe enough that plywood was nailed to the bottom of the joints to collect the dripping asphalt.

Another Forest Service bridge crossing the Little North Fork of the Santiam River showed a puzzling pattern of membrane dripping. The Shady Cove Bridge (figure 23) was constructed in 1991. The deck is longitudinal glued-laminated timber panels treated with pentachlorophenol in a type C light oil solvent. The deck was sealed with a primer before the rubberized paving membrane and asphalt overlay were installed. Some paving difficulties were experienced, but the deck was relatively tight with no apparent asphalt dripping for almost 9 years. In the spring of 2000, rubberized asphalt began dripping from the bridge (figure 24a). The asphalt that has dripped onto the bedrock under the bridge clearly reveals the location of the deck panel joints above (figure 24b).

Figure 22—Rubberized asphalt dripping from paving membranes on the Rogue River Bridge near Medford, OR.

Figure 23—Asphalt leaching to the pavement surface of Shady Cove Bridge near Eugene, OR.

Figure 24a—Rubberized asphalt dripping from the underside of the Shady Cove Bridge.

Figure 24b—Asphalt dripping onto rocks under the Shady Cove Bridge.

Asphalt bled to the pavement surface, forming pools about 6 inches in diameter. Forest personnel cut out a 12-inch-square piece of asphalt pavement. The bottom 1 inch of the 2-inch-thick pavement was semiliquid.

The summer of 2000 was an abnormally warm summer that followed a very dry, warm winter. Perhaps the weather contributed to the asphalt bleeding observed that summer. Most of the bridges were treated with preservatives carried in heavy oil solvents. But the Shady Cove Bridge, probably the most extreme case of asphalt bleeding, was treated with penta in a light oil solvent. Both the light and heavy oil solvents were dissolving asphalt in the paving membranes, and possibly dissolving asphalt from the pavements.

Testing

To validate whether preservative treatment dissolved paving membranes, several tests were conducted on three different paving membranes. The membranes were submerged in four solutions:

- Light oil solvent (AWPA type C)
- Pentachlorophenol in light oil solvent
- Copper naphthenate in light oil solvent
- Heavy oil solvent (AWPA type A)

All the solvents and solutions dissolved all of the asphalt in the paving membranes within 3 days.

The residual light-oil-only and heavy-oil-only solutions contained finely ground rubber particles from the membranes. The residual penta and copper naphthenate light oil solutions appeared to have dissolved the rubber particles as well as the asphalt material.

Solvents leach from the treated timber members and merge with the asphalt when heat is supplied by the sun or by application of hot asphalt pavement. This leaching dissolves priming or tack materials recommended by membrane and fabric manufacturers.

Proper Methods—Membranes Can Work

Engineers in the Nicolet and Chequamegon National Forests in Wisconsin (Johnson 1987 and Faurot 1984) experienced good results with rubberized membranes on treated timber decks by waiting about 2 years before placing the membrane and paving. The preservative solvents evaporated or were removed by traffic. Preparation for paving included thorough cleaning with shovels, brushes, and compressed air before applying the membrane and pavement. A light tack coat was used.

In most cases, paving membranes should not be placed directly against treated wood. They can be used over a base layer of asphalt. A crowned $1\frac{1}{2}$- to 2-inch layer of asphalt should be placed directly onto the treated timber bridge deck. The paving membrane is applied and a final $1\frac{1}{2}$- to 2-inch layer of asphalt is placed over the membrane (Weyers, Loferski, Dolan, Haramis, Howard, and Hislop 2001). This is a thicker asphalt pavement wearing surface than typically is used on a bridge deck. The bridge design must include this additional weight, which is higher than normally anticipated.

Deck Preparation—A properly prepared deck can add measurably to the success of an asphalt application. The Forest Service publication *Timber Bridges: Design, Construction, Inspection, and Maintenance* (Ritter 1990) outlines a number of steps to successful asphalt paving:

- Preparing the timber deck properly before applying the asphalt surface
- Using the "empty cell" process for treatment followed by expansion bath or steaming
- Allowing about 30 to 45 days of warm weather for preservatives to evaporate

Spreading sand (blotter) on the deck and removing it after about a week helps to absorb excess preservatives before asphalt pavement or a liquid asphalt tack coat is applied.

Existing decks can be repaved to stop ongoing problems. The pavement can be removed using heavy equipment and then scraped. Excess preservatives can be absorbed by a sand blotter before cleaning the deck and placing a new layer of asphalt. If additional preservative solvent bleeding is anticipated, a dry, nonwoven paving fabric can be stapled to the deck before it is paved.

Recommendations

Roadway Design

Freshly placed asphalt pavement is not impervious to moisture, but if the roadway surface is crowned or sloped a minimum of 1 percent, very little moisture will penetrate through the pavement to the deck. Standing water damages pavement by interacting with the asphalt cement. The water tends to strip the asphalt from the aggregate particles, weakens the pavement, causes crumbling, and compromises the bond between the asphalt and the deck. Such pavement becomes increasingly susceptible to destruction by weather and the pounding of traffic loads. Water and deicing salts can also damage timber bridges, particularly if the beams that carry the bridge load are steel or if the bridge deck is stressed with high-strength steel rods.

Bridge decks should be crowned, super elevated, or constructed on a grade—preferably 2 percent, but at least 1 percent. Removing surface water before it can percolate through the asphalt surfacing is a simple, effective alternative to using waterproofing paving membranes.

Structural Design

When bridges with glued-laminated deck panels are paved, the deck panel deflection should be limited to 0.05 inch or the deck panels should be mechanically interconnected. To minimize shrinkage, deck panels should be treated with an oilborne preservative and be protected from the weather before installation. If deck panels must be treated with waterborne treatments, the panels should be redried to a maximum 19-percent moisture before being shipped to the jobsite. When stored at the jobsite, the deck panels should be protected from moisture.

Preservative Treatment

Treated wood should meet the requirements specified in *Best Management Practices for the Use of Treated Wood in Aquatic Environments* (Western Wood Preservers' Institute 1996) for treatment, posttreatment procedures, and visual inspection before installation. Complying with these BMPs will minimize preservative residue on the timber surfaces as well as future chemical and solvent leaching, reducing environmental risks and improving the performance of asphalt pavement on treated timber bridge decks.

Asphalt Pavement Design

Design also affects the performance of asphalt pavement. The use of performance-graded asphalt is recommended for sites that are subject to heavy loads, high traffic volumes, and a harsh environment. Superpave (an improved mix design for asphalt pavements) and performance-graded asphalt (a better method of specifying the most compatible asphalt cement for a particular environment and expected traffic load and volume) are important results of the Strategic Highway Research program and Long-Term Pavement Performance program. State departments of transportation are a good source of information about these asphalts and pavement designs.

Paving Membranes

Timber decks treated with oilborne preservatives are very resistant to moisture penetration and damage. The deck acts as a water-resistant cover over the beams and hardware. Constructing the bridge on a minimum road grade, crown, or superelevation of 1 percent also will help keep the bridge deck dry. However, if road salts are present, a waterproof paving system may more fully protect critical steel components such as stressing bars, beams, and connecting hardware.

Paving membranes are designed to leave a continuous layer of flexible asphalt as a barrier to prevent water from penetrating the structure. However, treatment chemicals and oil solvents dissolve asphalt. Paving membranes should be used only on treated timber bridge decks that are free of preservative residue and are expected to remain that way.

When a paving membrane is to be placed on a timber deck treated with creosote or heavy oil solvent treatment, the wood must be treated in compliance with the BMPs by the Western Wood Preservers' Institute. These practices will ensure that the wood was properly prepared before treatment, was subjected to appropriate procedures after treatment, and was properly inspected at the job site. The amount of preservative treatment chemical retained in the wood should be less than 150 percent of the AWPA-specified minimum retention. The pavement system also will perform best if the bridge deck has been allowed to cure before paving to ensure that treatment residue evaporates. The length of time varies, depending on many factors, including climate.

The same requirements should be used for timber decks treated with light oil solvents. Proper curing may be more critical with these treatments. If the light oil solvent has not evaporated from the wood before a paving membrane is placed, the solvent vapors will be trapped. Eventually, they will attack the paving membrane and asphalt in the pavement. The time required to cure timber decks that have been treated with light oil solvents requires further research.

Paving Practices

Meet all specifications regarding mix temperature and thickness. Ensure that air temperatures and weather conditions are within recommended limits. If a tack coat is applied, use it sparingly. Minimizing free asphalt is essential for long-term pavement performance.

Summary

Long-term asphalt pavement performance on treated timber bridge decks depends on a number of factors. The structural design of the deck must restrict differential deck deflection between deck panels to 0.05 inches, either through deck stiffness or through mechanical interconnection of deck panels. The asphalt paving system must be properly designed. Contact between preservative-treatment residue and free asphalt must be minimized.

Contact between the asphalt and timber decks treated with preservative cannot be avoided. The most important factor is to prevent treatment chemicals and solvents from leaching to the wood surface. Compliance with new BMPs for timber treatment, and proper curing of the bridge deck before placing paving membranes or asphalt pavement will greatly reduce treatment residues.

Free asphalts at the surface of treated timber decks should also be avoided. Proper surface drainage of decks may eliminate the need for waterproof paving membranes. If a paving membrane must be used, the deck should be treated and cured to minimize future interaction between the treatment and the asphalt. Another alternative is to sandwich the paving membrane between two layers of asphalt pavement.

Use the thinnest possible tack coat. Follow the mix and application specifications and all BMPs.

Glossary

This glossary includes terms related to asphalt pavement as well as terms normally associated with bridges. Some of the terms shown may not be included in the report. Many of the definitions are from the *Asphalt Institute Handbook*, the Asphalt Emulsion Manufacturer's Association, the Federal Highway Administration's *Bridge Inspector's Training Manual*, and *Timber Bridges—Design, Construction, Inspection, and Maintenance* (Ritter 1990).

AASHTO: American Association of State Highway and Transportation Officials.

AWPA: The American Wood Preservers' Association.

Abutment: A substructure supporting the end of a single span or the extreme end of a multispan superstructure. The abutment may retain or support the approach embankment.

Aggregate: Any hard, inert material of mineral composition such as gravel, crushed rock, slag, or sand used in pavement applications, either by itself or for mixing with asphalt.

Aggregate, dense graded or well graded: An aggregate mixture that has a particle-size distribution graded from the maximum size to smaller sizes so that a compacted layer has high stability and a relatively low ratio of void spaces.

Aggregate, open graded: An aggregate having little or no small-size gravel or rock as filler. The void spaces in a compacted layer of open-graded aggregate are relatively large and interconnected.

Asphalt (also referred to as asphalt cement and asphalt binder): A dark brown to black cementitious material in which the predominant constituent is bitumen, occurring in nature or obtained during petroleum processing. Asphalt is a constituent of most crude petroleum.

Asphalt leveling course: A mixture of asphalt and aggregate of variable thickness used to eliminate irregularities in the contour of an existing surface before placing a pavement layer.

Asphalt overlay: One or more courses (layers) of asphalt pavement placed on an existing pavement or bridge deck.

Asphalt pavement: Pavements consisting of a surface course (layer) of mineral aggregate coated and cemented together with asphalt cement on supporting courses, such as asphalt bases; crushed stone, slag, or gravel; or on Portland cement concrete, brick, or block pavement.

Asphalt pavement system: Pavements consisting of mineral aggregate coated and cemented together with asphalt cement and possible paving fabric or membranes on a supporting surface (road base course or bridge deck).

Asphalt prime coat: An application of a low-viscosity cutback asphalt product to an absorbent surface. It is used to prepare an untreated base for an asphalt surface. The prime coat penetrates into the base and plugs the voids, hardens the top, and helps bind the base to the overlying asphalt course.

Asphalt seal coat: A thin asphalt surface treatment used to waterproof and improve the texture of an asphalt wearing surface. Depending on the purpose, seal coats may or may not be covered with aggregate. The main types of seal coats are aggregate seals, fog seals, emulsion slurry seals, and sand seals.

Asphalt tack coat: A very light application of asphalt, usually asphalt emulsion diluted with water. It is used to help bond the surface being paved and the overlying course.

Assay: Determination of the amount of preservative in a sample of treated wood by appropriate physical and chemical means.

Backwall: The topmost portion of an abutment above the elevation of the bridge seat, functioning primarily as a retaining wall. It also may serve as a support for the extreme end of the bridge deck and the approach slab.

Base: Road layers below the primary structural layer.

Beam: A structural member supporting a load applied transverse to it. Beams used in bridge construction include stringers, girders, and floor beams.

Bleeding: The secretion of liquid preservative from treated wood. The secreted preservative may evaporate, remain liquid, or harden into a semisolid or solid state. Bleeding also describes the secretion of liquid asphalt to pavement surfaces and is usually caused by too much asphalt or other hydrocarbons in the pavement mix.

BMP: Best management practices.

Charge: All the wood treated at one time in one cylinder of a treating tank.

Check: A lengthwise separation of the wood that extends across the rings of annual growth, commonly caused from stress set up in wood during seasoning.

CITW: Canadian Institute of Treated Wood.

Continuous spans: Spans without joints designed to extend over one or more intermediate supports.

Creosote: A wood preservative that is a distillate of coal tar produced by high-temperature carbonization of bituminous coal.

Crown of the roadway: The vertical dimension describing the total amount of the surface that is raised from the gutter to the centerline, sometimes termed the cross-fall of the roadway.

Cutback asphalt: Asphalt cement that has been liquefied by blending it with petroleum solvents (also called diluents). On exposure to atmospheric conditions, the diluents evaporate, leaving the asphalt cement to perform its function of cementing and waterproofing.

Decay: Disintegration of wood by wood-destroying fungi.

Deck: The portion of a bridge that provides direct support for vehicle and pedestrian traffic.

Deck bridge: A bridge in which all supporting members are beneath the roadway.

Delamination: Separation of layers of pavement or of the paving from the bridge deck.

Differential deflection: Movement of a structure or displacement between two adjoining members of a structure.

Dowels: Short steel rods used to join deck panels by transferring shear forces to prevent differential deflection.

Dry: Wood with a relatively low moisture content: 19 percent for sawed lumber and 16 percent for glued-laminated lumber.

Durability: A general term for permanence or resistance to deterioration. As applied to wood, durability refers to lasting qualities or permanence in service, particularly with reference to its resistance to decay and other forms of deterioration.

Empty-cell process: Any process for impregnating wood with preservatives or chemicals in which air, trapped in the wood under pressure, is released to drive out part of the injected preservative or chemical. The intent is to obtain good distribution of preservative in the wood, leaving the cell cavities only partially filled to minimize preservative bleeding.

Emulsified asphalt: A mixture of asphalt cement and water containing a small amount of an emulsifying agent that creates a heterogeneous system with two normally immiscible phases (asphalt and water) in which the water forms the continuous phase of the emulsion and minute globules of asphalt form the discontinuous phase. Emulsified asphalts may be either positively (cationic) or negatively (anionic) charged, depending on the emulsifying agent.

Expansion joint: A joint designed to allow expansion and contraction caused by temperature changes, load, or other forces.

Floor beam: A beam located transverse to the centerline or direction of travel on a bridge that supports the deck or other components of the floor system. A deck comprised of glued-laminated panels placed transversely across longitudinal girders or longitudinally across floor beams.

Geotextiles: A fabric (woven or nonwoven) used to reinforce soils or asphalt pavement. Geotextiles are also used as filters.

Girder: A flexural member designed to resist bending that is the main or primary support for the structure. In general, a girder is any large beam.

Glued-laminated timber: An engineered, stress-rated product of a timber-laminating plant comprising assemblies of specially selected and prepared wood laminations securely bonded with adhesives.

Heartwood: The interior wood in a tree extending from the pith to the sapwood.

Hot mix asphalt (HMA): A mixture of asphalt and aggregate produced in a batch or drum-mixing facility. To dry the aggregate and obtain sufficient fluidity of the asphalt cement, both must be heated before mixing—giving rise to the term "hot mix."

Laminated wood: An assembly made by bonding layers of veneer or lumber with an adhesive so that the grain of all laminations is essentially parallel. When the laminations are dimensional lumber (2 by 4, and so forth), they are commonly referred to as glued-laminated lumber.

—**Horizontally laminated**: Laminated wood in which the laminations are arranged with their wider dimension about perpendicular to the direction of load.

—**Vertically laminated**: Laminated wood in which the laminations are arranged with their wider dimension about parallel to the direction of load.

Longitudinal: The direction of travel on a bridge parallel to the roadway or bridge centerline.

Lumber: Sawed or planed wood.

Medium-curing (MC) asphalt: Cutback asphalt composed of asphalt cement and kerosene-type diluent of medium volatility.

Moisture content: The amount of water contained in wood, usually expressed as a percentage of the weight of the wood after it has been oven dried.

Monolithic: One single piece of material. In the case of stress-laminated timber decks, a single timber slab.

Nail-laminated deck: A timber bridge deck, usually installed across longitudinal beams, comprised of a series of dimensional lumber laminations placed on edge and nailed together on their wide faces.

Open-graded asphalt friction course: A pavement surface course that consists of a high-void asphalt plant mix that allows rapid drainage of rainwater through the course and out the shoulders. The mixture is characterized by a large percentage of one-sized coarse aggregate. This surface prevents tires from hydroplaning and increases skid resistance.

Paving fabrics: A geotextile used with asphalt pavement to stabilize and reinforce the pavement.

Paving membranes: An asphalt-impregnated paving fabric (usually rubberized or polymer-modified asphalt) intended to make a waterproof layer.

Penetration: The depth to which preservative enters the wood.

Pentachlorophenol (penta): A chlorinated phenol used as a wood preservative, usually carried in a base of petroleum oil.

Performance graded (PG): Asphalt grade designation used in Superpave based on the binder's mechanical performance at critical temperatures and aging conditions. This system uses engineering principles to directly correlate laboratory testing to field performance.

Polymer-modified asphalt: Conventional asphalt cement to which a styrene block copolymer or styrene butadiene rubber (SBR) latex or neoprene latex has been added to improve performance.

Plank deck: Timber planks, usually aligned transversely and nailed to the load-carrying member.

Plant mix: A mixture produced in an asphalt mixing facility that consists of mineral aggregate uniformly coated with asphalt cement, emulsified asphalt, or cutback asphalt.

Preservatives: Insecticides injected into wood to inhibit deterioration caused by insects and fungi.

Pressure process: Any process of treating wood in a closed container where the preservative is forced into the wood under pressure. The American Wood Preservers' Association usually specifies pressure greater than 50 pounds per square inch.

Prime coat: An application of a low-viscosity cutback asphalt product to an absorbent surface. It prepares an untreated base for an asphalt surface finish. The prime coat penetrates into the base and plugs the voids, hardens the top, and helps bind the base to the overlaying asphalt course.

Rapid-curing (RC) asphalt: Cutback asphalt composed of asphalt cement and naphtha or gasoline-type diluent of high volatility.

Reflective cracking: Cracks that migrate up from lower layers of the subgrade or a timber deck.

Retention: The amount of preservatives remaining in the wood after treating, usually expressed as pounds per cubic foot.

Retort: A steel tank, commonly horizontal, in which wood is placed for pressure treatment.

Rigid pavement system: A concrete slab serves as the structural component. Because of the slab's structural capacity, it tends to distribute loads over a wide area. Underlying bases are provided as a surface only and do not contribute to the strength of the system. Minor variations in subgrade strength have little influence on the structural capacity of the rigid pavement.

Roadway: The portion of the bridge deck intended for use by vehicles and pedestrians.

Rutting: Depressions in an asphalt pavement from traffic use over a "soft" pavement.

Sapwood: The wood of pale color near the outside of the log. Sapwood is more porous than heartwood and less resistant to decay.

Shrinkage: A change in the dimension of structural timber caused primarily by changes in moisture content.

Slow-curing (SC) asphalt: Cutback asphalt composed of asphalt cement and oils of low volatility.

Solid lumber: Sawed lumber that has not been modified, or built up by gluing.

Solvents: Carriers for chemical preservatives.

Span: The distance between the end supports center-to-center when applied to the design of beams, stringers, or girders.

Stiffener beam: A load distributor beam attached to the underside of the deck. A longitudinal stiffener beam is placed midway between the longitudinal load-carrying beams. The stiffener beam is the length of the bridge, helping reduce differential deflections between deck panels.

Stress-laminated deck: A longitudinal deck without beams or stringers, stressed into a monolithic slab by high-strength reinforcing rods.

Stringer: A longitudinal beam supporting the bridge deck.

Structural capacity: The measure of carrying capacity of a structure or member.

Subgrade: The layer in the asphalt pavement structure immediately below the base course is called the subgrade course. The subgrade soil is sometimes called foundation soil.

Substructure: The structural members that carry the loads from a bridge's superstructure to its foundation.

Superelevation: The difference in elevation between the inside and outside edges of a roadway in a horizontal curve. This elevation counteracts the effects of centripetal force.

Superpave: Short for ***su***perior ***per***forming asphalt ***pave***ment, a performance-based system for selecting and specifying asphalt binders and for designing an asphalt mixture.

Superpave mix design: A mixture design system that integrates the selection of materials (asphalt, aggregate) and their volumetric proportions with the project's climate and the designed traffic.

Tack coat: A very light application on asphalt, usually asphalt emulsion diluted with water. It ensures a bond between the surface being paved and the overlying course.

Timber: Wood members at least 5 inches in the shortest dimension that are suitable for building purposes.

Transverse: Perpendicular to the direction of travel, the roadway, or the bridge centerline.

Wearing surface: The topmost layer of material applied to a roadway or bridge that receives the traffic loads and resists the resulting tire abrasion—also known as the wearing course.

Wheel load: The total load transferred by one wheel of a vehicle.

Wingwall: The retaining wall extension of an abutment that is intended to hold the sideslope material in place.

WWPI: Western Wood Preservers' Institute

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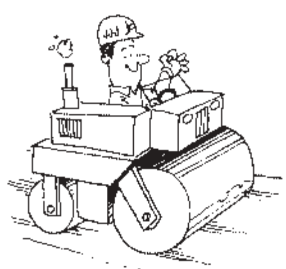

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Notes

Notes

About the Authors

Merv Eriksson has a bachelor's degree in civil engineering from the University of North Dakota. He worked as a highway and bridge engineer with the U.S. Federal Highway Administration before joining the Forest Service's Northern Region in 1979 as a structural engineer. Merv was the leader of the bridge design and construction group from 1986 until 1997. He then joined MTDC and served as the technical coordinator for the Wood in Transportation program and managed a number of projects for the technology and development centers and the Forest Products Laboratory. Merv is now the regional bridge engineer for the Pacific Northwest Region.

Homer Wheeler (retired) graduated from the Montana State University in 1959. When he retired from his 35-year career with the Montana Department of Transportation, he was assistant director of engineering. He worked another 6 years for the Strategic Highway Research program as the Southeast Region engineer for long-term pavement performance.

Sharon Kosmalski graduated from the University of Minnesota's Institute of Technology in 1993 with a degree in civil engineering. She began her Forest Service career in 1991 and has been involved in bridge design, construction, maintenance, and specialized inspections for three forests in three regions. She is currently the bridge program manager and inspector-in-charge on the Payette National Forest.

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Provides guidance for designing timber decks and long-lasting asphalt paving systems. More treated timber bridges are being constructed in the United States now that the efficiencies of these bridges have been recognized. Asphalt pavement wearing surfaces applied to these bridges can enhance their long-term performance and reduce deck abrasion. Problems associated with the asphalt surfaces are due to deck flexibility and shrinkage, excess preservative treatment and asphalt, and incompatibility between the treatment and the paving system. Improper treatment and construction can contribute to problems. Proper timber treatment and correct bridge and pavement design will ensure economical, long-term pavement performance, while minimizing environmental problems.

Keywords: adhesion, best management practices, cleaning, deflection, design, glued laminated, nail laminated, paving membranes, preservatives, shrinkage, stress laminated, wood

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For further technical information, contact Merv Eriksson at:

USDA Forest Service, Pacific Northwest Region
333 SW. First Ave.
Portland, OR 97204
Phone: 503–808–2230
Fax: 503–808–2511
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