TBIRC
Timber Bridge Information Resource Center

CROSSINGS

NEWSLETTER OF THE WOOD IN TRANSPORTATION PROGRAM

Editor - Tinathan Coger | Issue 23 | August 1996

Final Reminder

National Conference on Wood Transportation Structures

This conference will be held on **October 23-25, 1996,** in Madison, Wisconsin at the University of Wisconsin - Memorial Union near Lake Mendeta.

The purpose of the conference is to present state-of-the-art information on wood utilization in transportation applications. The target audience for the conference is practicing engineers in government and private practice and members of the academic and industry communities.

For additional information and/or to register, contact:

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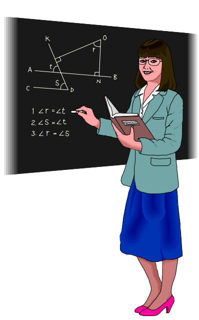

FIELD PERFORMANCE OF STRESS-LAMINATED TIMBER BRIDGES

ABSTRACT

Stress-laminated timber bridges were first introduced in the United States in the late 1980s. Since that time, the concept of stress-laminating has received a great deal of attention and hundreds of bridges have been built. Most of these bridges are located on rural, low volume roads. To evaluate the performance of stress-laminated bridges, the UDSA Forest Service, Forest Products Laboratory, implemented a nationwide bridge monitoring program in 1988 which was expanded in 1992 to include a cooperative program with the Federal Highway Administration. This paper presents a summary of monitoring results and observations obtained through that program for stress-laminated bridges which have been continuously monitored for two years or more. Included are discussions related to bridge construction, wood moisture content, stressing bar force, thermal response, vertical creep, load test behavior, and condition evaluation. Based on the monitoring program results, performance of stress-laminated timber bridges is generally satisfactory, although there are several areas where performance can be improved.

INTRODUCTION

Stress-laminated timber bridge decks consist of a series of wooden laminations placed edgewise between supports and stressed together with high-strength steel bars (Figure 1). The bar force, which typically ranges from 111 to 356 kN (25,000 to 80,000 lb.), squeezes the laminations together so that the stressed deck acts as a solid wood plate. The concept of stress-laminating was originally developed in Ontario, Canada in 1976 as a means of rehabilitating existing nail-laminated lumber decks that delaminated due to cyclic loading and wood moisture content fluctuations (Taylor and Csagoly 1979; Taylor et al. 1983). In the 1980s the concept was adapted for the construction of new bridges and numerous structures were successfully built or rehabilitated in Ontario using the stress-laminating concept. The first stress-laminated timber bridges in the United States were built in the late 1980s. Since that time, several hundred stress-laminated bridges have been constructed, primarily on rural, low volume roads. Although most stress-laminated bridges are slab-type decks

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constructed of sawn lumber or glued-laminated timber (glulam), the technology has been extended to systems employing stress-laminated trusses, T-beam and box sections. This paper is limited to slab-type decks.

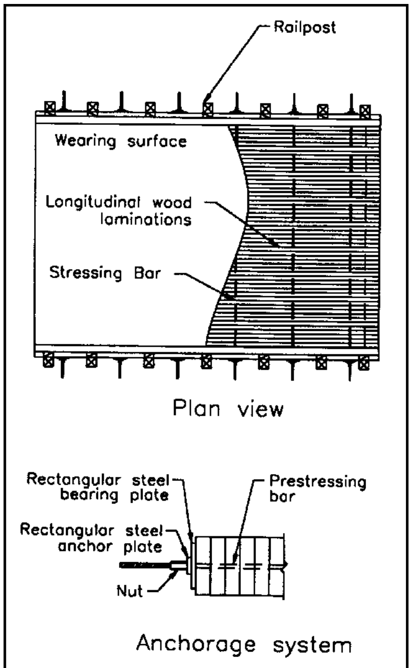

Figure 1.—Typical configuration of a stress-laminated timber deck bridge.

From a material aspect, stress-laminated bridges generally require smaller, lower quality lumber than is typically required for other types of mechanically laminated timber decks. Because load transfer between the deck laminations is developed by friction, all laminations need not be continuous over the bridge span and butt joints are permitted within certain limitations (Figure 2). This reduces the length of lumber required and is more conducive to the use of locally available wood species. Additionally, the laminating process disperses natural defects in the wood so that variability is reduced and higher design values are possible. The bridges are relatively simple to build and are often assembled by local crews in one day or less.

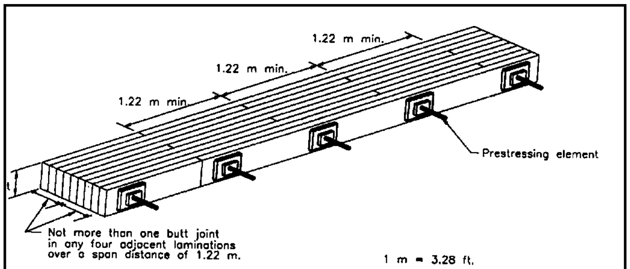

Figure 2.—Common butt joint configuration used in stress-laminated timber bridges.

To evaluate the field performance of stress-laminated bridges, the USDA Forest Service, Forest Products Laboratory (FPL) implemented a nationwide bridge monitoring program in 1988. In 1992 the program was expanded through a cooperative program with the Federal Highway Administration (FhWA). Its purpose is to monitor and evaluate bridge performance and behavior in order to develop, confirm and improve methods of design, fabrication and construction. This is being accomplished by obtaining representative information on the performance of different bridge designs and materials under various geographical and environmental conditions. Presented here are results for stress-laminated bridges continuously monitored for two years or more. Included are observations and discussions related to bridge construction, wood moisture content, stressing bar force, thermal response, vertical creep, load test behavior, and condition evaluation. This paper is a condensed version of a paper presented at the 6th International Conference on Low Volume Roads (Ritter et al. 1995).

BRIDGE MONITORING

Bridges included in the bridge monitoring program are selected on the basis of location, configuration, wood species, and preservative treatment. In most cases, the monitoring is undertaken as a cooperative venture with the bridge owner, and local personnel play a key role in collecting field data. Data on each bridge is normally collected over a period of 2 to 3 years using monitoring methods developed by FPL (Ritter et al. 1991). Key activities and methods include:

Bridge construction: Information on bridge construction is obtained by visiting the site and documenting the construction sequence and methodology.

Moisture content: The moisture content of the bridge deck is typically measured with a resistance-type moisture meter at 6 to 12 locations on its underside. Core samples are also taken when the accuracy of the meter is questionable, such as when waterborne preservatives are used or when the deck moisture content exceeds the fiber saturation point (approximately 25 to 30%).

Stressing bar force: To monitor stressing bar force, two or three load cells are installed on each bridge. The strain in the load cell is a good approximation of the stressing bar force and is measured manually with a portable strain indicator, or automatically by a remote data acquisition system.

Thermal response: The response of stress-laminated decks to temperature changes is measured with thermocouples installed at various locations in the bridge deck. Deck temperatures are then compared with ambient temperatures and load cell readings to evaluate bridge response to temperature change.

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Vertical creep: Long-term vertical creep is measured by referenced elevation readings taken from various locations at the bridge centerspan with surveyor's equipment.

Load test behavior: Bridge behavior under vehicle loading is determined for various vehicle positions by measuring the relative displacements of the bridge deck from an unloaded to loaded condition. For single-lane bridges, one vehicle is used. For two-lane bridges, one vehicle is used in each lane with both lanes loaded simultaneously.

Condition evaluation: A condition evaluation of each bridge is completed several times during the monitoring period and involves intensive visual inspections and photographic documentation.

The FPL/FhWA bridge monitoring program currently includes about 40 stress-laminated timber bridges across the United States. Each year, five to eight new bridges are added and approximately the same number of bridges are completed. The information presented in this paper is based on data obtained over the past 6 years from 24 bridges continuously monitored for 2 years or more. Performance trends and conclusions are representative of the general behavior demonstrated by the bridges. Specific information on individual bridges will be available in the future as reports are published. Additional information on stress-laminated bridge performance is available in Wacker and Ritter 1992, 1995a, 1995b; Ritter et al. 1995; Dickson and GangaRao 1989; Gutkowski and Lewis 1989; and Mozingo and DiCarlantino 1988.

FIELD PERFORMANCE OF STRESS-LAMINATED DECKS

The field performance of stress-laminated timber deck bridges has generally been satisfactory when proven design and construction practices are followed. However, deviations from recommended practice have resulted in performance problems in some cases. The majority of these problems relate to serviceability rather than the structural integrity (safety) and have resulted from the evolutionary nature of the stress-laminated system in the United States. Although proven design and construction criteria have been in place in Ontario for a number of years, definitive guidelines on design, construction and maintenance practices are still evolving in the United States. Additionally, many United States designs differ from those in Ontario and do not necessarily fit within existing standards of practice. One method to improve field performance of stress-laminated timber bridges is to learn from past experience and incorporate proven technology into future bridges.

Bridge Construction

Stress-laminated timber bridges have been constructed using a number of methods (Ritter 1990). When laminations are continuous (i.e. no butt joints), they may be individually placed on abutments, bars inserted, and the bridge stressed in-place. When butt joints are used, the bridge may be prefabricated into nailed or banded panels that are stressed together in the same manner. Additionally, bridges may be prefabricated into prestressed panels that are joined with bar couplers at the site. Regardless of the construction method used, current practice requires that stress-laminated timber bridges be stressed three times during the construction process: at initial assembly; 1 to 2 weeks after the first stressing; and 4 to 6 weeks after the second stressing (Ritter 1990). Most bridges in the United States have been stressed using one jack rather than multiple jacks commonly used in Ontario. This is primarily an economic issue since the high cost of a multiple jack system cannot be justified unless a large number of stress-laminated bridges are built on a continuing basis. A single jack system costs about $1,200 and provides similar results if proper stressing procedures are followed.

Field monitoring has shown that construction methods and practices can affect bridge performance and appearance. When using a single jack for stressing, the most frequent problems have resulted from a failure to recognize the laminations are compressed together and the bridge width narrows as the bars are stressed. The narrowing is generally most pronounced during the first stressing but may also occur during the second stressing at a lesser level. By the third stressing, deck narrowing is minimal. The amount of compression during the first stressing can vary from 25 to 75 mm (1 to 3 in.) depending on bridge width, wood species, the straightness of the lumber laminations, and other factors. More compression occurs as the bridge width increases and most softwoods compress more than dense hardwoods. Warped laminations compress more because they straightened during the stressing operation.

The most frequent construction problems were encountered during the stressing procedure and were evidenced as insufficient prestress, deck distortion, and deck attachment damage.

Insufficient Prestress. — For acceptable bridge performance, all bars must be uniformly stressed to the full design level during each of the three required stressings.

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Field observations indicate that when a single jack is used, stressing one bar compresses the deck at that location and reduces the force in adjacent bars. In bridges where each bar was stressed only once, substantial variations in bar force were noted. To prevent this from occurring each bar must be stressed several times as the deck compresses, until the prestress level is uniform for all bars. The most successful method for accomplishing this is to begin stressing at one end of the bridge and sequentially stress each bar along the bridge's length. This is repeated until three to six passes have been made and the force reaches the designated level in all bars.

Deck Distortion. — Compression of the laminations during stressing has led to deck distortion in numerous bridges. To keep the bridge's edges straight and parallel, the initial stressing must be gradual, starting at a low prestress that is progressively increased. If the full prestress level is placed initially in one bar, the deck will compress significantly at that location and deck distortion can result. This can lead to an “hourglass” shape (the bridge is narrower at centerspan than at the ends) if the midspan bar is fully stressed first, or a “reverse hourglass” (ends narrower than centerspan) if the end bars are fully stressed first. Other patterns of distortion have been observed. To minimize deck distortion during the initial stressing, a low initial prestress of 10 to 25 percent of the design level should be placed in the bars and the deck shape observed. If distortion is evident, the prestress is adjusted accordingly until the distortion is removed. The prestress is then increased to 25 to 50 percent of the design level and the bridge restressed. The process is repeated until the entire deck is stressed to the full design level.

Deck Attachment Damage. — When attachments to the bridge deck are made prior to deck narrowing, damage to the deck and attachments may occur. This has been most evident when curbs are bolted in-place or the bridge is attached to the substructure before stressing is complete. As a result, fasteners and other metal components may bend and wood may be damaged. To prevent such damage, deck attachments should be added only after the second stressing is complete. In addition, the use of slotted mechanical connectors may help to compensate for further deck narrowing in-service.

Moisture Content

The moisture content of wood at the time of installation and in-service is a primary consideration for the design of all exposed wooden structures. Changes in moisture content affect wood's dimensions, stiffness and strength. Changes in stiffness, and strength are recognized in the design process by applying wet-use reductions to design values, when applicable. Of primary concern in stress-laminated bridges are the dimensional changes that occur in the wood as its moisture content changes. Below the fiber saturation point (approximately 25 to 30%), wood will expand as moisture is gained and contract when moisture is lost. In stress-laminated bridges these dimensional changes can affect bridge performance. Moisture content changes in stress-laminated decks can be generally considered as global and localized changes. Global changes affect the entire structure and occur slowly as the moisture content of the laminations at the time of construction moves toward an equilibrium moisture content dictated by the environment (Ritter 1990). Localized changes affect the exposed portions of the bridge and occur more rapidly in response to surface wetting or seasonal fluctuations in equilibrium moisture content.

Global Moisture Content Effects. — The effect of global moisture content changes in stress-laminated timber bridges depends on the moisture content of the wood laminations at the time of construction and the average equilibrium moisture content for the bridge site. With few exceptions, bridges in the monitoring program used sawn lumber at a relatively high moisture content. Typical moisture content at the time of construction ranged from 25 to 29 percent; moisture contents in excess of 30 percent have been measured on numerous bridges. At these levels, the wood moisture content substantially exceeds the expected equilibrium moisture content, which typically averages from 16 to 20 percent depending on the location (McCutcheon et al. 1986). Conversely, several stress-laminated timber bridges constructed with glulam members have been installed with average moisture contents as low as 12 percent. Field measurements have shown that global moisture content changes toward an equilibrium level are relatively slow. As a result, the observed effects of global moisture content changes are minimal during the first several months after bridge construction. However, the effects become pronounced as the deck eventually loses or gains moisture. Global moisture content changes directly affect stressing bar force levels which decrease when moisture is lost and increase when moisture is gained. The best bridge performance has been observed when the moisture content of the wood laminations at the time of construction averages 10 to 16 percent. Acceptable performance has been observed when the moisture content is 16 to 20 percent. As the moisture content at time of installation increases above 20 percent, adverse performance becomes more pronounced.

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Localized Moisture Content Effects. — Field data indicate that localized moisture content changes caused by surface wetting and seasonal moisture content changes also affect the performance of stress-laminated timber bridges. The most pronounced effect appears to occur in relatively deep decks, (300 to 400 mm or 12 to 16 in. thick) whose surface is exposed or covered with a lumber plank wearing surface. In such cases the deck's surface absorbs moisture more rapidly than its inner and lower portions. As a result, repeated wetting or standing water may cause the upper portion of the deck's volume to swell relative to the lower portion. Although no adverse structural effects have resulted from this response, evidence of differential moisture content is manifest as a slight transverse crown in the deck, wood crushing in the outside edge laminations along the top of the bar anchorages and/or an increase in stressing bar force. The comparative performance of several bridges indicates that the potential for these conditions can be greatly reduced or eliminated if the deck surface is paved with asphalt, preferably in combination with a waterproof geotextile membrane.

Stressing Bar Force

The structural integrity and serviceability of stress-laminated decks depends on the compressive stress maintained between the lumber laminations. For acceptable performance, this compression must be sufficient to prevent vertical slip due to shear and opening of gaps between the laminations due to transverse bending. Current design procedures recommend a minimum interlaminar compression of 690 kPa (100 lb./in.^{2}) at the time of bridge construction. This initial compressive stress is based on the assumption that 50 to 60 percent of the stress will be lost over the life of the structure due to wood stress relaxation and minor changes in wood moisture content (Ritter 1990). Slip between the laminations does not begin until the interlaminar compression has been reduced to 140 to 165 kPa (20 to 24 lb./in.^{2}).

Construction procedures for stress-laminated timber bridges recommend that bridges be stressed three times over a period of 6 to 8 weeks. Based on monitoring program results, it appears that this stressing sequence is not adequate in all cases. Many of the bridges in the monitoring program have required restressing within the first 2 years afterconstruction. For bridges constructed of sawn lumber, the bar force should be checked annually for the first 2 years after construction, and every 2 years thereafter. This period may be extended after bar force stabilizes to 2- to 5-year intervals. For bridges constructed of glulam, the bar force should be checked every 2 years for the first 4 years after construction and every 5 years thereafter. These general guidelines may have to be adjusted for site-specific conditions.

Bar force loss has resulted in structural problems in one bridge in the monitoring program. In this case it was known that the bar force was dropping rapidly, yet no corrective action was taken. Vertical slip of the laminations resulted from heavy truck traffic and was evident in one lane at centerspan as a depression where the wheels tracked. After the slip occurred, the bridge continued to carry traffic at a reduced load level until it was restressed and subsequently repaired. When this type of slip occurs, the stressing bars act as dowels between the laminations. The initial failure affects primarily serviceability and is plainly evident, so ample warning is given so that repairs can be made before further problems develop.

Compressive stress between the laminations is determined by measuring the stressing bar force. Bar force, and thus interlaminar compression, is a complex interaction of many effects including wood stress relaxation, moisture content changes, bar anchorage performance, and temperature fluctuations. When evaluating the causes of stressing bar force losses in bridges, it is impossible to accurately determine the individual effect of the numerous contributing factors. However, the following observations were made relative to the general performance of bridges in the monitoring program.

Stress Relaxation. — When laminations are subjected to the long-term loads applied by stressing bars, the wood slowly deforms across the entire bridge width and the bar force is reduced. This phenomenon is known as stress relaxation. The rate of stress relaxation is greatest when the bridge is initially stressed and normally decreases with each subsequent stressing. Bar force loss due to stress relaxation continues at a slow rate which gradually decreases after construction. Stress-relaxation losses increase as the moisture content of the wood increases and are greater for softwoods such as Douglas-fir and southern pine than for dense hardwoods like oak or maple. In addition, bar force loss due to stress relaxation increases as the bridge width (i.e., the volume of wood between the bar anchorages) increases.

Moisture Content. — The moisture content of the wood laminations at the time of construction is one of the most influential factors on maintaining bar force. The best performance has been demonstrated when the wood laminations are installed at an average moisture content less than 16 percent. At this level, global increases in lamination moisture content toward a higher equilibrium

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level result in beneficial swelling which increases bar force and offsets loss due to stress-relaxation. When installed at moisture contents between 20 and 30 percent, moisture content decreases are gradual, but have resulted in a loss of bar force of as much as 80 percent over 18 months. When laminations are above the fiber saturation point at the time of construction, drying is slow. At these high moisture contents, no loss in bar force due to wood shrinkage is evident until the wood dries below the fiber saturation point. Once the moisture content drops below this level however, bar force losses are substantial.

Anchorage System Performance. — The anchorage system for stressing bars must distribute the bar force into the deck without crushing wood along the outside laminations. This is achieved by placing a bearing plate under the nut at each bar end. When crushing does occur, force reduction in the stressing bars can be substantial. When properly sized plates are used on softwoods, crushing into the bridge's outside laminations has typically ranged from 3 to 6 mm (1/8 to 1/4 in.). With dense hardwoods, properly designed plates have produced virtually no crushing. Anchorage performance on softwood bridges is improved when two or more dense hardwood laminations are used along each of the bridge's edges.

Thermal Response. — Bridges in the monitoring program are located across the United States. Many are subjected to annual temperature variations of 38°C (100°F) or more. Two bridges have been instrumented to measure the effect of large temperature changes on stressing bar force. The bridges are located where ambient temperatures have reached 38°C (100°F) in summer and -40°C (-40°F) in winter. Data for both bridges indicate that there is a decrease in bar force when the temperature drops, due primarily to differential thermal contraction of the metyal and wood components. The magnitude of this decrease depends on the magnitude of the temperature change, the duration of cold temperature, the wood species and moisture content, and other factors. The temperature effect is most pronounced when the wood is at or above fiber saturation point. Short-term temperature declines of 24 hours or less have little effect on bar force since the thermal conductivity of wood is very low. The cold temperature effect appears to be fully recoverable, with the bar force returning to the original level once the temperature rises. At this time, there is no evidence to indicate that temperature effects alone have produced any structural or serviceability problems in stress-laminated timber bridges. Laboratory and field work in this area is continuing.

Vertical Creep

Wood is subject to permanent deformation due to long-term sustained loads. This deformation, known as creep, depends on a number of factors and is more pronounced when the magnitude of the applied load and the moisture content of the wood increase. For timber bridges, creep results in vertical deformation of the span and, in extreme cases, a noticeable sag. Although this is not a significant structural problem, it is alarming to the public. Additionally, creep can disrupt bridge drainage and facilitate water ponding which may be a hazard to bridge users. To offset the effects of creep, stress-laminated timber bridges made with glulam or lumber with butt joints can be constructed with a camber; those made with continuous lumber cannot.

Creep has not been a problem in stress-laminated bridges where the live load deflection for standard highway loading has been limited to 1/360 or 1/400 of the bridge span, regardless of the presence of butt joints or the moisture content of the laminations. Three bridges, which were among the first built in the United States, are exceptions in that creep has resulted in a sag at centerspan of 50 to 75 mm (2 to 3 in.). In each case, the bridges have a high span -to -depth ratio, were installed with a lamination moisture content greater than 28 percent, and had butt joints.

Load Test Behavior

Load tests were conducted on all stress-laminated timber bridges in the monitoring program to assess structural behavior under static loading. Each bridge is load-tested twice; once shortly after construction and again at the end of the monitoring period, 2 to 3 years later. Dynamic load tests have also been conducted on 9 bridges. In all cases, load tests have shown that stress-laminated timber decks act as large orthotropic plates. The magnitude of the deck displacements and the deformed shape of the loaded bridge depend on the bridge span and width, vehicle weight and configuration, deck material properties, the location and frequency of butt joints, the prestress level, the edge-stiffening effects of curb and rail systems, and other factors. Based on results of the static and dynamic tests, and analytical modeling, revised methods for predicting the behavior of stress-laminated timber bridges are currently being developed at the FPL.

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Condition Evaluation

The condition of each bridge in the program is evaluated several times during the monitoring period. Information is collected relative to the bridge's general condition, stressing system corrosion and asphalt wearing surface performance.

***General Condition.* —** General condition assessments are performed on stress-laminated timber decks to evaluate the performance of various components and design features unrelated to those associated with stress-laminating. The majority of the noted deficiencies have been minor, but typically have the potential to develop into more serious problems. Most deficiencies are attributable to poor design detailing and/or construction methods. Unfortunately, many of the same deficiencies are also common on other types of timber bridges. This is attributable primarily to the inexperience of most engineers and contractors in wood design and construction methodology.

Common observations related to the general condition of stress-laminated timber bridge decks point to the need for:

1. *An increased emphasis in the area of field treating site-cut wood with a preservative.* On numerous bridges, field drilling and cutting of wood without subsequent field-treatment with a preservative was evident. This can lead to decay and premature deterioration of bridge members. Ideally, machining of all wood used in bridge construction should be completed before it is treated with a preservative. This is difficult with stress-laminated decks because the location of bolt holes for deck attachments cannot be confirmed until the bridge is stressed. Consequently, holes for curbing, railing and substructure attachment are often field-drilled. When this is done, untreated wood is exposed in the member's interior. To prevent decay, untreated wood must be field-treated with a preservative. Field treating in accordance with American Wood Preservers' Association (AWPA) Standard C14 (AWPA 1993) will significantly reduce the potential for decay.

2. *Improved design detailing and maintenance for debris control.* Accumulations of dirt and debris on wood bridges can trap moisture and create an environment suitable for decay and deterioration. Although wood preservatives effectively protect the wood, decay is possible at locations of field-drilling and cutting, and where the preservative treatment is inadequate. On many of the stress-laminated bridges in the monitoring program, significant debris accumulations were observed on the bridge deck, under curb openings, and at the bearings. Although no adverse affects were noted, the potential for future deterioration was evident. To some degree, debris accumulation can be reduced by proper design detailing. However, periodic maintenance to remove debris is essential for maximizing bridge longevity.

3. *Special attention to ensure proper preservative retention.* Wood used in stress-laminated decks is typically treated with oil-borne preservatives in accordance with AWPA Standard C14 (AWPA 1993). Dripping of the preservative from bridges has not been a widespread problem; however, minor dripping has been observed on several bridges. In such cases, the wood was treated to preservative retentions substantially above those required by AWPA standards. Compression of the laminations by stressing and heating by the sun forced minor amounts of preservative from the wood. Dripping does not appear to be a problem when laminations are treated in accordance with AWPA standards to the stated preservative retention.

***Stressing System Corrosion.* —** Adequate corrosion protection of the steel stressing system has been a primary consideration since the development of stress-laminated timber bridges. The original bridges constructed in Ontario used a plastic tube filled with grease to protect the stressing bars. Bridges built in the United States have typically used galvanizing as a means of corrosion protection, although several bridges have been built with galvanized bars placed in grease-filled tubes. Over the 6 years of the bridge monitoring program, corrosion has been occasionally observed in exposed bar locations where anchorage nuts were not oversized to compensate for the thickness of the bar galvanizing. Corrosion resulted when the nuts were forced onto the bars and the galvanizing was damaged. Properly sizing nuts or field-applying galvanizing compound to the damaged areas will eliminate this problem. Inside the deck, bar corrosion has not been a problem; however, the monitoring period has been relatively short and conclusions on long-term corrosion potential cannot be made. Based on preliminary observations, enclosing the bars in grease-filled plastic tubes may be warranted if the bridge is subjected to corrosive de-icing chemicals in winter. Additionally, protective tubes may be warranted when the lumber laminations are treated with waterborne preservatives containing copper, and it is anticipated that their moisture content will exceed 20 percent. Under these conditions, depletion of zinc in the galvanizing is possible due to an electrochemical reaction with copper in the preservative.

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NEW PUBLICATIONS

Field Performance of Timber Bridges - 5. Little Salmon Creek Stress-Laminated Deck Bridge

The report describes the development, design, construction, and field performance of the Little Salmon Creek bridge on the Allegheny National Forest in Pennsylvania. The bridge was constructed in November 1988 as part of a commitment by the USDA Forest Service-National Forest System to demonstrate new and emerging timber bridge technology. The bridge is a single-lane, single-span, stress-laminated deck that is approximately 26-ft. long and 16-ft. wide. The bridge is unique in that it is the first known stress-laminated deck superstructure constructed of hardwood lumber.

For a copy of this report, please contact the Timber Bridge Information Resource Center at 304-285-1591.

New Technology, Local Labor, Local Material Timber Bridge Demonstration Project
The North Road Bridge
Foster, Rhode Island

This 12-page report, written by Eileen D. Young and produced by Cooperative Extension, College of Resource Develoment, University of Rhode Island, describes the first timber bridge demonstration project in Rhode Island in regard to its design, construction, and monitoring performance. The bridge is a stress-laminated design. It was manufactured from Red Oak and constructed in 1992. For a copy of the report or a project video titled *"Modern Timber Bridges: A New Return for Old New England"*, contact:

Bryan Wolfenden, Executive Director
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17 Smith Ave.
Greenville, RI 02828
Phone: 401-949-4418
FAX: 401-949-3650

Best Management Practices for the Use of Treated Wood In Aquatic Environments

Western Wood Preservers Institute and Canadian Institute of Treated Wood have combined efforts in developing and making available to the public Best Management Practices (BMPs) for treated wood used in aquatic environments. The purpose of the BMPs is to assure that treated wood products are manufactured and installed in a manner which minimizes any potential for adverse impacts to aquatic environments. BMPs have been developed for Creosote, Chromated Copper Arsenate (CCA), Pentachlorophenol (Penta), Ammoniacal Copper Quat (ACQ) as well as several other preservatives.

For a copy of the publication, please contact:

Western Wood Preservers Institute
601 Main Street, Suite 405
Vancouver, WA 98660
Phone: 360-693-9958 or 1-800-729-9663
FAX: 360-693-9967

Canadian Institute of Treated Wood
200-2430 Don Reid Drive
Ottawa, ON K1H 8P5 Canada
Phone: 613-737-4337
FAX: 613-247-0540

Article contributions, questions or comments may be sent to Ed Cesa, Acting Program Director, Timber Bridge Information Resource Center or Ms. Tinathan A. Coger, Information Assistant; USDA Forest Service; 180 Canfield Street; Morgantown, WV 26505; Phone: 304-285-1591 or 304-285-1596; or FAX: 304-285-1505; DG: S24L08A.

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FIELD PERFORMANCE ... *continued from page 7*

***Asphalt Wearing Surface Performance.* —** The performance of asphalt wearing surfaces on wooden bridge decks has long been a concern. Wooden deck systems employing nail-laminated lumber or unconnected deck panels have been associated with cracking or disintegration of asphalt wearing surfaces. This is caused by differential movement between individual laminations or vertical movement at joints. Many of the stress-laminated timber bridges in the monitoring program have been paved with an asphalt wearing surface. In most cases, the asphalt is placed to a compacted thickness of 50 to 75 mm (2 to 3 in.) at the centerline that tapers to about 40 mm (1.5 in.) along the deck edges. Because stress-laminated decks act as large plates, and the applied prestress sufficiently prevents vertical movement of the individual laminations, asphalt cracking has not been observed on any of the stress-laminated decks. Even decks designed for full highway loads and a design live load deflection as high as 1/250 of the bridge span have shown no asphalt cracking during the monitoring period.

SUMMARY

Several hundred stress-laminated timber bridges have been built in the United States since 1988. Based on observations of 24 bridges monitored over a period of 2 years or more, bridge performance has generally been satisfactory. Performance can be improved in several areas, however. A summary of key recommendations based on monitoring program observations follows.

1. When bridges are stressed with a single jack, three to six stressing passes should be made along the bridge's length to ensure uniform prestress at the required level. In addition, the stress level should be gradually increased over the first several passes to minimize deck distortion.

2. Attachments to the bridge superstructure including curbings, railings, and substructure should not be made until after the bridge has been fully stressed two times.

3. The average moisture content of the wood laminations at the time of bridge construction should be 10 to 16 percent, and should not exceed 20 percent.

4. For bridges constructed of sawn lumber, bar force should be checked annually for the first two years after construction, and every two years thereafter. This period may be extended after bar force stabilizes to 2- to 5-year intervals. For bridges constructed of glulam, bar force should be checked every 2 years for the first 4 years after construction and every 5 years thereafter.

5. Live load deflection should be limited to a maximum of 1/360 to 1/400 of the bridge span.

6. When oil-borne wood preservatives are used, the preservative retention should not exceed that recommended in AWPA Standard C14.

7. Consideration should be given to enclosing stressing bars in grease-filled plastic tubes if the bridge is subjected to corrosive de-icing chemicals or if the laminations are treated with waterborne preservatives containing copper and it is anticipated that their moisture content will exceed 20 percent.

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Editor's Note:

Field Performance of Stress-Laminated Timber Bridges is the lead article for the Summer 1995 Issue of *Wood Design Focus*. For this issue of *Crossings*, the article was reprinted in its entirety.

The theme for the Summer 1995 Issue of *Wood Design Focus* is Stress-Laminated Timber Bridges. Other articles include Stress-Laminated T Beam and Box Beam Bridges in West Virginia, Metal Plate Connected Wood Truss Bridges, and Stress-Laminated Bridges of Structural Composite Lumber. For a copy of this publication, contact:

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Assessing the Effectiveness of the Wood In Transportation Program in Creating Additional Markets for Wood

The Wood In Transportation(WIT) program, formerly known as the National Timber Bridge Initiative, sponsored a study in the winter of 1995-96, to measure the impact modern timber bridges have had upon manufacturing operations in regards to expanding the range of markets for wood products.

Methods

A comprehensive list of 93 companies involved in the manufacture and sale of timber bridges was developed. The sources used were the WIT program, the Timber Bridge Manual, and interviews with knowledgeable people in the industry. A questionnaire mailed to plant managers was the primary source of data collection. The first part of the questionnaire used categorical questions to identify the type of firm, products it produced, and years it has supplied materials for timber bridges. The second portion of the questionnaire used rating scales to measure respondents' evaluation of specific areas of market and economic development activities. The final part of the questionnaire asked open-ended questions to assess future research and educational needs in regards to modern timber bridges.

The questionnaire was reviewed by knowledgeable faculty members and people in the industry. The responses of the pretest were used to clarify question wording and order. The questionnaire, along with a hand-signed cover letter, was mailed to 93 firms in December of 1995. After three mailings, seventy-one questionnaires were returned, 40 of which replied that their companies were involved in the manufacturing of modern timber bridges. Thirty-one of the companies were no longer in business or responded that they were not involved in timber bridges. This resulted in an adjusted response rate of 64 percent.

Results and Discussion

One-third (14) of the responding companies listed wood treating as their primary business activity. Over 20 percent (9) of the firms were categorized as glue-laminated timber manufacturers, and 17 percent (7) listed themselves as timber bridge manufacturers. All firms, on average, felt that timber bridge sales would increase approximately 15 percent over the next five years, with a range from a decline of 50 percent to an increase of 200 percent. Companies were asked how many employees worked directly with timber bridge manufacturing five years ago, presently, and a prediction of five years from now. On average, responding firms indicated that 10 employees worked five years ago, 11 employees work currently, and they predicted that 12 employees will work in timber bridge manufacturing five years from now.

Two objectives of the WIT program are to expand markets for wood products and create service industries for bridge construction and related transportation uses. To evaluate the attitudes of manufacturers toward these goals, a series of questions were asked in which the respondents were asked to rate, on a scale from one to seven, whether they agreed or disagreed with a given statement. Firms agreed most with the statements that the WIT program has assisted them with *selling more bridge materials, utilizing important research to expand markets for wood, and convincing local decisionmakers on the importance of timber as a bridge material.* These results indicate that WIT technology transfer and research goals are being valued by industry participants.

They agreed least with the statements that the WIT program has assisted them in *hiring new workers, retaining workers that would have been laid off, expanding their operations, and using species they otherwise would have not used.* These data indicate that although more material is being used in timber bridges, it is not enough to substantially increase the economic activity of the respondents. They do not appear to be using alternative species or different fabrication methods. This supports the concept that responding firms do not feel there has been a substantial economic impact upon their operations by involvement in supplying wood for modern timber bridges.

To see if a difference existed between new timber bridge firms (i.e., firms that have started producing bridge material since the start of the Wood In Transportation program) and old bridge firms (i.e., firms that were providing bridge materials before the WIT program began), nonparametric statistical tests were run on all 16 statements. New firms did not significantly differ from old firms on the rating of the statements at a .05 level. Although the order of agreement differed slightly between new and old firms, in general, the two groups agreed with the statements.

The firms were asked to rank the overall effectiveness of the WIT program on a scale from one to seven, with seven indicating that the program was highly effective in expanding markets for wood. The average rating for all responding firms was 3.91. In other words, the program was <u>moderately effective</u> in expanding the markets for wood. New firms ranked the Program slightly lower (3.67) compared to old firms (4.04). However, again there was no statistical difference at the .05 level.

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This information indicates that manufacturers feel that the WIT program has assisted them in expanding markets and products.

Manufacturers identified the greatest obstacles to the advancement of timber as:

- education of engineers on timber for bridge construction; poor perceptions of wood by highway officials;
- in certain situations, the cost of timber bridges are not competitive with other materials;
- many highway officials are resistant to change;
- and, there are environmental concerns over harvesting timber and the use of wood preservatives.

When asked to identify how to overcome these obstacles, the primary method suggested was to educate and train students in engineering schools as well as professional engineers. It was felt that since engineers are not properly exposed to wood engineering as they acquire their formal education, biases are developed early that are difficult to change. Another method to overcome these obstacles is to increase the distribution of information to engineers that are already making bridge decisions. This could be accomplished through more technical literature, short courses, and continued conferences and demonstration bridges that can teach the effectiveness of timber as a bridge material. The final method, which many respondents felt was imperative, is that standard cost-effective timber bridge designs should be distributed to all state highway departments. It is believed that if states' departments of transportation have access to timber bridge designs, they will use them. Within the past year, standard plans have been developed for timber bridges using southern pine.

Respondents were asked to identify the best aspects of the WIT program and the areas that they felt could be improved. Overwhelmingly, respondents felt that the awareness created about timber bridges by the WIT program and the educational materials and activites were the best aspects. Areas in which the WIT program could be improved include: better distribution of publications and research findings; there was too much emphasis on poor, uneconomical designs in the beginning of the Program; there should be less emphasis on hardwoods; and that a comprehensive report on all WIT demonstration projects to date should be available.

Conclusion

This study identified that modern timber bridges have positively affected the industry in increasing the sales of bridge material, utilizing new research methods to expand markets, and convincing local decisionmakers on the importance of timber for bridges. This has not led, however, to expansion of operations or additional employment. Since many of these modern timber bridges have been experimental, it may take many years before evaluation and acceptance by highway officials. Only then may additional employment be seen in the industry. It is the belief of the industry that the greatest obstacle is the lack of education for highway officials and college students. Distribution of information to officials was also identified as an important need. This would support the current educational and information efforts of the Wood In Transportation program.

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