USDA
United States
Department of
Agriculture

Forest Service

Forest
Products
Laboratory

National Wood
in Transportation
Information
Center

Research
Paper
FPL–RP–599

In cooperation
with the

United States
Department of
Transportation

Federal
Highway
Administration

Effect of Wood Preservatives on Stress-Laminated Southern Pine Bridge Test Decks

James A. Kainz
Nur Yazdani
Joy Kadnar

Abstract

For wood to work successfully in external environments, it must be treated with chemical preservatives. This study determined the effect of various oil- and water-based preservatives on the performance of stress-laminated Southern Pine bridge decks. This 2½-year study was limited to one species for the wood laminations and one type of stress-laminated system. Nine half-width, full-length stress-laminated test decks were constructed of Southern Pine lumber. Each test deck was treated with one of seven preservatives and outfitted with one of three bar anchorage types. Moisture content levels did not change significantly throughout the monitoring period, which implies that the wood had achieved moisture equilibrium prior to testing. According to this study, when Southern Pine stress-laminated bridge decks are properly designed, (1) the anchorage system has a negligible effect on bar force retention and (2) water-based preservatives may be successfully used to treat these bridge decks. We recommend that the design guidelines currently available for stress-laminated decks treated with oil-based preservatives be extended to decks treated with water-based preservatives and constructed with any bar anchorage system. This recommendation is based on the similarity of the behavior of water- and oil-based preservatives in the stress-laminated test decks treated in this study.

Keywords: preservatives, waterborne, oil-based, stress-laminated, timber, bridges

August 2001

Kainz, James A.; Yazdani, Nur; Kadnar, Joy. 2001. Effect of wood preservatives on stress-laminated Southern Pine bridge test decks. Res. Pap. FPL-RP-599. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 12 p.

A limited number of free copies of this publication are available to the public from the Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53705–2398. Laboratory publications are sent to hundreds of libraries in the United States and elsewhere.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

Acknowledgments

This research is part of the joint U.S. Department of Agriculture Forest Service, Forest Products Laboratory, and the Federal Highway Administration Timber Bridge Research Program. The research was conducted at Florida A&M University, Tallahassee, Florida. We thank the Florida Division of Forestry for donating most of the Southern Pine lumber used in this study. Appreciation is also extended to CSI Laporte, Hickson Corporation, and Osmose Wood Preserving, Inc., for donating the preservative treatment used on the test decks.

Contents

Effect of Wood Preservatives on Stress-Laminated Southern Pine Bridge Test Decks

James A. Kainz,[1] General Engineer
Forest Products Laboratory, Madison, Wisconsin

Nur Yazdani, Professor
Joy Kadnar,[2] Engineer
Florida State University, Tallahassee, Florida

Introduction

It is widely recognized that the condition of transportation infrastructure in the United States is deteriorating, with approximately 30% of the nation's 575,000 highway bridges listed as either structurally deficient or functionally obsolete (FHWA 1998). Of the deficient or obsolete bridges, approximately 75% are located on secondary and rural roads. Repair or replacement of these structures is considered critical to the development and economy of rural America.

Historically, wood has been shown to be an excellent material for bridge construction and rehabilitation. Modern timber bridges can provide a design life of more than 50 years with minimum maintenance when properly fabricated and treated with preservatives. The life-cycle cost of timber bridges is competitive with concrete and steel bridges, and timber is an economical option for rural highway bridges where spans average 12 m (40 ft) or less. Wood also has a high strength-to-weight ratio, which makes it ideal for bridges in rural areas where access to heavy lifting equipment is limited. Wood becomes even more attractive as a bridge material as new systems are developed and construction contractors become familiar with them.

Background

One type of timber bridge that has become increasingly popular for short-span bridge construction is the stress-laminated wood deck. This bridge type consists of a series of lumber laminations placed edgewise between supports that are compressed together with high strength steel bars (Fig. 1). The resulting deck performs like an orthotropic plate of wood. The configuration of the deck makes it ideal for construction using local labor and requires little "high-tech" equipment to complete.

The stress-laminated bridge concept was originally developed in the late 1970s in Ontario, Canada (Batchelor and others 1979). The concept was used to rehabilitate nail-laminated bridges that were delaminating under repeated highway loading. It was subsequently discovered that the stress-laminated technique also improved performance. Over time, the stress-laminating technique was applied to new construction as well. Ultimately, design procedures and specifications were drafted and included in the Ontario Highway Bridge Design Code (OMTC 1983) for new and rehabilitated bridges. Both new and rehabilitated stress-laminated bridges have been used in Canada for many years, and they have performed well. Substantial research on stress-laminated decks was also conducted at the USDA Forest Service, Forest Products Laboratory (FPL), and the University of Wisconsin (Oliva and Dimakis 1988, Oliva and others 1990).

Stress-laminated bridges continue to increase in popularity as technology transfer progresses. More than 400 stress-laminated deck bridges have been built in the United States during the past few years, and many more are under construction. Recent modifications of the stress-laminated system include the stress-laminated T- and box-beam bridges (Barger and others 1993, Lopez–Anido and Gangarao 1993). These modifications were intended to improve material efficiency and provide longer spans. A typical stress-laminated timber bridge is shown in Figure 2.

For wood to work successfully in external environments, it must be treated with chemical preservatives to protect it from decay and insect attack. Two broad categories of preservatives commonly used for this purpose are oil-based

---

[1] Currently Senior Engineer, Applied Research Associates, Inc., Raleigh, North Carolina.

[2] Currently Engineer, Gas Operations Division, City of Tallahassee, Florida.

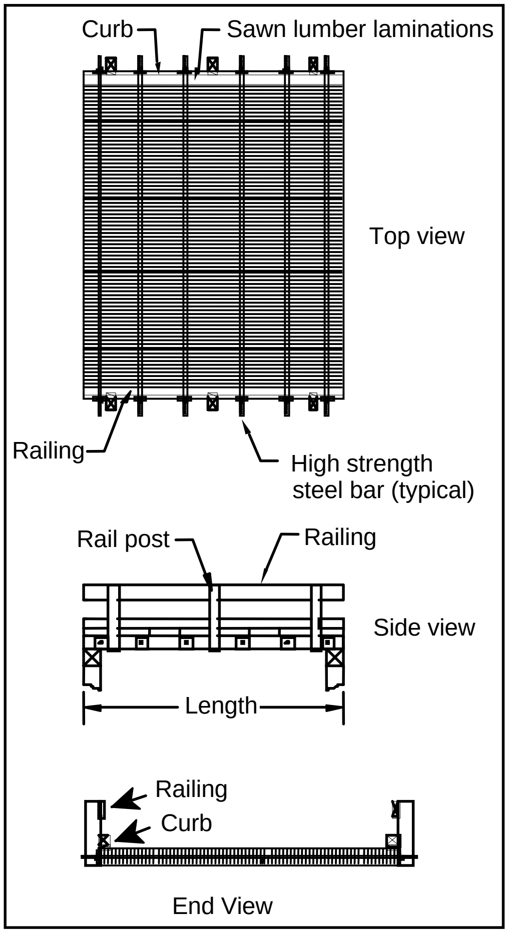


Figure 1—Configuration of stress-laminated timber deck.

Figure 2—Typical bridge with stress-laminated deck.

and water-based. In transportation structures, the American Association of State Highway Officials (AASHTO) (AASHTO 1992) recommends the use of oil-based preservatives unless pedestrian contact is a concern. Currently, oil-based preservatives such as creosote and pentachlorophenol (also known as penta) are the primary types of wood preservatives used in structural transportation applications. In these preservatives, the oil carrier provides a natural resistance to moisture penetration that protects the lumber from dimensional changes caused by moisture content fluctuations. Water-based preservatives such as chromated copper arsenate (CCA) are used when pedestrian contact is a concern. However, there has been a reluctance to use water-based preservatives in structural applications because they do not provide the same inherent resistance to moisture change as do oil-based preservatives.

The dimensional stability of wood is important in stress-laminated bridges because the wood laminations and the steel bars act together. If the wood laminations shrink or swell, the bar force in the steel bars decreases or increases. The performance of the stress-laminated deck depends on maintaining a certain level of bar force in the steel bars. In this way, the wood lamination dimensional change can affect performance. Although there was concern regarding treating stress-laminated timber bridges with water-based preservatives (Ritter and others 1990), several stress-laminated CCA-treated bridges have been built. Performance monitoring of these bridges has shown positive results (Wacker and Ritter 1995, Wacker and others 1996). However, additional information is needed to determine the effect, if any, of water-based preservatives on the performance of stress-laminated timber bridge decks.

Objectives and Scope

The overall purpose of this study was to determine the effect of various oil- and water-based preservatives on the performance of stress-laminated Southern Pine bridge decks. Specific objectives were to (1) assess the effect of various wood preservatives on bar force and moisture content changes with time in stress-laminated Southern Pine bridge decks, (2) evaluate the effectiveness of three types of bar anchorage on stress-laminated Southern Pine bridge test decks treated with the same preservative, and (3) formulate recommendations for design standards and specifications for stress-laminated bridge decks made of CCA-treated Southern Pine lumber.

The scope of this research was limited to one wood lamination species and one type of stress-laminated system. Nine half-width, full-length stress-laminated test decks were constructed of Southern Pine lumber. Each test deck was treated with one of seven preservatives and outfitted with one of three bar anchorage types.

Materials and Methods

To evaluate the effects of different preservatives on the performance of stress-laminated bridges, nine test decks were constructed and monitored at Florida State University, Florida Agriculture and Mining, College of Engineering, in Tallahassee. The test decks were constructed and left in an exposed environment for 2½ years, during which time bar force, moisture content, deck width, temperature, and relative humidity were monitored.

Test Decks

Each test deck measured 1.5 by 6.1 m (5 by 20 ft) and was constructed of 40 standard 38- by 286-mm (nominal 2- by 12-in.) sawn lumber laminations. The test deck laminations were visually graded No. 2 or better Southern Pine sawn lumber of various lengths. The lamination lengths were not full span; therefore, butt joints were provided at a frequency of not more than one joint in any four laminations over a 1.2-m (4-ft) distance, as specified in AASHTO (1992).

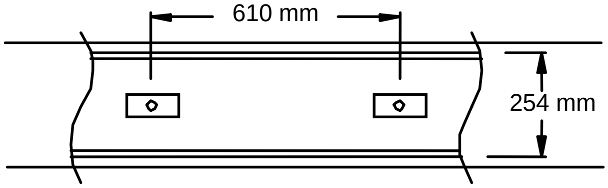
Preservative

The test decks were treated with seven different oil- and water-based preservatives that complied with the American Wood Preservers' Association (AWPA) standard C14 (AWPA 1990). Four test decks were treated with water-based preservatives that are variations of the CCA formulation as determined by AWPA standard P5. To control the water movement through the wood laminations, three of these CCA formulations contained water-repellent additives at the manufacturer's standard levels. The three additives are proprietary products and were labeled CCA/type 1, CCA/type 2, and CCA/type 3. The CCA preservatives were chosen based on market popularity and availability.

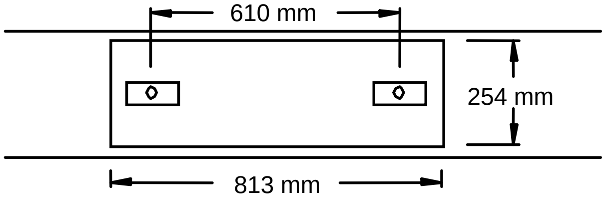
Three of the test decks were treated with oil-based preservatives. The oil-based preservatives were penta/heavy (P9) oil, creosote, and CCA/Hickson in an oil emulsion. These are the most available in the market. The CCA/Hickson in oil is a proprietary formulation of standard CCA and was referred to as CCA/type 4 (oil) for this report. The following retention levels were used for the various preservatives: creosote 192 kg/m^3 (12 lb/ft^3), penta/heavy oil 9.60 kg/m^3 (0.60 lb/ft^3), and CCA/type 4 (oil) 9.60 kg/m^3 (0.60 lb/ft^3).

Bar Anchorage System

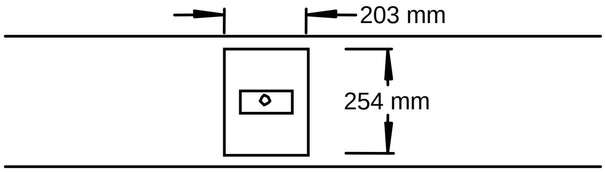
Three bar anchorage types were used in this study: a continuous steel channel, a semicontinuous plate system, and a discrete plate system (Fig. 3). These three anchorage systems were installed on test decks 1, 3, and 5, which had been treated with CCA/type 1 preservative (Table 1). The remaining six test decks were configured with the discrete bearing plate system. The continuous steel channel and discrete plate were designed according to procedures in Ritter (1990). The semicontinuous plate had no specific design guidelines but was considered a combination of the continuous channel and the discrete plate anchorage systems. According to design specifications, the discrete bearing plate system creates the most critical value for compression perpendicular to grain on the outside laminations. The design compressive stress of 2.28 kPa (330 lb/in^2), obtained through the design method, was well below the allowable wet-use compressive stress perpendicular to grain of 2.61 kPa (378 lb/in^2) for Southern



Continuous steel channel



Semicontinuous bearing plate



Discrete bearing plate

Figure 3—Bar anchorage systems.

Table 1—Test deck preservative and anchorage type

Test deck	Preservative	Anchorage type
1	CCA/type 1	Continuous channel
3	CCA/type 1	Semicontinuous plate
5	CCA/type 1	Discrete plate
2	Pentachlorophenol (penta)	Discrete plate
4	CCA/type 4 (oil)	Discrete plate
6	CCA/type 2	Discrete plate
7	Creosote	Discrete plate
8	CCA/type 3	Discrete plate
9	CCA	Discrete plate

Pine lumber (AFPA 1991). All anchorage systems were designed correctly; therefore, the discrete plate system controlled the design, and all other systems should perform equally or better.

Common to all anchorage configurations was the use of a 51- by 127- by 25.4-mm (2- by 5- by 1-in.) anchor plate and a high strength steel nut. The discrete bearing plate system consisted of these common elements plus a properly sized bearing plate that contacted the outside lamination. The continuous channel bearing system also used the common elements plus a continuous C12 by 30 channel (AISC 1986) along the length of the bridge to contact the outside laminations.

The semicontinuous bearing system used the common elements plus a plate that extended between two bars, with an additional 100 mm (4 in.) on each side of the bars. The 100-mm (4-in.) extension on either side of the bar was based on the design procedure for discrete bearing plates.

Test Deck Construction

The lumber used for the test decks was supplied in lengths of 1.2, 2.4, 3.7, and 6.1 m (4, 8, 12, and 20 ft). All lumber laminations were predrilled with 25.4-mm (1-in.) holes spaced at 0.61 m (2 ft). The lumber was then sent out for preservative treatment. After treatment, each batch of lumber was delivered to the testing site and stored on the ground. During the initial construction process, the lumber was placed in position on a timber frame on the ground. In compliance with ASTM 722 (ASTM 1988), 15.9-mm- (5/8-in.-) diameter galvanized coarse high strength steel bars were then inserted through the holes, and the test decks were lifted with a forklift onto concrete traffic barriers. One end of the barrier was slightly elevated to provide drainage. Because the test decks were wider than the lifting equipment, the test decks became misaligned during the lifting process. To alleviate this problem, the test decks were subsequently refabricated directly on the concrete barriers. The high strength rods were reinserted through the predrilled holes during the edgewise placement of lumber. When all laminations were positioned to achieve a width of 1.52 m (5 ft), bar anchorages were placed on the rods.

The nuts were initially hand tightened. A hydraulic jack was then used to progressively tighten the nuts to achieve a snug fit between the laminations by tensioning alternate rods on each test deck. After all laminations were in contact, the test decks were stressed to design forces by applying pressure on each successive bar. Three passes of the hydraulic jack were made on each test deck to achieve a force of approximately 117.4 kN (26,400 lb), which equates to an interlaminar stress of 689 kPa (100 lb/in^2). The stressing was done over 4 weeks, starting January 1994, based on recommended procedures (Ritter 1990). The test decks were placed as shown in Figure 4. Test decks on the concrete barriers are shown in Figure 5.

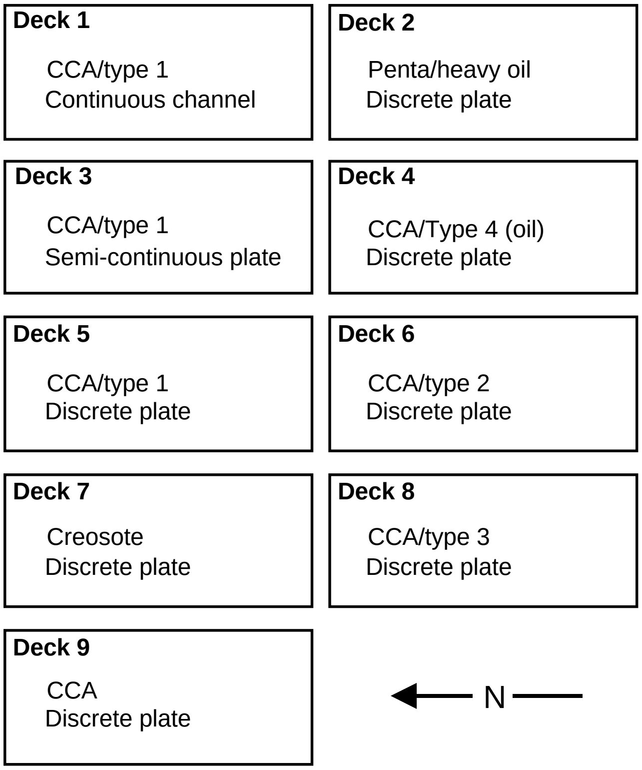


Figure 4—Test deck layout.

Figure 5—Test decks on concrete barriers.

Performance Monitoring

To evaluate performance and bar force retention of the test decks, we collected ambient air and deck temperature, relative humidity, moisture content, and bar force data. A data logger was installed on site to automatically measure air and internal deck temperature and bar force. Measurements for relative humidity and moisture content were taken with hand-held probes. In addition, bar anchorage performance was evaluated.

Temperature and Relative Humidity

Ambient temperature and relative humidity set the equilibrium moisture content of the surrounding environment, which in turn sets the equilibrium moisture content in the wood (Forest Products Laboratory 1999). Ambient air temperature and internal deck temperature were measured at 6-h intervals using thermocouples attached to the data logger located on site. Additional ambient temperatures and relative humidity levels were measured once daily at 6 a.m. with a hand-held probe.

Tallahassee, Florida, is located about 36 km (20 miles) from the Gulf of Mexico and has a mild and moist climate. In contrast to the southern part of the Florida peninsula, Tallahassee experiences four well-defined seasons, with considerable winter rainfall and significantly less sunshine in winter than in summer. The annual average temperature is about 20°C (68°F). During winter, topographic effects and cold air drainage into the lower elevations produce a wide variation of low temperatures on clear and calm nights. The airport, which is in close proximity to the location of the test decks, and the surrounding suburban areas average about 36 freezing occurrences each winter. During summer months, high temperatures and humidity are common in northern Florida. Temperatures of 32°C (90°F) or higher are expected about 90 days per year, but only about 22 of these days have readings as high as 35°C (95°F). The wettest month is July, followed by August, September, and June. The driest months are October, November, and April.

Moisture Content

As a result of the concern about dimensional stability of the lumber laminations caused by changes in moisture content, accurate moisture meter readings were essential to monitoring the performance of the test decks. Moisture content of the wood laminations was determined by two methods: moisture meter readings and moisture coring.

The moisture meter readings were taken at four numbered locations on each test deck: two from the top of the deck and two from the underside. Readings were taken at quarter- and mid-span in the longitudinal direction. At each location, readings were taken at depths of 25, 50, and 75 mm (1, 2, and 3 in.). To obtain moisture content, probe pins were hammered into the wood, parallel to the grain, in accordance with standard ASTM procedures (ASTM 1992a,b). Readings were obtained in this manner at 2-week intervals that began August 21, 1994, and continued throughout the monitoring period.

Moisture cores were extracted at the final stressing from between the pin entry points of the moisture meter. After a sample was extracted, the core holes were closed with treated plugs. The cores were placed in sealed numbered bottles for future moisture content determination per ASTM (1992a). Additional core samples were taken and tested on two other occasions at approximately 6-month intervals. The cores were taken from each test deck from the top and bottom at quarter- and mid-spans, respectively, in a similar manner. These cores were collected in January and August 1994. In October 1995, only two cores were obtained from the top and underside of the test deck at mid-span. The average core depth was 75 to 100 mm (3 to 4 in.), with an average weight of 7 to 9 g (0.25 to 0.30 oz) each.

Bar Force and Data Acquisition

Collection of bar force data began at the completion of the initial stressing on January 22, 1994. A second stressing was performed 7 days later, with the final stressing performed about 6 weeks after the first stressing (Ritter 1990). At each stressing, the bars were tensioned to the full design force of approximately 120 kN (27,000 lb).

The force levels in two bars on each test deck were measured with hollow-core load cells made by FPL. The load cells were placed on bar numbers 5 and 7 on each test deck and were connected directly to the data logger unit. Load cells were provided with metal covers for protection from direct weather exposure. Cables for the load cells were attached to the underside of the test deck and routed to the data logger. Zero balances of the load cell were verified throughout the study at 6-month intervals. Bar force readings were also taken at 6-h intervals. On a regular basis, data were downloaded from the data logger to a portable personal computer. The data logger was placed in a locked metal enclosure beneath test deck 6.

Anchorage Performance

Measurements of the test deck’s width provided an indication of wood crushing, but additional measurements at the anchorage perimeter were also made. Horizontal measurements were taken to detect anchorage deformations. Each week, the test decks were visually inspected for general condition. Any unusual features were noted and photographically recorded. In addition, photographs of each test deck were periodically taken to document performance.

Results and Discussion

The following results include all data from the monitoring period and supersede a previous report on this study (Kainz and others 1996).

Temperature and Relative Humidity

Figure 6 represents the temperature data collected at 6-h intervals by the data logger. Temperature and relative humidity readings collected with a hand-held probe are shown in Figure 7. The representation of temperatures in Figures 6 and 7 compare well with one another. Temperature and relative humidity data followed patterns that are typical for Tallahassee. Examination of the late fall and winter data revealed the considerable change in temperature that occurs between days. This was also consistent with established

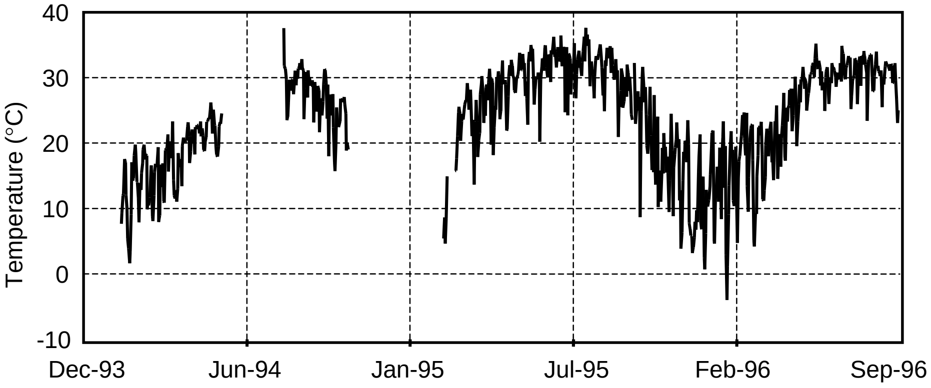


Figure 6—Ambient temperature data from data logger.

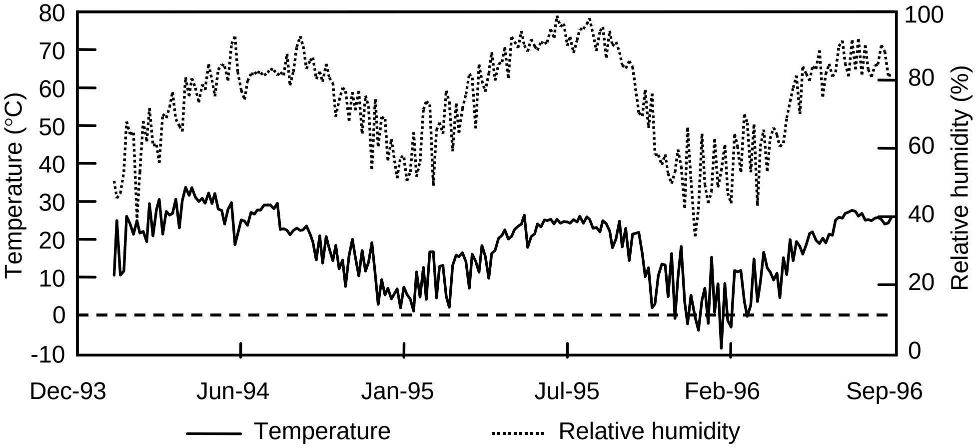


Figure 7—Temperature and relative humidity data collected with hand-held probe.

ambient patterns in Tallahassee. In the 1994 fall and winter seasons, this trend varied considerably, primarily because of the large amount of precipitation. In the 1995 fall season, the relative humidity fell below normal and the precipitation decreased. In the 1995–1996 season, Tallahassee had a considerably colder than usual winter, with the relative humidity increasing considerably. Weather conditions in the spring of 1996 followed typical, well-established patterns that occur in the Florida panhandle.

Moisture Content

Figures 8 and 9 show electrical resistance moisture content readings from test decks 2 and 5. These moisture content levels were based on a 75-mm (3-in.) moisture content depth and were taken at mid-span of both test decks. As shown, small differences were observed between the readings taken from the top of the test decks compared with the bottom. It appears that the top of the test decks experienced slightly more moisture content variation than did the bottom. This is probably the result of increased wetting caused by rainfall, although the test decks were sloped to provide runoff.

We also observed that the test decks had similar moisture content levels throughout the monitoring period, even though test deck 2 had an oil-based preservative and test deck 5 had a water-based preservative. The moisture content did not change significantly throughout the monitoring period, which implies that the wood had achieved moisture equilibrium prior to testing. Moisture content levels from the individual cores were combined and averaged to obtain top and bottom measurements. Moisture content results from the core analyses are presented in Table 2. Test decks 2 and 7, treated with penta/heavy oil and creosote, respectively, exhibited the highest moisture content levels. These high moisture content readings were possibly caused by the lumber being treated when it was relatively green, thus trapping the moisture within its interstitial spaces. These moisture content readings could also be a result of the chemical treatment that fills the wood cell cavities and evaporates during the ovendrying process, thus creating a false high reading. Except for test deck 9, all test decks treated with a water-based preservative showed an average moisture content of 18%.

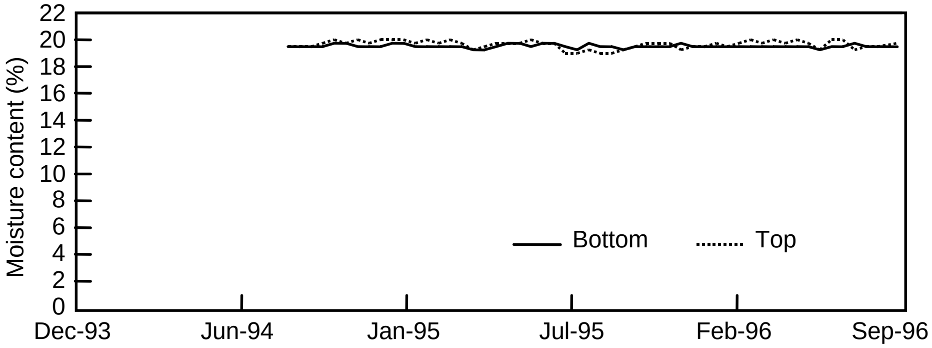


Figure 8—Electrical resistance moisture content measured on the top and bottom of test deck 2 at mid-span.

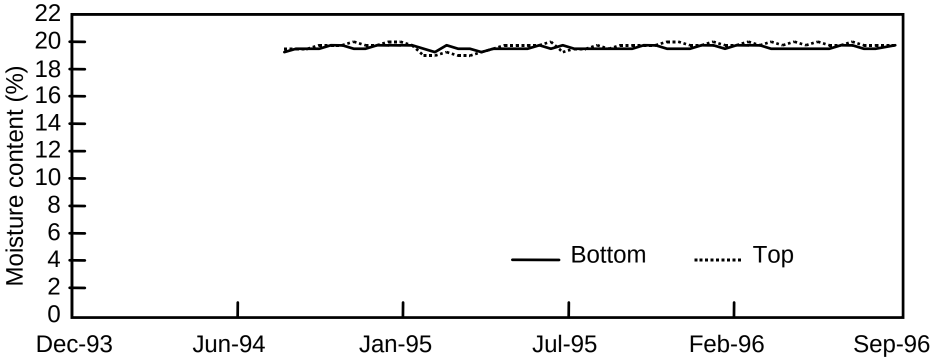


Figure 9—Electrical resistance moisture content measured on the top and bottom of test deck 5 at mid-span.

Table 2—Moisture content results from core analyses

Test deck	Moisture content (%)					
	January 1994		August 1994		October 1995	
	Top	Bottom	Top	Bottom	Top	Bottom
1	18	16	17	15	18	16
2	27	27	33	30	51	30
3	16	20	16	21	16	17
4	17	17	24	21	25	15
5	18	15	20	16	15	17
6	15	16	13	15	15	14
7	28	31	42	25	38	23
8	19	16	17	15	20	15
9	20	23	23	19	28	17

At the time of construction, the moisture content of the test decks ranged from 15% to 20%. During monitoring, the moisture content increased slightly from 18% to 22%. In addition, some discrepancies existed between moisture readings from the meter and the core analysis, especially for the oil-based preservatives. One reason for the discrepancy was the size of the core. Another reason was the treatment process that may have left excess amounts of preservative in the wood after treatment, which would give a false increase reading in moisture content. Both methods showed that the moisture content of the test decks did not change significantly with time.

Bar Force Retention

Bar force data obtained from each load cell were averaged for the purpose of comparing the forces with time. To illustrate the general trend, which was exhibited in all test decks, Figure 10 shows the bar forces from test deck 5. The two interruptions in bar force data were a result of flooding at the test site. During these times, the data logger was damaged and being repaired. Data were assumed to be accurate because test decks were not submerged and these data followed trends observed in other stress-laminated bridges.

In Figure 10, the two sharp peaks in early 1994 were a result of the initial bar tensioning, because the load cells were installed immediately following the first bar tensioning. The bar force in all test decks averaged approximately 110 kN (25,000 lb) after completion of the three initial bar

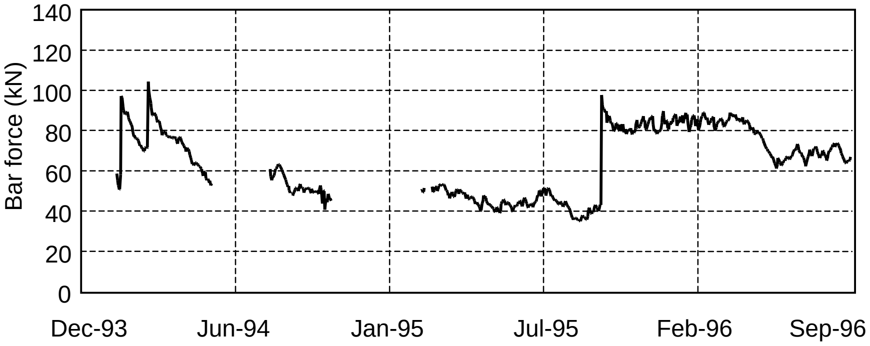


Figure 10—Sample of overall bar force variation in the stress-laminated test decks (Test deck 5 treated with CCA/type 1).

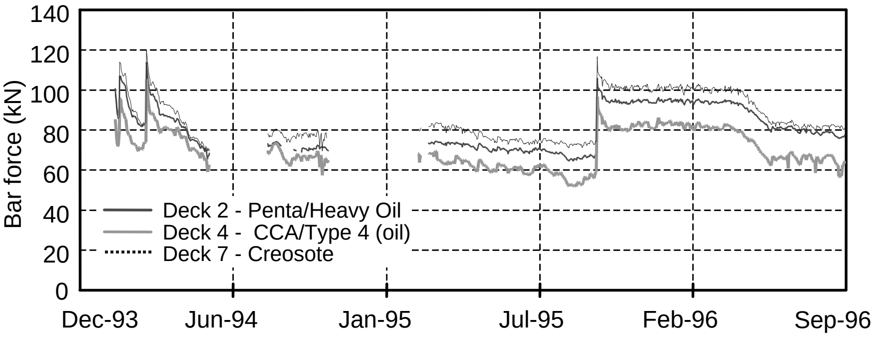


Figure 11—Comparison of bar forces in test decks treated with oil-based preservatives.

tensionings. The bar forces continued to decrease at a steady rate until they stabilized in the spring of 1995. In October 1995, we decided to retention the bars in all the test decks, because the bar force in some test decks was below recommended minimum levels. Figure 10 shows that, after the bar retensioning, the forces in the bars decreased at a much smaller rate and thereafter remained relatively stable, which was observed in all test decks. The stability in the bar forces in the latter part of the monitoring period was evident in all nine test decks.

In addition, bar force data were combined and studied for the following effects:

- Oil-based preservative treatment (test decks 2,4,7)
- Water-based preservative treatment (test decks 5,6,8,9)
- Comparison of water- and oil-based preservative treatments (test decks 2,5,7,8)
- Anchorage system configuration (test decks 1,3,5)
- Temperature and relative humidity (test decks 2,5)

Effect of Oil-Based Treatments

Figure 11 displays bar force data from the three oil-based preservative test decks (2,4,7) observed in this study. The design bar force of 120 kN (26,978 lb) was obtained in the three test decks after the third initial tensioning in March 1994.

Test decks treated with oil-based preservatives exhibited many similarities in the bar force reduction pattern. Of the three oil-based preservatives, test deck 2 treated with penta/heavy oil exhibited the maximum average reduction in bar force (44.5%) from March through May 1994. Both the creosote-treated test deck 7 and the CCA/type 2-treated test deck 4 showed an average bar force reduction of 33%. Only test deck 4 exhibited wood crushing at the edges of the discrete anchorage plates. However, there was no evidence of increased reduction in bar forces in this test deck as a result of crushing. The patterns in bar force reduction were similar in all three test decks. The bar force then remained relatively stable until October 1996 when all test decks were retensioned.

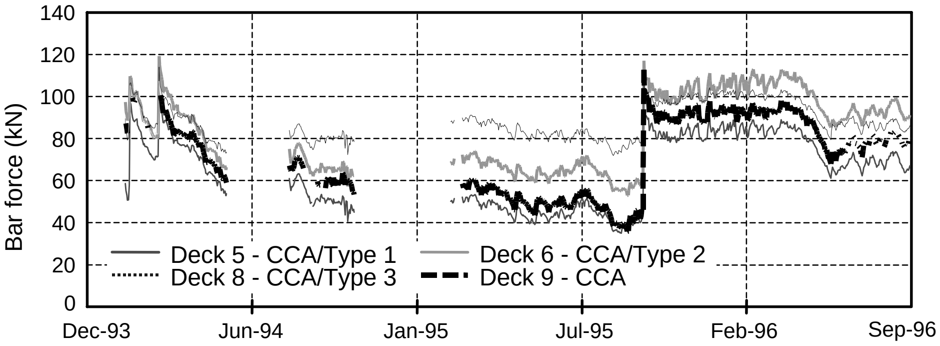


Figure 12—Comparison of bar forces in test decks treated with water-based preservatives.

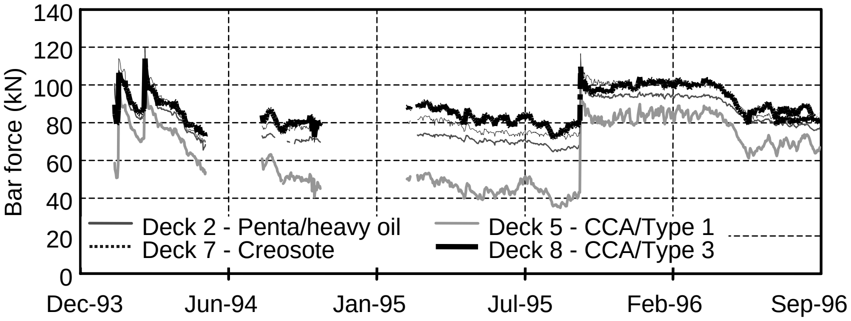


Figure 13—Comparison of bar forces in test decks treated with oil- and water-based preservatives.

After the bars were retensioned, the bar force level remained relatively stable after a slight initial reduction. We observed a substantial decrease in bar force in the three test decks in May 1996, the second summer season.

Effect of Water-Based Preservatives

We compared bar force levels in test decks 5, 6, 8, and 9 because the only variable among them was the type of water-based preservative. Figure 12 displays bar force data for these four test decks throughout the monitoring period. The bar forces in these four test decks also followed a consistent pattern. Test deck 9, treated with straight CCA, experienced the greatest reduction in bar force (45.5%) after the completion of the initial bar tensioning sequence, whereas test deck 8, treated with CCA/type 3, experienced the lowest bar force decrease (21%). Test deck 5 (CCA/type 1) displayed an average bar force reduction of 39.4%. The bar forces in the water-based preservative test decks then remained relatively stable until retensioning in October 1995.

After retensioning, the bar forces decreased by approximately 20 kN (4,496 lb) in the first month. Subsequently, bar forces remained relatively stable in the four test decks until May 1996. At this time, the bar force in all test decks decreased by approximately 15 kN (3,372 lb) and stabilized until the end of the monitoring period.

Comparison of Oil- and Water-Based Preservatives

To investigate the effects of oil- and water-based preservatives, the average bar force levels in test decks 2, 5, 7, and 8 were plotted (Fig. 13). Test decks 2 and 7 were treated with penta/heavy oil and creosote, respectively, whereas test decks 5 and 8 were treated with CCA/type 1 and CCA/type 3 water-based preservatives, respectively. Although the trends in bar force variations were similar in the four test decks, the reduction in bar force levels in test decks 2 and 7 occurred with less variations than those exhibited by the other two test decks. The largest variation of 5.5 kN (1,237 lb) occurred in test decks 5 and 8 during the second week of April 1994. Test decks 2 and 7 exhibited fewer variations in bar force levels during this period.

Figure 13 shows that the test decks treated with water-based preservatives had a much larger short-term variation in bar force than did the tests decks treated with oil-based preservatives. These bar force variations were probably a result of short-term temperature and moisture content changes in the test decks. Those treated with the water-based preservatives did not have an inherent moisture barrier. Therefore, changes in relative humidity had a greater effect on the dimensional stability of the lumber laminations, which ultimately created a larger variation in short-term bar force.

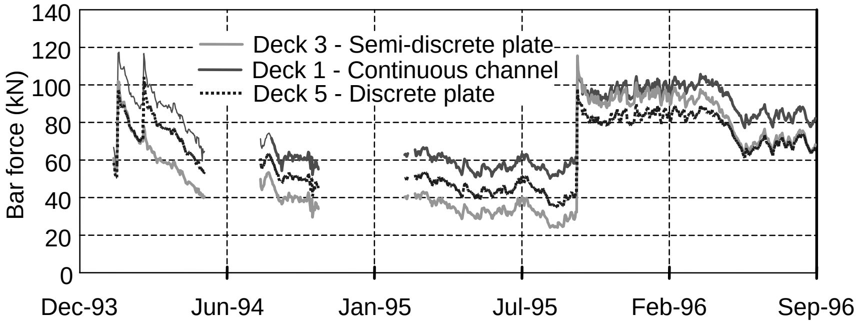


Figure 14—Comparison of bar forces in test decks configured with different anchorage systems.

Effect of Anchorage Systems

Figure 14 shows the average bar forces in tests decks 1, 3, and 5 during the monitoring period. These tests decks were treated with CCA/type 1 and outfitted with a continuous steel channel (test deck 1), a semicontinuous plate (test deck 3), or a discrete anchorage plate (test deck 5). There were variations in bar force performance for each anchorage configuration. However, these differences can be explained by examining the differences in the initial bar force level. Test deck 1 had the best bar force performance as a result of having the highest initial bar force of 120 kN (26,978 lb). The other test decks had a slightly lower initial bar force level, which corresponds to a lower bar force performance level.

Even with the differences in initial bar force level, the relative differences between test decks during the monitoring period were small (<20 kN (<4,496 lb)). The differences were not attributable to anchorage problems. In addition, the exterior of the laminations during bar retensioning in October 1995 gave no indication of crushing. Similar bar force performance and satisfactory crushing resistance show that all three anchorage systems can be used adequately on CCA-treated Southern Pine stress-laminated bridges.

Effect of Temperature and Relative Humidity

Figures 15 and 16 compare bar force levels from test decks 2 and 5 with temperature and relative humidity, respectively. Test deck 2 was treated with an oil-based preservative, and test deck 5 was treated with a water-based preservative. These plots show the effect of temperature and relative humidity in a typical summer week from June 1–7, 1996. Ambient temperature data were recorded by the data logger, and relative humidity data were gathered through a hand-held probe.

The low temperature of the test deck during this typical summer week occurred at about 6 a.m. each day. During this week, the low temperature varied from a minimum of 25.3°C (77.5°F), which occurred June 5, to a maximum of 32.3°C (90.1°F), which occurred June 6. The average test deck temperature during this week was 28.6°C (83.5°F).

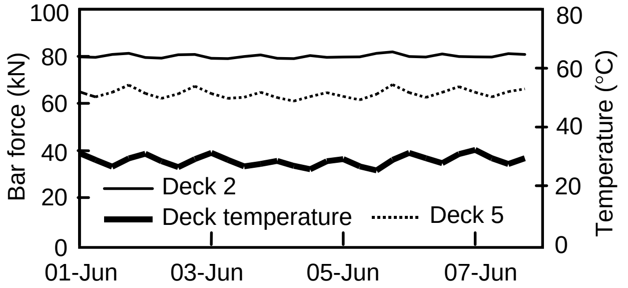


Figure 15—Effect of temperature on bar forces in a typical summer week.

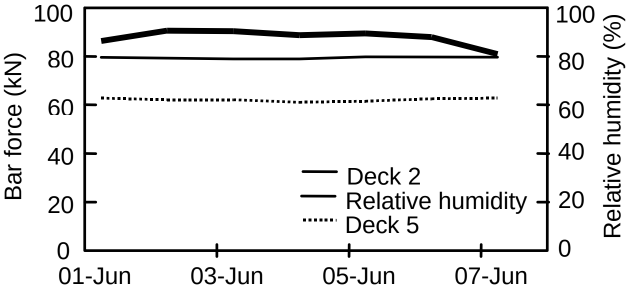


Figure 16—Effect of relative humidity on bar forces in a typical summer week.

The relative humidity varied from a low of 81% on June 7 to a high of 91% on June 2. The average relative humidity during this summer week was 87.9%. The relative humidity readings were recorded through the hand-held probe only at 6 a.m.

The equilibrium moisture content of wood is controlled by the temperature and relative humidity of the surrounding environment (Forest Products Laboratory 1999). Figure 15 shows that the average bar forces varied in proportion to the recorded temperatures. This implies that a temperature effect is associated with the bar force retention of stress-laminated decks. In contrast, the average bar force did not vary as dramatically with the relative humidity (Fig. 16). This implies that relative humidity has a more global effect on the stress-laminated deck performance by changing the overall moisture content over a greater amount of time. Even though average bar force data shown in Figures 15 and 16 were from the same period, the reading interval for Figure 16 was one reading every 24 h compared with one reading every 6 h in Figure 15.

Conclusions

Based on the results of this study, we concluded the following:

- There was little difference in the overall moisture content during the monitoring period for the test decks treated with various preservatives. There was an average moisture content increase of approximately 3% to 4% during the monitoring period. The small change in moisture content was due to the moisture content condition of the lumber prior to test deck construction. The lumber was near equilibrium condition when the test decks were constructed. Significant moisture changes probably occurred before the construction of the test decks, while the lumber was stored on the ground.

- There was less relative fluctuation in bar force in the test decks treated with oil-based preservatives than in the test decks treated with water-based preservatives. The relative bar force fluctuations for all test decks treated with oil-based preservatives were very similar, with a maximum variation of 4.44 kN (1,000 lb) during the critical summer months. Test decks treated with water-based preservatives experienced larger changes in relative bar force of about 11.1 kN (2,500 lb) for the same period. This slight variation is not expected to significantly affect performance. However, the net bar force loss or gain during extended periods in the two sets of test decks was similar.

- Bar force retention in test decks treated with oil-based preservatives was very similar and ranged from 60 to 80 kN. For the same period, bar force in test decks treated with water-based preservatives was more varied and ranged from 40 to 80 kN. Although bar force retention in the water-based preservative test decks was more variable, the test deck treated with CCA/type 3 had the least bar force loss of all test decks during this period. The relative bar force fluctuations in the test decks treated with water-based preservatives seemed to have little or no long-term effect on bar force retention. Except for the test deck treated with CCA/type 1, bar forces remained above the minimum design value of AASHTO.

- There was little difference in bar force retention or performance of the continuous channel, semicontinuous plate, and discrete plate bar anchorage systems. We conclude that when properly designed, the anchorage system has a negligible effect on the bar force retention of Southern Pine stress-laminated decks. The similar bar force performance and satisfactory crushing performance show that all three anchorage systems can be used on CCA-treated Southern Pine stress-laminated bridges.

- Various water-based preservatives such as CCA, CCA/type 1, CCA/type 2, or CCA/type 3 showed no significant difference in their effects on stress-laminated Southern Pine test decks. Water-based preservatives may be successfully used to treat stress-laminated bridge decks made of Southern Pine.

- The test decks required a full bar retensioning after approximately 1 year of monitoring. This retensioning stabilized the bar forces and improved their performance. It is understood that many stress-laminated decks perform adequately without an intermediate bar retensioning if the decks are properly installed and specified.

- The design guidelines presently available for stress-laminated decks treated with oil-based preservatives may be extended to the design of stress-laminated decks treated with water-based preservatives using any bar anchorage system. We base this recommendation on the similarity in the behavior of stress-laminated test decks treated with water- and oil-based preservatives observed in this study.

Literature Cited

AASHTO. 1992. Standard specifications for highway bridges. 15th ed. Washington, DC: American Association of State Highway and Transportation Officials. 686 p.

AFPA. 1991. Design values for wood construction. A supplement to the 1991 edition of the national design specification. Washington, DC: American Forest Products Association. 51 p.

AISC. 1986. Manual for steel construction: load and resistance factor design. 1st ed. Chicago, IL: American Institute of Steel Construction. 1,168 p.

ASTM. 1992a. Standard test methods for direct moisture content measurement of wood and wood-base materials. ASTM D4442–92. Philadelphia, PA: American Society for Testing and Materials. 6 p.

ASTM. 1992b. Standard test methods for the use and calibration of hand-held moisture meters. ASTM D4444–92. Philadelphia, PA: American Society for Testing and Materials. 6 p.

ASTM. 1988. Standard specification for uncoated high-strength steel bar for prestressing concrete. ASTM A722–86. Philadelphia, PA. American Society for Testing and Materials. 3 p.

AWPA. 1990. Book of standards. Woodstock, MD. American Wood-Preservers' Association. 200 p.

Barger, S.; Gangarao, H.V.S.; Raju, P. 1993. Experimental and theoretical evaluation of stress-laminated timber T, Bulb T and Box Systems. Rep. CFC–93–162. prepared for the Federal Highway Administration. Morgantown, WV: West Virginia University, Constructed Facilities Center.

Batchelor, B.; Van Dalen, K.; Hachborn, A.; Lee, E. 1979. Structural characteristics of transversely prestressed laminated wood bridge decks. Report 8305, Kingston, ON, Canada: Queen's University, 127 p.

FHWA. 1998. National bridge inventory. Washington, DC: Federal Highway Administration.

Forest Products Laboratory. 1999. Wood handbook: wood as engineering material. Gen. Tech. Rep. FPL–GTR–113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 463 p.

Kainz, J.A.; Ritter, M.A.; Yazdani, N.; Kadnar, J.O. 1996. Effect of preservative treatment on bar force in stress-laminated bridge decks. In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., eds. National conference on wood transportation structures; 1996 October 23–25; Madison, WI. Gen. Tech. Rep. FPL–GTR–94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 245–251.

Lopez–Anido, R.; Gangarao, H.V.S. 1993. Systematic approach towards the design of stressed timber T- and Box-beam bridges. Rep. CFC–93–163, prepared for the Federal Highway Administration. Morgantown, WV: West Virginia University, Constructed Facilities Center. October, 1993. Revised May 1995.

OMTC. 1983. Ontario Highway Bridge Design Code. 2d ed. Downsview, Ontario, Canada: Ontario Ministry of Transportation and Communications.

Oliva, M.G.; Dimakis, A. 1988. Behavior of stress-laminating timber highway bridges. Journal of Structural Engineering. 114(8): 1850–1869.

Oliva, M.G.; Dimakis, A.G.; Ritter, M.; Tuomi, R.L. 1990. Stress-laminated wood bridge decks; experimental and analytical evaluations. Res. Pap. FPL–RP–495. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 24 p.

Ritter, M.A.; Geske, E.A.; Mason, L.; [and others]. 1990. Performance of stress-laminated bridges. Wood Design Focus. 1(3): 12–16.

Ritter, M.A. 1990. Timber bridges: design, construction, inspection and maintenance. EM 7700–8. Washington, DC: U.S. Department of Agriculture, Forest Service, Engineering Staff. 944 p.

Wacker, J.P.; Ritter, M.A. 1995. Field performance of timber bridges—4. Graves Crossing stress-laminated deck bridge. Res. Pap. FPL–RP–539. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 17 p.

Wacker, J.P.; Ritter, M.; Conger, D. 1996. Field performance of timber bridges—8. Lynches Woods Park stress-laminated deck bridge. Res. Pap. FPL–RP–551. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 17 p.