Effect of Preservative Treatment on Bar Force in Stress-Laminated Bridge Decks

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Abstract

Stress-laminated timber bridge decks have gained increased popularity in the United States since the late 1980s. Like all exposed wood, the laminations in these bridges must be treated with wood preservatives to prevent deterioration from decay and insect attack. Traditionally, stress-laminated bridges are constructed using wood treated with an oil-type preservative. Waterborne preservatives are not widely used because of concerns about dimensional stability of the wood laminations. This paper describes a 2-year study that examines the performance of nine stress-laminated timber test decks constructed of Southern Pine lumber. The decks were treated with seven different preservatives to assess comparative bar force retention over time. In addition, three different bar anchorage systems were evaluated on decks treated with the same wood preservative. Preliminary results indicate that there are subtle differences in short-term bar force performance between decks treated with oil-type and waterborne preservatives. In addition, the bar force retention magnitude was more varied in the decks treated with waterborne preservatives than in the decks treated with oil-type preservatives. However, little difference was noted in the performance of the three bar anchorage systems.

Keywords: Preservative, timber, stress laminated, bridge, deck, bar force, retention, performance, bar anchorage

Introduction

It is widely recognized that a major problem is posed by the condition of the infrastructure in the United States. Of the 237,000 deficient and/or obsolete bridges, nearly 75 percent are located on secondary and rural highways (USDA 1995). Wood is an excellent material for bridge construction and rehabilitation, and often is the most economical and convenient option for rural highway bridges with spans under 12.2 m (40 ft). Research to better understand the behavior of timber bridges has been in progress at the USDA Forest Service, Forest Products Laboratory (FPL), and several universities. This research is directed at the structural behavior, construction methods, preservatives, and economic evaluation of modern timber bridges.

Background

One relatively new timber bridge system, the stress-laminated deck, was first developed in Ontario, Canada, as a rehabilitation method for nail-laminated decks. During the past 10 years, the popularity of these decks has increased significantly in the United States. A stress-laminated timber deck bridge consists of multiple longitudinal laminations that are placed on edge to form a wood plate. High strength steel bars are then inserted through holes in the wide face of the laminations. The bars are anchored to the deck edges using either a steel bearing channel or discrete bearing plates. The steel bars are tensioned with a hydraulic jack until the wood laminations reach a compressive interlaminar stress of approximately 690 kPa (100 lb/in^2) (Ritter 1990). This interlaminar compression creates an orthotropic wood plate that improves structural performance compared with conventional nail laminated decks (Oliva and others 1990). Interlaminar compression depends on dimensional stability of the wood laminations; therefore, any dimensional change in the wood will affect bar force.

As with all wood used in exposed environments, the wood for a stress-laminated bridge must be treated with chemical preservatives to protect it from decay and insect attack. In general, there are two types of preservatives: oil-type and waterborne. Currently, oil-type preservatives, such as creosote and pentachlorophenol (penta), are the primary types of wood preservatives used in structural highway applications. For these preservatives, the preservative and/or oil carrier provides a natural resistance to moisture penetration that protects the lumber from dimensional changes caused by moisture content fluctuations. Waterborne preservatives, such as copper chromated arsenate (CCA), are also used, but there is a reluctance to use these preservatives because they provide no moisture barrier, which leads to increased dimensional changes in wood members. As a result, there is concern regarding the construction of stress-laminated timber bridges using laminations treated with waterborne preservatives, because dimensional stability of the laminations is critical to maintaining force in the deck (Ritter and others 1990).

In response to these concerns, a cooperative study with Florida State University–Florida Agriculture and Mining University (FSU/FAMU), College of Engineering; FPL; and the Federal Highway Administration (FHWA) was initiated in January 1994 to examine the comparative performance of wood preservatives in Southern Pine stress-laminated bridge decks. This paper describes this study through the first 2 years of monitoring, ending March 1996.

Objective

The objective of this study was to compare the bar force retention of stress-laminated decks treated with several wood preservatives. In addition, the performance of three bar anchorage types were examined.

Research Methods

The cooperative study plan called for constructing and monitoring nine test decks on the FSU/FAMU College of Engineering facility in Tallahassee, Florida. Monitoring including data collection of bar force, lamination moisture content, relative humidity, and temperature for approximately 2 years. A discussion of the research methods follows.

Test Decks

Each test deck measured 1.5 by 6.1 m (5 by 20 ft) and was constructed of 40 nominal 51- by 305-mm (2- by 12-in.) sawn lumber laminations (Fig. 1). The deck laminations were visually graded No. 2 or better, Southern Pine sawn lumber of random 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.

Preservatives–- Seven different wood preservatives were used in this study: four waterborne and three oil-type. Each preservative complied with American Wood Preserver's Association (AWPA) Standard C14 (AWPA 1992). The four waterborne preservatives were variations of the CCA formulation as determined by American Wood Preserver's Association Standard P5 (AWPA 1990). In an effort to curb the movement of moisture in and out of the wood, three of the CCA treatments included proprietary water-repellent additives, designated as Type 1, Type 2, and Type 3. The oil-type preservatives were penta/heavy oil, creosote, and CCA in an oil emulsion. The CCA in oil is a proprietary formulation of standard CCA and is generally not considered an oil-type preservative because it only has 10- to 20-percent oil. However, it was grouped with the oil-type preservatives for this study.

Bar Anchorage Systems— The three most common bar anchorage types for stress-laminated bridge decks were also examined during the testing period. These included a continuous channel, a semi-discrete plate system, and discrete plate system (Fig. 2). All decks were configured with the discrete bearing plate system, except for two decks treated with CCA/Type 1, which were provided with one of the other systems. According to design specifications (Ritter 1990), the discrete bearing plate system creates the most critical value for compression perpendicular to grain on the outside laminations. Therefore, if all the anchorage systems are designed correctly, the discrete plate system has the highest compression underneath the plate. Following the design procedures for the discrete plate system, a design compression stress of 2,275 kPa (330 lb/in^2) is obtained. This value is less than the wet-use, compression perpendicular-to-grain allowable stress of 2,606 kPa (378 lb/in^2) for Southern Pine lumber.

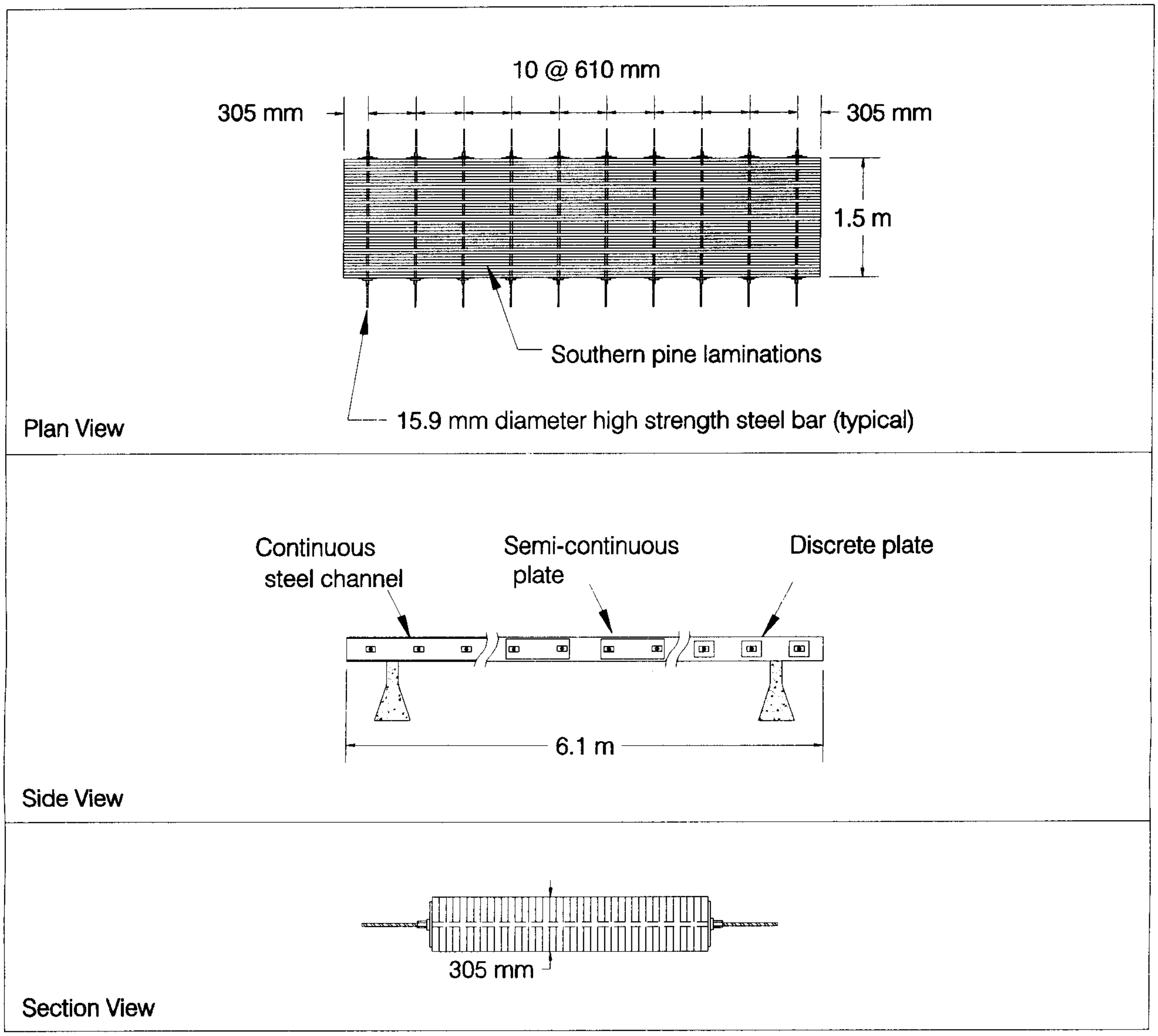

Figure 1—Test deck configuration.

Table 1 summarizes the deck numerical designations, preservative type, and bar anchorage system.

Deck Construction— After fabrication, the laminations were pressure treated with preservatives. The material was then shipped to an open field adjacent to the college. Each deck was assembled by placing the laminations on two concrete barriers used as abutments. After the laminations were in place, 15.9-mm-(5/8-in.-) diameter high strength steel bars, complying with the requirements of ASTM A-722 (ASTM 1988), were inserted through predrilled holes. The bars were spaced at 610-mm (24-in.) intervals, beginning 305 mm (12 in.) from the deck ends (Fig. 1). The bars were tensioned to 117.4 kN (26,400 lb), which corresponds to 690-kPa (100-lb/in^2) interlaminar compression. The bar tensioning was completed in three stages during 4 weeks, starting January 1994. The decks were designed to the same standards used by the USDA Forest Service for stress-laminated decks (Ritter 1990). The decks after construction are shown in Figure 3.

Performance Monitoring

To evaluate performance and bar force retention of the test decks, ambient air temperature, relative humidity, bar force, and moisture content data were collected.

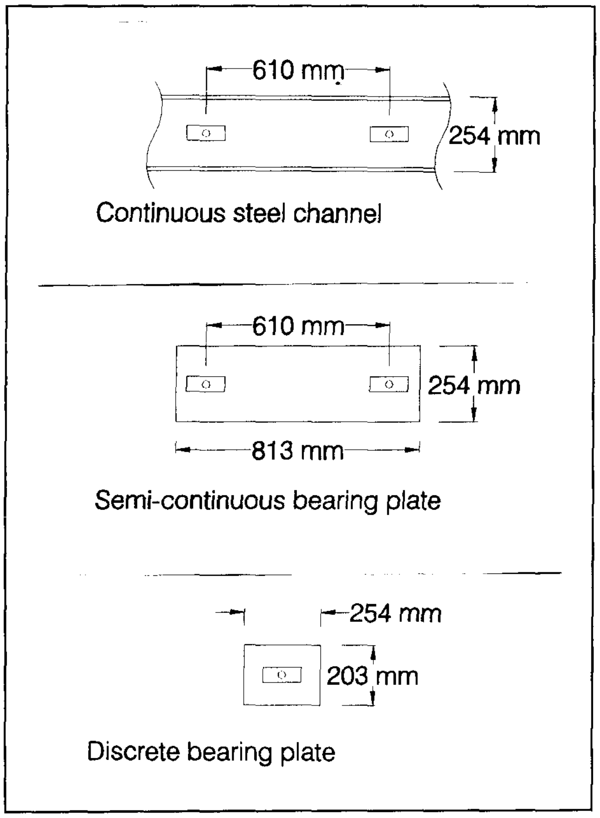

Figure 2—Bar anchorage configuration.

Table 1—Deck preservative and anchorage layout.

Deck number	Preservative type	Anchorage system
1	CCA/Type 1	Continuous channel
3		Semi-continuous plate
5		Discrete plate
2	Penta	
4	CCA/Oil Emulsion	
6	CCA/Type 2	
7	Creosote	
8	CCA/Type 3	
9	CCA	

Figure 3–Test site on FSU/FAMU College of Engineering Campus.

In addition, visual inspections were completed in order to assess the general condition of the decks in an exposed environment. A remote data acquisition system (data logger) was installed at the site to collect bar force and temperature data. The methods used to acquire data follow.

Temperature and Relative Humidity— Ambient air temperature was measured with a thermocouple attached to the data logger and recorded at 6-hour intervals. Relative humidity was measured daily with a hand-held humidity probe.

Moisture Content— Electrical resistance moisture content measurements were obtained at four locations (at center span and quarter span every week) on each deck: two from the deck and two from the bottom. The measurements were taken at 25-, 51-, and 76- mm (1-, 2- and 3-in.) pin penetration depths. In addition, moisture content cores were taken from the decks on three occasions (January 1994, August 1994, October 1995) in similar locations as the moisture content readings. The moisture content from the cores was determined at FPL.

Bar Force— The force in two bars of each deck was measured with load cells. The load cells were calibrated at FPL using a strain box and the data logger. Each load cell was directly connected to the data logger, and bar force readings were recorded at the same 6-hour intervals as the temperature readings. Data from the data logger were downloaded to a lap-top computer on a periodic basis.

Visual Inspections— Visual inspections were conducted periodically throughout the monitoring period to monitor the condition and performance of the test decks.

Research Results

The following preliminary study results include a presentation of temperature and humidity data, lamination moisture content, bar force retention, and a comparison of bar anchorage performance.

Temperature and Humidity

The temperature and humidity data reveal, as expected, that the weather conditions for the test decks are most severe in the summer months, between May and September when the temperature and relative humidity in the Tallahassee area are highest. The average measured temperature and humidity during this period was approximately 26.7°C (80°F) and 90 percent relative humidity.

Moisture Content

Data from moisture meter readings and core samples revealed that the moisture content of the test decks was between 15 and 20 percent at the time of construction During the monitoring period, the moisture content increased slightly to 18-22 percent at the conclusion of the monitoring period. The overall increase in moisture content is the result of the high temperature and relative humidity in the testing area. This increase in moisture content is relatively small; therefore, the effect on the bar force is minimal. However, short-term changes in humidity and temperature have a limited effect on wood moisture content and ultimately bar force in stress-laminated decks. This phenomenon is discussed in detail in the next section.

Bar Force

Figure 4 presents the average bar force data from deck 5 for the entire monitoring period, beginning January 22, 1994, and ending March 8, 1996. This plot is representative of the general bar force trend experienced by all nine test decks. The two areas of bar force data interruption noted on the graph were due to flooding, which made the data unreliable. No deck was submerged during the flooding; therefore, it is assumed that the bar force trend during the interruptions is approximately linear, as displayed.

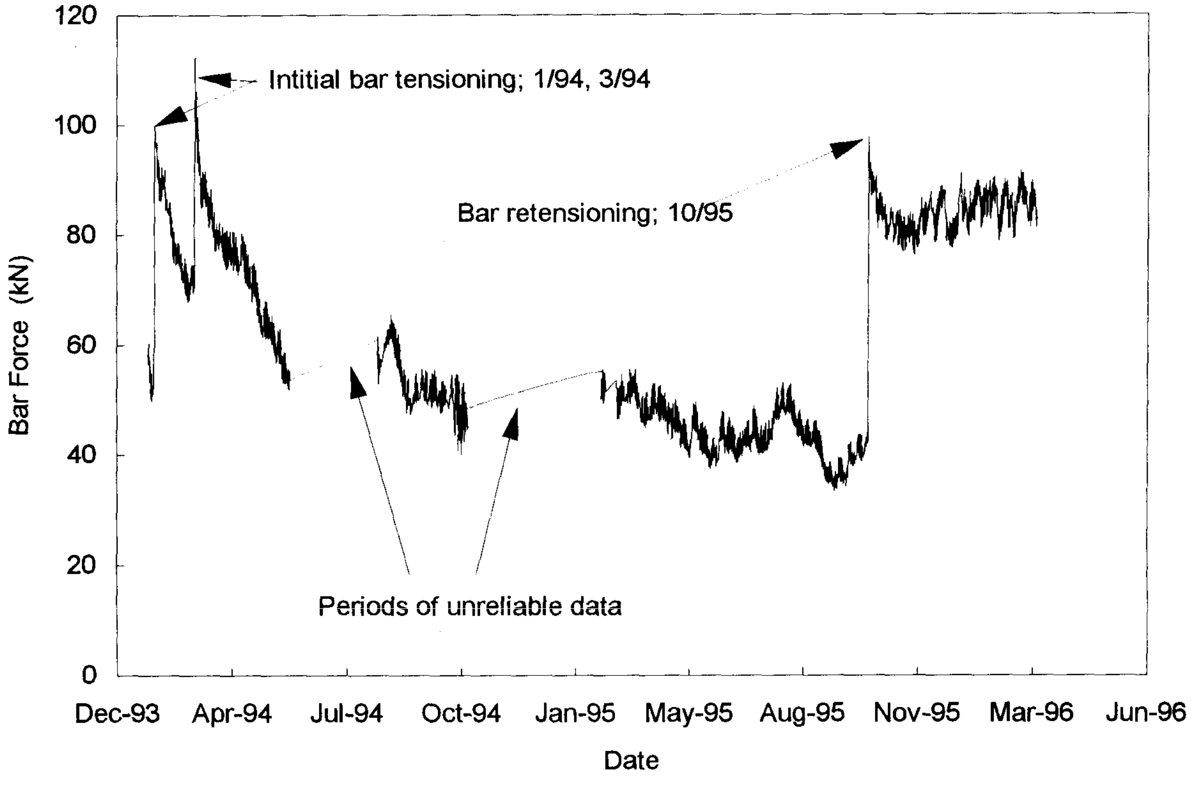

Figure 4—Bar force in deck 5; January 22, 1994, to March 8, 1996.

After the third stressing, all test decks were at a bar force of approximately 100 kN (22,500 lb). Bar force then decreased at a steady rate until it stabilized in the spring of 1995. All decks were restressed in October 1995. The bar force in the decks has not decreased significantly since the second restressing. Complete results from all decks will be presented in an FPL research paper that will be published when testing is completed.

The results that are presented in the remaining paragraphs of this section are from May through September 1995. As mentioned, these months are representative of critical temperature and humidity experienced during the monitoring period.

Figure 5 presents the bar force for the waterborne preservatives in decks 5, 6, 8, and 9. Although the magnitude of the bar force is different, the trend is similar for each deck, with an average maximum variation over time of approximately 11.1 kN (2,500 lb). After 1-1/2 years of monitoring, it appears that CCA/Type 3 retained nearly 75 percent of the design bar force. Decks treated with CCA/Type 2, CCA, and CCA/Type 1 did not perform as well with bar force retention levels of 55, 43, and 34 percent, respectively.

A comparison of bar force for the oil-type preservatives in decks 2, 4, and 7 is presented in Figure 6. The bar forces underwent similar peaks and valleys, with an average variation of approximately 4.44 kN (1,000 lb). The test deck treated with creosote retained nearly 65 percent of the design bar force after 1-1/2 years of monitoring. The decks treated with penta and CCA/Oil Emulsion performed similarly, with bar force retention levels of 60 and 50 percent, respectively.

The average bar force for all decks treated with oil-type preservatives and waterborne preservatives is shown in Figure 7. It is apparent that the time variation of bar force in decks treated with oil-type preservatives is smaller than that for decks treated with waterborne preservatives. The variations in bar force are a result of short-term temperature and moisture content changes in the decks. The decks treated with waterborne preservative do not have a moisture barrier. Therefore, changes in relative humidity have a greater effect on the dimensional stability of the lumber laminations, which ultimately creates a greater variation in bar force.

As shown in Figures 5 and 6, the bar force magnitude range is smaller for the oil-type preservative decks than for the waterborne preservative decks. The bar force levels range from 60 to 80 kN for the oil-type preservatives and 40 to 80 kN for the waterborne preservatives.

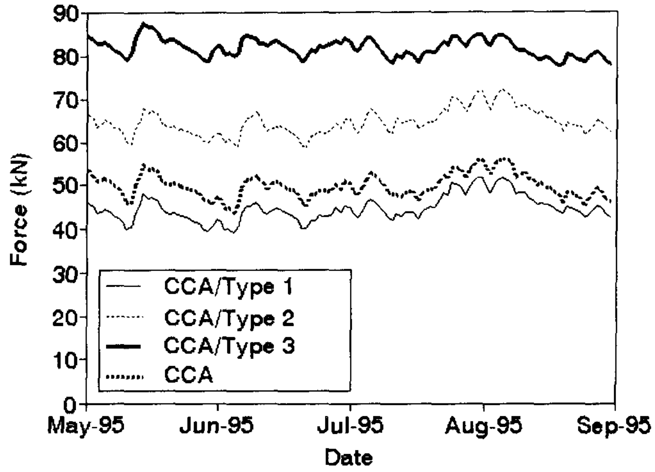

Figure 5—Bar force variation in stress-laminated decks treated with waterborne preservatives.

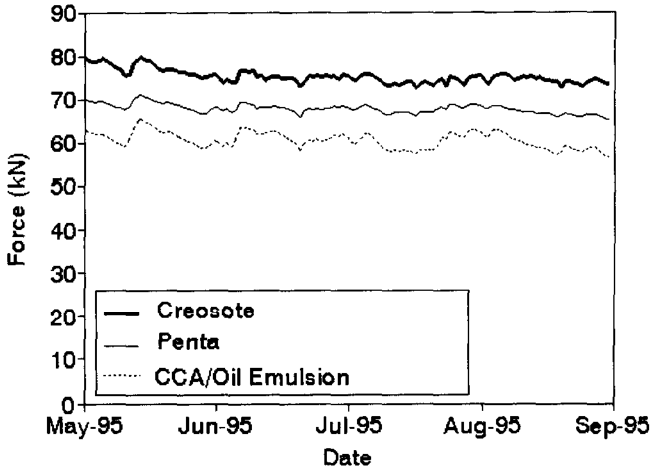

Figure 6—Bar force variation in stress-laminated decks treated with oil-type preservatives.

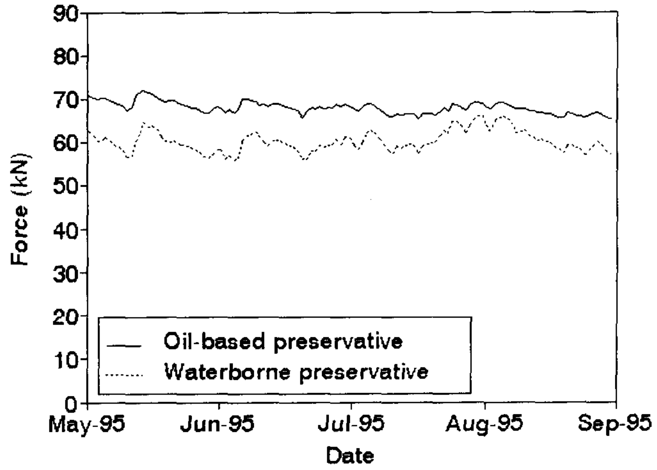

Figure 7—Bar force comparison in decks treated with oil-type and waterborne preservatives.

These differences in bar force magnitude will be investigated in detail after testing is completed in August 1996.

Bar Anchorage Performance

Bar force data from the three decks with different bar anchorages indicate that performance is similar. Each deck had similar variations in bar force, with the maximum variation being about 12.45 kN (2,800 lb). In addition, examinations of the exterior laminations during bar restressing 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.

Concluding Remarks

The following conclusions are based on preliminary research results obtained from this study:

- There was little difference in the global moisture content change during the monitoring period for decks treated with various preservatives. The average global moisture content increased approximately 3 to 4 percent for all decks during the 2-year monitoring period.

- There was less relative fluctuation in bar force in decks treated with oil-type preservatives than in decks treated with waterborne preservatives. The relative bar force fluctuations for all decks treated with oil-type preservatives were very similar, with a maximum variation of 4.44 kN (1,000 lb) during the four summer months. Decks treated with waterborne preservatives experienced greater changes in relative bar force (11.1 kN (2,500 lb)) for the same period.

- After 1-1/2 years of field evaluation, bar force retention in decks treated with oil-type preservatives was very similar and ranged from 60 to 80 kN. For the same period, bar force retention in decks treated with waterborne preservatives was more varied and ranged from 40 to 80 kN. Although bar force retention in the waterborne preservative decks was more variable, the deck treated with CCA/Type 3 had the least bar force loss of all decks during this period. The relative bar force fluctuations in the waterborne preservative decks seemed to have had little or no long-term effect on bar force retention. Except for the deck treated with CCA/Type 1, the bar force of the test decks remained above the minimum bar force design value.

- There was little difference in bar force retention or performance of the continuous channel, semi-continuous plate, discrete plate bar anchorage systems. It can be concluded that when properly designed, the anchorage system has a negligible effect on the bar force retention of Southern Pine stress-laminated decks.

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