# Field Performance of Timber Bridges

## 17. Ciphers Stress-Laminated Deck Bridge

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# Abstract

In September 1989, the Ciphers bridge was constructed within the Beltrami Island State Forest in Roseau County, Minnesota. The bridge superstructure is a two-span continuous stress-laminated deck that is approximately 12.19 m long, 5.49 m wide, and 305 mm deep (40 ft long, 18 ft wide, and 12 in. deep). The bridge is one of the first to utilize red pine sawn lumber for a stress-laminated deck application. The performance of the bridge was monitored continuously for 24 months beginning July 1993, approximately 46 months after installation. Performance monitoring involved evaluating data relative to the moisture content of the wood deck, the force level of stressing bars, and the behavior of the bridge under static load conditions. In addition, temperatures were collected from the bridge superstructure and ambient air. Based on field evaluations, the Ciphers bridge is performing satisfactorily with no structural or serviceability deficiencies.

Keywords: Timber, bridge, red pine. Minnesota

# Acknowledgments

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## Introduction

Two national programs have offered an incentive to state and local governments to choose timber for their highway bridges by providing funds to assist with design and construction costs. In 1988, the U.S. Congress passed legislation known as the Timber Bridge Initiative (TBI). The objective of this legislation was to establish a national program to provide effective and efficient utilization of wood as a structural material for highway bridges (USDA 1991). Responsibility for the development, implementation, and administration of the TBI was assigned to the USDA Forest Service. To implement a program, the Forest Service established three primary emphasis areas: demonstration bridges, technology transfer, and research. Responsibility for the demonstration bridge and technology transfer programs was assigned to the National Wood In Transportation Information Center (NWITIC), formerly the Timber Bridge Information Resource Center, in Morgantown, West Virginia. Under the demonstration bridge program, the NWITIC provides matching funds to local governments to construct demonstration timber bridges and encourage innovation through the use of new or previously underutilized wood products, bridge designs, and design applications.

Responsibility for the research portion of the TBI was assigned to the USDA Forest Service, Forest Products Laboratory (FPL), a national wood utilization research laboratory. As part of this broad research program, FPL assumed a lead role in assisting local governments in evaluating the field performance of demonstration bridges, many of which employ design innovations or materials that have not been previously evaluated. Through such assistance, FPL is able to collect, analyze, and distribute information on the field performance of timber bridges, thus providing a basis for validating or revising design criteria and further improving efficiency and economy in bridge design, fabrication, and construction.

In addition to the TBI, the U.S. Congress passed the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991, which included provisions for a timber bridge program aimed at improving the utilization of wood transportation structures. Responsibility for the development, implementation, and administration of the ISTEA timber bridge program was assigned to the Federal Highway Administration (FHWA) and included demonstration timber bridge, technology transfer, and research programs. Because many aspects of the FHWA research program paralleled those underway at FPL, a joint effort was initiated to combine the respective research of the two agencies into a central research program. As a result, the FPL and FHWA merged resources to jointly develop and administer a national timber bridge research program.

This report, seventeenth in a series, documents the field performance of the Ciphers bridge located in Roseau County of Northern Minnesota. It describes the design, construction, and a 2-year field evaluation study of the Ciphers bridge. The bridge is a single-lane stress-laminated deck bridge with a total length of approximately 12.19 m (40 ft). Built in the summer of 1989, this bridge is unique in that it is the first known bridge application to utilize red pine sawn lumber in a stress-laminated deck superstructure. The owner of the bridge received matching funds through the TBI demonstration bridge program. An information sheet on the specific characteristics of the Ciphers bridge is given in Appendix A.

## Background and Development

The Ciphers bridge is located approximately 22.5 km (14 miles) southeast of the city of Warroad in Roseau County, Minnesota, within the boundaries of the Beltrami Island State Forest (Fig. 1). The bridge is located along the Tangnes Trail where it crosses the East Branch of the Warroad River. This single-lane gravel road provides access to the forest for logging and fire control activities. The estimated average daily traffic is 60, consisting of passenger and logging vehicles.

Before replacement in 1989, the Ciphers bridge was a flatbed railcar with a wooden deck (Fig. 2). Originally constructed in the 1950s, the bridge was vandalized with fire in 1988. The damage caused by the fire was severe and necessitated replacement of the bridge.
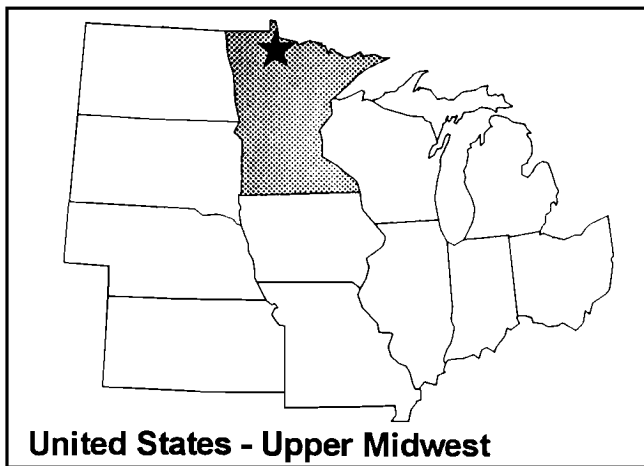
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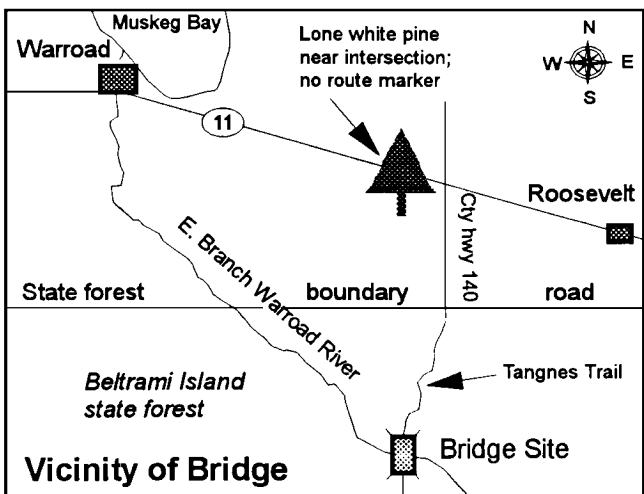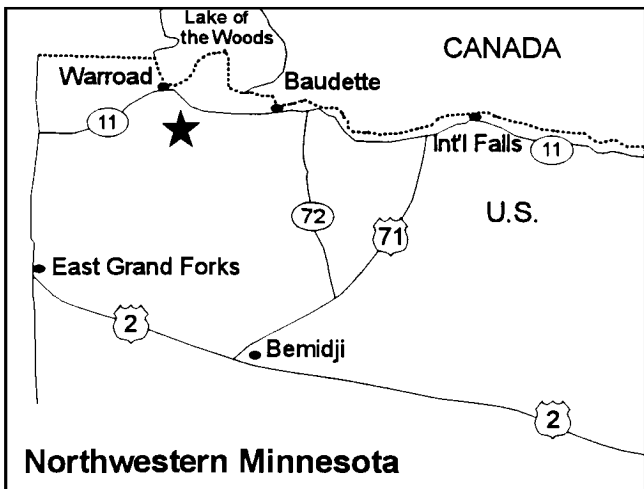


Vicinity of Bridge

**Figure 1—Location of Ciphers bridge.**

Through a cooperative effort betweenthe Minnesota Department of Natural Resources (MN–DNR) and the Department of Forest Products at the University of Minnesota, a proposal was submitted to the USDA Forest Service for partial funding under the TBI for the replacement structure. The project



**Figure 2—Ciphers bridge before replacement in 1989.**

proposed a stress-laminated deck superstructure that used red pine sawn lumber for the deck laminations. In 1989, the project received funding and the final design and construction plans for the Ciphers bridge were completed.

After construction in the summer of 1989, the performance of the bridge was monitored by the MN–DNR in cooperation with the University of Minnesota for approximately 2 years (Franck 1991). During this initial monitoring, the bridge exhibited substantial bar force loss during the winter seasons. These bar force losses were of concern to the MN–DNR because of winter hauling operations on the bridge. To gather additional information about the performance of the Ciphers bridge, especially during the cold winter months, the MN–DNR contacted FPL for assistance. Subsequently, FPL and MN–DNR mutually developed a field evaluation program for the Ciphers bridge.

# Objective and Scope

The objective of this project was to evaluate the field performance of the Ciphers bridge for 2 years, beginning in July 1993, approximately 46 months after bridge installation. The project scope included data collection and analysis related to the wood moisture content, stressing bar force, bridge behavior under static truck loading, and general structure condition. In addition, data were collected to determine the effects of extremely cold temperatures on the bridge. Results of this project will be used to formulate recommendations for future design and construction of similar stress-laminated bridges.

# Design, Construction, and Cost

The Ciphers bridge project was completed as part of a mutual effort between several agencies and individuals. An overview of the design, construction, and cost of the project follows.

## Design

Design of the Ciphers bridge was completed during 1989 by the MN–DNR in cooperation with the University of Minnesota–Department of Forest Products. The stress-laminated deck superstructure was designed according to USDA Forest Service standards (Ritter 1990) under development at the time and met American Association of State Highway and Transportation Officials (AASHTO) load requirements (AASHTO 1989). The design included procedures for prefabricating into two half-width panels that were interconnected during construction.

The design geometry provided for a stress-laminated deck superstructure 12.19 m long, 5.49 m wide, and 305 mm deep (40 ft long, 18 ft wide, and 12 in. deep) with a single support at mid-length (Fig. 3). Design calculations were based on a 11.76-m (38.6-ft) bridge length (center–center of end bearing) in a two-span continuous orientation. Each span was designed for 5.88 m (19.3 ft) (center–center of bearing) between supports. Deck laminations were specified as 102 by 305 mm, S1S to 98 mm (nominal 4 by 12 in., S1S to 3-7/8 in.), red pine, grade No. 2 and better, pressure treated with creosote. The deck lamination moisture content
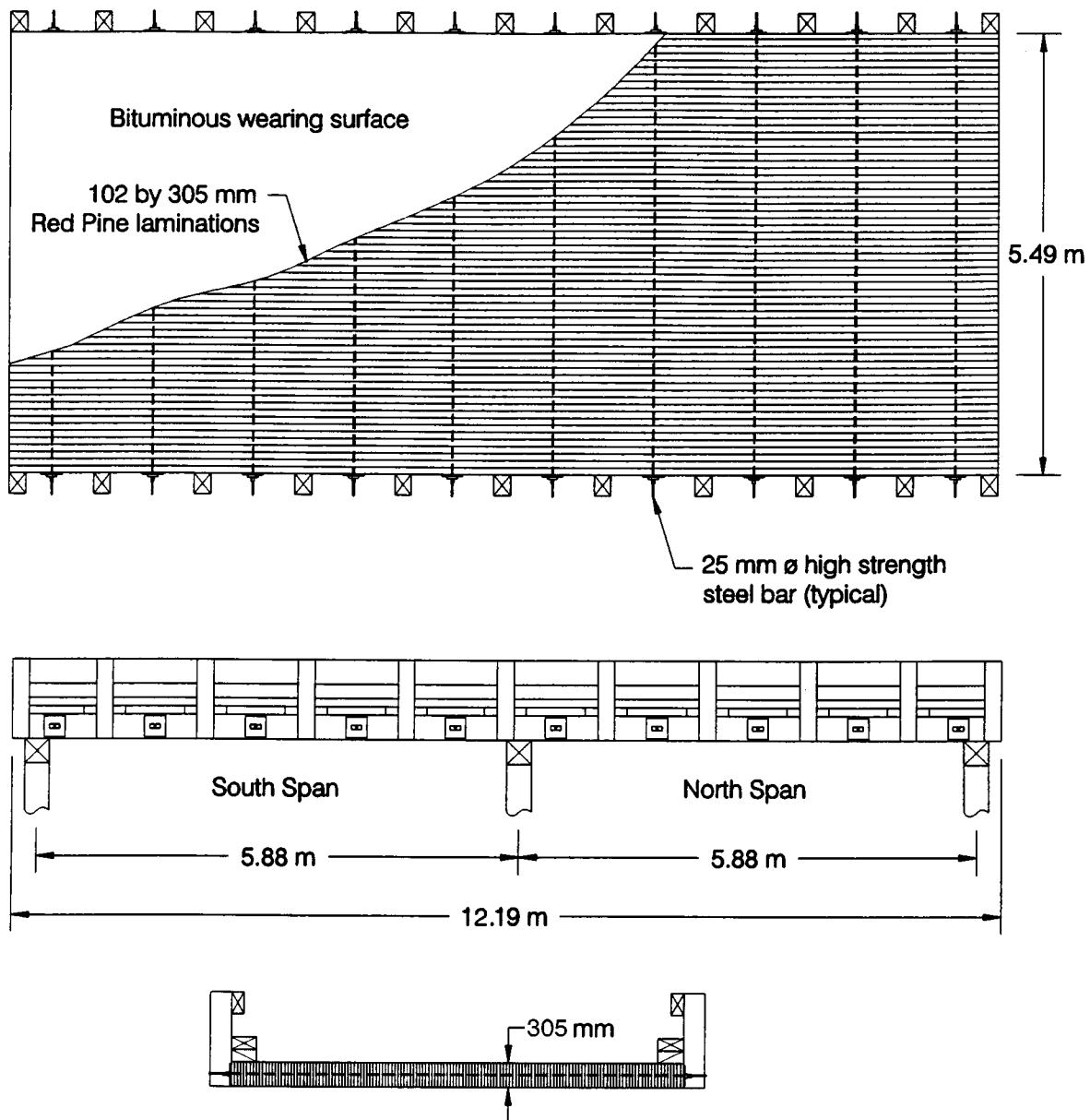


**Figure 3—Design configuration of the Ciphers bridge.**

was specified to be 19% maximum. Because the deck laminations were not available in lengths required to span the entire bridge, the deck design included lamination butt joints in a repetitive pattern. Transversely, butt joints were limited to no more than one in every fourth adjacent lamination. Longitudinally, rows of butt joints were spaced at 1.22-m (4-ft) intervals.

For stress laminating, the design specified the use of 25-mm- (nominal 1-in.-) diameter ASTM A722 high strength, threaded steel bars with an ultimate strength of 1.034 GPa ($150 \times 10^3$ lb/in$^2$) (ASTM 1988). The bars were spaced at 1.22-m (4-ft) intervals, beginning 610 mm (2 ft) from the ends of the bridge. The design tension bar force of 300 kN (67,500 lb) provided an interlaminar compressive stress of 807 kPa (117 lb/in$^2$). Bars were anchored with a discrete-plate system consisting of 279- by 533- by 25-mm (11- by 21- by 1-in.) steel bearing plates, 152- by 305- by 38-mm (6- by 12- by 1-1/2-in.) steel anchor plates, and hexagonal nuts. All components of the stressing system and other steel hardware were galvanized for corrosion protection.

All components of the rail and curb system were designated as visually graded Douglas Fir sawn lumber. The bridge rail was specified as 152 by 254 mm (nominal 6 by 10 in.); rail posts were specified as 203 by 254 mm (nominal 8 by 10 in.) spaced at 1.22-m (4-ft) intervals along the bridge. The curbs were specified as 203 by 305 mm (nominal 8 by 12 in.).

To protect the deck of the bridge from deterioration, a 51- to 76-mm- (2- to 3-in.-) thick asphalt wearing surface was designated. To offset deck deadload deflection, a positive deck camber in the longitudinal direction was specified by raising the center pier elevation 102 mm (4 in.) with respect to the abutment elevations.

## Construction

Construction of the Ciphers bridge by a local contractor was completed in the summer of 1989. The existing railroad flatbed car bridge was removed and demolished. New timber pile abutments were installed while the bridge superstructure was being preassembled at the fabrication facility.

The deck was preassembled into two half-width panels at the fabrication facility to simplify transportation to the site. At the bridge site, an overhead crane lifted and placed the preassembled deck panels next to each other on the abutments. The stressing bars extended only through the half-width panels and were interconnected with couplers along the deck interface. After removal of anchorage plates from every other bar on each panel at the interface, the coupled bars were tensioned to the required design force level to achieve a single deck unit from the two half-width panels (Fig. 4).



**Figure 4—Ciphers bridge was prefabricated in two half-width panels that formed the deck after the initial bridge stressing.**

The initial bridge stressing was conducted with a single hydraulic jack stressing system. Beginning at one end of the bridge, prestress was introduced by tensioning alternating bars to the required design tension force in a successive manner at both sides of the bridge. This bar tensioning procedure was repeated several times at the time of the initial stressing to achieve uniformity in the bar forces. Subsequent stressings followed similar procedures and were performed 2 and 8 weeks after the initial stressing.

Attachment of the deck to the substructure was made with through-bolts passing through the deck and abutment/pier cap and was performed after the second bridge stressing. At the third bridge stressing, approximately 8 weeks after construction was completed, the rail and curb system was installed. In addition, the asphalt wearing surface was applied approximately 10 weeks after the initial bridge stressing.

A view of the completed bridge, at the initiation of FPL monitoring, after approximately 46 months in service, is shown in Figure 5.

## Cost

Cost for the fabrication and construction of the Ciphers bridge project, including substructure, superstructure, and approach roadway work, totaled $54,350. The portion of this cost pertaining to the superstructure was estimated at $38,045 (70% of the total cost). Cost figures were not available for the design of the Ciphers bridge project. Based on a total deck area of 63.6 m$^2$ (685 ft$^2$), the unit cost of the Ciphers bridge superstructure was estimated at $598/m$^2$ ($55/ft$^2$).

## Evaluation Methodology

To evaluate the structural performance of the Ciphers bridge, the MN–DNR contacted FPL for assistance. Through mutual

**Figure 5—Ciphers bridge after 46 months in service: side view (top); end view (bottom).**

agreement, a 2-year monitoring plan was developed by FPL and implemented through a Cooperative Research and Development Agreement with the MN–DNR. The plan called for performance monitoring of the deck moisture content, stressing bar force, static load test behavior, and general bridge condition. The evaluation methodology used procedures and equipment previously developed by FPL on similar structures in the past (Ritter and others 1991). In addition, the monitoring plan included an evaluation of the effects of cold temperatures on the performance of the deck superstructure.

## Moisture Content

An electrical-resistance moisture meter was used to collect moisture content data in accordance with ASTM D4444–84 (ASTM 1990). To monitor deck moisture content, 76-mm- (3-in.-) long, insulated probe pins were driven approximately 64 mm (2.5 in.) into the underside of the deck at several locations. After recording the reading from the meter, adjustments were made for temperature and wood species accordingly (FORINTEK 1984). Moisture content measurements were collected at the initiation and conclusion of the monitoring period. In addition to electrical-resistance meter

readings, core samples were removed from the deck of the bridge to determine moisture content by the ovendry method in accordance with ASTM D4442–84 (ASTM 1984). The core sample locations were adjacent to the electrical-resistance locations in all cases.

## Bar Force and Deck Temperature

To monitor bar force changes in the steel stressing bars, three load cells were installed at the beginning of the monitoring period. The hollow-core load cells were placed over the stressing bar, between the bearing and anchorage plates, and compressed as the stressing bars were tensioned. Load cell measurements were converted to corresponding bar force levels, based on the laboratory calibrations. At the conclusion of the monitoring period, load cells were removed and recalibrated.

To monitor temperatures inside the deck superstructure, several copper-constantine thermocouple wires were embedded into the deck at various depths. In addition, thermocouple wires were placed beneath the deck, not in direct sunlight, to measure the surrounding air temperature. On several occasions, the accuracy of the thermocouple readings was checked with a hand-held thermometer.

A remote data acquisition system was used to collect bar force and deck temperature data (Fig. 6). A battery-powered datalogger was preset to collect bar force and temperature readings each hour. Data were stored in solid-state memory modules that were interchanged by local MN–DNR personnel and sent to FPL on approximately a monthly basis throughout the monitoring period.

## Load Test Behavior

Static-load testing of the Ciphers bridge was conducted at the beginning and end of the monitoring period to determine the response of the bridge to highway truck loads. In addition, predicted deflections based on analytical modeling were determined for each load test. Load testing consisted of positioning a fully loaded truck on each span of the bridge deck and measuring the resulting deflections at a series of locations along the centerspan and abutment cross-sections. Bridge deflections were measured prior to testing (unloaded), after placement of the test truck for each load case (loaded), and at the conclusion of testing (unloaded). Bridge deflections from an unloaded to loaded condition were measured by hanging calibrated rules on the underside of the deck and reading the values with a surveying level.

For each load test, the test truck consisted of a flatbed truck with a bulldozer loaded on the truckbed. The adjustable truckbed was positioned such that the total weight of the bulldozer was directly over the rear truck axles. The placement of the test truck on the bridge deck for each load case
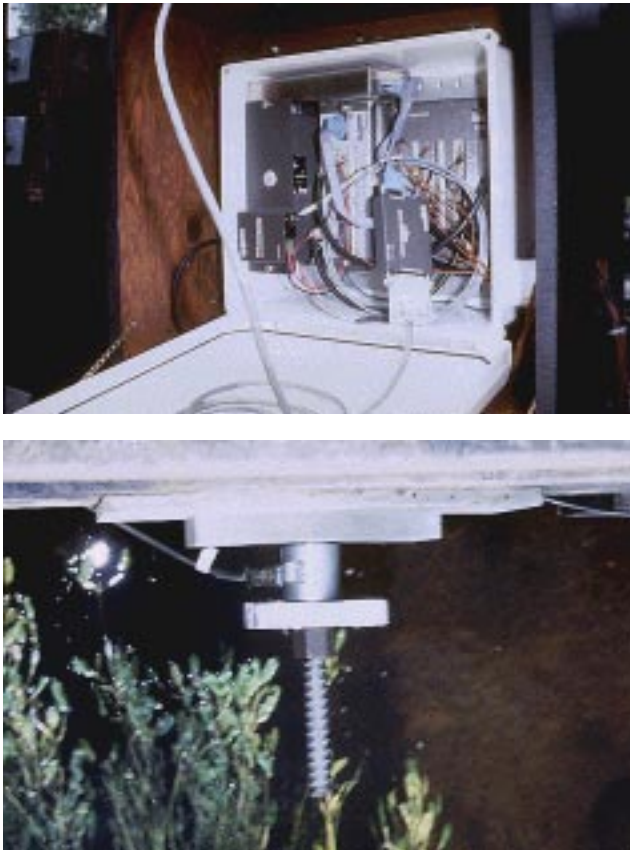
**Figure 6—Remote data acquisition system used at the Ciphers bridge: datalogger attached to the bridge rail (top); load cell installed over stressing bar (bottom).**
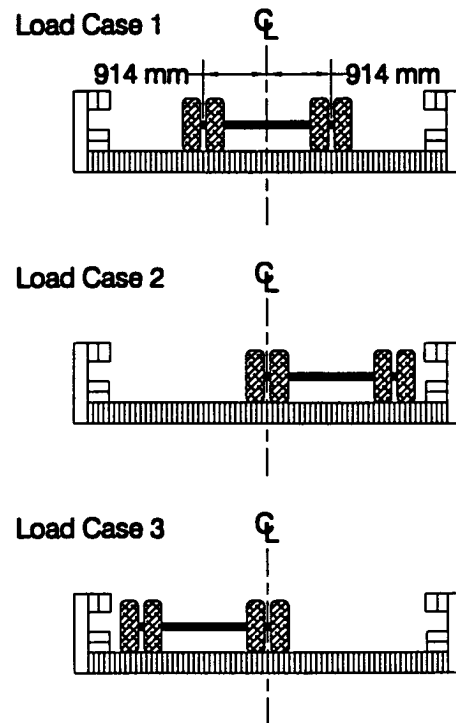


**Figure 7—Transverse test truck positions used for both load tests, as viewed from the south end of the bridge (looking north). For all load cases, the test truck was placed longitudinally with the rear axles at the centerspan and the front axle off the end of the bridge.**

was identical for both load tests. In the longitudinal direction, the test truck was positioned such that the midpoint between the rear axles was directly over the centerspan of each span tested. Because each span was relatively short, the longitudinal positioning of the test truck resulted in the front axle being just off the bridge. In the transverse direction, the test truck was positioned at three different locations for each span (Fig. 7). For load case 1, the test truck was centered on the centerline of the roadway. For load case 2, the test truck was placed adjacent to the upstream curb, with the inside wheel line at the centerline of the bridge. For load case 3, the test truck was placed adjacent to the downstream curb with the inside wheel line at the centerline of the bridge.

Load test 1 was conducted July 12, 1993, with a gross vehicle weight of 174 kN (39,020 lb) for the test truck. Load test 2 was completed June 29, 1995 with a gross vehicle weight of 176 kN (39,660 lb) for the test truck (Fig. 8).

## Analytical Evaluation

At the conclusion of load testing, the behavior of the bridge was modeled for load test conditions and AASHTO

HS 20–44 loading using an orthotropic plate computer program developed at FPL. In addition, the AASHTO HS20–44 predicted deflection was computed for each load test using the recommended design method given in *Guide Specifications for the Design of Stress-Laminated Wood Decks* (AASHTO 1991).

## Condition Assessment

General condition of the bridge was assessed at the initiation and conclusion of the monitoring period. The assessments involved visual inspections, measurements, and photographic documentation of the condition of the bridge. Items of specific interest included the condition of the wood components, wearing surface, and the stress-laminating system.

# Results and Discussion

Performance monitoring of the Ciphers bridge was initiated in July 1993, approximately 46 months after bridge construction, and continued for 24 months until June 1995.
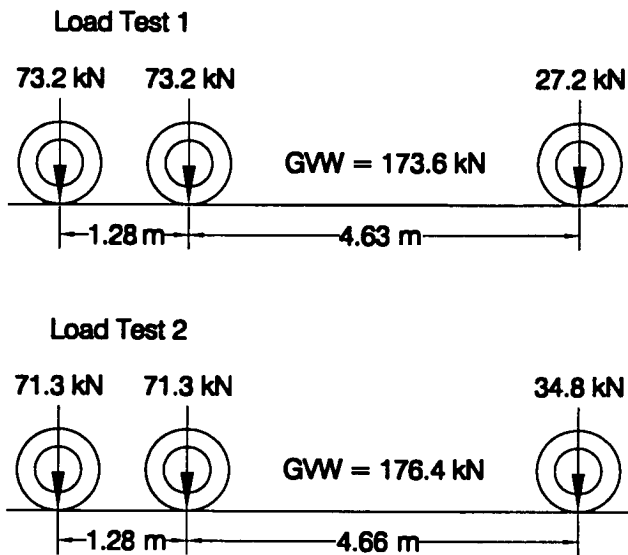
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## Load Test 1

73.2 kN    73.2 kN                27.2 kN

GVW = 173.6 kN

|← 1.28 m →|←———— 4.63 m ————→|

## Load Test 2

71.3 kN    71.3 kN                34.8 kN

GVW = 176.4 kN

|← 1.28 m →|←———— 4.66 m ————→|

**Figure 8—Test truck axle weights and spacings used for load testing.**

## Moisture Content

Results indicate that the average moisture content of the deck laminations is decreasing but remains substantially greater than that recommended by design. For the electrical-resistance meter readings, the average moisture content reading decreased from 30 to 26%. For the ovendry analyses, the average moisture content reading decreased from 45% to 39%.

These results indicate that the moisture content of the deck laminations is still decreasing from levels recorded as high as 50% at the time of construction (Franck 1991). The interior portion of the deck laminations (ovendry analyses) were, on average, at a higher moisture content than the exterior portion (electrical-resistance meter), as a result of the gradual air drying of the deck in service. All moisture content readings were in excess of the long-term maximum level of 19% included in the design specifications. This elevated moisture content had an adverse affect on the bar tension forces and is discussed in the following section.

## Bar Force and Deck Temperature

Although the Ciphers bridge had been in service for nearly 4 years and the bars were re-tensioned to 258 kN ($58 \times 10^3$ lb), or 690 kPa (100 lb/in$^2$) interlaminar deck compression, at the initiation of monitoring, substantial bar force loss was observed during the monitoring period and was attributed to stress relaxation in the deck laminations caused by high moisture content. Daily bar force and deck temperature data are presented in Figure 9. The bar forces decreased rapidly during the first few weeks but leveled off at approximately 156 kN ($35 \times 10^3$ lb), or 414 kPa (60 lb/in$^2$)

interlaminar deck compression, for the remainder of the monitoring period. However, during both winter seasons, bar force temporarily decreased an additional 67 kN ($15 \times 10^3$ lb). The bar force remained greater than 80 kN ($18 \times 10^3$ lb), or 207 kPa (30 lb/in$^2$) interlaminar deck compression, for the duration of the monitoring period.

Temporary bar force losses were observed during both winter seasons because the rate of thermal contraction for the deck laminations exceeded that of the steel stressing bars. In both winters, the correlation between the interior deck temperature and the bar force loss was most pronounced when the interior deck temperature remained less than 0°C (32°F) (freezing point of water). The bar force loss observed during the winter of 1994 is presented in Figure 10. During the first winter, temperatures at the deck interior remained below −18°C (0°F) for several weeks and reached as low as −32°C (−25°F) during January. The bar force loss observed during the winter of 1995 is presented in Figure 11. During the second winter, temperatures at the interior of the deck remained at approximately −18°C (0°F) for several weeks and reached as low as −22°C (−8°F) during February. As temperatures began to increase during the spring, bar forces recovered to levels observed the previous fall.

The rate of thermal contraction of the wood laminations while compressed together in a stress-laminated deck configuration is strongly dependent upon moisture content, while the rate for the steel bars is unaffected. A recent laboratory study of red pine stress-laminated deck sections under extreme cold temperatures also reported substantial bar force loss when the lamination moisture content was greater than 30% (Wacker and others 1996). However, when the lamination moisture content was reduced to 17%, the amount of bar force loss reported was significantly less. For the Ciphers bridge, the interior lamination moisture content remained at or above fiber saturation (approximately 30%) for the entire monitoring period and magnified the bar force loss during the winter seasons. Additional laboratory and field results are forthcoming on bar force retention in stress-laminated deck bridges in cold environments.

## Behavior Under Static Load

Results of the static-load testing and analytical evaluation are presented. For each load case, transverse deflection measurements are given at the bridge midspan as viewed from the south end (looking north). For both load tests, no permanent residual deflection was measured between load cases or at the conclusion of testing. In addition, no measurable deflection was observed at the bridge supports. The average bridge prestress during testing was approximately 620 kPa (90 lb/in$^2$) for load test 1 and 414 kPa (60 lb/in$^2$) for load test 2.
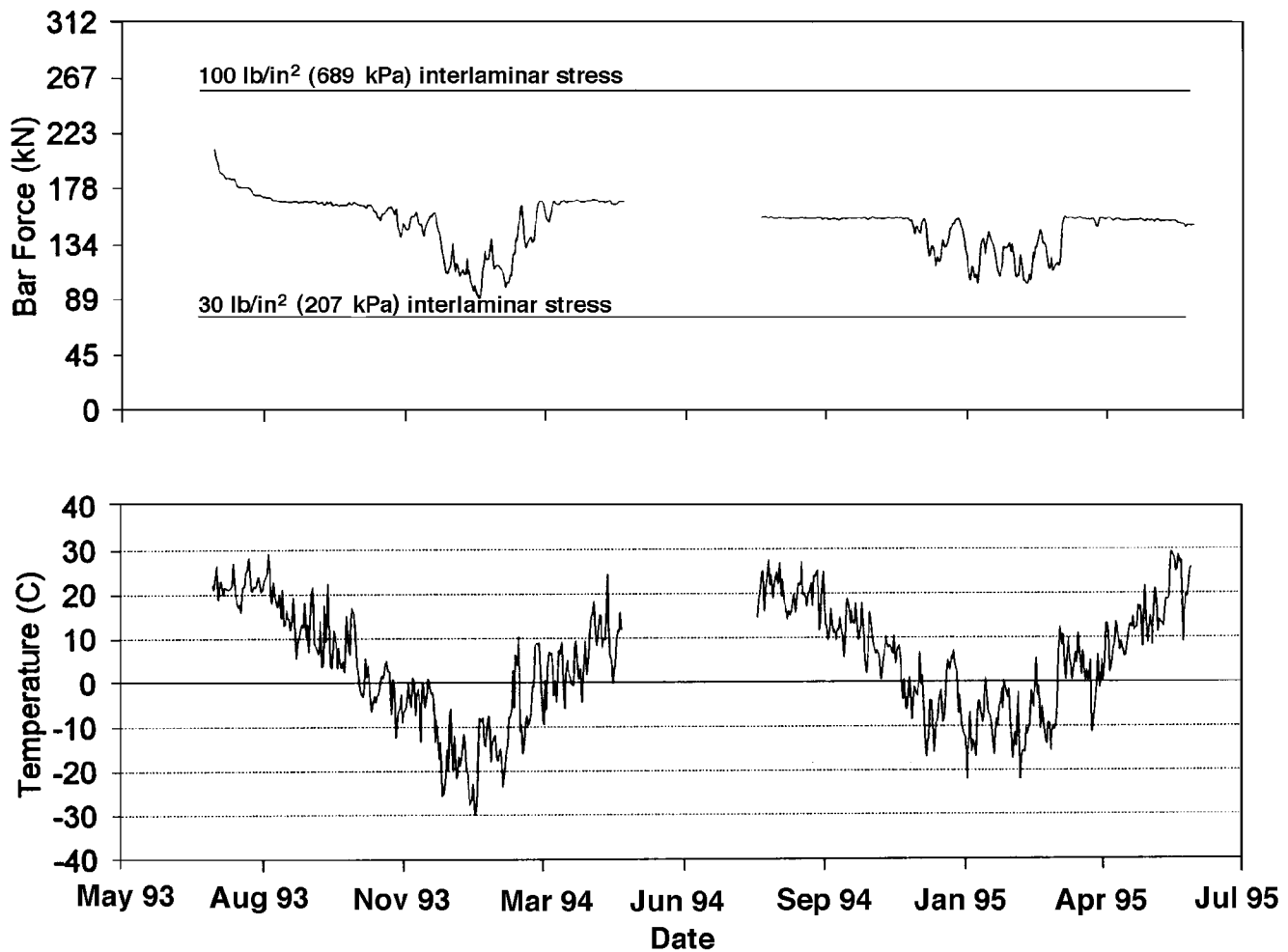
**Figure 9—Bar force and deck temperature summary: Average daily load cell readings (top); interior deck temperatures (bottom). Note that the gap in the data was due to a computer hardware failure that occurred during summer when bar forces are not significantly affected by temperature.**

### Load Test 1

Measured and predicted transverse deflections for load test 1 are shown in Figure 12. For load case 1 on the south span, the maximum measured deflection near the centerline of the bridge was 6 mm (0.23 in.) (Fig. 12a). For load cases 2 and 3 on the south span, the maximum measured deflections occurred near the outside truck wheel line and were both 6 mm (0.25 in.) (Fig. 12b,c). For load case 1 on the north span, the maximum measured deflection near the centerline of the bridge was 6 mm (0.25 in.) (Fig. 12d). For load cases 2 and 3 on the north span, the maximum measured deflections occurred near the outside truck wheel line and were 7 and 6 mm (0.28 and 0.24 in.), respectively (Fig 12e,f).

### Load Test 2

Measured and predicted transverse deflections for load test 2 are shown in Figure 13. For load case 1 on the south span, the maximum measured deflection near the bridge centerline was 6 mm (0.23 in.) (Fig. 13a). For load cases 2 and 3 on the south span, the maximum measured deflections occurred near the outside truck wheel line and were 6 mm (0.24 and 0.23 in., respectively) (Fig. 13b,c). For load case 1 on the North span, the maximum measured deflection near the centerline of the bridge was 6 mm (0.24 in.) (Fig. 13d). For load cases 2 and 3 on the north span, the maximum measured deflections occurred near the outside truck wheel line and both were 6 mm (0.24 in.) (Fig 13e,f). Additional load test figures that further present load test data are given in Appendix B.
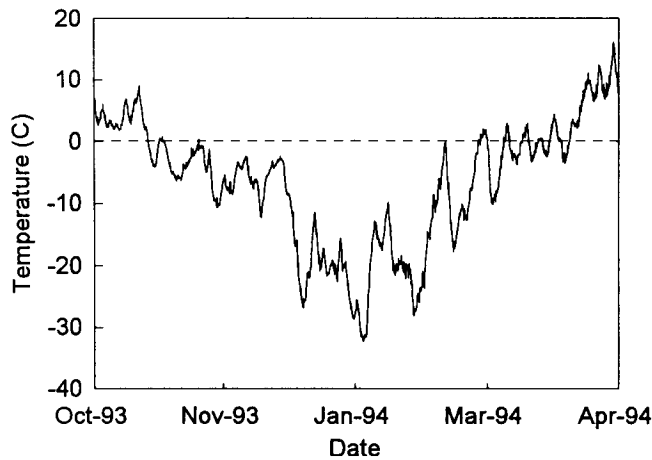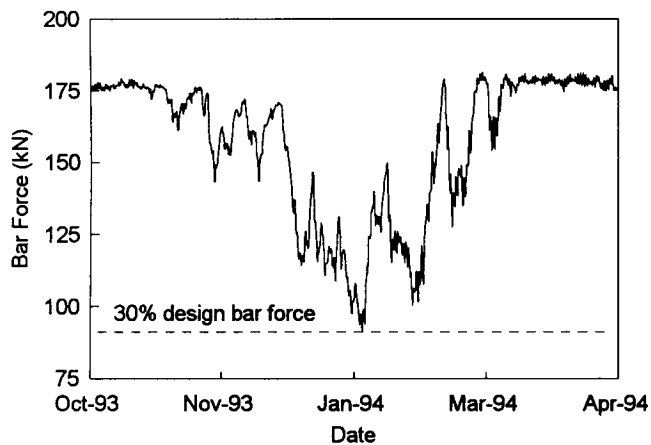
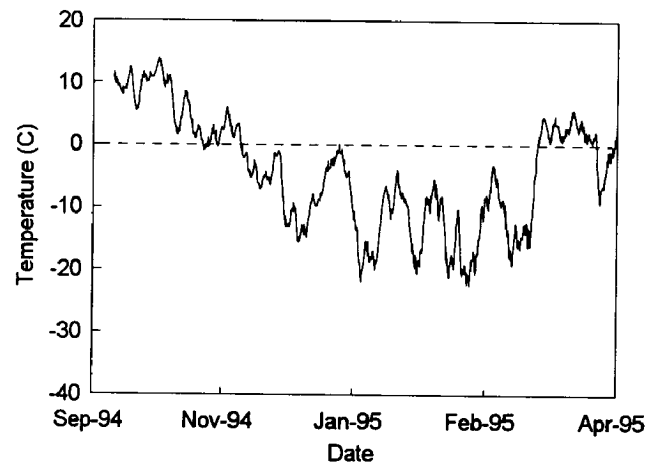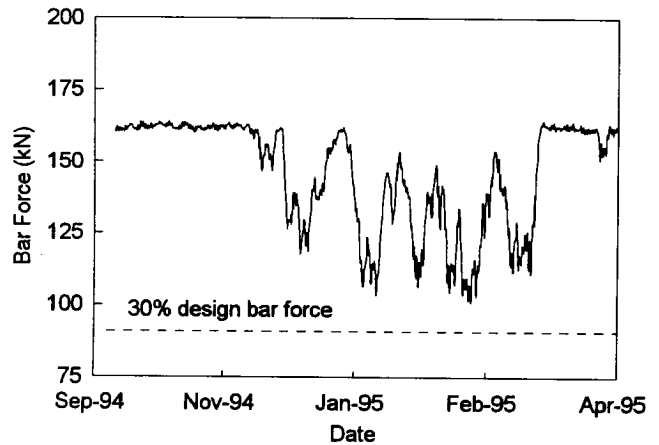**Figure 10—Bar force and deck temperature summary, Winter 1994.**



**Figure 11—Bar force and deck temperature summary, Winter 1995.**

## Analytical Evaluation

Predicted deflections given in Figures 12 and 13 provide a good approximation of the measured deflection for each load case. Minor differences between measured and predicted deflection are noticeable at the edges of the bridge and are caused, in part, by the edge-stiffening effect of the sawn lumber curb assemblies.

Deflections for the AASHTO HS20–44 design loading are not provided because they were not significantly different from the predictions for each load test. However, the maximum predicted deflection values for each load case under AASHTO HS20–44 loading conditions and the design deflection are presented in Table 1 for each load test. Deflections were converted to an equivalent span/deflection ratio based on the appropriate span length (center–center of bearing). The HS20–44 predicted maximum deflections are significantly less than predicted by design and are below the new recommended design deflection limit of L/500 established after design and construction of the Ciphers bridge.

## Condition Assessment

General condition assessments indicated that the structural and serviceability aspects of the Ciphers bridge were satisfactory.

### Wood Components

Visual inspection of the wood components of the bridge indicated no signs of distress. Preservative accumulation on the surface of rail members was evident during the summer months, but did not cause significant leaching problems. Checking on the end grain top-surface of the rail posts was minor and did not penetrate the preservative envelope.
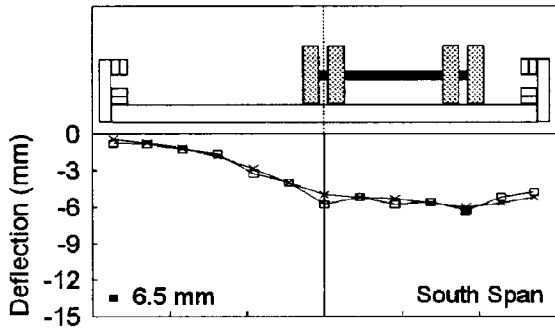
### Wearing Surface

The asphalt wearing surface was observed to be in satisfactory condition at the conclusion of monitoring, approximately 6 years after bridge installation. There was no cracking evident on the asphalt wearing surface.
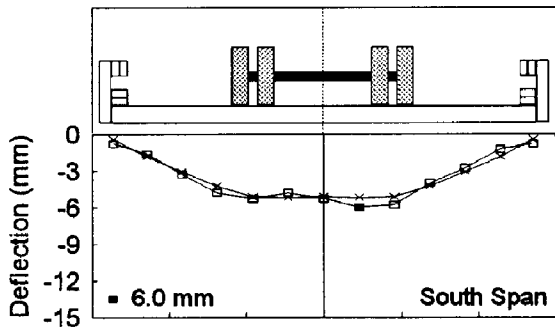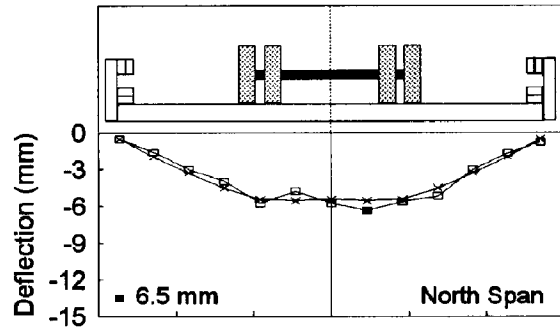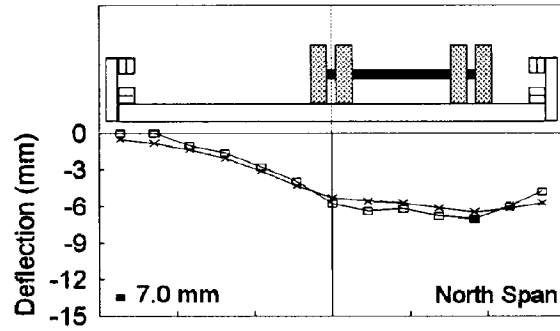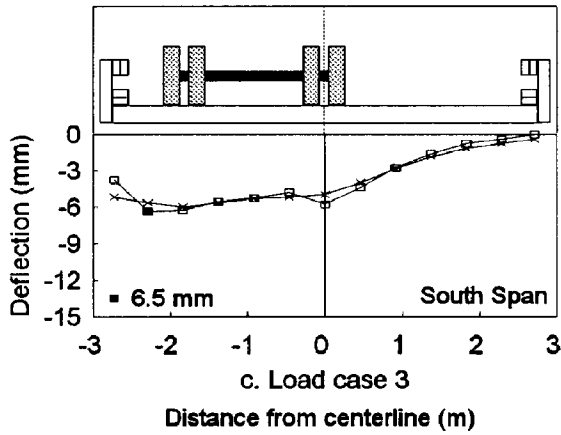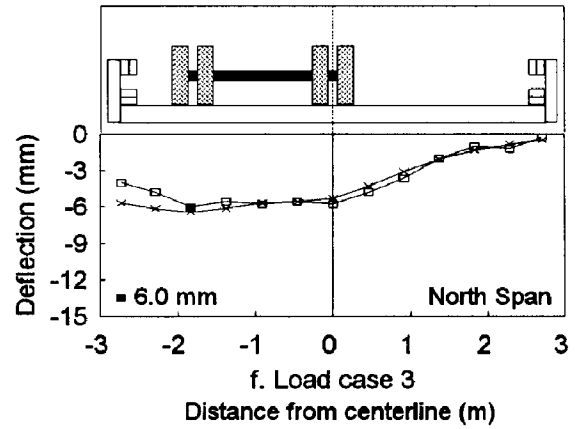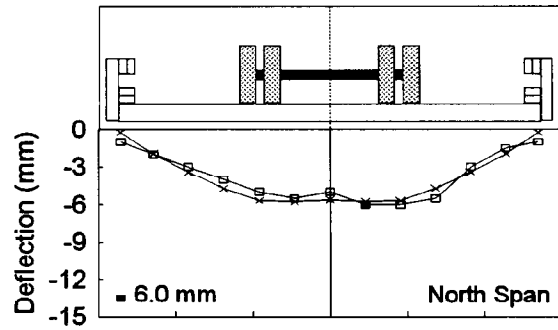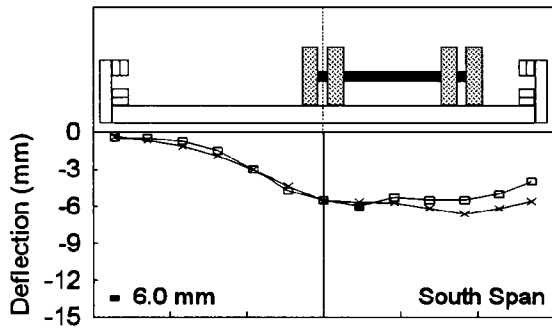
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Figure 12—Load test 1 comparing measured and predicted centerspan deflection (looking north). Bridge cross-sections and vehicle positions are presented to aid interpretation only and are not to scale.
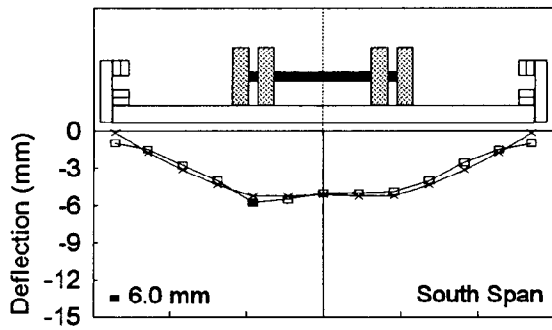
Figure 13—Load test 2 comparing measured and predicted centerspan deflection (looking north). Bridge cross-sections and vehicle positions are presented to aid interpretation only and are not to scale.
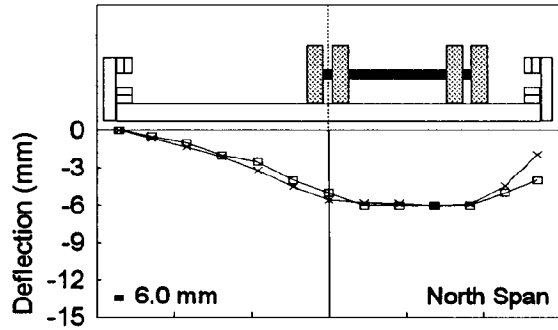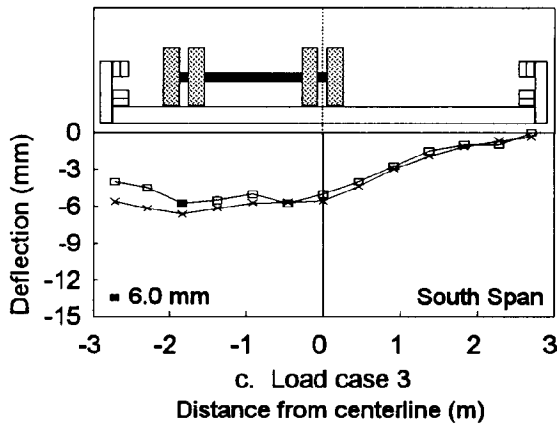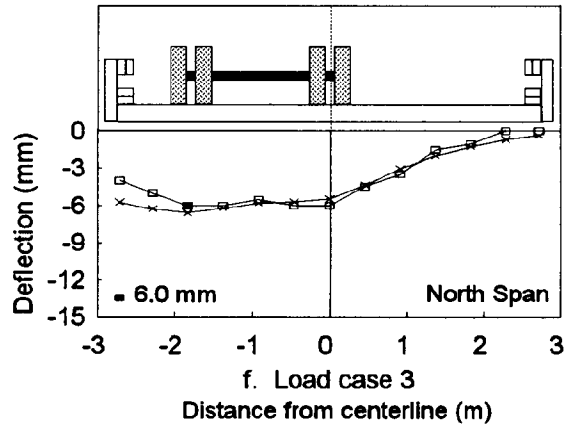
**Table 1—Predicted maximum midspan deflections and corresponding span/deflection ratios using HS20–44 loading conditions for both load tests**

| Load test | Estimated interlaminar compression (kPa) (lb/in$^2$) | Predicted HS20–44 maximum midspan deflections and span/deflection ratios | | | | |
|---|---|---|---|---|---|---|
| | | Load case | South span | | North span | |
| | | | Model[a] | AASHTO[b] | Model[a] | AASHTO[b] |
| 1 | 620 (90) | 1 | 5 mm L/1052 | 21 mm L/275 | 6 mm L/987 | 21 mm L/275 |
| | | 2,3 | 6 mm L/884 | 21 mm L/275 | 7 mm L/841 | 21 mm L/275 |
| 2 | 414 (60) | 1 | 6 mm L/1004 | 21 mm L/275 | 6 mm L/946 | 21 mm L/275 |
| | | 2,3 | 7 mm L/850 | 21 mm L/275 | 7 mm L/810 | 21 mm L/275 |

[a]Using orthotropic plate prediction model with L = 5.60 m (18.4 ft) (south span) and L = 5.76 m (18.9 ft) (north span) based on as-built measurements.
[b]Using recommended method in *Guide Specification for Stress-Laminated Decks* (AASHTO 1991) with L = 5.79 m (19 ft).

## Stress-Laminating System

The steel stressing bars and steel plate anchorages were in good condition. The exposed portion of the steel stressing bars were slightly corroded in areas were the anchor nuts had removed the galvanized protective coating. The affected areas should be wire-brushed to remove the corrosion and recoated with galvanizing paint.

# Conclusions

Based on the results of a 2-year field evaluation program, performance of the Ciphers bridge is satisfactory. However, as a result of the northern location, the bridge is susceptible to substantial bar force loss during the winter season because of its high lamination moisture content. Low bar force in a stress-laminated deck leads to structural and serviceability deficiencies that may prevent the bridge from providing satisfactory performance in the future. The following conclusions are based on our findings:

- The sawn lumber components slightly decreased in average moisture content during the monitoring period. After approximately 6 years in-service, the average moisture content of the deck is approximately 30%.

- The majority of bar force loss during the monitoring period was attributed to stress relaxation of the deck laminations and totaled approximately 89 kN ($20 \times 10^3$ lb), or 33% of the restressing force of 258 kN ($58 \times 10^3$ lb) introduced at the initiation of monitoring. However, during winter seasons the bar force loss was

accelerated due to low temperatures and high lamination moisture content. This temperature-induced bar force loss was up to an additional 67 kN ($15 \times 10^3$ lb) for short periods when the temperature dropped below the freezing point of water during the winter season but fully recovered when temperatures increased.

- For the entire monitoring period, bar force remained above the minimum required design levels and did not compromise the structural efficiency of the bridge. However, future inspections of the Ciphers bridge should include hydraulic equipment measurements to ensure that bar forces remain above 80 kN ($18 \times 10^3$ lb). These bar force measurements are strongly recommended prior to any winter hauling operations across the bridge.

- Static-load testing and analysis indicate that the Ciphers bridge is performing in a linear-elastic manner. When subjected to truck loading at interlaminar compression levels of 620 kPa (90 lb/in$^2$) and 414 kPa (60 lb/in$^2$), the bridge deck deflection was substantially below limitations determined during design.

- The predicted maximum deflection under AASHTO HS20–44 loading was 7 mm (0.28 in.), or 1/810 of the bridge span measured center–center of bearing.

- Visual inspection indicated no signs of deterioration of the wood components. Minor corrosion was observed on the exposed portions of the steel stressing bars and should be removed and re-coated with galvanized paint.

# References

**AASHTO.** 1989. Standard specifications for highway bridges 14th ed. Washington, DC: American Association of State Highway and Transportation Officials.

**AASHTO.** 1991. Guide specifications for the design of stress-laminated wood decks. Washington, DC: American Association of State Highway and Transportation Officials.

**ASTM.** 1984. Standard test methods for direct moisture content measurement of wood and wood-based materials. ASTM D4442–84. Philadelphia, PA: American Society for Testing and Materials. 5 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.

**ASTM.** 1990. Use and calibration of hand-held moisture meters. ASTM D 4444–84. Philadelphia, PA: American Society for Testing and Materials. 6 p.

**FORINTEK**. 1984. Moisture content correction tables for the resistance-type moisture meter. Eastern Species. SP511E. Ottawa, Canada: FORINTEK Corp. 37 p.

**Franck, Bruno M**. 1991. Long term behavior of a stress-laminated timber deck. In: Proceedings, International Association of Bridge and Structural Engineers (IABSE) symposium; 1991, September; Leningrad, Russia.

**Ritter, Michael A.** 1990. Timber bridges: design, construction, inspection and maintenance. EM 770–8. Washington, DC: U.S. Department of Agriculture, Forest Service, Engineering Staff. 944 p.

**Ritter, M.A.; Geske, E.A.; McCutcheon, W.J. [and others]**. 1991. Methods for assessing the field performance of stress-laminated timber bridges. In: Proceedings, 1991 international timber engineering conference; 1991 September 2–5; London, United Kingdom. High Wycombe, United Kingdom: Timber Research and Development Association: 3.319–3.326. Vol. 3.

**USDA.** 1991. The timber bridge initiative, fiscal year 1991 status report. Radnor, PA: U.S. Department of Agriculture, Forest Service, State and Private Forestry, Northeastern Area. 12 p.

**Wacker, James P.; Ritter, Michael A.; Conger, Don**. 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.

# Appendix A—Information Sheet

## General

Name:  Ciphers bridge

Location:   Beltrami Island State Forest
(Roseau County, Minnesota)

Date of Construction:  September 1989

Owner:  Minnesota Department of Natural Resources

## Design Configuration

Structure Type: Stress-laminated deck with butt joints

Butt Joint Frequency: 1 in 4 laminations transversely
separated 1.2 m (4 ft) longitudinally

Total Length (out–out): 12.19 m (40 ft)

Skew: 0 degrees

Number of Spans:  2 (continuous over an intermediate
support)

Span Lengths (center-to-center bearings):  5.88 m (19 ft;
19.3 ft, as-built)

Width (out–out): 5.49 m (18 ft; 17.8 ft, as-built)

Width (curb–curb): 4.88 m (16 ft; 15.8 ft, as-built)

Number of Traffic Lanes:  1

Design Loading:  AASHTO HS20–44

Wearing Surface Type:  Asphalt pavement; 25 to 51 mm
(1 to 2 in.) thick

## Material and Configuration

Wood Laminations:

Species: Red pine

Size: 102 by 305 mm (4 by 12 in.
(3-7/8 by 12 in. actual))

Grade: No. 2 and better

Moisture Condition:  approximately 30% at initiation
of monitoring

Preservative Treatment:  Creosote

Stressing Elements:

Type:   High strength steel threaded bar, conforming
to ASTM A722, Type II

Diameter: 25 mm (nominal 1 in.)

Number:  9

Design Force: 320 kN ($72 \times 10^3$ lb)

Spacing:  1.22 m (4 ft) center–center, 610 mm (2 ft)
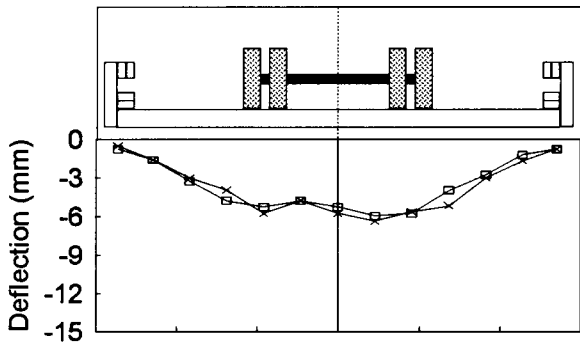from bridge ends

Anchorage Configuration:

Discrete Steel Plates:  279 by 533 by 25 mm
(11 by 21 by 1 in.) bearing

152 by 305 by 38 mm
(6 by 12 by 12 in.) anchor
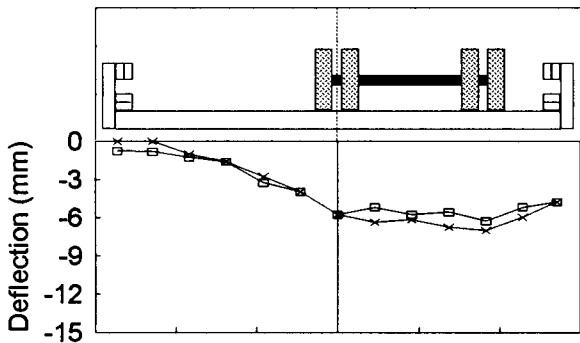
Rail and Curb System:

Design: AASHTO 44.5 kN (10, 000 lb) static load

Species: Douglas-fir

Grade: No. 1

Member Sizes:

Rails: 152 by 254 mm (6 by 10 in.)
Posts: 203 by 254 mm (8 by 10 in.)
Curbs: 203 by 305 mm (8 by 12 in.)

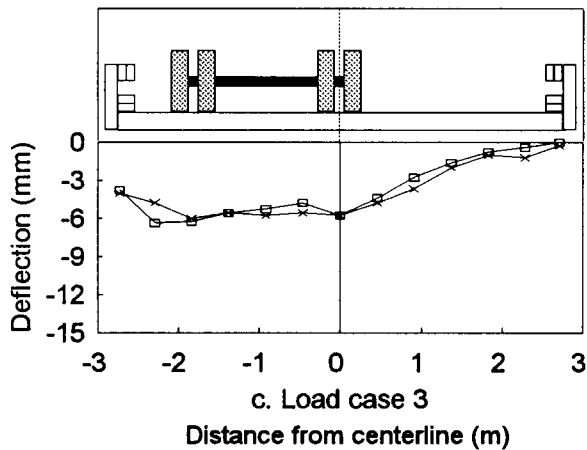# Appendix B—Load Testing Results

The following transverse deflection figures present additional data comparisons from both load tests. Figures B1 and B2 compare the deflection measured at each span for Load Test 1. Figures B3 and B4 compare the deflection measured at each span for Load Test 2. Both sets of figures serve to validate the deflection data collected during load tests.
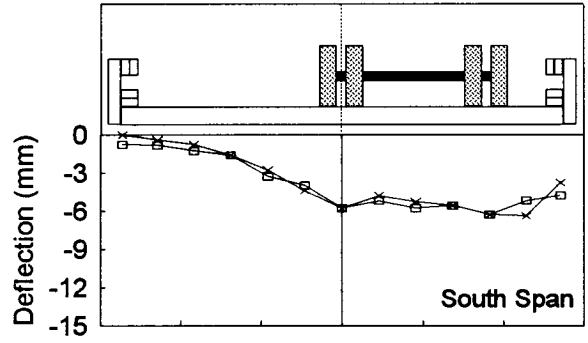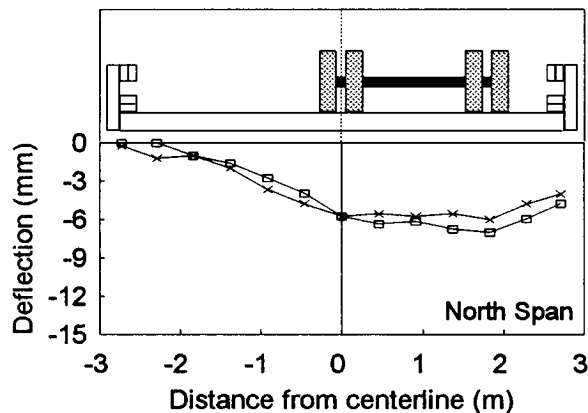


a. Load case 1



b. Load case 2



South Span



North Span

Distance from centerline (m)

LC3 reversed   LC2

**Figure B2—Load test 1 comparing measured center-span deflection from load cases 2 and 3 (looking north). Bridge cross-sections and vehicle positions are presented to aid interpretation only and are not to scale.**
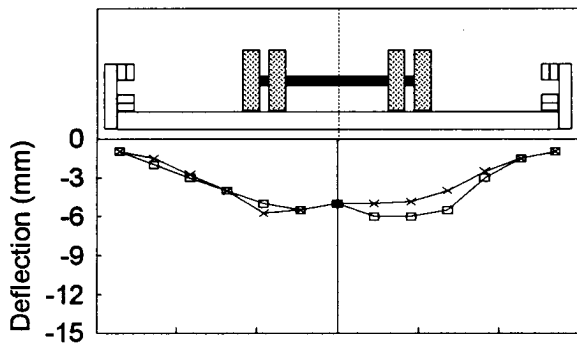
c. Load case 3

Distance from centerline (m)

North span   South span

**Figure B1—Load test 1 comparing measured center-span deflection of the north and south span from load cases 1, 2, and 3 (looking north). Bridge cross-sections and vehicle positions are presented to aid interpretation only and are not to scale.**
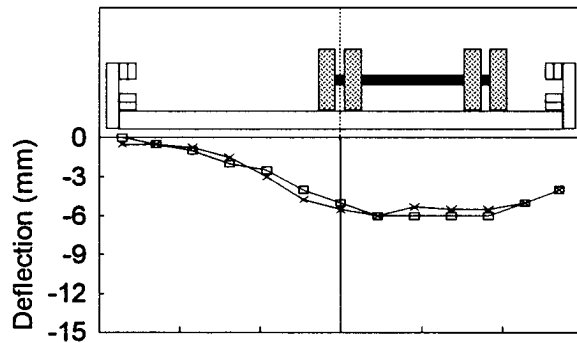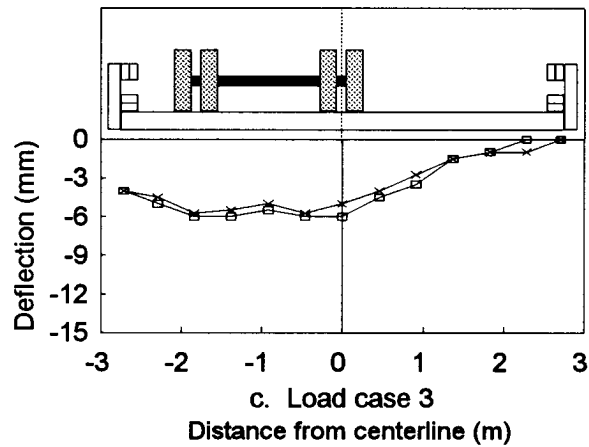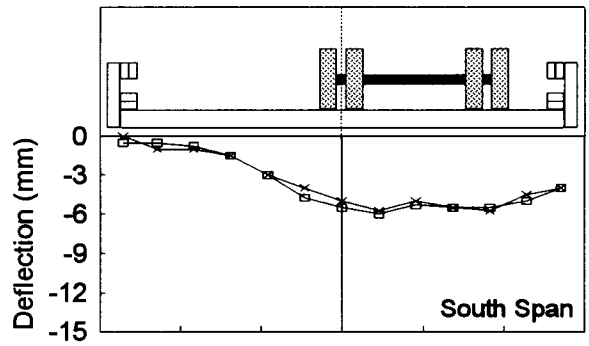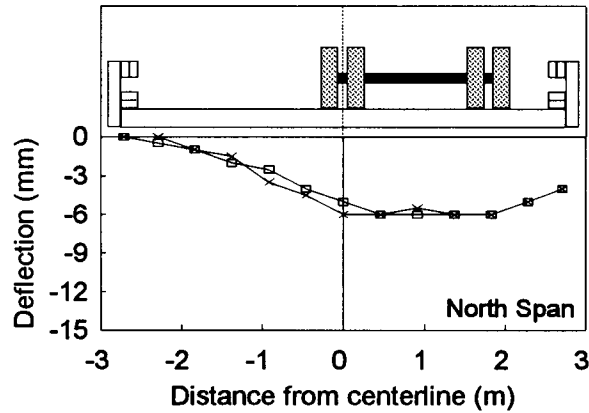
a. Load case 1

b. Load case 2

c. Load case 3
Distance from centerline (m)

North span    South span

**Figure B3—Load test 2 comparing measured center-span deflection of the north and south span from load cases 1, 2, and 3 (looking north). Bridge cross-sections and vehicle positions are presented to aid interpretation only and are not to scale.**



South Span

North Span

Distance from centerline (m)

LC3 reversed    LC2

**Figure B4—Load test 2 comparing measured center-span deflection from load cases 2 and 3 (looking north). Bridge cross-sections and vehicle positions are presented to aid interpretation only and are not to scale.**

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