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Field Performance of Timber Bridges

4. Graves Crossing Stress-Laminated Deck Bridge

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Michael A. Ritter

Abstract

The Graves Crossing bridge was constructed October 1991 in Antrim County, Michigan, as part of the demonstration timber bridge program sponsored by the USDA Forest Service. The bridge is a two-span continuous, stress-laminated deck superstructure and it is 36-ft long and 26-ft wide. The bridge is one of the first stress-laminated deck bridges to be built of sawn lumber treated with chromated copper arsenate (CCA) preservative. The performance of the bridge was continuously monitored for 2 years, beginning at the time of installation. This performance monitoring involved gathering and evaluating data relative to the stiffness of the lumber laminations, the moisture content of the wood deck, the force level in the stressing bars, and the behavior of the bridge under static truck loading. In addition, comprehensive visual inspections were conducted to assess the overall condition of the structure. Based on 2 years of field observations, the bridge is performing well with no structural or serviceability deficiencies.

Keywords: Timber, bridge, wood, stress laminated

Acknowledgments

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Contents

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4. Graves Crossing Stress-Laminated Deck Bridge

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Introduction

In an effort to improve rural transportation networks and revitalize rural economies, the U.S. Congress established the Timber Bridge Initiative (TBI) in 1988 as part of a comprehensive legislation package aimed at enhancing rural America. Administrative responsibility for the program was assigned to the USDA Forest Service and implemented through three distinct program areas aimed at improving the utilization of timber as a bridge material (USDA 1993). These program areas include a demonstration program to construct timber bridges, a research program to develop and refine new timber bridge technologies, and a technology transfer program to disseminate available information to bridge engineers and builders.

Administrative responsibility for the demonstration bridge program was assigned to the State and Private Forestry (S&PF) branch of the USDA Forest Service. The Northeast Area office of S&PF has been awarding grants for demonstration bridges on an annual basis since 1989. An evaluation panel selects the grant recipients based on proposals submitted by state and local governments. The research program is administered within the USDA Forest Service by the Forest Products Laboratory (FPL). In conjunction with a wide range of timber bridge studies being conducted in the laboratory and the field, the FPL established a nationwide bridge monitoring program. The objective of this program is to collect, analyze, and distribute information on the field performance of timber bridges. The technology transfer program is coordinated through the Timber Bridge Information Resource Center (TBIRC) in Morgantown, West Virginia. Information resources on all aspects of timber bridges are available through the Morgantown office.

This report is fourth in a series that documents the results from the FPL bridge monitoring program. The report includes sections on the development, design, construction, and field performance of the Graves Crossing bridge. Built in 1991, this bridge is a two-lane, two-span continuous, stress-laminated deck with an overall length of 36 ft. (See Table 1 for metric conversion factors.) The bridge is one of the first stress-laminated deck bridge to be built of sawn lumber treated with chromated copper arsenate (CCA). An information sheet on the Graves Crossing bridge is provided in the Appendix.

Table 1—Factors for converting English units of measurement to SI units

English unit	Conversion factor	SI unit
acre	4,046	square meter (m^2)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
square foot (ft^2)	0.09	square meter (m^2)
mile	1,609	meter (m)
pound (lb)	0.14	Newton (N)
lb/in^2 (stress)	6,894	Pascal (Pa)
ton (short, 2,000 lb)	907	kilogram (kg)

Background

The Graves Crossing bridge is located approximately 35 miles west of Gaylord, Michigan, in Antrim County (Fig. 1). The bridge is on a two-lane gravel roadway that crosses the Jordan River at Graves Crossing, approximately 15 miles upstream of its terminus into Lake Charlevoix. The gravel road provides access for several private residences and a 4,000-acre state forest preserve. The average daily traffic (ADT) for the road is estimated to be 100 vehicles.

Before replacement in 1991, Graves Crossing consisted of a series of four corrugated steel culverts with a 3-ton posted load limit (Fig. 2). The culverts were in poor condition and insufficient to meet the hydraulic flow requirements at the site. Past roadway washouts and severe scour problems required that the culverts be replaced with a new bridge structure designed for greater hydraulic capacity. In addition, a new bridge capable of supporting standard highway loads was needed to provide safe access for fire-fighting vehicles, school buses, and logging trucks. Replacement of the existing culverts with a skewed bridge was determined to be the best alternative, because it would allow alignment of the abutments with the natural stream channel and reduce adverse impacts on the Jordan River.

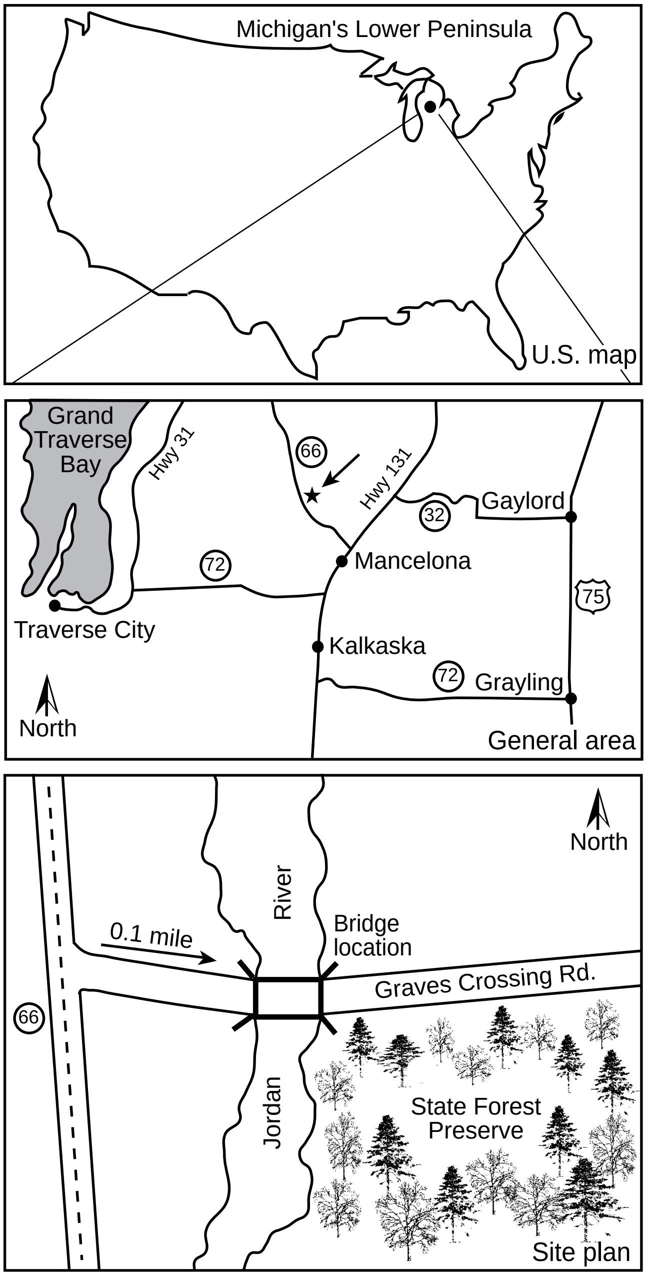

Figure 1—Location maps for the Graves Crossing bridge.

Through a cooperative effort between the Huron Pines Resource Conservation and Development Council and the Antrim County Road Commission, a proposal was submitted to the USDA Forest Service for partial funding of the Graves Crossing replacement as a demonstration bridge under the Timber Bridge Initiative (USDA 1993). The project proposed a stress-laminated deck utilizing local Red Pine lumber treated with CCA preservative. In 1990, the project received funding through the TBIRC, and plans for the design and construction of the Graves Crossing bridge were finalized. Subsequently, FPL was contacted to provide assistance in

Figure 2—Original Graves Crossing site prior to bridge construction.

developing and implementing a field evaluation program to monitor the performance of the bridge.

Objective and Scope

The objective of this project was to evaluate the field performance of the Graves Crossing stress-laminated deck bridge for 2 years, beginning at bridge installation. The scope of the project included data collection and analysis related to the lamination stiffness, wood moisture content, stressing bar force, behavior under static truck loading, and general structure condition. The results of this project will be considered with similar monitoring projects in an effort to improve design and construction methods for future stress-laminated timber bridges.

Design, Construction, and Cost

The Graves Crossing bridge project was a mutual effort among several agencies and individuals. An overview of the design, construction, and cost of the project is presented.

Design

Design of the Graves Crossing bridge was completed by an engineering consultant retained by the bridge owner. Except for features relating to stress laminating, the bridge was designed in compliance with the American Association of State Highway and Transportation Officials (AASHTO) *Standard Specifications for Highway Bridges* (AASHTO 1989) for two lanes of HS20-44 loading. Specific design requirements for stress laminating were based on a draft version of the AASHTO *Guide Specifications for the Design of Stress-laminated Wood Decks* (AASHTO 1991).

The design geometry of the Graves Crossing bridge provided for a two-span continuous deck, 36 ft long, 26 ft wide, and 12 in. deep (Fig. 3). The stress-laminated deck consists of

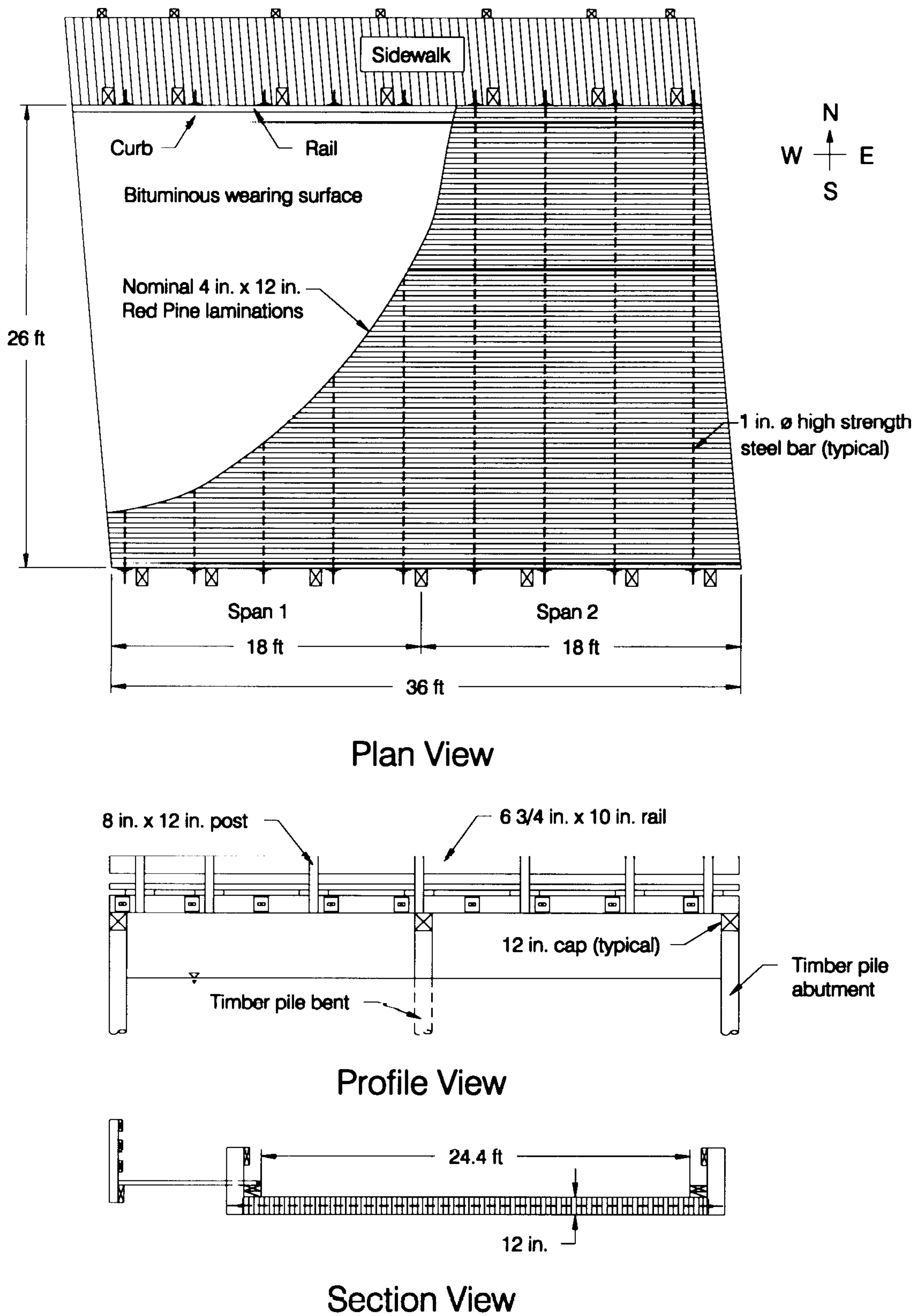

Figure 3—Design configuration of the Graves Crossing bridge.

4-in.-thick Red Pine lumber treated with CCA preservative in accord with AWPA Standard C14 (AWPA 1989). Because none of the laminations extended the bridge length, butt joints were employed in the deck. Butt joints were spaced across the width and length at intervals of four laminations and 4 ft, respectively.

Design values for the Red Pine laminations were based on the *National Design Specification for Wood Construction* (AFPA 1986, 1988) for lumber visually graded No. 2 in accordance with Northeastern Lumber Manufacturing Association (NELMA) rules. Tabulated design values were for the Northern Pine species combination and were 950 lb/in^2 for bending, 1,300,000 lb/in^2 for modulus of elasticity (MOE), and 435 lb/in^2 for compression perpendicular-to-grain. Wet-use adjustment factors were applied to all design values.

The lumber laminations were stress-laminated with threaded steel bars to provide the interlaminar compression required to develop load transfer between adjacent laminations. The design specified the use of 1-in-diameter, high strength, threaded and galvanized steel bars with an ultimate strength of 150,000 lb/in^2 that met the requirements of ASTM A722 (ASTM 1988); these bars were spaced 4 ft along the bridge length. The design tension force for the bars was 58,000 lb, which provides an interlaminar compressive stress of 100 lb/in^2. Galvanized steel bearing plates measuring 12 in. long by 16 in. wide by 1 in. thick and galvanized steel anchor plates measuring 4 by 6-1/2 by 1-1/4 in. were specified along with spherical hex nuts to anchor the bar along the deck edges.

Design of the bridge rail and curb system was based on a crash-tested design conforming to AASHTO Performance Level 1 criteria (FHWA 1990). The bridge rail was specified as glued-laminated Southern Pine measuring 6-3/4 in. wide by 10 in. deep that was continuous over the bridge length. The rail posts were designated as visually graded, Dense Select Structural, Douglas Fir sawn lumber measuring 8 in. wide by 12 in. deep and spaced 6 ft on-center along the bridge edges.

A 3-in.-thick asphalt wearing surface in conjunction with a waterproof geotextile membrane were also specified.

Construction

Construction of the Graves Crossing bridge was contractually administered by the Antrim County Road Commission in the fall of 1991. The existing steel culverts were removed and coffer dams were installed, while timber piles were driven and timber abutments and a center bent were constructed (Fig. 4). A temporary bridge structure was installed to provide uninterrupted traffic flow during bridge construction (Fig. 5).

Figure 4—Coffer dam used during installation of timber piling, abutments, and bent.

Figure 5—This temporary (Bailey-type) bridge allowed uninterrupted traffic flow across the bridge during the construction of the Graves Crossing bridge.

The lumber laminations for the superstructure were delivered to the site in 4-ft-wide strapped bundles that extended the full length of the bridge. These bundles were placed on the completed substructure by a small crane (Fig. 6). Before removing the metal straps from the bundles, steel stressing bars were inserted through the prebored holes and anchorage plates and nuts were attached. The bridge laminations were intentionally oversized in length because of the bridge skew and were trimmed on-site with a chainsaw (Fig. 7). The field cuts exposed untreated end-grain areas of the laminations that were field-treated with copper napthanate preservative. A preferable method is to cut the laminations to the correct length prior to preservative treatment.

Figure 6—Small crane used to place the strapped lamination bundles onto the abutments.

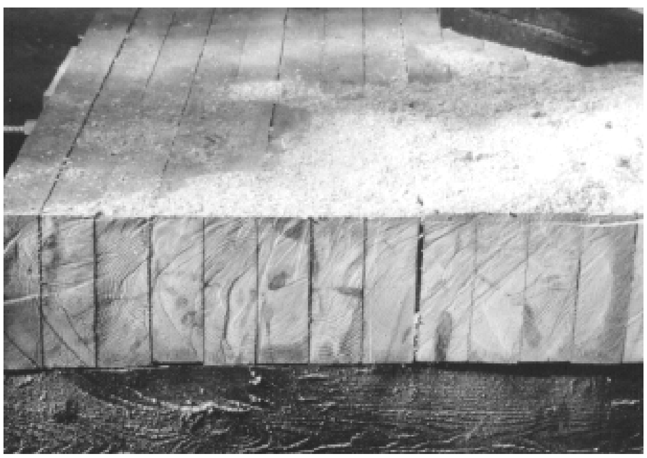

Figure 7—All deck laminations were trimmed to length with a chainsaw, and the exposed end-grain was field treated with copper napthanate preservative.

Figure 8—Initial tensioning of the stressing bars was completed with a hollow-core hydraulic cylinder and pump at each successive bar, beginning at one end of the bridge.

Figure 9—Completed sidewalk structure attached to the superstructure on the downstream side of the bridge.

After anchoring the centerline of the deck to the substructure with drift pins, hydraulic equipment was used to tension the stressing bars. The initial tensioning was completed immediately after the deck laminations were set on the abutments. Tensioning was completed at each successive bar with a single hydraulic jack system to a force level of 58,000 lb (Fig. 8). During this initial tensioning, the bars were tensioned four separate times to achieve a uniform 100 lb/in^2 interlaminar compressive stress. Subsequent tensioning used the same procedure and force level and was conducted at 1, 10, and 13 weeks after the initial tensioning.

The bridge rail and curb system was installed 3 days after initial tensioning of the bars. Shortly thereafter, a treated-lumber sidewalk was installed at the downstream side of the bridge to provide safe pedestrian access to an adjacent campground (Fig. 9). Approximately 1 month after the initial bar tensioning, the waterproof geotextile membrane and 3-in.-thick asphalt pavement were installed on the deck (Fig. 10). The completed Graves Crossing bridge is shown in Figure 11.

During construction, the west abutment of the Graves Crossing bridge was installed with a slight skew in relation to the east abutment and the center bent. Thus, the as-built configuration differed slightly from design configuration and is shown in Figure 12. Span 2 measures approximately 8 in. longer than span 1 (based on average center-center of

Figure 10—Asphalt pavement wearing surface was applied to the deck approximately 4 weeks after installation.

bearing); span 1, measured along the upstream and downstream edges, differs by approximately 5 in. The shortest span length (center-center of bearing) measured 16.75 ft at the upstream edge of span 1.

Cost

The total cost for the Graves Crossing bridge was approximately $150,000 and included design, fabrication, material, and construction of the substructure, superstructure, and approach roadways. Contract costs for the design of the superstructure totaled $8,000, and costs for the material, fabrication, and construction of the superstructure totaled $50,000. Based on 936 ft^2 of deck surface area, the cost for the Graves Crossing bridge superstructure was $62/ft^2.

Evaluation Methodology

To evaluate structural performance of the Graves Crossing bridge, the Antrim County Road Commission contacted FPL for assistance. Through mutual agreement, a 2-year bridge monitoring plan was developed by the FPL and implemented through a Cooperative Research and Development Agreement with the Antrim County Road Commission. The plan called for stiffness testing of the lumber laminations prior to construction and monitoring of several key performance indicators. This included lamination stiffness, moisture content, bar force, static load behavior, and general structure condition. At the initiation of field monitoring, FPL representatives visited the bridge site to install instrumentation and train Antrim County personnel in data collection procedures for moisture content and bar force measurements. Load tests and general condition assessments were conducted by FPL personnel during site visits. The evaluation methodology utilized procedures and equipment previously developed (Ritter and others 1991; Wacker and Ritter 1992) and is discussed in the following sections.

Lamination Stiffness

Although several highway bridges have been constructed of Red Pine lumber, additional information on lumber MOE was considered necessary to verify assumed design values and obtain accurate information for load test analyses. To accomplish this, stiffness testing was completed at the fabrication plant on a representative sample of the Red Pine laminations prior to preservative treatment. A transverse vibration technique (Ross and others 1991) was used to measure the flatwise MOE of 50 deck laminations: 10 each in lengths of 6, 10, 14, 16, and 18 ft. Flatwise MOE values were converted to equivalent edgewise MOE values using a conversion factor of 0.965 (Williams and others 1994).

Moisture Content

Electrical-resistance moisture content readings were collected from the Graves Crossing superstructure at installation in accordance with ASTM standard requirements (ASTM 1990). In addition, lumber samples were obtained from field cuts at installation and used to measure moisture content by the ovendry method (ASTM 1992). After installation, the general trend in moisture content during the monitoring period was characterized by electrical-resistance measurements taken from the superstructure on a bimonthly basis. Measurements were taken at a series of locations on the deck’s underside at probe penetrations of approximately 1 in. (ASTM 1990). When necessary, adjustments for species and temperature were applied to determine actual moisture content values (Forintek 1984).

Bar Force

Periodic measurements of stressing bar force were obtained to monitor loss and ensure that adequate bar force was maintained during the monitoring period. Calibrated load cells were installed on four of the nine stressing bars prior to the initial stressing (Fig. 13). Load cell measurements were collected on a monthly basis with a portable strain indicator (Fig. 14) and converted from units of strain to bar force based on laboratory calibrations. In addition, the accuracy of the load cells was validated with recalibrations and hydraulic force checks performed at the end of the monitoring period (Ritter and others 1991) .

Behavior Under Static Load

A static-load test of the Graves Crossing bridge was conducted approximately 6 months into the monitoring period to determine the bridge response under static-loading conditions. In addition, an analytical assessment was completed to predict the bridge response using computer modeling.

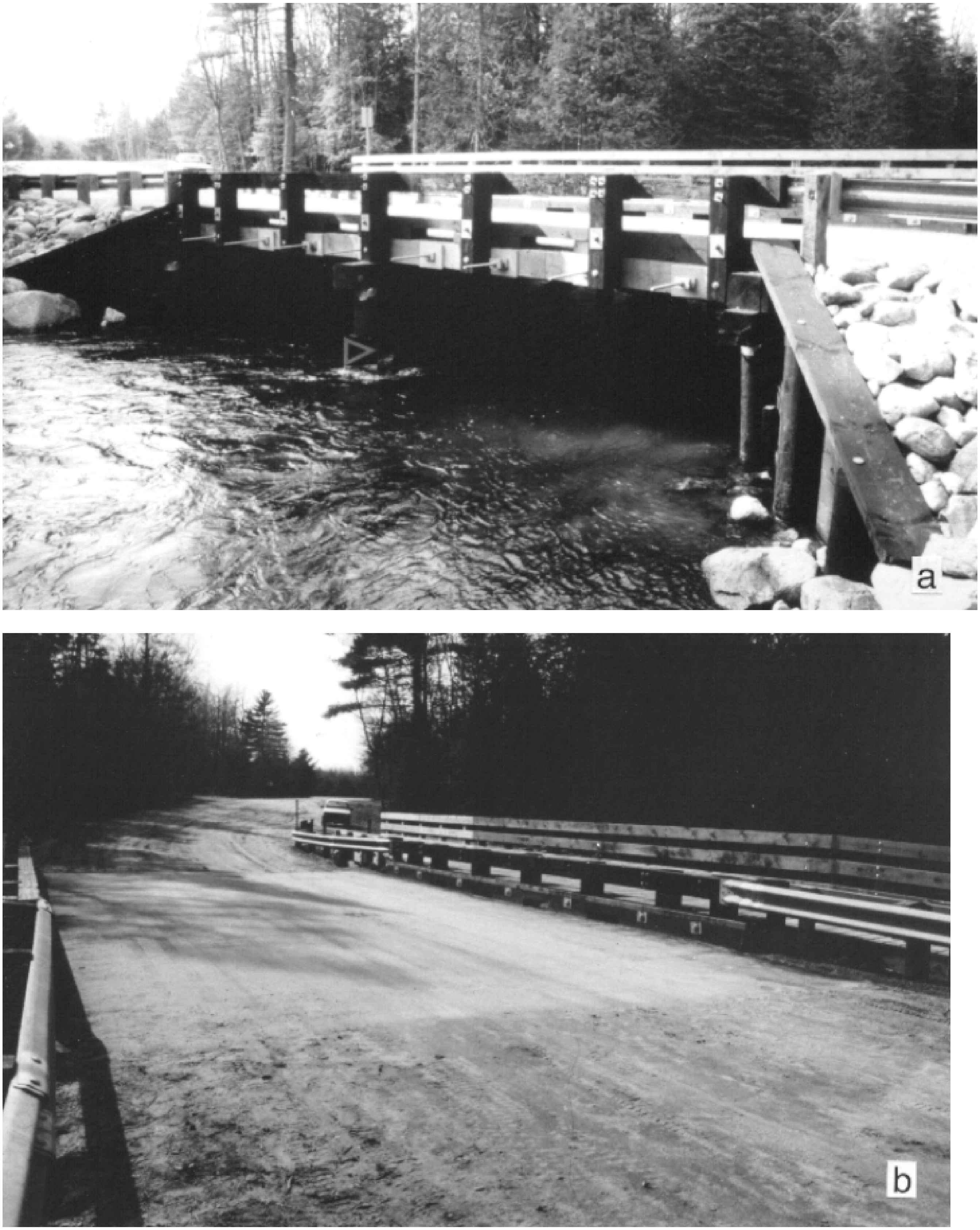

Figure 11—Completed Graves Crossing bridge: (a) side view, (b) end view.

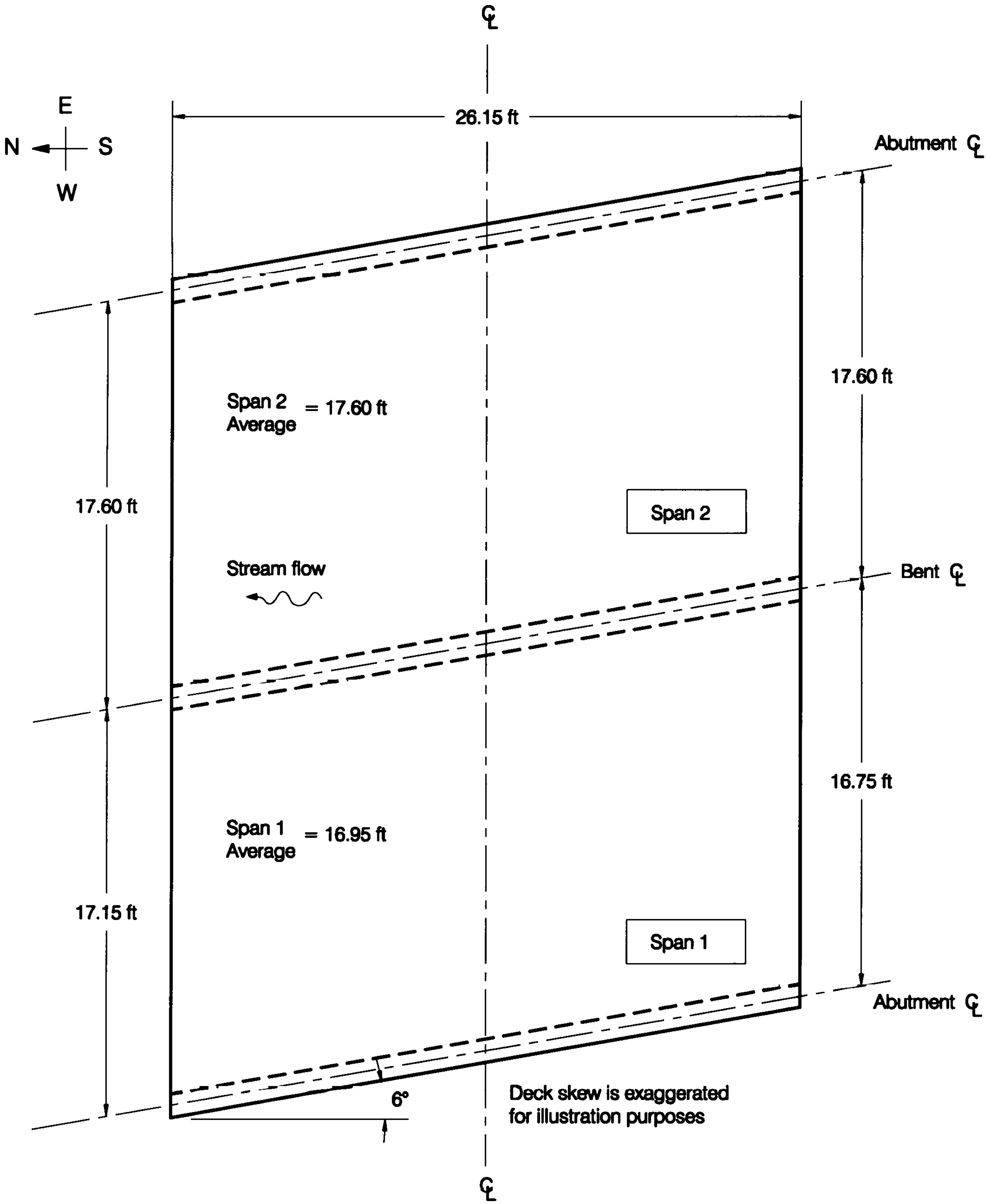

Figure 12—As-built configuration of the Graves Crossing bridge.

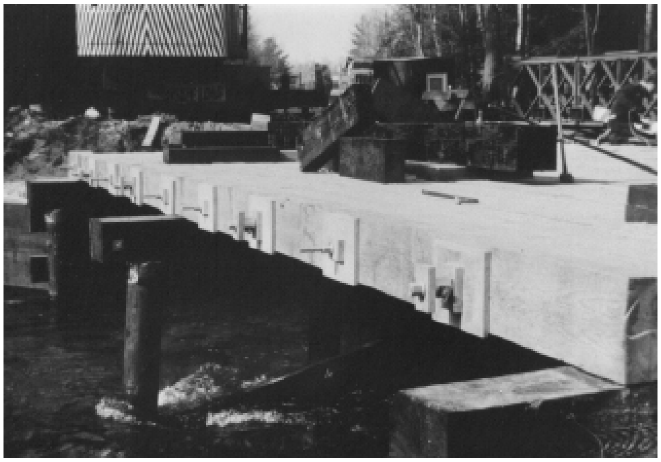

Figure 13—Load cells were placed between anchor plates at four locations prior to the initial tensioning of the stressing bars.

Figure 14—Antrim County personnel collecting load cell readings with a portable strain indicator shortly after the initial tensioning of the stressing bars.

Static-Load Testing

The load test of the Graves Crossing bridge consisted of positioning loaded dump trucks on the bridge and measuring the resulting deflections at a series of locations along a transverse cross section at the midpoint of each span and near the bridge supports. A surveyor's level was utilized to read deflection-values from calibrated rules suspended from the bridge underside to the nearest 0.04 in. Deflection measurements were obtained prior to testing (unloaded), after placement of the test vehicle (loaded), and at the conclusion of testing (unloaded).

The load test was performed April 20, 1992, with two trucks: truck 20 with a gross vehicle weight of 31,250 lb and truck 22 with a gross vehicle weight of 30,850 lb (Fig. 15). Each of the two spans was tested separately using designated positions in the longitudinal and transverse directions to produce the maximum deflection in accordance with AASHTO recommendations (AASHTO 1989). For each span, three load cases were completed by longitudinally positioning the midpoint of the rear truck axle over the skewed centerspan cross section (Fig. 16). For load case 1, truck 20 was positioned with a wheel line 2 ft from the roadway centerline in the downstream lane. For load case 2, truck 22 was positioned with a wheel line 2 ft from the roadway centerline in the upstream lane. For load case 3, trucks 20 and 22 were simultaneously positioned in the same locations as load cases 1 and 2, but facing in the opposite direction. Figure 17 shows the three load positions completed for span 1.

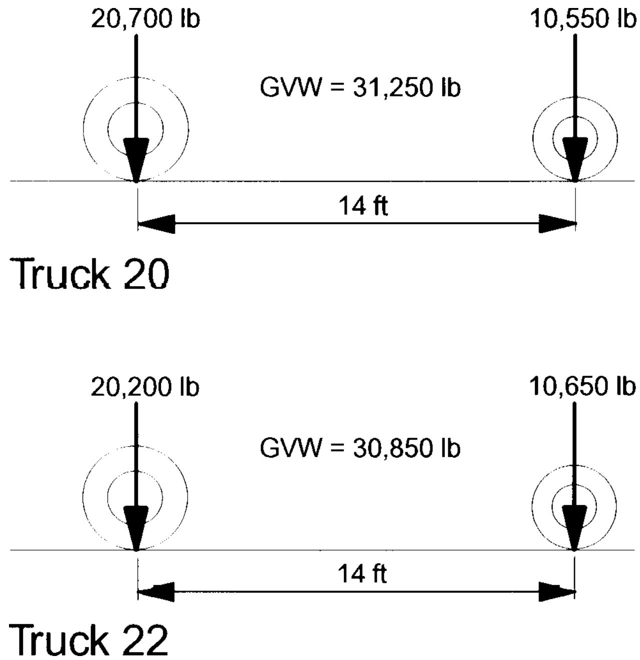

Figure 15—Load test vehicle axle loads and configuration.

Analytical Assessment

At the completion of load testing, actual truck loading and AASHTO HS20-44 loading conditions were analyzed by an orthotropic plate computer model to predict the centerspan deflection values.

Condition Assessment

The general condition of the Graves Crossing bridge was assessed on three occasions during the monitoring period. The first assessment occurred at installation when monitoring instrumentation was installed. The second assessment occurred at the time of load testing, approximately 6 months into the monitoring period. The final assessment occurred at the end of the monitoring period, approximately 24 months

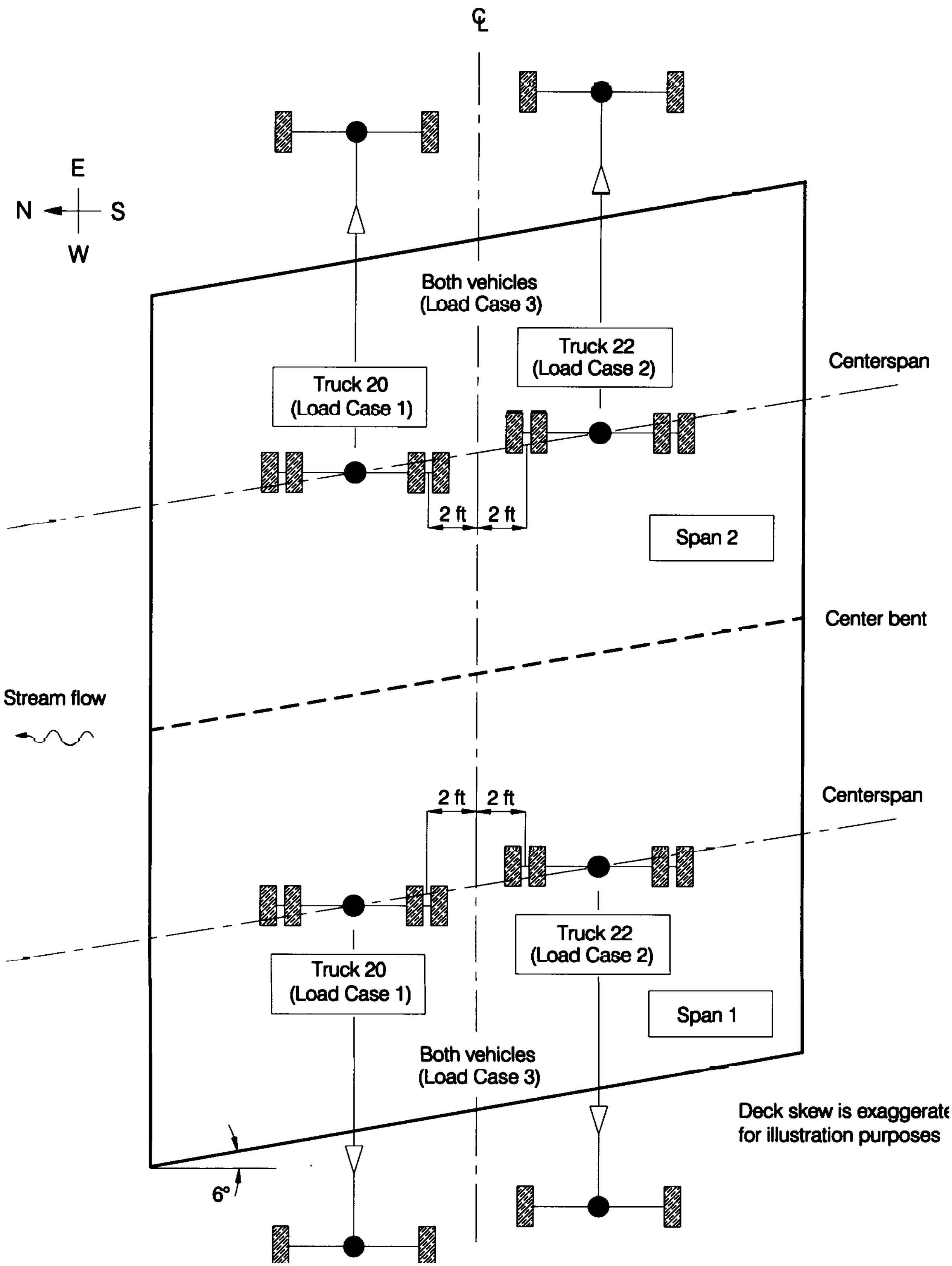

Figure 16—Load test vehicle positioning for all load cases.

Figure 17—Load cases 1,2, and 3 used during load testing of span 1 (west): (a) load case 1, (b) load case 2, (c) load case 3.

after installation. These assessments involved visual inspections, measurements, and photographic documentation of the bridge condition. Items of specific interest included deck camber, wood components, wearing surface, and stressing bar anchorage system.

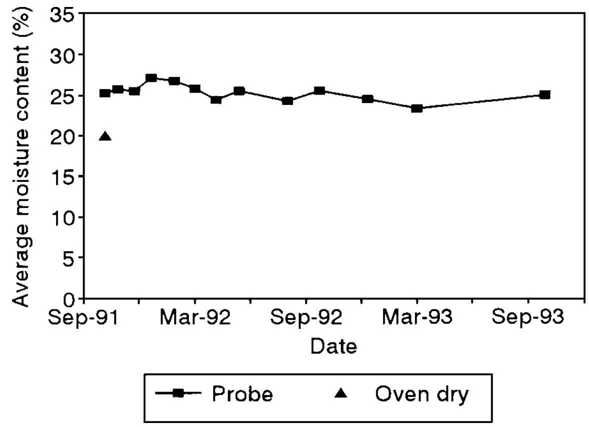

Figure 18—General trend in moisture content based on electrical-resistance measurements.

Results and Discussion

Performance of the Graves Crossing bridge was monitored for 2 years, beginning October 1991 and ending October 1993.

Lamination Stiffness

Results of stiffness testing of the Red Pine lumber yielded an average edgewise MOE of 1.14×10^6 lb/in^2. The design edgewise MOE adjusted for wet-use conditions was 1.26×10^6 lb/in^2. Thus, the actual MOE of the Red Pine lumber was approximately 10 percent less than the nominal design value.

Moisture Content

The general trend of electrical-resistance moisture content measurements is shown in Figure 18. Results of the electrical-resistance moisture content measurements taken at installation indicated that the lower 1 in. of the deck laminations was at approximately 25 percent moisture content. Results of ovendry analyses performed on samples collected at installation indicated that the interior portion of the deck laminations, where the CCA preservative had not penetrated, was at approximately 20 percent moisture content.

During the monitoring period, the lower 1-in. of the deck laminations maintained approximately 25 percent moisture content, despite small seasonal fluctuations related to the local environmental conditions. Average moisture content of the deck laminations did not significantly change during the 2-year monitoring.

Bar Force

The general trend in bar force measurements is shown in Figure 19. Bar tensioning was conducted on four occasions during the first several months after installation. After each

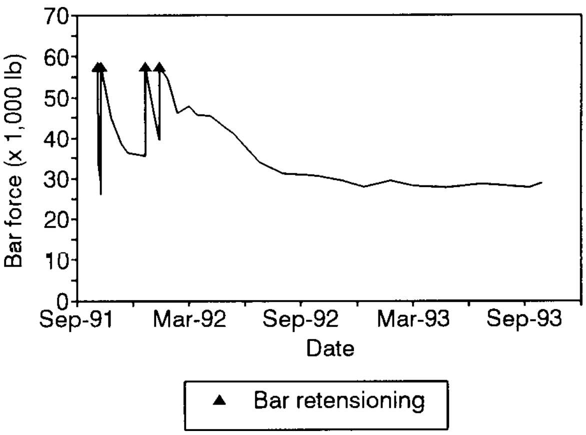

Figure 19—General trend in stressing bar forces based on load cell measurements.

successive bar retensioning, the rate of bar force loss decreased. After the final retensioning in January 1992, the average bar force decreased to 30,000 lb, or 50 lb/in^2 interlaminar compressive stress, during the next 12 months. During the last 8 months, the bar forces stabilized at approximately 30,000 lb, or 50 lb/in^2 interlaminar compressive stress. Stressing bar forces measured with hydraulic equipment at the end of the monitoring period confirmed the 30,000-lb load measured with the load cells.

The majority of the bar force loss during the monitoring period is attributable to stress-relaxation of the lumber laminations and occurred within 1 year of the final deck stressing in January 1992. Other factors that contributed to bar force losses were relatively minor and included fluctuations in lamination moisture content, slight deck deformation under steel anchorage plates, and thermal effects. It is anticipated that the bar force will drop below the 40 percent of design level during the next several years. At that time, retensioning the bars to a full design load of 58,000 lb is recommended.

Behavior Under Static Load

Results of the static-load testing and analytical assessment are presented. For each load case, transverse deflection measurements are given at the bridge centerspan as viewed from the west end (looking east). No permanent residual deflection was measured between load cases or at the conclusion of load testing. In addition, no measureable deflection was observed at the bridge supports during load testing. At the time of the tests, the average bar force was 46,000 lb and is equivalent to a deck prestress of 80 lb/in^2.

Static-Load Testing

Figure 20 presents transverse deflection for the three load cases for each span. For span 1, the maximum deflection measured for load case 1 was 0.19 in., occurring under the wheel line near the downstream curb (Fig. 20a). Maximum deflection measured for load case 2 was 0.13 in., occurring under both wheel lines (Fig. 20b). Maximum deflection measured for load case 3 was 0.19 in., occurring under the wheel line near the outside wheel line of truck 20 (Fig. 20c). Similarly at span 2, the maximum deflection measured for load case 1 was 0.16 in., occurring under the wheel line near the downstream curb (Fig. 20d). Maximum deflection measured for load case 2 was 0.19 in., occurring between the wheel lines (Fig. 20e). Maximum deflection measured for load case 3 was 0.19 in., occurring under both wheel lines closest to the bridge centerline (Fig. 20f).

If both spans of the two-span continuous bridge were equal in length, the measured deflections for the same truck loading should be the same. However, small differences in the measured deflections for each span were recorded for the same truck loading. These small differences are attributed to the variations in the span lengths previously noted (Fig. 12) and are within the precision of the measurement technique.

A comparison between load case 3, with the summation of load cases 1 and 2 for each span is given in Figure 21. The near exact overlay of the plots illustrates the linearly elastic behavior of the bridge deck under static loading.

Analytical Assessment

The predicted deflection based on the orthotropic plate analysis and measured deflection from load case 3 of the static-load testing are shown in Figure 22. The predicted deflections are equal or slightly greater than measured deflections at most data point locations. For span 1, the measured deflection beneath the outer wheel line of truck 20 was slightly greater than predicted. For span 2, the measured deflection between the wheel lines of both wheel lines was slightly greater than predicted. In general, the analytical prediction represents a close approximation of the actual deflections, because the minor differences noted are within the precision of the measurement technique.

The predicted deflection for two HS20-44 vehicles positioned similar to load case 3 is presented in Figure 23. The maximum predicted deflection of 0.32 in. occurs at the bridge centerline and is equivalent to 1/650th of the bridge span, which measures 17.3-ft center-to-center of bearings.

Condition Assessment

General condition assessments indicated that the structural and serviceability aspects of the Graves Crossing bridge were satisfactory. Results of the specific areas inspected follow.

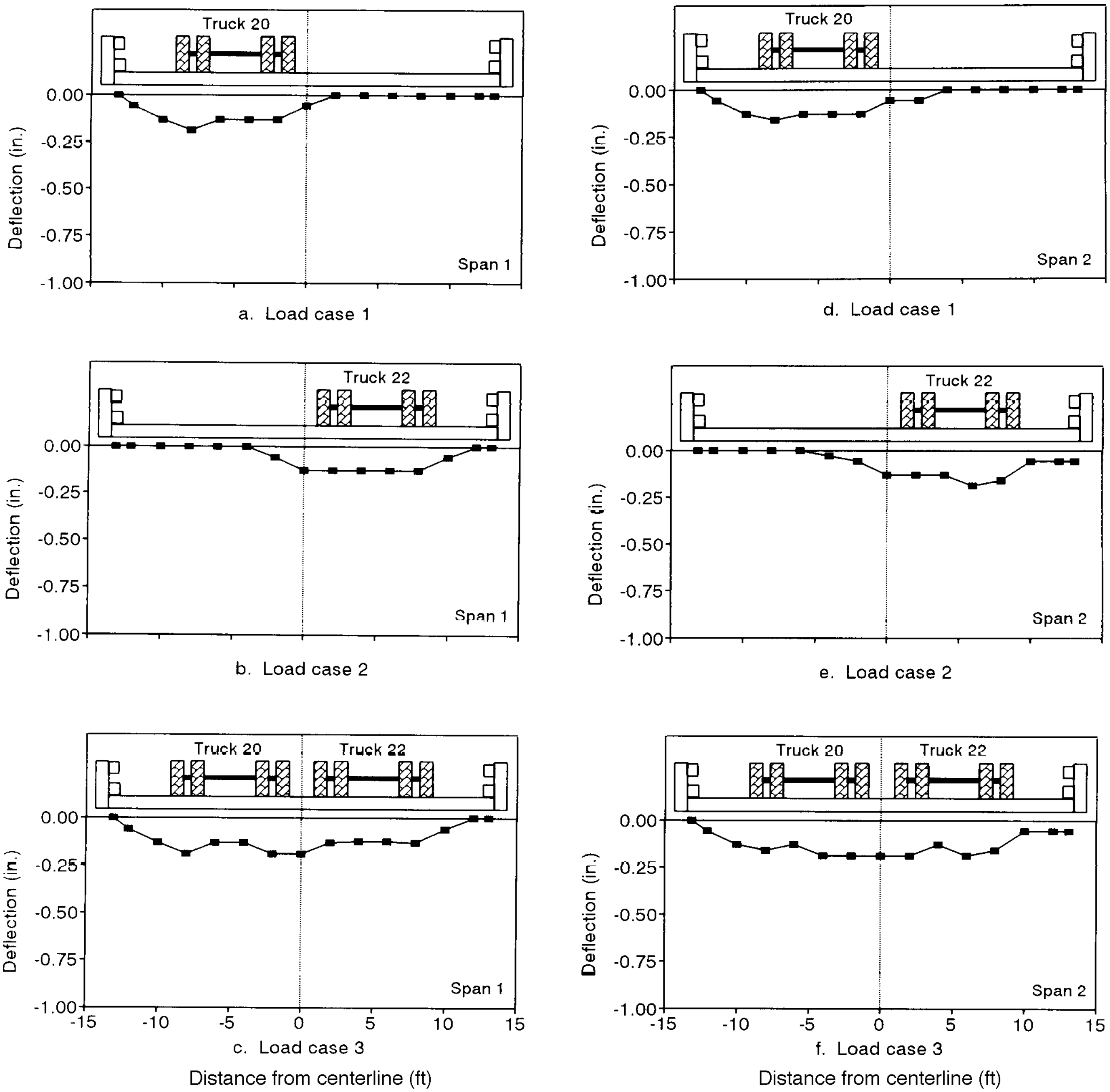

Figure 20—Transverse deflection measured at bridge centerspan (looking east) of the Graves Crossing bridge. Bridge cross-sections and vehicle positions are presented to aid interpretation only and are not to scale.

Deck Camber

Measurements of the deck camber at installation indicated that the deck was relatively flat with no measurable camber (positive or negative) for either span. Measurements of the deck camber at the end of the monitoring indicated that the deck remained flat, and no vertical creep occurred at either span.

Wood Components

Visual inspection of the wood components of the bridge indicated no signs of deterioration or damage. Minor checking was evident on the top surface of the lumber rail posts, which encounter rapid wetting and drying cycles as a result of the exposure of the end-grain. Potential rail post deterioration caused by excessive checking could be prevented by applying

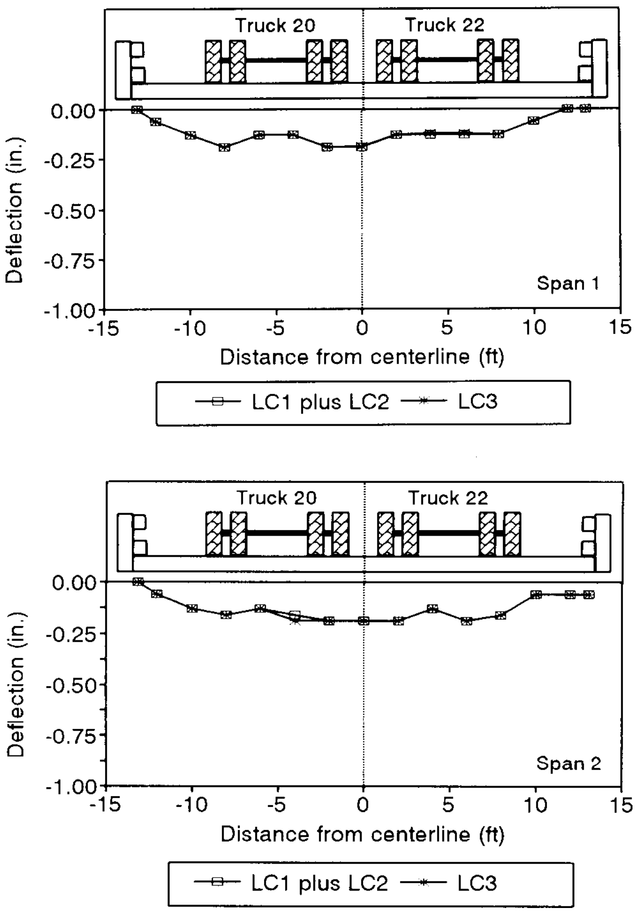

Figure 21—Comparison of the sum of measured deflections from load cases 1 and 2 to the measured deflections from load case 3.

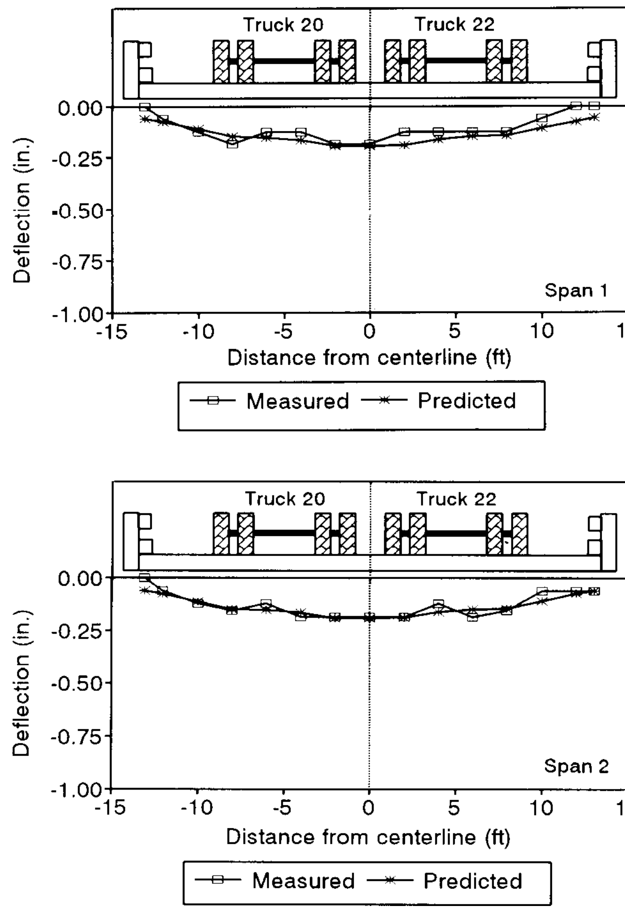

Figure 22—Comparison of the measured deflections from load case 3 and the predicted deflection using orthotropic plate analysis.

a bituminous seal to the end-grain top surface, but the seal is typically not considered in design. All bolted connections remained tight with no signs of wood member crushing beneath the connectors.

Wearing Surface

The asphalt wearing surface appeared in good condition at the conclusion of the monitoring. Substantial sand and gravel debris had accumulated on the wearing surface, because the Graves Crossing bridge is situated at the bottom of a slight vertical sag curve with unpaved approaches. These roadway drainage conditions may lead to future asphalt damage, unless the wearing surface is periodically cleaned of all debris.

Anchorage System

Visual inspections of the stressing bar anchorage system indicated satisfactory performance. Wood crushing was not evident in the area beneath the steel bearing plates, with only slight deformations visible in the edge deck laminations. Corrosion was not visible on any of the galvanized steel components.

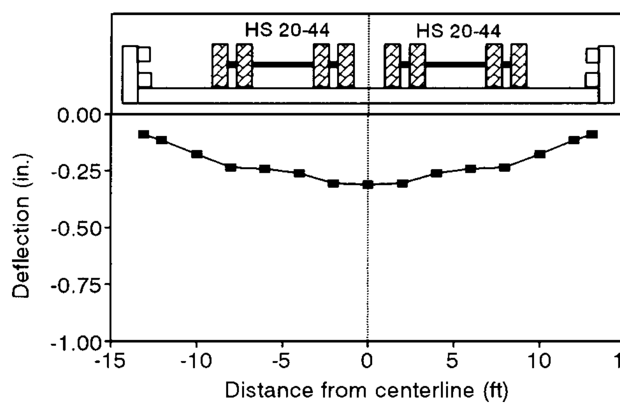

Figure 23—Predicted deflection at the bridge centerspan for two HS-20 vehicles, each positioned 2 ft from the roadway centerline (load case 3).

Conclusions

Based on the monitoring results from the Graves Crossing bridge, we conclude the following:

- After 2 years in service, the CCA-treated, Red Pine stress-laminated deck is performing well with no structural or serviceability deficiencies.
- Results from the lamination MOE tests performed at the fabrication plant yielded an average edgewise MOE of 1.14×10^6 lb/in^2. This was slightly less than the assumed design value for visually graded No. 2 Red Pine lumber.
- The general trend in moisture content indicates that the deck is experiencing slight seasonal fluctuations but remains relatively unchanged at 25 percent during the 2-year monitoring.
- The general trend in stressing bar force indicates that losses during the 2-year monitoring totaled approximately 30,000 lb, or 50 percent of the design force of 58,000 lb. The majority of bar force losses occurred within 1 year after the final restressing of the deck and was attributed to stress relaxation of the Red Pine laminations. It is anticipated that the Graves Crossing bridge will require retensioning of the stressing bars to the full design level in the near future.
- Deck camber measurements indicate that no measurable vertical creep occurred in either span of the bridge.
- Static-load testing and orthotropic plate analysis predicts a maximum deflection under HS20-44 loading conditions of 0.32 in., or 1/650th of the bridge span length.
- Visual inspections indicate no signs of deterioration of the wood or steel components.

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Appendix—Information Sheet

General

Name: Graves Crossing bridge

Location: Antrim County, Michigan

Date of Construction: October 1991

Owner: Antrim County Road Commission

Design Configuration

Structure Type: Stress-laminated deck

Butt Joint Frequency: Every 4th lamination transversely

Every 4 ft longitudinally in adjacent laminations

Total Length (out-out): 36.0 ft

Skew: 6 degrees

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

Span Lengths (center-center of bearings): 17.5 ft

Width (out-out): 26.0 ft

Width (curb-curb): 24.4 ft

Number of Traffic Lanes: 2

Design Loading: AASHTO HS20-44

Wearing Surface Type: 2- to 3-in.-thick asphalt pavement

Material and Configuration

Timber:

Species: Red Pine

Size (actual): 4 by 12 in.

Grade: Visual No. 2

Moisture Condition: Approximately 25 percent at installation

Preservative Treatment: Chromated Copper Arsenate

Stressing Bars:

Diameter: 1 in.

Number: 9

Design Force: 57,600 lb

Spacing (center-center): 4 ft

Type: High strength steel thread bar with coarse right-hand thread, conforming to ASTM A722

Anchorage Type and Configuration:

Steel Plates: 12 by 16 by 1 in. bearing
4 by 6-1/2 by 1-1/4 in. anchor