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Field Performance of Timber Bridges

2. Cooper Creek Stress-Laminated Deck Bridge

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Abstract

The Cooper Creek bridge was constructed in February 1992, in Centerville, Iowa. The bridge is a two-span, continuous stress-laminated deck structure 42-ft long and approximately 26.5-ft wide. The bridge is unique in that it is one of the first known stress-laminated timber bridge applications to use eastern cottonwood. The performance of the bridge was monitored continuously for 28 months beginning at the time of installation. Performance monitoring involved gathering and evaluating data relative to the moisture content of the wood deck, force level of the stressing bars, vertical creep, and behavior of the bridge under static-load conditions. In addition, comprehensive visual inspections were conducted to assess the overall condition of the structure. Based on field evaluations, the bridge is performing well with no structural or serviceability deficiencies.

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Acknowledgments

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We also wish to thank the following: the Appanoose County Board of Supervisors for providing engineering and construction assistance; Mayor of Centerville, Marlin Henderson, for support during construction and field evaluation; Rick King and Vern Milburn of the Centerville Municipal Water Works for their assistance in obtaining field measurements; and Terry Wipf of Iowa State University for assistance in conducting load tests.

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Dedication

We dedicate this paper to Chuck McCarty, Coordinator for the Chariton Valley Resource Conservation and Development Council, Centerville, Iowa. It was the vision of Mr. McCarty to construct the cottonwood bridge over Cooper Creek, and he provided the primary drive for the realization of the project. Unfortunately, Mr. McCarty passed away a short time before the bridge was built.

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Introduction

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. Responsibility for the development, implementation, and administration of the timber bridge program was assigned to the USDA Forest Service. Within the program, the Forest Service established three primary program areas: demonstration bridges, technology transfer, and research. The demonstration bridge program, which is administered by the Forest Service Timber Bridge Information Resource Center (TBIRC) in Morgantown, West Virginia, provides matching funds on a competitive basis to local governments to demonstrate timber bridge technology through the construction of demonstration bridges (USDA 1991). The TBIRC also maintains a technology transfer program to provide assistance and state-of-the-art information related to timber bridges. One objective of these program areas is to 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 program 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 has taken a lead role in assisting local governments in evaluating the field performance of timber 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.

Table 1-SI conversion factors

English unit	Conversion factor	SI unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
foot^2 (ft^2)	0.09	square meter (m^2)
pound (lb)	0.14	Newton (N)
lb/in^2 (stress)	6,894	Pascal (Pa)

This paper is the second in a series that documents field performance of timber bridges. It describes the development, design, construction, and field performance of the Cooper Creek bridge located in Appanoose County, Iowa. The bridge is a two-lane, two-span, continuous stress-laminated deck with a total length of 42 ft. (See Table 1 for metric conversion factors.) Built in 1992, the Cooper Creek bridge was constructed entirely from local funds with technical assistance provided through the Forest Service TBI program. The Cooper Creek bridge is one of the first known applications that utilizes eastern cottonwood in a stress-laminated deck superstructure. The bridge characteristics are briefly summarized in the Appendix.

Objective and Scope

The objectives of this project were to design and construct the Cooper Creek bridge and evaluate its field performance for a minimum of 2 years beginning at bridge installation. The project scope included data collection and analysis related to the bridge behavior under static truck loading and general structure performance. The results of this project will be used to formulate recommendations for the design and construction of similar stress-laminated cottonwood bridges in the future.

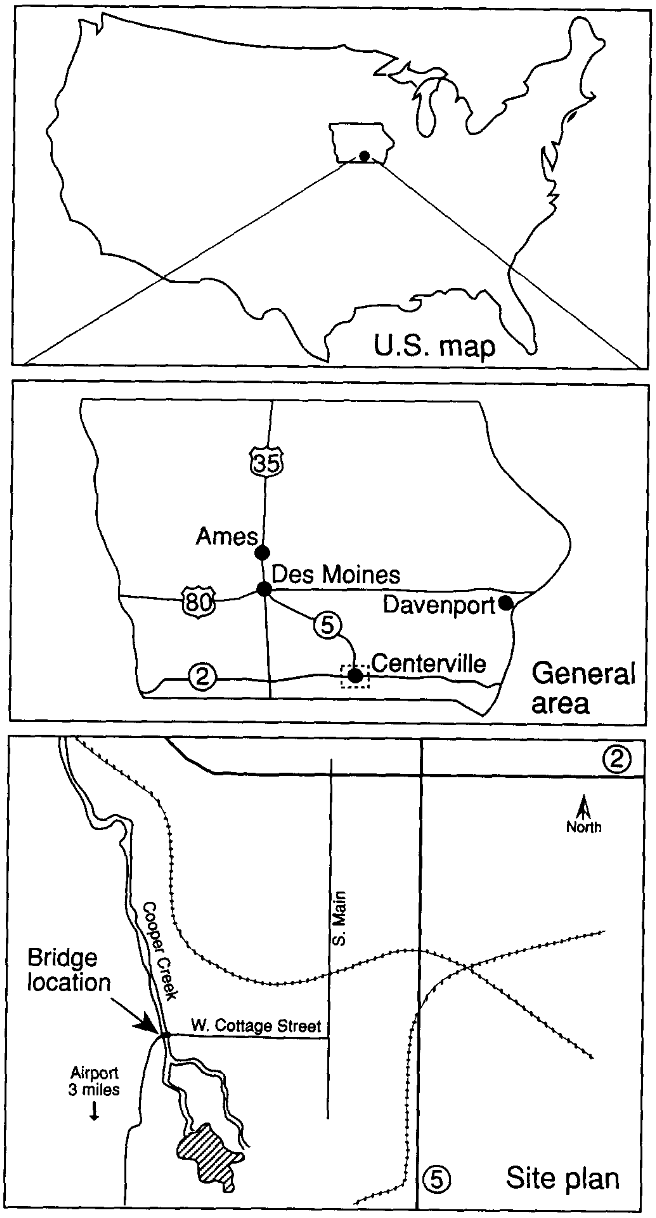


Figure l-Location and site layout of the Cooper Creek bridge.

Background and Development

The Cooper Creek bridge site is in Centerville, Appanoose County, Iowa, (Fig. 1). The bridge is on West Cottage Street, which serves as the primary access road to a large community park surrounding the Centerville reservoir. The bridge crosses Cooper Creek, which carries daily flow from the backwashing of city water supply filters and occasional overflow from the nearby reservoir dam. The roadway over the bridge was a two-lane gravel road. Traffic is mostly light passenger vehicles with an estimated average daily traffic of 200 vehicles.

Figure 2—Original Cooper Creek bridge constructed in the 1940s.

The original Cooper Creek bridge was constructed in the 1940s and consisted of steel stringers with a concrete deck supported by concrete abutments (Fig. 2). Inspection of the bridge in the mid-1980s indicated that the concrete deck was in poor condition and steel stringers were badly corroded. Replacement of the bridge, along with another bridge in the reservoir area, was subsequently included within a large waterworks project at the Centerville reservoir. This project was made possible through a grant from the Chariton Valley Resource Conservation and Development Council (RC&D) to the State of Iowa and was initiated to improve the city's water supply system. In the initial stages of the project, both bridges were scheduled to be constructed using reinforced concrete. However, information obtained through the TBIRC prompted the Chariton Valley RC&D to change the Cooper Creek bridge to a timber structure using the relatively new stress-laminated deck design concept. A timber bridge was considered the best option by the RC&D because of the opportunity to use native Iowa materials and the aesthetics of a timber bridge would blend well into the natural park setting.

As the waterworks project progressed at the Centerville reservoir, difficulties were encountered in the design of the Cooper Creek bridge. Because the concept of stress-laminating timber bridges was new in the United States, little information was available on design criteria and construction specifications. To provide assistance in this area, the FPL was contacted for technical advice. Through a series of meetings with state, local, and FPL representatives, options were discussed and it was determined that a stress-laminated deck bridge constructed using Iowa eastern cottonwood was feasible for the site. Subsequent to these meetings, an agreement was drafted for the design, construction, and evaluation of the Cooper Creek bridge. The agreement involved a cooperative effort between the City of Centerville, Chariton Valley RC&D, Iowa Department of Transportation, Forestry Division of the Iowa Department of Natural Resources, Iowa Department of Economic Development, TBIRC, and FPL.

Design, Construction, and cost

The design and construction aspects of the Cooper Creek bridge involved a mutual effort among the City of Centerville, Appanoose County Engineering, which served as the engineering representative for the City of Centerville, and FPL. Construction assistance was also provided by the Centerville Water District. An overview of the design, construction, and cost of the bridge superstructure is presented in this section.

Design

Design of the Cooper Creek bridge superstructure was completed by FPL in collaboration with Appanoose County Engineering. At the time of the design, in early 1990, a national design specification for stress-laminated timber bridges did not exist. Those aspects of the design dealing specifically with stress laminating were based primarily on research completed by the University of Wisconsin and FPL (Oliva and others 1990; Ritter 1990). In addition, FPL experience with stress-laminated decks from an ongoing field evaluation program contributed to the design details. All other aspects of the superstructure design were based on the *Standard Specifications for Highway Bridges,* published by the American Association of State Highway and Transportation Officials (AASHTO) (AASHTO 1989).

Design requirements for the Cooper Creek bridge called for a crossing of 42 ft with an out-to-out bridge width of 26 ft. The bridge was to carry two lanes of AASHTO HS 20-44 loading with a maximum design live-load deflection of 1/360 of the bridge span. In addition to these geometric and loading requirements, several other design requirements were related to the eastern cottonwood laminations. Because of limitations on local supply and fabrication, lamination length was limited to 18 ft. It was also considered economically advantageous to limit the deck depth to a maximum of 12 in., although a maximum deck thickness of 14 in. was feasible based on lumber availability.

The first step in the design process was to identify material design values for the eastern cottonwood laminations. Because eastern cottonwood had not been commonly used for structural applications, design values were not included in AASHTO, and referenced design values *in the National Design Specification for Wood Construction* (NDS) (NFPA 1988) were limited to material 2 to 4 in. thick and 2 to 4 in. wide. Because the bridge laminations would be greater than 4 in. wide, the NDS values were not entirely applicable to the bridge design. Further examination indicated that the NDS also included design values for black cottonwood in widths greater than 4 in. Subsequent review by FPL of the green, clear wood material properties for the two similar species indicated that modulus of rupture (MOR) and modulus of elasticity (MOE) properties for eastern cottonwood were greater than those for black cottonwood (ASTM 1988). Thus, the decision was made to use the NDS tabulated design values for bending strength and MOE based on black cottonwood, which would result in a slightly conservative design. The design value for compression perpendicular to grain was based on tabulated values for eastern cottonwood, which is independent of member size. The results were tabulated bending design values for visually graded lumber of 750 and 650 lb/in^2 for material graded No. 1 and No. 2, respectively, and MOE values of 1,200,000 and 1,100,000 lb/in^2 for the same grades. The tabulated value for compression perpendicular to grain was 320 lb/in^2 for all grades.

Given the required bridge length and limitations on material size, a two-span continuous structure with equal span lengths was selected for the final design (Fig. 3). The layout of the bridge laminations was based on available lamination lengths of 4 to 18 ft in 2-ft increments. To meet span requirements for the continuous deck, a butt joint frequency of 1:4 at a 4-ft spacing was used (Fig. 4). As in most stress-laminated timber bridge decks, it was anticipated that bridge stiffness rather than strength would control the design. After adjusting tabulated design values for wet-use conditions and other applicable modification factors required by AASHTO, it was determined that a full-sawn deck 12 in. thick would meet design requirements if visually graded No. 1 lumber was used. Using this configuration, the design live-load deflection for HS 20-44 loading was 0.52 in., or 1/473 of the bridge span. A check of bending stress indicated that the applied stress of 931 lb/in^2 was less than the allowable 968 lb/in^2.

The stressing system for the Cooper Creek bridge was designed to provide a uniform compressive stress of 100 lb/in^2 between the lumber laminations. To provide this interlaminar compression, 5/8-in.-diameter high strength stressing bars were spaced 24 in. on-center, beginning 1 ft from the bridge ends. The tensile force required in the bars for the 100 lb/in^2 interlaminar compression was determined to be 28,800 lb. The bars were specified to comply with the requirements of ASTM A 722 (ASTM 1988) and provide a minimum ultimate tensile strength of 150,000 lb/in^2. The bar anchorage system was the discrete plate anchorage system consisting of 10- by 10- by 3/4-in. steel bearing plates with 2- by 5- by l-in. steel anchorage plates (Fig. 5). To provide additional strength in distributing the stressing bar force into the deck without damaging the eastern cottonwood laminations, it was determined that the two outside laminations along the deck edge would be Northern Red Oak sawn lumber.

Following initial deck design, the bridge railing was designed and specifications were summarized. The bridge railing consisted of a sawn lumber curb and glued laminated timber rail and was based on a crash-tested railing system developed by

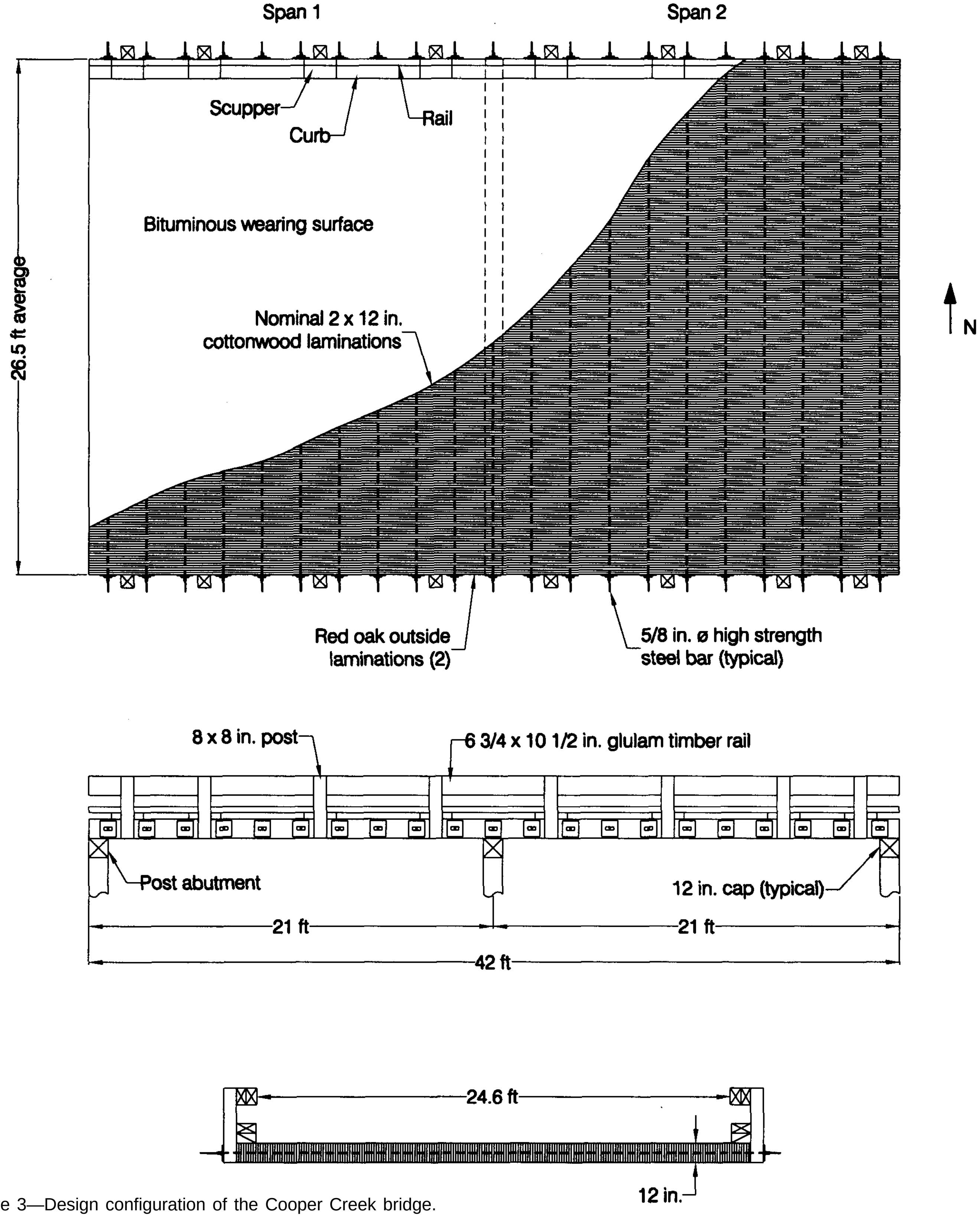


Figure 3—Design configuration of the Cooper Creek bridge.

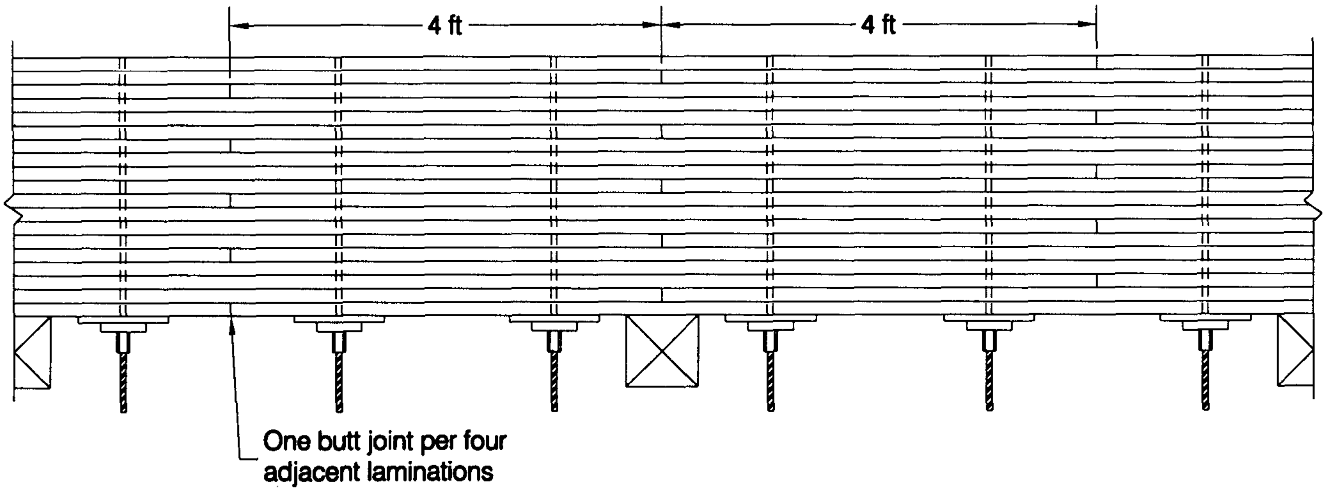


Figure 4—Butt joint configuration used for the Cooper Creek bridge. A butt joint was placed transverse to the bridge span in every fourth lamination. Longitudinally, butt joints in adjacent laminations were separated by 4 ft.

the Federal Highway Administration (FHWA 1990). Specifications for wood members require that all components be pressure treated with creosote after fabrication in accordance with American Wood Preservers' Association (AWPA) Standard C14 (AWPA 1990). To protect from deterioration, all steel components including hardware, stressing bars, and anchorage plates were galvanized per AASHTO specifications (AASHTO 1990).

Construction

Construction of the Cooper Creek bridge was completed by personnel from the City of Centerville, Appanoose County Engineering, the Centerville Municipal Water Works, and the FPL. Following work on the approach roadway and the design and construction of the sawn lumber post and sill abutments and center bent by Appanoose County Engineering, construction of the bridge superstructure commenced February 25 and was completed February 28. The construction process was slowed by rain and cold temperatures, which made work conditions difficult but did not adversely affect the construction process. Construction of the bridge railing and backfill of the approach roadways were completed shortly after the superstructure construction.

Superstructure construction began with delivery of the bridge laminations and other materials to the bridge site. The bridge laminations arrived in banded bundles and were stacked approximately 200 ft from the substructure (Fig. 6). The laminations were prefabricated at a local mill in Centerville and sent to a pressure-treating facility in Nebraska for the creosote treatment. Inspection of the laminations at the site indicated that the material had not been surface planed to a uniform thickness, and measurements of lamination ends indicated a range in thickness of 1-3/4 to 2-3/8 in. This

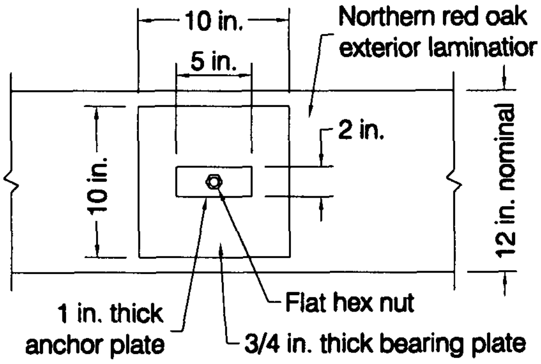


Figure 5—Details of discrete plate bar anchorage configuration.

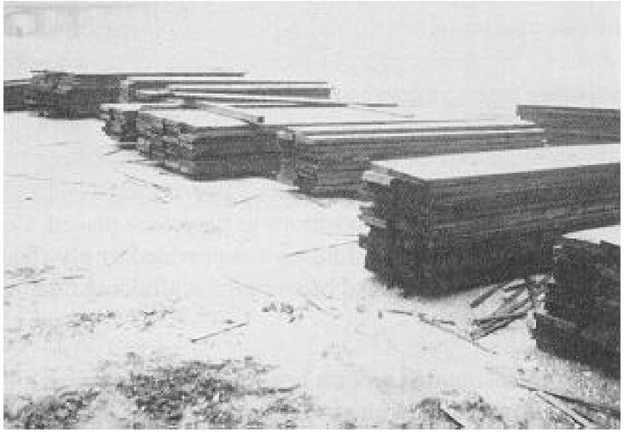


Figure 6—Eastern cottonwood laminations stacked at bridge site prior to construction.

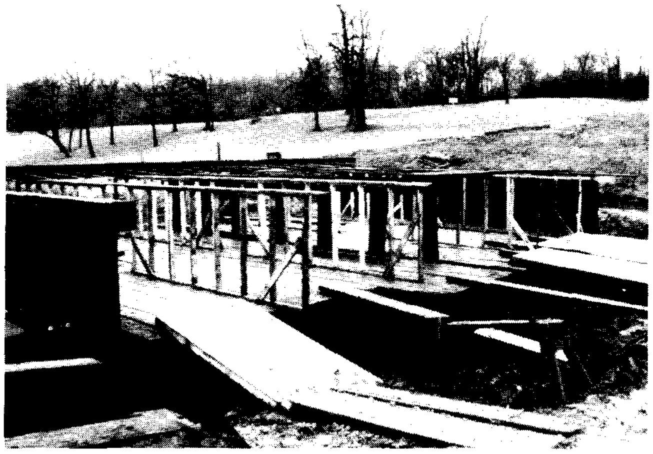


Figure 7—Scaffolding and floor erected for bridge construction. Floor and scaffolding were supported by temporary stringers connected to the bridge supports.

presented a potential problem for construction at the deck butt joints where uniform contact is required between laminations for load transfer. To account for this variation, the end thickness of each lamination was measured and written in chalk on the lamination end. The order of lamination placement was then scheduled so that the end thickness of the two laminations at a butt joint were the same. Laminations with odd thicknesses that could not be matched, which were generally 2-1/4 in. and thicker, were positioned over the abutments.

The construction of the Cooper Creek bridge involved a unique construction methodology that has not been widely used. Rather than prefabricating the deck in sections, which is common practice for stress-laminated decks with butt joints, scaffolding was erected between the substructures and laminations were individually placed on the scaffolding supports. This methodology was considered to be the most cost effective because of the unavailability of a large crane to lift prefabricated bridge sections into place. The scaffolding consisted of a full floor under the deck that was supported by temporary stringers between the bridge abutments and center bent (Fig. 7). The elevation of the floor was approximately 5 ft below the cap elevations of the abutments and bent. Lumber supports were erected on the floor to support the laminations in their final positions as they were placed. Construction access to the scaffolding was provided by plywood ramps that were constructed between the scaffolding floor and the ground.

The deck construction process began by placing approximately 1-ft width of laminations along the south bridge edge (Fig. 8a). The laminations were nailed together and wood dowels were inserted in the bar holes to maintain the relative lamination alignment. Stressing bars were then inserted through the lamination holes approximately 8 ft toward the bridge centerline (Fig. 8b). The bar overhang away from the bridge was supported by a wood frame to prevent excessive bending and damage to the bars (Fig. 8c). After approximately 7 ft of deck width was erected, the bars were pulled through the laminations so that they extended across the bridge width. Bridge construction progressed by sequentially adding laminations. This involved placing the bars through lamination holes and sliding the laminations along the temporary construction supports to the completed deck section (Fig. 8d). Laminations were sequentially added in this manner until the bridge width was completed and ready for bar tensioning (Fig. 8e,f).

Initial stressing of the bridge occurred immediately after all laminations were in position and steel plates and nuts were placed on stressing bar ends. Bar tensioning was accomplished with a single hydraulic jacking system consisting of a hydraulic pump, a hollow core jack, and a stressing chair (Wacker and Ritter 1992) (Fig. 9). During the stressing operation, one pass with the stressing equipment involved tensioning the first bar at an abutment, then sequentially tensioning all other bars along the bridge length. Prior to beginning the stressing, visual inspection of the deck indicated gaps between the laminations at several locations as a result of warp in the laminations. To minimize deck distortion across the bridge width during stressing, bar force was applied gradually over several passes. During the construction process, a total of six passes were completed. The first pass tensioned bars to 25 percent of the design level and was intended to bring all laminations into direct contact. The second pass brought bar force to 50 percent of design. The remaining four passes were at the full design level and were required to bring all bars to a uniform tension. Between the first and final stressing, the deck width narrowed approximately 1 in. as a result of the compression introduced between the laminations.

Following initial stressing, the bridge was restressed several times, and the timber railing and asphalt wearing surface were placed. The bridge stressing followed an accelerated procedure that has not been widely used. It is general practice in stress-laminated deck construction to stress the bridge three times: at the time of initial construction, 1 week later, and 6 to 8 weeks after the second stressing (Ritter 1990). The Cooper Creek bridge was stressed four times: at construction and at 4,7, and 14 days after construction. This accelerated procedure was completed because of limitations on equipment availability and opportunities to evaluate bar force loss using an alternative stressing sequence. Following the final stressing, the timber curb and rail system were installed. Placement of the asphalt wearing surface occurred approximately 4 months later in early July 1992. The completed bridge is shown in Figure 10.

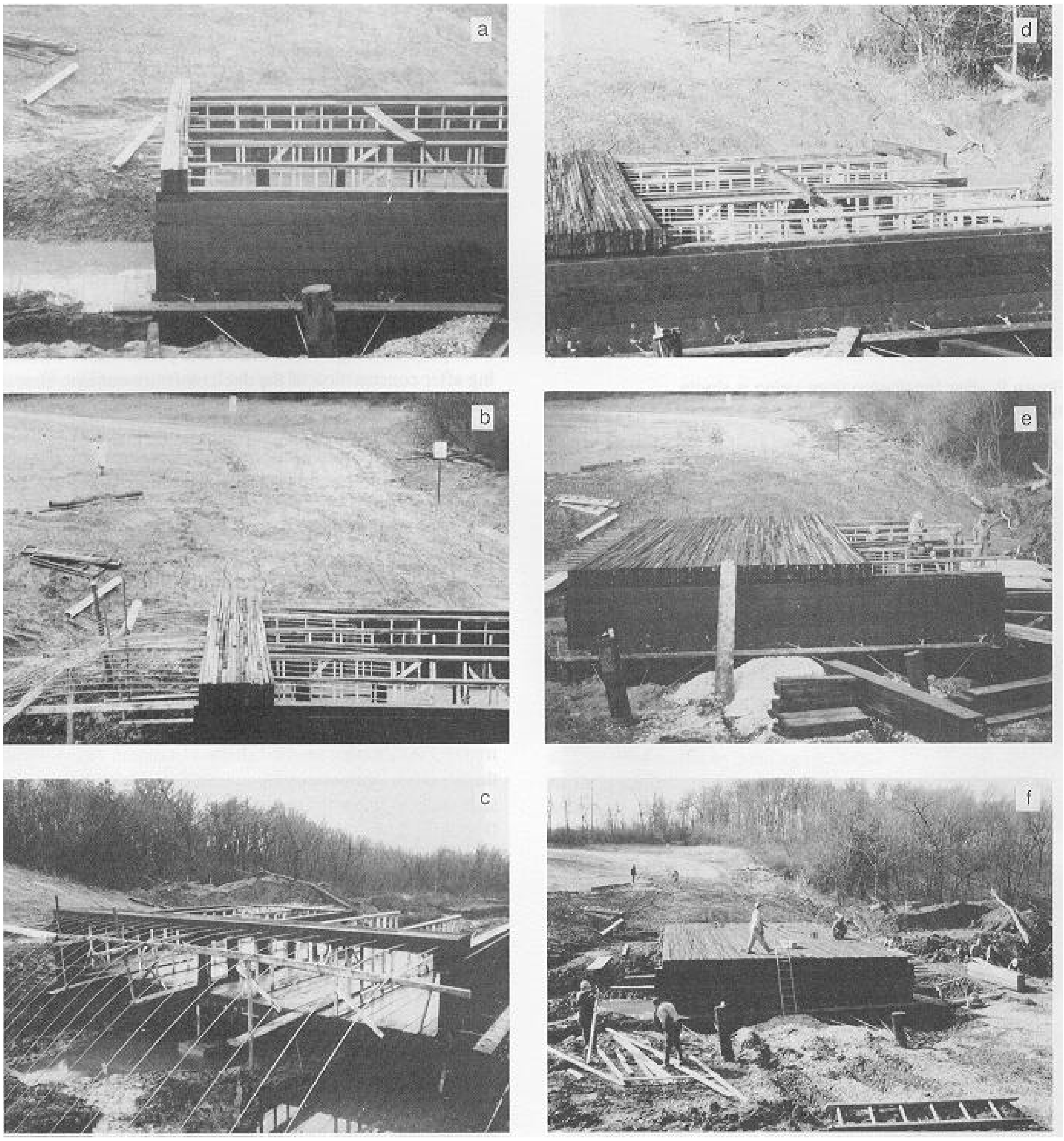


Figure 8—Construction sequence (a-f) for the Cooper Creek bridge.

Figure 9—Bar tensioning bars using a single hydraulic jacking system.

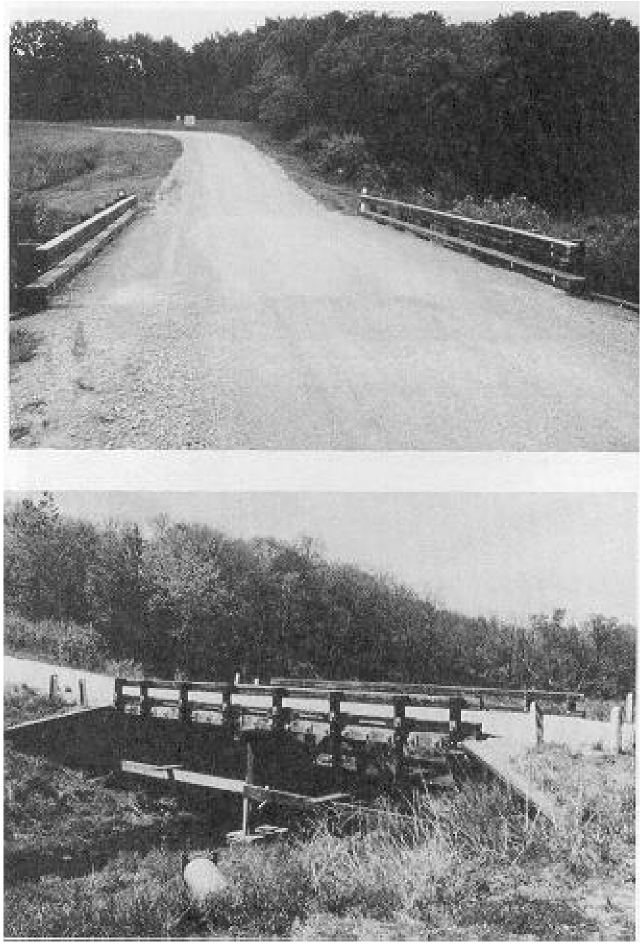


Figure 10—Completed Cooper Creek bridge.

cost

Cost for the fabrication and construction of the Cooper Creek bridge superstructure, railing, and asphalt wearing surface was \$34,200. Based on an average deck area of 1,120 ft^2, the cost was approximately \$31/ft^2.

Evaluation Methodology

Through mutual agreement with the cooperating parties previously mentioned, a bridge monitoring plan for the Cooper Creek bridge was developed and implemented by FPL. The plan included stiffness testing of the lumber bridge laminations prior to bridge construction and performance monitoring after construction of the deck moisture content, stressing bar force, vertical bridge creep, static-load behavior, and general bridge condition. The evaluation methodology employed procedures and equipment previously developed by FPL and used on similar structures (Ritter and others 1991; Wacker and Ritter, 1992).

Lamination MOE

At the time of the Cooper Creek bridge design, eastern cottonwood was not widely used for structural applications, and verification of the assumed design MOE was considered necessary. To measure actual lamination MOE values, portable equipment was taken to the bridge site and a group of laminations was tested just prior to bridge construction using the transverse vibration method (Ross and others 1991). Using this method, laminations are placed flatwise on instrumented supports and impacted to induce a transverse vibration (Fig. 11). Based on the vibratory response, the natural frequency of the lamination is measured and converted to MOE. For the Cooper Creek bridge, 50 laminations were tested using this method: 10 each in lengths of 8, 10, 12, 14, and 16 ft.

Moisture Content

The moisture content of the Cooper Creek bridge was measured using an electrical-resistance moisture meter with 3-in. probe pins in accordance with ASTM D4444-84 (ASTM 1990). Measurements were obtained by driving the pins into the underside of the deck at depths of 1 to 3 in., recording the moisture content value from the unit, then adjusting the values for temperature and wood species. Moisture content measurements were taken at the time of bridge installation, approximately 6 months after installation, and at the end of the monitoring period. In addition to the electrical-resistance readings, core samples were removed from the bridge deck at the conclusion of the monitoring to determine moisture content by the ovendry method in accordance with ASTM D4442-84 (ASTM 1984).

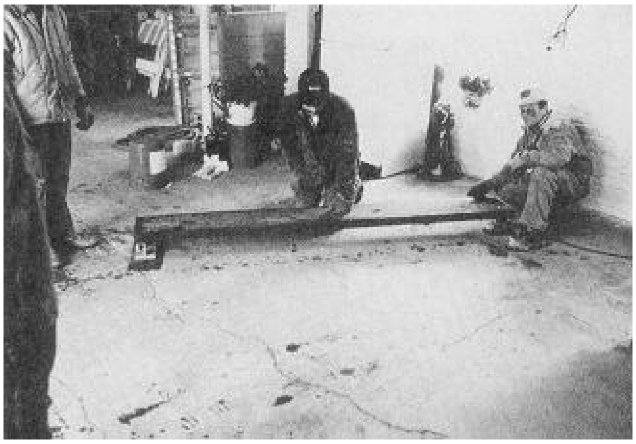


Figure 11—Measurement of bridge lamination MOE using the transverse vibration technique. Measurements were taken in the garage of the Centerville Water Department adjacent to the bridge site.

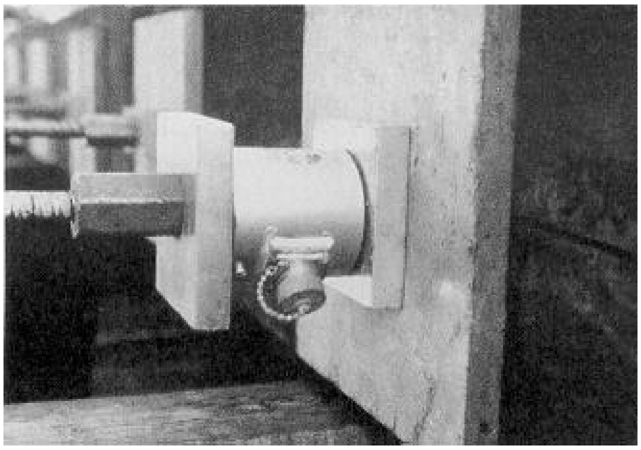


Figure 12—One of four load cells installed on stressing bars to measure changes in bar tension.

Bar Force

To monitor bar force, four calibrated load cells were installed on the Cooper Creek bridge when it was constructed. Two load cells were placed on each span on the third and seventh stressing bars from each abutment. The load cells were developed by FPL and consisted of a small steel cylinder with two 90° strain gage rosettes that measure strain in the load cell body. The cells were placed between the stressing bar bearing plate and anchorage plate to monitor strain changes in the stressing bars (Fig. 12). Load cell measurements were obtained by local personnel by connecting a portable strain indicator to a plug on the load cell. Strain measurements from the indicator were then converted to force levels, based on the laboratory calibration, to determine the tensile force in the bar. Measurements were taken approximately bimonthly during the monitoring period. At the conclusion of the monitoring period, the load cells were removed, checked for zero balance shift, and recalibrated to determine time-related changes in the initial load cell calibration.

Creep

Vertical creep of the bridge was measured at the beginning and end of the monitoring period. Measurements were obtained to the nearest 0.10 in. by reading the midspan elevations along deck edges relative to a stringline between supports.

Load Behavior

Static-load testing of the Cooper Creek bridge was conducted at the end of the monitoring period to determine the response of the bridge to full truck loading. In addition, an analytical assessment was completed to determine the predicted bridge response using computer modeling and current design recommendations.

Load Testing

Load testing involved positioning fully-loaded trucks on the bridge spans and measuring the resulting deflections at a series of locations along the bridge centerspan and abutments. Measurements of each span from an unloaded to loaded condition were obtained by placing calibrated rules at data points on the deck underside and reading values with a surveyor’s level to the nearest 0.02 in. Measurements were taken prior to testing (unloaded), for each load case (loaded), and at the conclusion of testing (unloaded).

Two trucks were used for load testing: truck T15 with a gross vehicle weight of 49,200 lb and truck T18 with a gross vehicle weight of 50,000 lb (Fig. 13). Each of the two spans was tested separately using designated positions in the longitudinal and transverse directions to produce the maximum live-load deflection in accordance with AASHTO recommendations (AASHTO 1989). Longitudinally, the trucks were positioned so that the transverse span centerline bisected the rear truck axles and the front axles were off the span. On span 1 (west), the trucks were facing west; span 2 (east), the trucks were facing east. Transversely, the trucks were positioned for three different load cases (Fig. 14). For load case 1, truck T18 was positioned in the north lane with the center of the inside wheel line 2 ft from the bridge centerline. For load case 2, truck T15 was positioned in the south lane with the center of the inside wheel line 2 ft from the bridge centerline. For load case 3, both trucks were positioned on the span in the positions used for load case 1 and 2. The three load cases are shown in Figure 15.

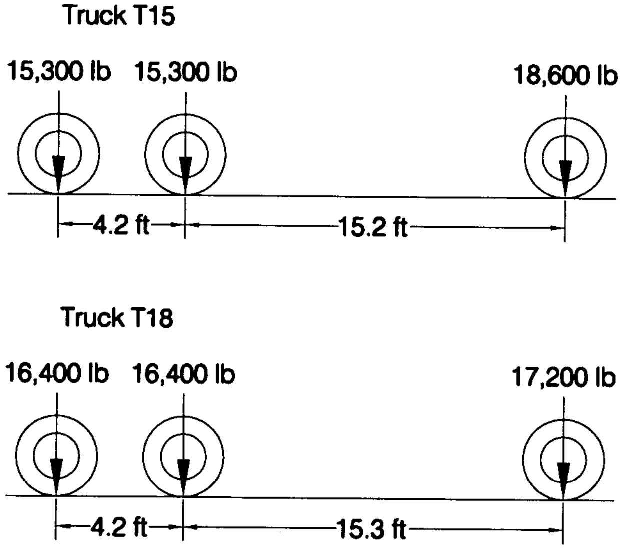


Figure 13—Load test truck configurations and axle loads. The transverse vehicle track width, measured center-to-center of the rear tires, was 6 ft.

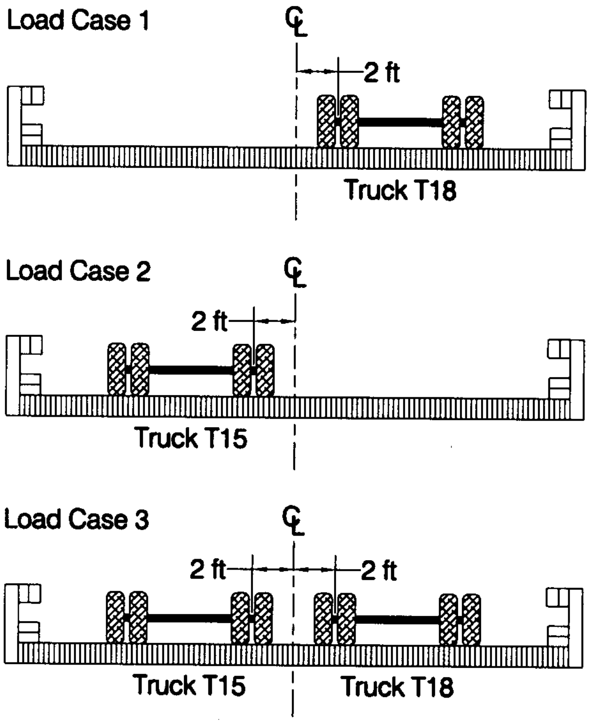


Figure 14—Transverse load positions (looking west). For all load cases, the two rear axles were centered over the bridge centerspan with front axles off the span.

Figure 15—Vehicle load test positions: (a) load case 1, span 2; (b) load case 2, span 2; (c) load case 3, span 1.

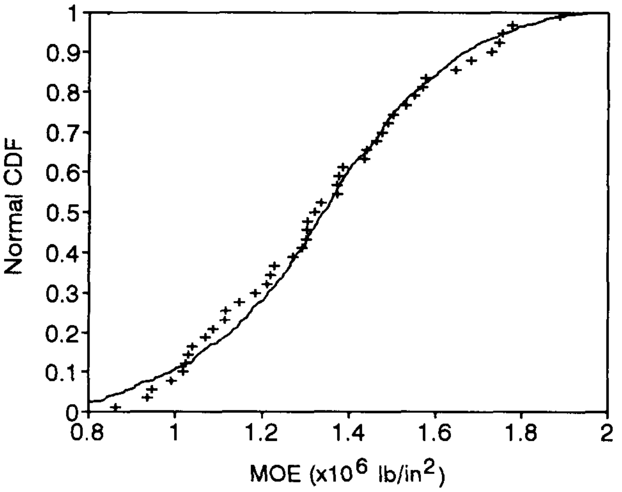


Figure 16—Normal cumulative frequency distribution of MOE values obtained at the bridge site.

Analytical Assessment

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

Condition Assessment

The general condition of the Cooper Creek bridge was assessed on five occasions during the monitoring period. The first assessment occurred at the time of installation. The second to fourth assessments took place during intermediate site visits. The final assessment occurred during the final load test at the conclusion of the monitoring period. These assessments involved visual inspections, measurements, and photographic documentation of the bridge condition. Items of specific interest included bridge geometry and conditions of the timber deck and rail system, asphalt wearing surface, stressing bar and anchorage systems.

Results and Discussion

The performance monitoring of the Cooper Creek bridge extended for 28 months, from February 1992 to May 1994. Results and discussion of the performance data follow.

Lamination MOE

Results of individual lamination MOE testing provided a mean flatwise MOE for eastern cottonwood of 1,335,000 lb/in^2 with a coefficient of variation of 0.192. The normal cumulative frequency distribution for the obtained values is shown in Figure 16. The flatwise MOE was converted to an edgewise value by applying a flatwise adjustment factor of 0.965 (Williams and others 1994). This resulted in an average edgewise MOE of 1,289,000 lb/in.^{2} After adjustment for wet-use conditions (moisture content greater than 19 percent), the design tabulated MOE of 1,200,000 lb/in^2 resulted in an allowable design value of 1,164,000 lb/in.^{2} Thus, the actual material MOE exceeded the assumed design value for black cottonwood by approximately 11 percent.

Since the completion of the Cooper Creek bridge design, the NDS has been revised to include tabulated design values for the cottonwood group that includes eastern cottonwood (NFPA 1991). For visually graded No. 1 material, the revised design MOE for wet-use conditions is 1,080,000 lb/in.^{2} The actual material MOE measured for the Cooper Creek bridge exceeds this value by approximately 19 percent.

Moisture Content

Electrical resistance moisture content readings taken at the beginning of the monitoring period indicated an average 25 percent in the outer 1 in. of the deck underside. At the conclusion of the monitoring period, the average electrical resistance moisture content at the same locations decreased to 22 percent. Moisture content measurements obtained at the end of the monitoring based on coring and the ovendry method indicated a relatively uniform average moisture content of 26 percent for the inner 2 to 7 in. of the deck underside. It is expected that the outer portions of the laminations will continue to loose moisture toward an equilibrium level, but will undergo seasonal fluctuations because of climatic variations. The inner portions of the laminations, which remain at a relatively high moisture content, will change more slowly. Based on the open exposure of the site and regional climatic conditions, it is estimated that the eventual equilibrium moisture content of the deck will be 16 to 18 percent.

Bar Force

The average trend in bar tension force measured from the load cells is shown in Figure 17. As indicated on the left side of Figure 17, the first three stressings ranged from 10 to 15 percent below the design level. The final stressing was approximately 6 percent below the design level at 27,000 lb., or 94 lb/in^2 interlaminar compression. After the final stressing, the bar force decreased rapidly during the first 100 days to a level of 16,800 lb, or 50 lb/in^2 interlaminar compression. For the remainder of the monitoring period, the bar force gradually decreased to a level of approximately 13,400 lb, or 46 lb/in^2.

The loss in bar force for the Cooper Creek bridge is likely the result of stress relaxation in the wood laminations as a result of the applied compressive force. The slight decrease in average lamination moisture content also contributed to wood

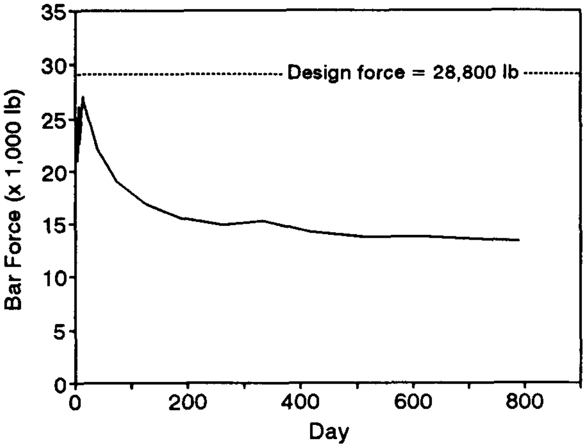


Figure 17—Average trend in bar tension force obtained from load cells installed on four stressing bars.

shrinkage and a minor loss in bar force. Although the bar force decreased approximately 50 percent during the monitoring period, it did not drop below acceptable levels. However, it was probable that the gradual decrease would continue, and the bridge was restressed at the conclusion of the monitoring period.

Compared with numerous other bridges in the FPL monitoring program (Ritter and others 1990), the bar force retention for the Cooper Creek bridge is similar or better. Thus, it does not appear from the data that the accelerated stressing sequence significantly affected bar force retention. However, a conclusion in this area cannot be justified until additional research is completed on other structures.

Creep

Laminations of the Cooper Creek bridge were approximately straight between supports after construction. At the conclusion of the monitoring period, the laminations remained in approximately the same position and there was no measurable sag in the spans.

Load Behavior

Results for the static-load test and analytical assessment of the Cooper Creek bridge are presented in this section. For each load case, transverse deflection measurements are given at the bridge centerspan as viewed from the east end (looking west). No permanent residual deformation was measured at the conclusion of the load testing, and there was no detectable movement at bridge supports. At the time of the tests, the average bridge prestress was approximately 46 lb/in^2, which is relatively close to the recommended minimum long-term prestress of 40 lb/in^2 (Ritter 1990).

Load Testing

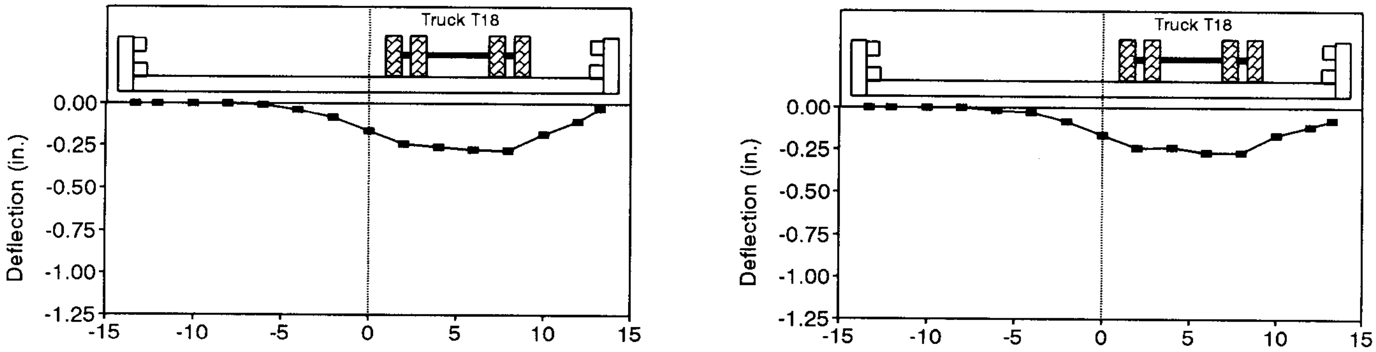
Transverse deflection for span 1 and 2 are shown in Figure 18. For span 1, load case 1 resulted in a maximum deflection of 0.28 in. under the outside wheel line nearest the north deck edge (Fig. 18a). The maximum deflection of 0.26 in. for load case 2 was measured under the outside wheel line nearest the south deck edge (Fig. 18b). For load case 3, the maximum deflection of 0.36 in. occurred under the inside wheel line of truck T18, 2 ft from the span centerline (Fig. 18c). As could be expected for the same loading on similar spans, the results for span 2 were similar to those for span 1. Load case 1 resulted in a maximum deflection of 0.27 in. under the outside wheel line nearest the north deck edge (Fig. 18d). The maximum deflection of 0.26 in. for load case 2 occurred under the outside wheel line nearest the south deck edge (Fig. 18e). For load case 3, the maximum deflection of 0.35 in. occurred under the inside wheel line of truck T18, 2 ft from the span centerline (Fig. 18f).

Measured deflection points on both spans for load case 1 plus load case 2 compared with load case 3 are shown in Figure 19. Assuming linear elastic behavior, the deflection resulting from the sum of the two individual truck loads should equal the deflection from both trucks applied simultaneously. As shown in Figure 19, the two plots are identical with only minor variations that are within the accuracy of the measurements. From this information, we concluded that bridge behavior under the applied loads was within the linear elastic range.

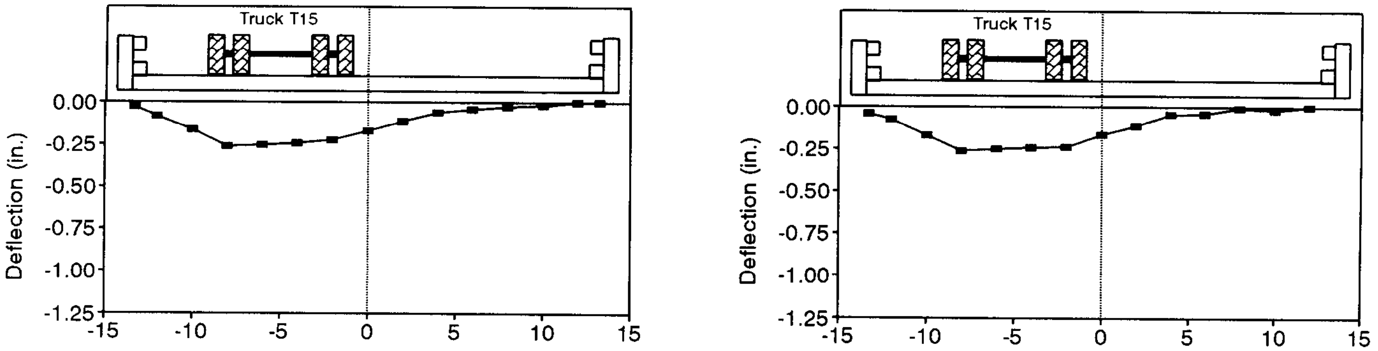
Analytical Assessment

Results of the actual deflection compared with the predicted bridge response based on orthotropic plate analysis for load case 3 are shown in Figure 20. As shown, the predicted response was close to the actual response with minor variations at the bridge edges. This was expected because the model included no provisions for edge stiffening, and the actual bridge edges were stiffened with a curb and rail system. Further orthotropic plate analysis, assuming two lanes of AASHTO HS 20-44 loading, resulted in a maximum predicted live-load deflection of 0.39 in. at the span centerline (Fig. 21). This deflection is equivalent to 1/630 of the span length measured center-to-center of bearings. Deflection computed using AASHTO recommended design procedures for the measured MOE was 0.50 in., or approximately 1/490 of the bridge span.

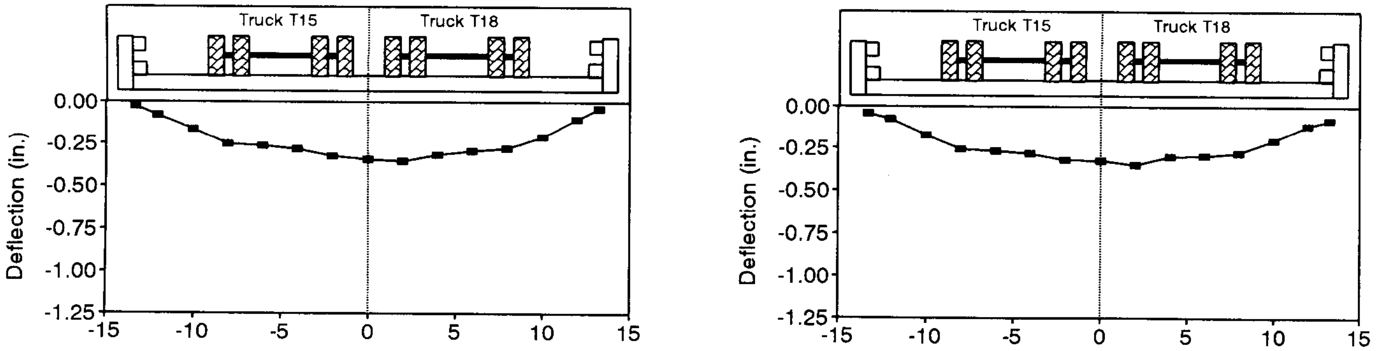
Span 1 **Span 2**



a. Span 1, Load Case 1 d. Span 2, Load Case 1



b. Span 1, Load Case 2 e. Span 2, Load Case 2



c. Span 1, Load Case 3 f. Span 2, Load Case 3

Distance from centerline (ft) Distance from centerline (ft)

Figure 18—Transverse deflection for the Cooper Creek load test, measured at the bridge centerspan (looking west). Bridge cross-sections and vehicle positions are shown to aid interpretation and are not to scale.

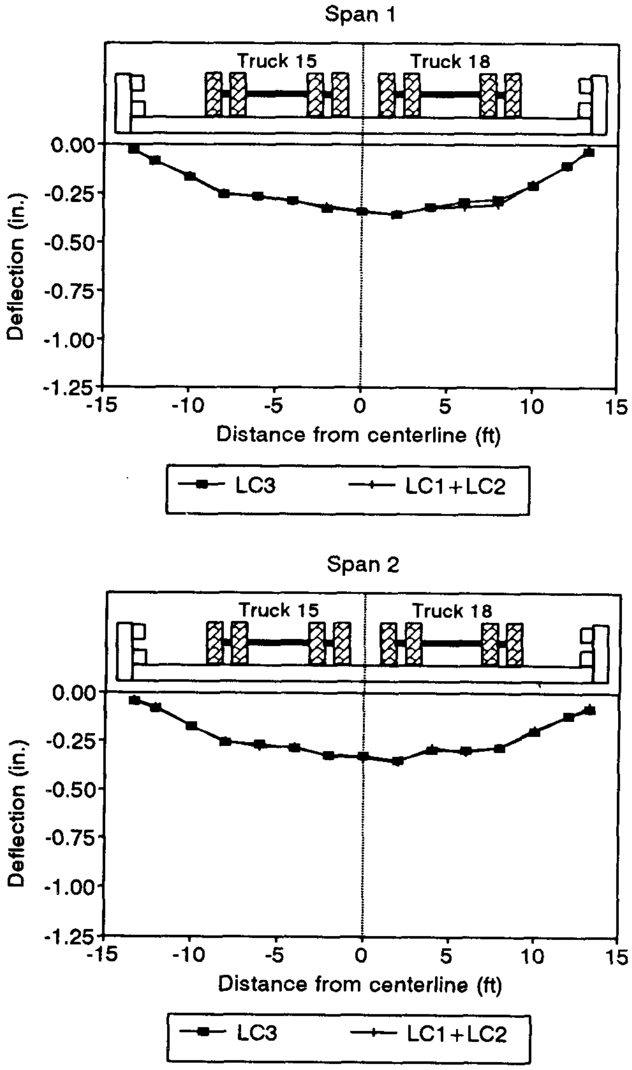


Figure 19—Comparison of the sum of the measured deflections from load case 1 and load case 2 to the measured deflections for load case 3 (looking west) for span 1 (top) and span 2 (bottom).

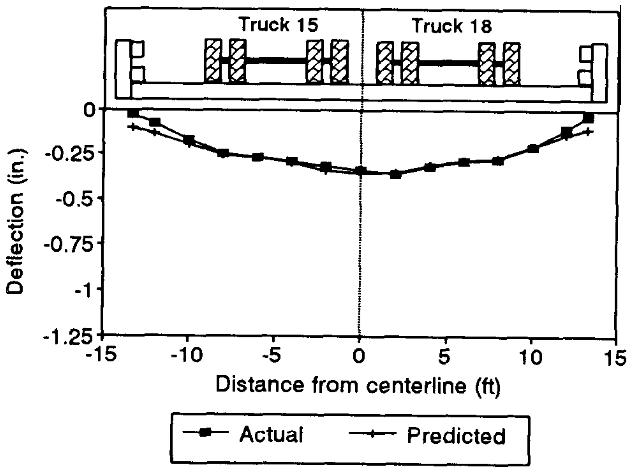


Figure 20—Comparison of the actual measured deflections for load case 3, span 1, to the predicted deflection using orthotropic plate analysis (looking west).

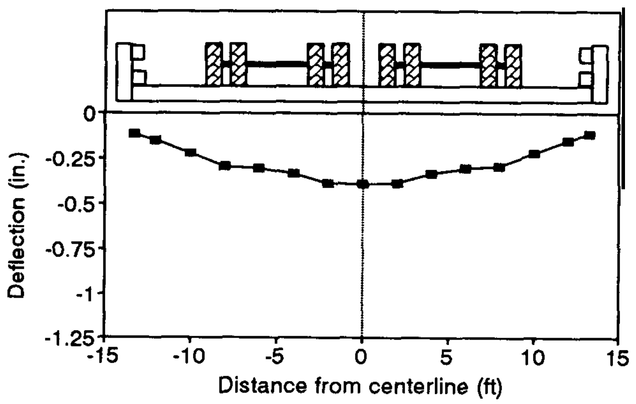


Figure 21—Predicted deflection profile at the bridge centerspan for two HS 20-44 trucks, each positioned 2 ft on either side of the bridge longitudinal centerline.

Condition Assessment

Condition assessments of the Cooper Creek bridge indicated that structural and serviceability performance were good. Inspection results for specific items follow.

Deck Geometry

Measurements of the bridge width at numerous locations indicated that the bridge was approximately 8 in. narrower over the center bent than at the abutments. This is most likely attributable to the lamination layout for consistent thickness at butt joints that resulted in the placement of the thickest odd-size laminations over the abutments. This would not have occurred if the laminations had been surfaced to a uniform thickness as specified in the material specifications.

Wood Condition

Inspection of the wood components of the bridge showed no signs of deterioration, although minor checking was evident on rail members exposed to wet-dry cycles. In several locations on the curb and railing, bolt heads were slightly crushed into wood. The crushing did not damage the preservative envelope and was likely caused by bolt overtightening at construction. For all wood components, there was no evidence of wood preservative loss and no preservative or solvent accumulations on the wood surface.

Wearing Surface

The asphalt wearing surface remained in good condition with no cracking or other deterioration. There was a substantial amount of gravel and other debris on the surface from the unpaved road, which could potentially lead to premature deterioration of the surface.

Stressing Bar and Anchorage System

The stressing bar and anchorage system performed as designed with no significant signs of distress. There was no indication of crushing of the discrete plate anchorage into the outside oak beams and no measurable distortion in the bearing plate. The exposed steel stressing bars, hardware, and anchorage plates showed no visible signs of corrosion or other deterioration.

Observations and Recommendations

After 28 months in service, the Cooper Creek bridge is performing well and should provide many years of acceptable service. Based on extensive bridge monitoring, we make the following observations and recommendations:

- It is both feasible and practical to design and construct stress-laminated timber decks using eastern cottonwood.
- The measured flatwise MOE of the eastern cottonwood laminations resulted in an average edgewise value of 1,289,000 lb/in^2. This is approximately 19 percent greater than the wet-use value currently specified in the NDS.
- Stress-laminated decks can be constructed in place using temporary scaffolding for lamination support prior to bridge stressing. This method of construction is labor intensive but can be a viable option when large equipment required for prefabricated bridge placement is not available.
- The use of northern red oak for outside edge laminations enhanced the performance of the discrete plate stressing bar anchorages. The oak provided sufficient strength to adequately distribute the bar force into the deck without wood crushing or anchor plate deformation.
- The average trend in deck moisture content in the lower 1 in. of the laminations indicates that moisture content changes are occurring slowly, with an average 3 percent decrease during the 2 years. The average moisture content in the inner 2 to 7 in. of the deck underside is 26 percent, which is expected to slowly decrease as time passes.
- Stressing bar force decreased approximately 50 percent during the 2 years of monitoring but remained within acceptable limits. The decrease is primarily attributable to transverse stress relaxation in the wood laminations. The bar force should be checked on a biannual basis and restressed as necessary until it reaches a constant level.
- Creep measurements of the bridge deck indicated no detectable vertical displacement during 28 months. The deck remains approximately straight between supports.
- Load testing and analysis indicated that the Cooper Creek bridge is performing as a linear elastic orthotropic plate when subjected to truck loading. The maximum deflection as a result of two lanes of AASHTO HS 20–44 loading is estimated to be 0.39 in., which is approximately 1/630 of the span length measured center-to-center of bearings.
- Wood checking is evident in the exposed end grain of bridge rail posts and other components. It is likely this would not have occurred if a sealer or cover had been placed over the end grain at the time of construction.
- There are no indications of corrosion on the stressing bars, hardware, or plates.

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APPENDIX-Cooper Creek Bridge Information Sheet

General

Location: On West Cottage Street in Centerville, Iowa
Date of Construction: February 25, 1992
Owner: City of Centerville, Iowa

Design Configuration

Structure Type: Stress-laminated deck with butt joints
Butt Joint Frequency: 1 in 4 laminations transverse with joints in adjacent laminations separated 4 ft longitudinally
Total Length (out-out): 42 ft
Skew: None
Number of Spans: 2 (continuous)
Span Length (center-to-center bearings): 20 ft 4 in.
Width (out-out): 26 ft 11 in. at abutments; 26 ft 3 in. at bent (as-built)
Width (curb-curb): 24 ft 11 in. at abutments; 24 ft 3 in. at bent (as-built)
Number of Traffic Lanes: 2
Design Loading: AASHTO HS20-44
Wearing Surface Type: Asphalt pavement; 2 in. to 2-1/2 in. thickness

Material and Configuration

- Timber:
  - Species: Eastern cottonwood deck laminations; nothern red oak exterior (edge) laminations
  - Size (actual): 1-314 to 2-3/8 in. wide; 11-3/4 to 12-1/4 in. deep
  - Grade: No. 1 visually graded
  - Moisture Condition: 25 percent average at 1 in. depth
  - Preservative Treatment: Creosote
- Stressing Bars:
  - Type: High strength steel thread bar with coarse right-hand thread, conforming to ASTM A 722
  - Diameter: 5/8 in.
  - Number: 21
  - Design Force: 28,800 lb
  - Spacing: 24 in. center-to-center beginning 1 ft from bridge ends
- Anchorage Type and Configuration:
  - Steel Plates: 10- by 10- by 3/4-in. bearing
    2- by 5- by l-in. anchor

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