Eastern Cottonwood Stress-Laminated Timber Bridges
Enhancing Rural America with Underutilized Species

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Abstract
In 1988, the U. S. Congress passed legislation known as the Timber Bridge Initiative (TBI). The purpose of the legislation was to establish a national program to provide effective and efficient utilization of wood as a structural material for highway bridges. As part of the TBI, a demonstration bridge program was developed to enhance rural America by encouraging innovation through the use of new or previously underutilized wood products. In south-central Iowa, two counties have constructed stress-laminated timber bridges using eastern cottonwood, a local, underutilized species. This paper presents a summary of the performance of three stress-laminated eastern cottonwood bridges constructed in 1994.

Keywords: Bridge, eastern cottonwood, field performance, stress-laminated, timber, wood

Introduction
Approximately 41% of the 578,000 highway bridges in the United States are currently in need of repair or replacement (USDA 1995). Because many of these bridges are short-span crossings, they are ideally suited for wood construction. To address the problem of the deteriorating infrastructure, the U. S. Congress passed legislation known as the Timber Bridge Initiative (TBI) in 1988. The objective of the TBI was to establish a national program to encourage the effective and efficient use of wood as a structural material for highway bridges.

The USDA Forest Service was assigned responsibility for the development and implementation of a National timber bridge program under the TBI. Three emphasis areas were identified: technology transfer, demonstration bridges, and research. The Forest Service Timber Bridge Information Resource Center (TBIRC) in Morgantown, West Virginia, maintains the technology transfer program and administers the demonstration bridge program. The demonstration bridge program provides matching funds on a competitive basis to local governments for the construction of timber bridges that illustrate the use of new or previously underutilized wood products, bridge designs, or 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 the research program, FPL assists local governments in evaluating the field performance of demonstration timber bridges. This enables FPL to collect, analyze, and distribute information regarding field performance and provides a basis for validating and/or revising design criteria, thereby improving efficiency and economy in timber bridge design, fabrication, and construction.

Background

As a result of the TBI, numerous timber bridges have been constructed from wood species not previously used in structural applications. One of these species is eastern cottonwood. Traditionally, eastern cottonwood is used for lightweight containers, interior furniture parts, plywood core stock, and pulp for paper production. Because it is an abundant, readily available species and is the fastest growing tree in North America, eastern cottonwood has the potential to be an economic alternative to traditional structural species (Kennedy 1985). However, the strength and stiffhess of cottonwood are considerably less than the commonly used structural species.

In 1992, the first known stress-laminated deck utilizing eastern cottonwood was constructed over Cooper Creek in Centerville, Appanoose County, Iowa. Although not a demonstration bridge under the TBI, the decision to construct this type of bridge was prompted by information obtained through the TBIRC. Because few stress-laminated timber bridges had been built in the United States at that time, and little information was available regarding design criteria and construction specifications, FPL was contacted for technical assistance. Through meetings with state, local, and FPL representatives, it was determined a stress-laminated bridge deck constructed with eastern cottonwood lumber laminations was feasible. Upon developing a cooperative agreement with several agencies, FPL developed and executed a 28-month bridge performance monitoring program (Ritter and others 1995b).

Based on the success of the Cooper Creek bridge, three more eastern cottonwood stress-laminated bridges were constructed in southern Iowa during 1994. Since the use of eastern cottonwood in stress-laminated decks was still a relatively new concept, FPL was contacted to implement performance evaluation programs for each of the three bridges. As a result, FPL initiated a field monitoring and evaluation program for these bridges.

Objective

The objective of the FPL monitoring program is to evaluate the performance of the stress-laminated cottonwood bridges for a minimum of 2 years, beginning shortly after bridge installation. The performance evaluation includes data collection and analysis related to the bridge behavior under static truck loading and general structural performance. The results will be evaluated with those of the Cooper Creek bridge to establish recommendations for the design and construction of future eastern cottonwood stress-laminated bridges. They will also be reviewed with results from field evaluations of stress-laminated bridges constructed using other species in order to formulate and improve design criteria for stress-laminated timber bridge decks.

Table 1 – SI conversion factors.

English unit	Conversion factor	SI unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile	1.609	kilometer (km)
pound (lb)	0.14	Newton (N)
lb/in^2 (stress)	6,894	Pascal (Pa)

Description of Bridges

In 1994, three eastern cottonwood stress-laminated bridges were constructed in southern Iowa: the Hibbsville and Dean bridges in Appanoose County and the Decatur bridge in Decatur County. Numerous similarities exist between the bridges. Each is a simple-span, stress-laminated deck, approximately 24 ft long and was constructed with eastern cottonwood lumber pressure treated with creosote (Figure 1). (See Table 1 for metric conversion factors.) Because available lamination material did not extend the full length of the bridge, butt joints were placed transverse to the bridge span in every fourth lamination. Longitudinally, butt joints in adjacent laminations were separated by 4 ft (Figure 2), Each bridge is located on a low-volume county road and is unpaved (Figure 3).

The stressing system for each of the three bridges consists of six 1-in.-diameter high strength steel bars, spaced 48 in. on-center. The bars were designed to be tensioned to provide a uniform compressive stress of 100 lb/in^2 between the lumber laminations. The bar anchorages are discrete plate systems that are similar in design, although actual plate dimensions vary. Figure 4 illustrates the anchorage configuration for the Dean bridge. A unique feature of the anchorage configuration for the Dean and Decatur bridges is an untreated white oak plate between the exterior lamination and the steel bearing plate. The anchorage system for the Hibbsville bridge uses a steel plate in place of the white oak plate.

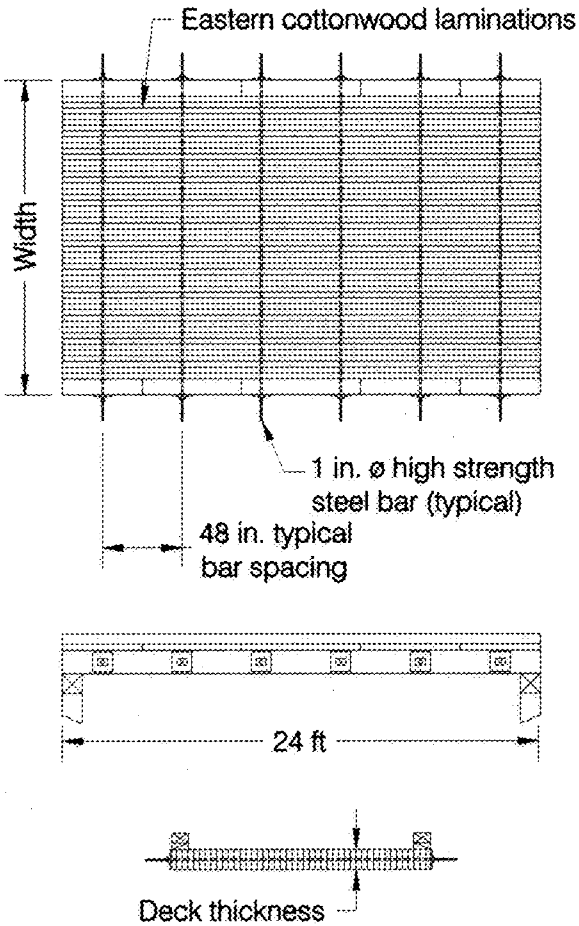

Figure 1 – Typical configuration of the eastern cottonwood stress-laminated bridges. Curb is shown for illustration only and does not represent actual systems used.

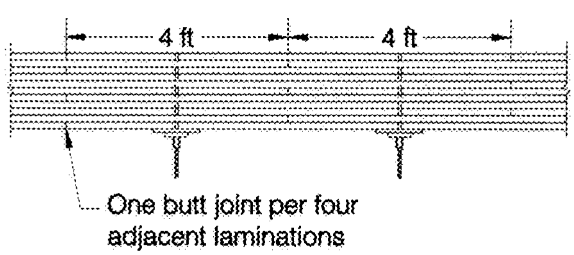

Figure 2 - Typical butt joint configuration. Butt joints were placed transverse to the bridge span in every fourth lamination. Longitudinally, butt joints in adjacent laminations were separated by 4 ft.

Although the general configuration and many characteristics of the Hibbsville, Dean, and Decatur bridges are similar, each has several distinct features. A brief summary of each bridge follows.

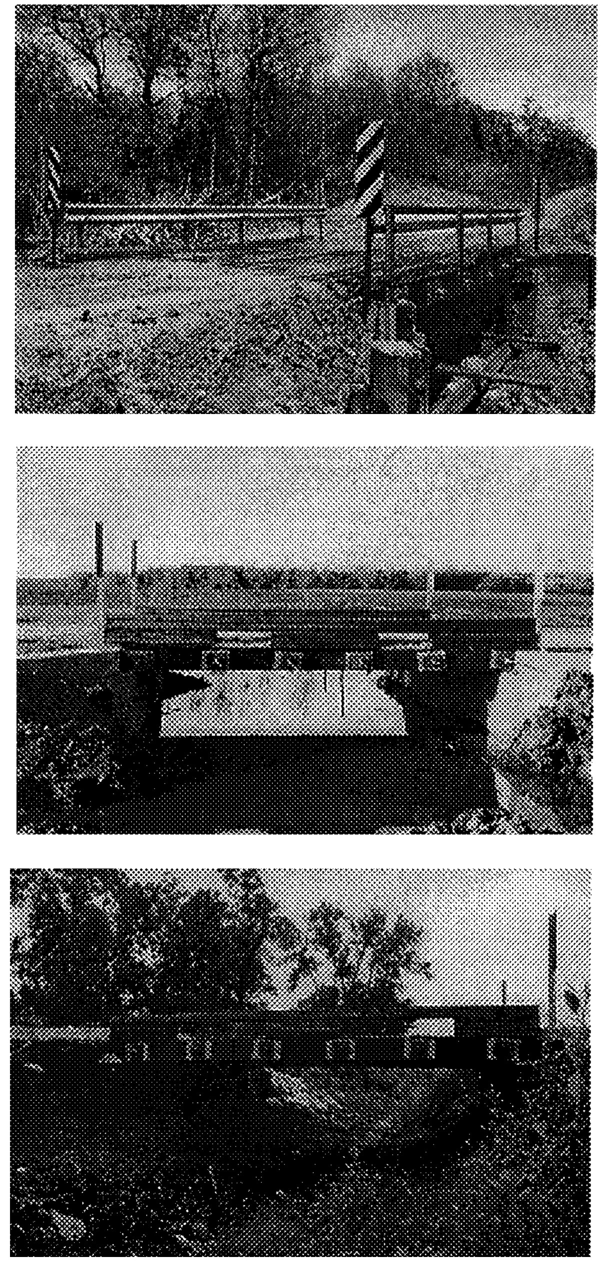

Figure 3 – Completed Hibbsville (top), Dean (middle), and Decatur (bottom) bridges.

Hibbsville

The Hibbsville bridge is located on a dead-end gravel roadway approximately 2 miles southwest of Numa, Iowa (Figure 5). It is a single-lane deck, 14-in. deep and approximately 17-ft wide. The design bar force required to achieve 100 lb/in^2 interlaminar compression is 67,200 lb. The rail system is composed of a steel w-beam bolted to steel angle posts. Vehicles ride directly on the deck surface because no wearing surface was applied.

Dean

The Dean bridge is on a double-lane, gravel roadway approximately 5 miles southwest of Moulton, Iowa (Figure 5). It is a double-lane bridge, approximately 23-ft wide, with a deck thickness of 15.5-in. A design bar force of 74,400 lb is required for 100 lb/in^2 interlaminar compression. The bridge includes an 18-in.-high timber curb and a 3-in.-thick gravel wearing surface.

Decatur

The Decatur bridge is located on a field entrance roadway approximately 2 miles southwest of Davis City, Iowa (Figure 5). It is a double-lane bridge, 14-in. deep, and approximately 2l-ft wide. As with the Hibbsville bridge, the design bar force of 67,200 lb is required to achieve 100 lb/in^2 interlaminar compressive stress. The bridge includes a 17-in.-high timber curb system and a gravel wearing surface.

Research Methods and Results

As previously mentioned, FPL was contacted by local government officials to develop and implement a performance evaluation program for the three eastern cottonwood stress-laminated bridges. The program required monitoring several performance indicators, including moisture content, bar force, static load behavior, and general structural condition. The research methods utilized procedures and equipment previously developed (Ritter and others 1991; Wacker and Ritter 1992). Preliminary results for the first 22 months of the 24-month monitoring for each bridge follow. In most cases, results from the Decatur bridge monitoring are presented but are also representative of the performance of the Hibbsville and Dean bridges.

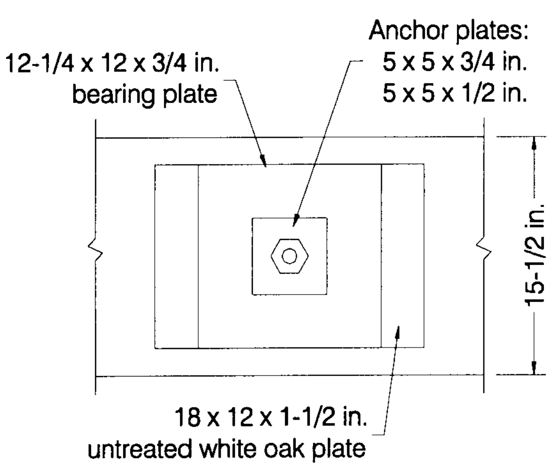

Figure 4 – Details of the Dean bridge discrete plate bar anchorage configuration.

Moisture Content

Global changes in the moisture content of stress-laminated decks can significantly affect the performance of the structure. If moisture is lost, the deck can shrink, resulting in a decrease in stressing bar force. Conversely, if moisture is gained, swelling of the timber can occur and cause an increase in stressing bar force. Changes in moisture content can also affect the deck stiffness, creep, transverse stress relaxation, and anchorage system performance. The effect of global moisture content changes in a stress-laminated timber bridge depends largely on the moisture content of the laminations at the time of construction.

Moisture content of the eastern cottonwood bridges was measured using an electrical-resistance moisture meter with 3-in. insulated 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 values, and adjusting the values for temperature and wood species (Forintek 1984).

For each bridge, the deck lamination moisture content was measured at the first load test, which occurred shortly after bridge installation. At that time, the average lamination moisture content for the Hibbsville, Dean, and Decatur bridges was approximately 25%, 24%, and 23%, respectively. These values substantially exceeded the equilibrium moisture content, which is expected to average 18% to 20% (McCutcheon and others 1986). Since bridge installation, the average lamination moisture content of each bridge has remained relatively stable with minor fluctuations of 3% to 5% in the measurement zone as a result of seasonal climatic changes.

As the lamination moisture content gradually decreases toward equilibrium, the deck width will decrease, resulting in bar force loss. Ideally, the moisture content at installation should be 16% or less. This would result in the global moisture content increasing toward equilibrium, thereby causing the deck to swell, which tends to increase bar force and offset bar force loss caused by stress relaxation.

At the conclusion of the monitoring period, the average lamination moisture content for each deck will be measured and compared with earlier measurements to determine if the global moisture content of the decks is moving toward an equilibrium level.

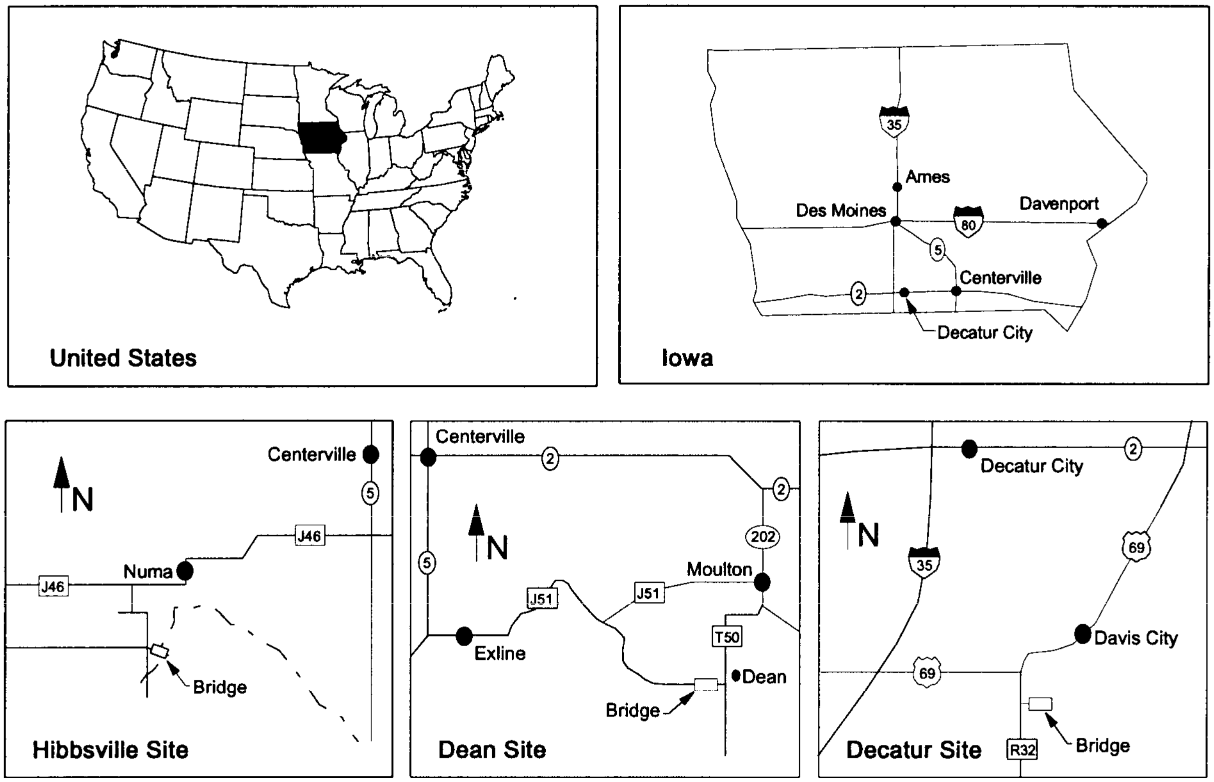

Figure 5 – Location maps for the Hibbsville, Dean, and Decatur bridges.

Bar Force

Stress-laminated bridges perform properly when adequate compression is maintained between the lumber laminations to prevent vertical slip. At the time of construction, stressing bars are normally tensioned to a design force that results in an interlaminar compression level of 100 lb/in^2. It is assumed that 50% to 60% of the compressive stress will be lost over time due to stress relaxation in the laminations. This loss is considered acceptable because slip between the laminations does not occur until the interlaminar compression level is 20 to 24 lb/in^2 (Ritter and others 1995a).

Interlaminar deck compression is evaluated by monitoring force in the stressing bars. To monitor bar force, load cells developed at FPL were installed on two stressing bars of each bridge (Wacker and Ritter 1992). Load cell measurements for the Hibbsville and Decatur bridges were obtained on a monthly basis by county personnel, using a portable strain indicator. For the Dean bridge, load cell measurements were obtained on an hourly basis through a remote data acquisition system. For each bridge, load cell strain readings were converted to units of bar tensile force by applying a laboratory calibration factor to the strain indicator reading.

The average trend in bar force for the Decatur bridge is illustrated in Figure 6 and is typical of the bar force trend for the Hibbsville and Dean bridges. At the start of the monitoring period, the bars were tensioned to approximately 53,900 lb, or 80% of the design force. As indicated in Figure 6, the average force dropped to approximately 37,400 lb, or 56% of the design force, within the first month of the monitoring period. At the end of the first month, the rate of loss greatly decreased.

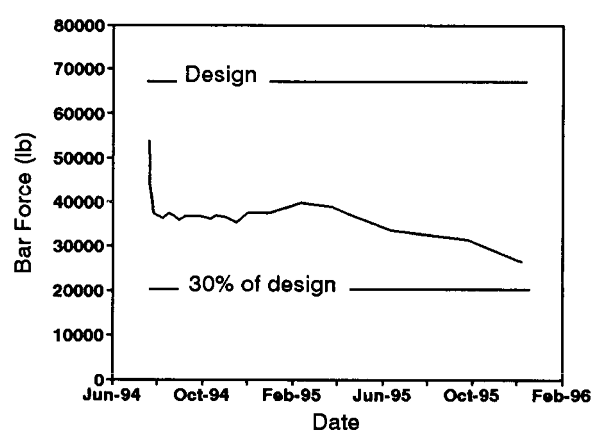

Figure 6 – Average trend in bar force of the Decatur bridge.

Several factors contribute to changes in bar force, including wood stress relaxation, moisture content, and bar anchorage performance. General observations can be made regarding the impact of each factor, although the exact effect of one variable cannot be accurately defined because of the complex interaction of the factors.

Stress Relaxation – When deck laminations are subject to long-term loads applied by the stressing bars, the wood slowly compresses across the bridge width resulting in bar force loss. This occurrence is known as stress relaxation and is greatest when the deck is initially stressed, then gradually decreases. The large initial bar force loss and subsequent slower force reduction illustrated in Figure 6 is indicative of stress relaxation. Because bar force loss caused by stress relaxation increases as the moisture content of the wood increases, bar force loss in the three cottonwood bridges was likely affected by the relatively high moisture content of the laminations.

Moisture Content – At this point in the monitoring period, the moisture content of the three bridges has not significantly decreased. Therefore, the current bar force loss cannot be attributed to a decrease in moisture content. This phenomena will be examined further when the moisture content is measured at the conclusion of monitoring. Long-term loss caused by the moisture content decreasing towards equilibrium is anticipated.

Bar Anchorage – The performance of the bar anchorage directly affects bar force. Anchorage systems are intended to distribute bar force into the deck without causing wood crushing in the exterior laminations. If crushing occurs, bar force loss can be great.

The discrete plate anchorage system employed on two of the cottonwood bridges is unique because a white oak plate was placed under the steel bearing plate. Normally fill-length dense hardwood exterior laminations are used in stress-laminated bridges, because they have stronger compression perpendicular to grain characteristics and are less likely to experience crushing beneath the anchorage plates. Cottonwood is relatively weak in compression perpendicular to grain; therefore, the white oak plates were added to the anchorage system in hopes that they would perform the same function as the full-length dense hardwood laminations. Crushing of the exterior laminations has not occurred, indicating that the white oak plates are effective in distributing the load. The bar force losses illustrated in Figure 6 cannot be attributed to anchorage performance because crushing has not been observed.

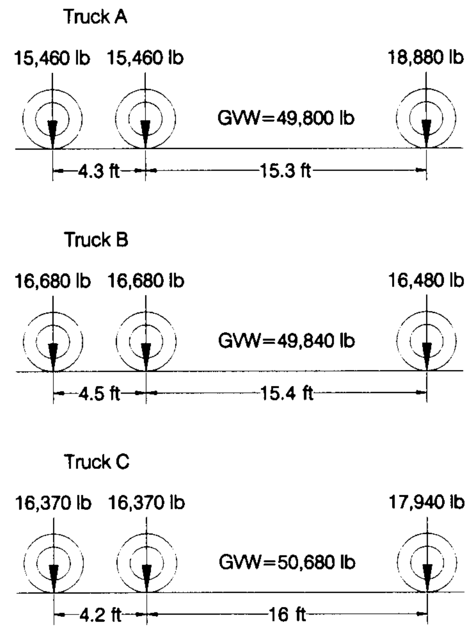

Figure 7 – Vehicle configurations and axle loads. The single axle (right) represents the front of the vehicle. The track width, measured center-to center of the rear tires, was 6 ft.

Load Test Behavior

Static load testing of the bridges is important to the overall bridge monitoring program because information obtained from the tests is used to refine and improve design procedures and evaluate effects of design variables on bridge performance. To date, one load test has been performed on each bridge. It is anticipated that the second group of tests will be conducted by the end of 1996. In each of the tests, fully-loaded trucks were positioned on the bridge deck and resulting deflections were measured at a series of locations along the bridge midspan. Measurements were taken prior to testing (unloaded), for the load positions (loaded), and at the conclusion of testing (unloaded) by suspending calibrated rules from the deck underside and reading values to the nearest 0.04 in. with a surveyor's level. The accuracy of the measurements is estimated to be +/- 0.02 in. A summary of each load test follows.

Hibbsville – The Hibbsville bridge load test was conducted May 11, 1994. A single test vehicle, Truck A, with a gross vehicle weight of 49,800 lb (Figure 7),

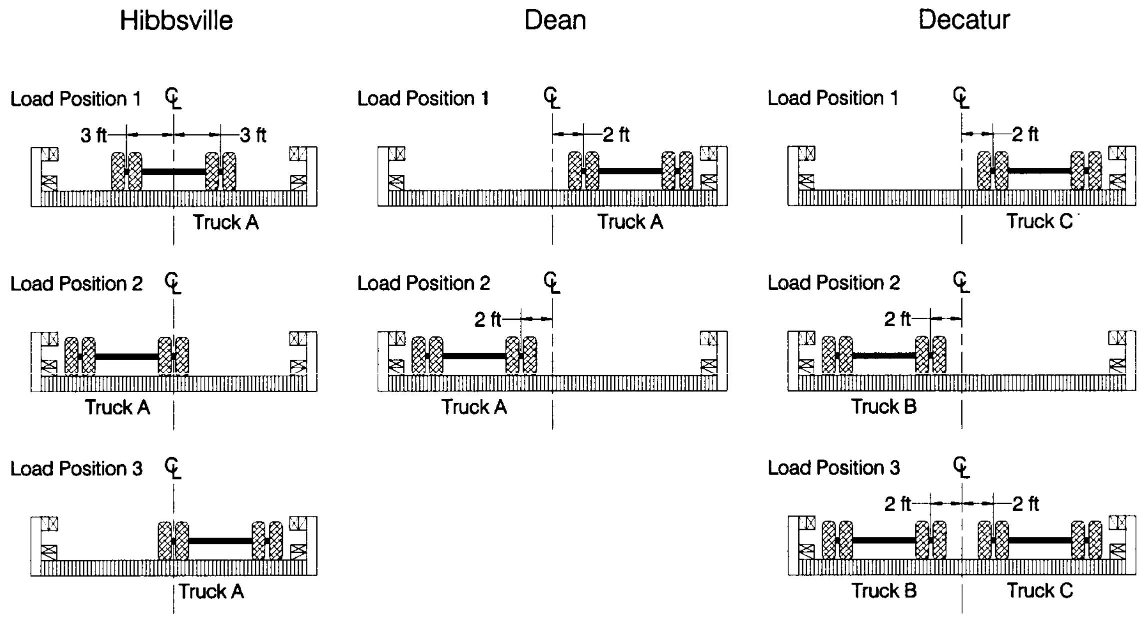

Figure 8 – Transverse load positions (looking east). For all load cases, the two rear axles were centered about the bridge midspan with the front axles off the span. Drawings are for illustration only and are not to scale.

was positioned longitudinally with the two rear axles centered about the bridge midspan. Transversely, three load positions were used (Figure 8).

Dean – The Dean bridge load test was also conducted May 11, 1994, and used the same test vehicle (Figure 7) and longitudinal vehicle position used for the Hibbsville bridge load test. Transversely, two load positions were used (Figure 8).

Decatur – The load test was conducted August 3, 1994. Two test vehicles were employed: Truck B with a gross vehicle weight of 49,840 lb and Truck C with a gross vehicle weight of 50,680 lb (Figure 7). As with the previous load tests, the trucks were positioned longitudinally with the two rear axles centered about the bridge midspan. Transversely, three load positions were used (Figure 8).

Results of the Decatur bridge static load test are presented in Figure 9. For each load position, transverse deflections are shown at the bridge midspan as viewed from the west, looking east. No permanent residual deformation was measured at the conclusion of testing and movement at the abutments was not detected. For load positions 1 and 2, the maximum measured deflection of 0.33 and 0.37 in., respectively, occurred beneath the outside wheel line. The absolute maximum measured deflection of 0.45 in. occurred at the bridge centerline for load position 3, with both vehicles on the bridge.

Assuming linear elastic behavior, uniform material properties, proper vehicle placement, and accurate deflection measurements, the summation of the deflections resulting from two individual truck loads applied separately should equal the deflection resulting from both trucks applied simultaneously. This is illustrated in Figure 10, where the sum of load positions 1 and 2 is compared to load position 3. The plots are virtually identical with only minor variations within the accuracy of the measurement methods. The results presented in Figure 10 indicate that the bridge behavior under the applied loads is within the linear elastic range. Results from the load tests performed on the Hibbsville and Dean bridges also indicate linear elastic behavior.

Condition Assessment

The general condition of each eastern cottonwood stress-laminated bridge was assessed at the beginning of the monitoring period and involved visual inspections, measurements, and photographic documentation. Items of specific interest included the bridge geometry and the condition of the timber deck, stressing bars, and anchorage system. A second assessment will be made at the conclusion of the monitoring period and compared to the first in order to further evaluate bridge behavior and performance. Specific observations pertaining to the individual bridges follow.

Hibbsville **–** The first condition assessment of the Hibbsville bridge indicated that the wood components are performing well with no signs of deterioration. Inspection of the anchorage system revealed no signs of crushing of the discrete plate anchorage into the outside laminations and no measurable distortion of the bearing plate. The exposed steel stressing bars and nuts showed no signs of corrosion; however, because the steel bearing and anchor plates were not galvanized, they are experiencing corrosion.

Dean **–** Results of the Dean bridge condition assessment were similar to those of the Hibbsville bridge. The wood components and exposed steel stressing bars and nuts showed no signs of deterioration. The anchorage system was performing properly with no noticeable signs of crushing into the exterior laminations; however, the steel bearing and anchor plates exhibited corrosion because they were not galvanized. Inspection of the bridge geometry revealed that the width was distorted. The south edge of the deck was essentially straight, and the north edge of the deck was approximately 8.5 in. narrower in width at the midspan than at the abutments. It is suspected that this is largely attributable to the layout of the cottonwood laminations, which varied in width as much as 0.5 in.

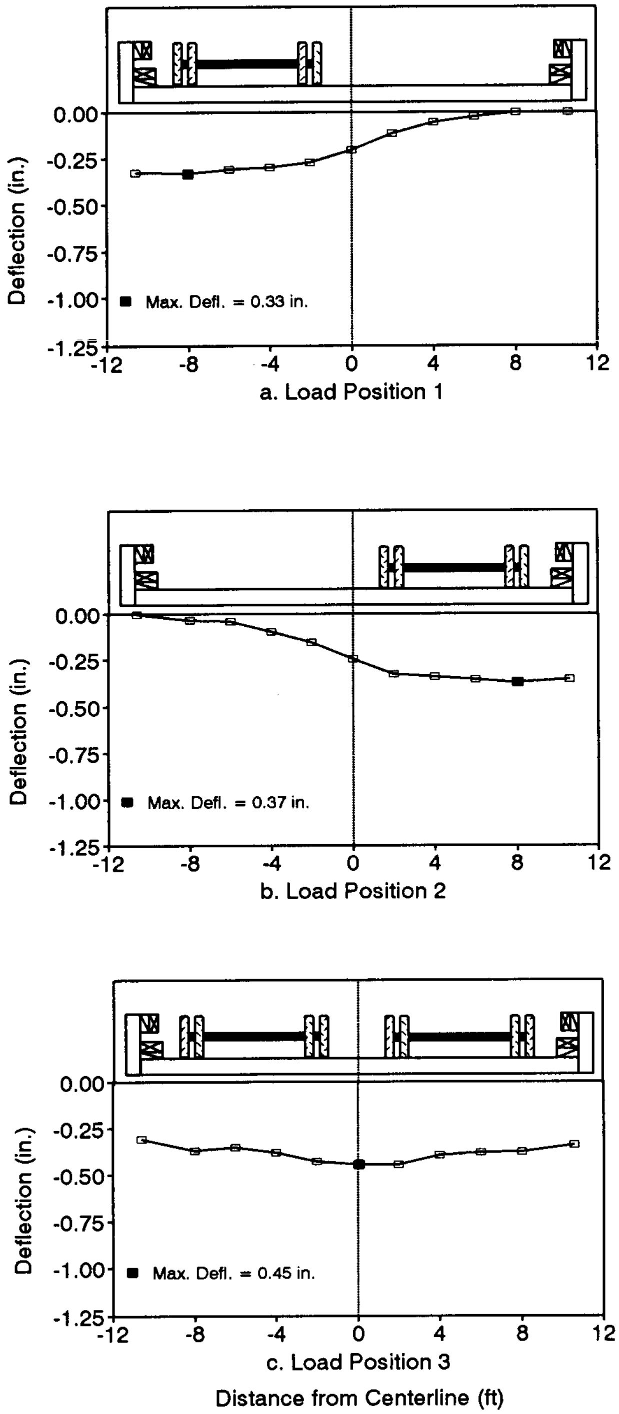

Figure 9 – Transverse deflection for the Decatur bridge load test, measured at the bridge centerspan (looking east). Bridge cross-sections and vehicle positions are shown to aid interpretation and are not to scale.

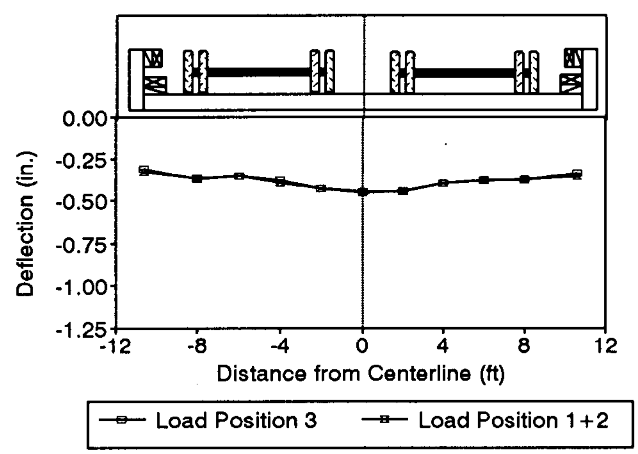

Figure 10 – Comparison of the sum of the deflections from load position 1 and 2 to the measured deflections of load position 3 (looking east). Transverse deflections were measured at the bridge centerspan.

Decatur – Evaluation of the individual wood components and the anchorage system during the condition assessment of the Decatur bridge indicated acceptable performance. The steel components exhibited no visible signs of corrosion. Along the west abutment, it was noted that both comers curled upward approximately 1.5 in. away from the abutment (Figure 11). At both edges, the displacement of the deck away from the deck gradually reduced until at 18 in. from each deck edge, the deck made contact with the abutment. This will be reexamined at the second condition assessment.

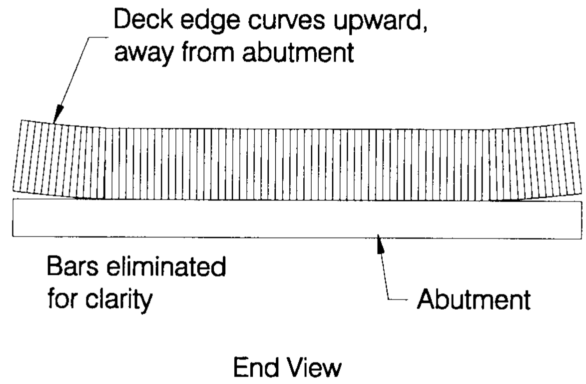

Figure 11 – Deck distortion at the west abutment of the Decatur bridge.

Concluding Remarks

To date, these three eastern cottonwood stress-laminated bridge decks in Iowa are performing well and are expected to provide many years of acceptable service. Based on the monitoring conducted thus far, the following observations and recommendations are given.

- It is feasible and practical to construct stress-laminated decks using eastern cottonwood, a species not typically used in structural applications.

- The moisture content of the Hibbsville, Dean, and Decatur bridges at installation was approximately 25%, 24%, and 23%, respectively. The moisture content of the bridges has remained relatively stable, with minor fluctuations of 3% to 5% in the measurement zone as a result of seasonal climatic changes. This somewhat high moisture content has not adversely affected the structural integrity of the bridges, although it has likely contributed to a high level of stress relaxation. A lamination moisture content less than or equal to 19% at installation is recommended.

- Currently the bridges are either unsurfaced or have a gravel wearing surface. The gravel and debris tracked onto the bridge trap moisture and do not allow the deck to dry. The addition of an asphalt wearing surface and an underlying asphalt impregnated geotextile fabric would help keep the wood decks dry.

- Each bridge experienced rapid bar force loss within the first month following stressing of the deck. The average bar force in the Decatur bridge decreased from 80% to 56% of the design force during the first month of monitoring, at which time the rate of loss greatly decreased and stabilized. The majority of the bar force losses in the bridges is attributed to stress relaxation in the cottonwood laminations.

- Load tests indicate that the bridges are performing within the linear elastic range. Results of a second load test on each bridge will be compared to the first load test to verify bridge behavior and performance characteristics.

- The anchorage system of each bridge is performing well, although the bearing and anchor plates are exhibiting corrosion because they were not galvanized. The exposed steel stressing bars and nuts show no visible signs of corrosion. All steel components should be galvanized to prevent deterioration. Crushing in the exterior laminations is not evident.

- In two of the bridges, white oak bearing plates were used. At this time, the plates are effectively distributing the bar force into the deck.

- The timber components of each bridge exhibit no signs of deterioration.

- The irregular width of the Dean bridge, is likely caused by unequal lamination widths and subsequent lamination layout.

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