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Field Performance of Stress-Laminated Highway Bridges Constructed with Glued Laminated Timber

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Abstract

This paper summarizes the field performance of three stress-laminated deck timber bridges located in Wisconsin, New York, and Arizona. The deck superstructures of these single-span highway bridges is comprised of full-span glued laminated timber (glulam) beam laminations manufactured with southern pine, hem fir/red maple combination, and/or Douglas fir lumber species. These bridge structures were evaluated as part of a National Timber Bridge Monitoring Program for 2-3 years following construction. Field data collection for these single-span bridges included moisture content, prestressing force, and static load tests. Based upon these collected field data and comprehensive visual inspections, the bridges have performed satisfactorily with no structural or serviceability deficiencies.

Introduction

Stress-laminated decks timber bridges are longitudinal deck superstructures that are assembled by placing alllumber laminations onto bridge supports and aligned adjacent to each other. High strength steel bars are then inserted through transversely pre-bored holes in the lumber laminations and anchor plates and nuts are attached along the bridge edges. When the steel bars are tensioned with hydraulic equipment resulting with an interlaminar stress in the range of 690–896 kPa (100 and 130 lb/in^2), the lumber laminations are effectively “stress-laminated” together so that they act as a deck slab, which exhibits orthotropic plate behavior. Stress-laminated decks with continuous laminations between supports are typically less than 6.1m (20ft) simply-supported spans due to the limited supply of longer lumber materials. However, it is common practice to introduce a staggered pattern of butt-joints which allows the stress-laminated deck system to span up to approximately 9.2m (30ft), due to the limited supply of wider lumber materials typically required for deeper stress-laminated decks exceeding 41cm (16 in.) in thickness. Several hundred stress-laminated deck bridges have been built in the U.S. over the past 15 years, with only a few bridges spanning more than 9.2m (30ft).

One longer-span design alternative is the stress-laminated deck bridge utilizing full-span glulam beams (Ritter and Williamson 1994, Taylor et al 2000). The primary advantage with the use of glulam beams is the ability to manufacture longer and deeper deck laminations (i.e., glulam beams) required for longer spans while eliminating the strength reductions required with butt-jointed stress-laminated decks.

Other advantages include dry glulam beam laminations at installation which helps to reduce prestressing force losses. The first known stress-laminated deck superstructure to utilize glulam beams is the Teal River bridge in Wisconsin (Wacker and Rittter 1990), constructed with a new glulam beam combination of southern pine and red pine lumber. Several additional stress-laminated glulam beam bridges have been constructed throughout the U.S., but their field performance has not been previously evaluated.

Soon after development of the stress-lamination concept as a rehabilitation technique for deteriorated longitudinal nail-laminated lumber decks in Canada in 1976, a number of prototype stress-laminated bridges were evaluated in Ontario, Canada and resulted in a new design methodology being included in the Ontario Highway Bridge Design Code (OHBDC 1983). The first U.S. stress-laminated timber highway bridges were introduced in Colorado and Pennsylvania during 1987. Field evaluations of the Colorado and Pennsylvania bridges and supplementary laboratory research augmented previous Canadian efforts to provide the technical basis for code acceptance in the U.S. In 1991, the stress-laminated superstructure design methodology was adopted by the American Association of State Highway Transportation Officials (AASHTO) as a guide specification (AASHTO 1991) for general use by design engineers.

This paper will focus on three stress-laminated timber deck timber bridges that were recently constructed in New York, Arizona, and Wisconsin which are summarized in Table 1. These double-lane bridge superstructures are comprised of full-span glued laminated timber (glulam) beam laminations manufactured with various species to span between 8.2 and 15.2m (27 and 50ft). The Moose River bridge was constructed with CCA-treated, southern pine glulam beams in February 1996 along an rural roadway in Sawyer county, WI. The Beardsley Hollow bridge was constructed with penta-treated, hem fir and red maple combination glulam beams in July 1994 along a rural roadway in Schuyler county, NY. The South Gila Canal bridge was constructed in July 1997 with penta-treated, Douglas fir glulam beams along a city roadway in Yuma, AZ.

Table 1. Description of the three stress-laminated glulam beam bridges.

Location	Name	Length, m (ft)	Width, m (ft)	Deck thickness, cm (in.)	Species	Preservative
Sawyer County, WI	Moose River	15.2 (50)	7.3 (24)	52.4 (20-5/8)	southern pine	CCA[a]
Schuyler County, NY	Beardsley Hollow Creek	9.8m (32)	9.2 (30)	39.7 (15-5/8)	hem fir & red maple	Penta[b] type A
Yuma County, AZ	South Gila Canal	8.2 (27)	10.4 (34)	30.5 (12)	Douglas fir	Penta[b] type A

a–chromated copper arsenate, a waterborne wood preservative;
b–pentachlorophenal in light oil, an oilborne wood preservative;

Field Performance Monitoring

Each of these stress-laminated bridge structures were evaluated for 2-3 year period following construction, as part of the National Timber Bridge Monitoring Program administered jointly by the USDA Forest Service–Forest Products Laboratory (FPL) and the Federal Highway Administration (FHWA). Field data collection for these single-span bridges involved moisture content, prestressing forces, and static load tests using methods that were previously developed (Ritter et al 1991).

Moisture Contents

The deck moisture content was periodically measured with an electrical resistance-type moisture meter with 76 mm (3 in.) long insulated probe pins. Moisture content readings were taken at approximately 7 locations from the deck underside, due to asphalt wearing surface on the roadway, and were adjusted for temperature and species as required. The average moisture content readings are summarized in Table 2 for each bridge.

Since the manufacture of glulam requires dry lumber, the moisture content readings near installation were expected to be less than 15 percent, except for the South Gila Canal bridge which was slightly higher. Moisture content readings remained stable within the 9-14 percent range at the Moose River and Beardsley Hollow bridges. However, moisture content readings at the South Gila Canal bridge decreased significantly from 16 percent at installation to 10 percent during the 1st year and then remained stable during the 2nd and 3rd year. Since all three bridges had asphalt wearing surfaces added shortly after construction, it was anticipated that the glulam beam moisture contents would remain stable and dry (i.e., less than 20 percent) during the first three years. The approximately 6 percent decrease in average moisture content at the South Gila Canal bridge was most likely due to the dry environmental conditions typical in southern Arizona. The relatively low moisture contents observed will play a key role in minimizing prestressing force losses, a critical parameter in the long-term performance of stress-laminated deck timber bridges.

Table 2. Summary of average moisture content readings.

Months since installation	Average moisture content (percent) at given penetrations					
	Moose River (WI)		Beardsley Hollow (NY)		South Gila Canal (AZ)	
	254mm	510mm	254mm	510mm	254mm	510mm
0	13.5	9.0			15.0	16.0
2			14.0	15.0		
9	12.0	--	13.5	14.0		
15						10.0
18	11.0	10.0				
24				13.0		
27						10.0
36				14.0		

Prestressing Forces

Stress-laminated decks rely upon sufficient interlaminar stress to maintain structural integrity. Therefore, it is important to monitor prestressing bar forces periodically to insure that they are stabilized and remain above the recommended minimum design level.

The Moose River and South Gila Canal bridge were instrumented with an automated data acquisition system to monitor on an hourly basis the prestressing force levels using calibrated load cells, and thermal variations using embedded thermocouple sensors. A hollow-core, hydraulic cylinder and pump was employed at the Beardsley Hollow bridge to periodically monitor prestressing forces during site visits because steel strand cables were utilized instead of the threaded steel bars typically used and load cell installation was not feasible.

Prestressing force monitoring results from the Beardsley Hollow bridge are summarized in Figure 1. Four different strands were monitored over three years with three of four locations stabilizing at approximately 89 kN, which represents two-thirds of the original design prestressing force of 133 kN. Data from the Moose River followed the general trend observed at the Beardsley Hollow bridge and maintained over 75 percent of its original design prestressing force throughout the monitoring period. Data from the South Gila Canal bridge indicated slightly decreasing prestressing forces approximately 50 percent of its original design prestressing force remaining at the end of the monitoring period.

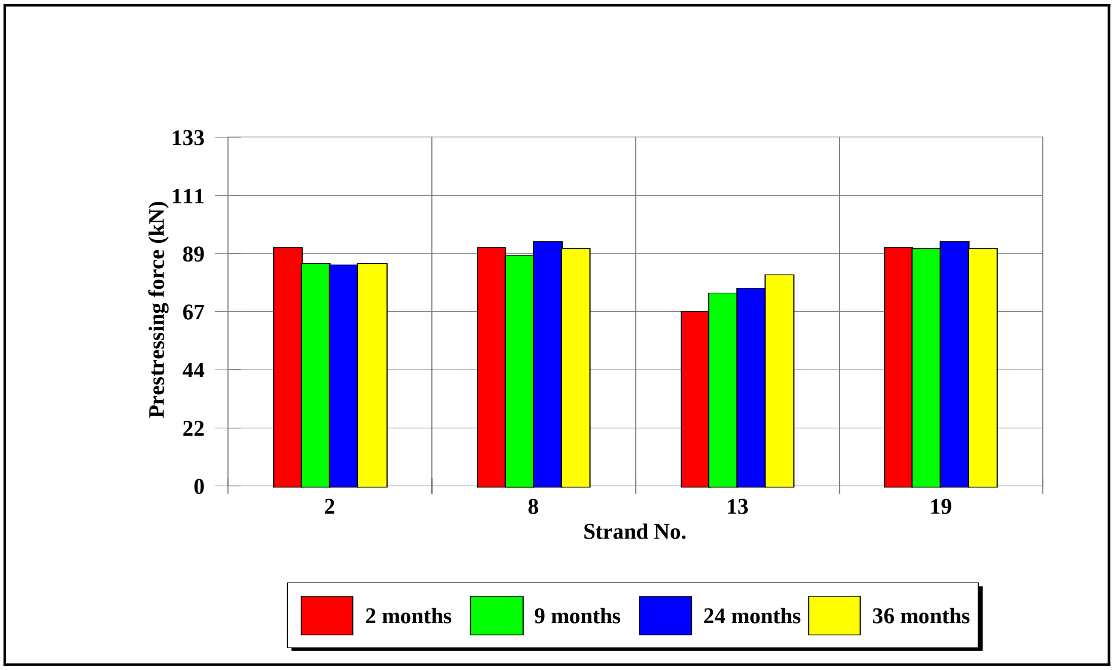

Figure 1. Summary of prestressing force measurements taken at the Beardsley Hollow Bridge in New York.

Static Load Tests

Load tests were conducted at each bridge by placing fully-loaded gravel trucks on the bridge and collecting data from an unloaded to loaded condition. A total of six transverse truck positions were typicallyused and the truck's center-of-gravity always placed at centerspan of the bridge. Load test deflection readings were measured on calibrated deflection rulers suspended from the deck underside at approximately 61cm (2ft) intervals across the width at the centerspan of the bridge. Load test results from the Beardsley Hollow bridge are presented in Figure 2. Two load cases are presented with a truck in each traffic lane: "center loading" (top) with trucks adjacent to roadway centerline; "eccentric loading" (bottom) with trucks adjacent to curbs.

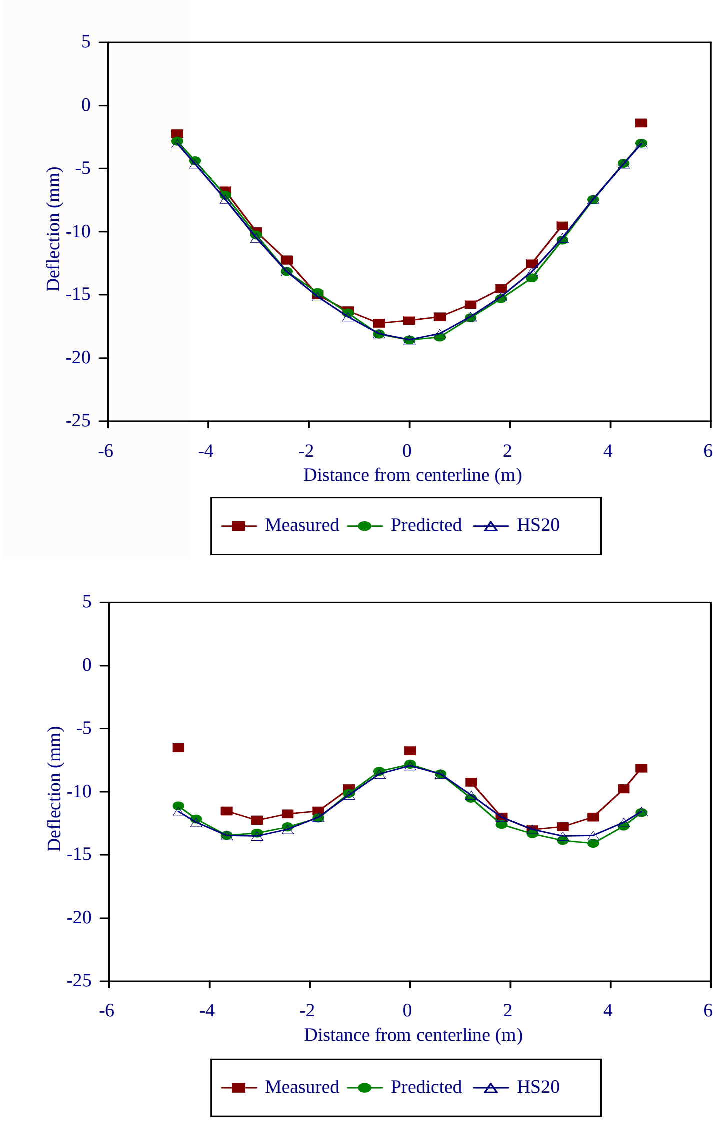

Figure 2. A comparison of measured and predicted deflections for two trucks placed for center loading (top) and eccentric loading (bottom) from the Beardsley Hollow bridge load testing conducted approximately 3 years after installation.

Measured deflections from load tests are compared with predicted deflections based upon on an orthotropic plate analysis model (Murphy 1993) using actual testing truck weights and the AASHTO HS20 design loading. For the Beardsley Hollow bridge, maximum deflection from load testing did not exceed the L/500 deflection (19.5mm) limit. Minor differences between measured and predicted deflections for the eccentric load case can be attributed to the edge stiffening effect of the rail and curb system. These results are typical of the analytical analysis of the load test results for the Moose River and South Gila Canal bridges.

Visual Inspections

Visual inspections, including photographic documentation, were conducted during periodic site visits to assess the overall condition of the bridge. Several areas of the bridge were investigated including the wood components, steel hardware, wearing surface. In general, the visual inspections did not detect any structural deficiencies in the bridges. The wood components were in satisfactory condition with no signs of deterioration and only minor surface and end grain checking observed in the curb and rail systems. The galvanized steel hardware was in good condition with no signs of corrosion. One area of concern at the Moose River bridge was a potentially corrosive interaction between the CCA wood preservative and the galvanized steel prestressing bars, but removal and inspection of several bars showed that the plastic sleeves installed over the bars shortly after installation was an effective mitigation measure. The asphalt wearing surfaces were in good condition, except for minor reflective cracking expected at the bridge end/approach roadway interface.

Summary and Recommendations

The bridges have performed satisfactorily during the 2-3 year monitoring period. Findings are summarized as follows:

- Moisture contents were low at installation, due to manufacturing requirements, and have remained stable over the three year monitoring period, which has aided in offsetting the anticipated losses of prestressing bar force.
- Prestressing bar forces were maintained satisfactorily throughout the three year monitoring period with at least 50 percent remaining. No prestressing bar re-tensioning was warranted during the first 2-3 years for these bridges.
- Static load tests indicate that the bridges are performing as anticipated in design. Predicted deflections based upon orthotropic analysis are within the L/500 live load deflection limit under full design loads.
- Visual inspections have not detected any structural deficiencies with any of the bridges.

The adoption of glulam beams for this bridge system presents distinct advantages over stress-laminated decks comprised of sawn lumber laminations which are limited to span crossings less than 30 ft (9.2m) and many experience substantial prestressing force losses which require repeated re-tensioning of the bridge decks. Longer simple spans are possible up to approximately 65ft long are possible with a single row of prestressing elements. In addition, the low moisture content of the glulam beams at installation minimizes prestressing force losses with the potential to nearly eliminate the maintenance task of periodic re-tensioning of these bridge decks.

More comprehensive results including additional bar force and load test results for each of the bridges are forthcoming in future research publications.

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