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Long-Term Performance Monitoring of Hardwood Timber Bridges in Pennsylvania

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Abstract

Several hardwood timber bridges were constructed in Pennsylvania during the early 1990s. This report summarizes the long-term field performance of seven stress-laminated deck bridges over a 4-year period beginning August 1997 and ending July 2001. Data collected include lumber moisture content, static load test deflection measurements, and bridge condition assessments. In addition, stressing bar force, temperature, and relative humidity conditions were monitored several times per day by a remote data acquisition system installed at each bridge site. Superstructure lamination moisture content ranged between 20% and 40% after nearly 10 years of service. The field performance of four bridges was unsatisfactory. Loss in prestressing bar force necessitated bar re-tensioning at the Millcross Road bridge (Lancaster County), and live load deflection limits were exceeded at the Brookson Road (Crawford County), Laurel Run (Huntingdon County), and Jacobs (Huntingdon County) sites. Several serviceability and/or maintenance deficiencies need immediate attention to achieve satisfactory field performance.

Keywords: Stress-laminated deck, timber, wood, highway bridge, red oak, beech, hardwood

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Factors for converting English units of measurement to SI units

English unit	Conversion factor	SI unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
square foot (ft^2)	0.09	square meter (m^2)
pound (lb)	4.448	newton (N)
lb/in^2 (stress)	6,894	pascal (Pa)
temperature (°F)	$[T_F–32]/1.8$	temperature (°C)

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Introduction

There is a long tradition of building timber bridges in the state of Pennsylvania, dating back to the era of covered bridges in the 19th century. Those historic American bridge structures were typically crafted from untreated decay-resistant wood species and were covered with a roof system to extend service life by keeping the bridges dry. Recent advances in treated timber bridge technology, including better wood preservatives and the development of new structural systems such as the stress-laminated deck superstructure, have led some bridge designers to choose timber as a structural material for short- to medium-span bridges. In addition, two national initiatives have been providing cost-sharing incentives to those local governments that decide to choose timber for highway bridge projects.

In 1988, the U.S. Congress passed legislation known as the Wood in Transportation initiative (WIT; formerly the Timber Bridge Initiative). Its objective 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, administered by the Forest Service National Wood in Transportation Information Center (NWITIC) 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. The NWITIC also maintains a technology transfer program to provide assistance and state-of-the-art information related to timber bridges (USDA 1999).

Responsibility for the research portion of the WIT program was assigned to the Forest Products Laboratory (FPL), the national wood utilization research laboratory of the USDA Forest Service. The primary focus of WIT research has been the development of new and improved technology for timber bridge materials and systems. In 1992, the FPL research program was expanded to include wood transportation structures such as noise barriers, marine facilities, retaining walls, and sign supports. At the same time, a joint research program was initiated between FPL and the Federal Highway Administration (FHWA) to implement a national timber bridge research program mandated for FHWA under the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. As of 2001, nearly 350 bridges have been built through the WIT demonstration program and more than 100 bridges through the FHWA demonstration program.

In 1989, the Pennsylvania Department of Transportation (PennDOT) established the Pennsylvania Demonstration Hardwood Timber Bridge program to increase the utilization of timber as a bridge material (PennDOT 1991). This program paralleled the efforts of the two national programs, and it designated 18 timber bridges to be built throughout the State using locally available and underutilized hardwood species such as red oak, red maple, beech, and yellow poplar.

In 1992, PennDOT contacted West Virginia University for assistance in monitoring the field performance of their recently constructed hardwood timber bridges. Under a cooperative agreement, data were manually collected during periodic visits to several stress-laminated hardwood bridge sites; the data included moisture content, bar force, and static load tests (PennDOT 1994). In 1995, PennDOT officials contacted FPL for assistance in collecting additional long-term data on the field performance of seven Pennsylvania hardwood bridges.

Table 1—Description of Pennsylvania hardwood bridges selected for long-term performance monitoring

Name of bridge	County	City or township	Body of water bridged	Roadway	Construction completed	PA DOT district
Dutch Hill Road	Crawford	City of Titusville	Hammon Run	Dutch Hill Rd (city rd)	December 1992	1–0
Brookston Road	Forest	Howe	Tionesta Creek	Crane Run Rd (T–372)	June 1992	1–0
Laurel Run	Huntingdon	Jackson	Laurel Run	Peachey Lane (T–527)	August 1992	9–0
Jacobs	Huntingdon	Todd	Great Trough Creek	Jacob Road (T–340)	November 1991	9–0
Millcross Road	Lancaster	East Lampeter	Stauffer Run	Millcross Road (T–548)	July 1992	8–0
Dogwood Lane	Schuylkill	West Brunswick	Pine Creek	Dogwood Lane (T–471)	October 1993	5–0
Birch Creek	Sullivan	Cherry	Birch Creek	Connels Dam Rd (T–380)	March 1992	3–0

The FPL had been conducting research for the national timber bridge-monitoring program (Ritter and others 1995) for several years and welcomed the opportunity to gather long-term performance data on hardwood bridges in Pennsylvania. Through mutual agreement, a multi-year monitoring plan was developed for seven stress-laminated hardwood bridges (Table 1). Detailed information about each bridge is included in the Appendix. Two of the seven bridges were also recently evaluated under dynamic loading conditions (Wipf and others 1999).

Background

The technique of stress-laminating timber bridge superstructures was initially developed in the 1970s to rehabilitate longitudinally nail-laminated decks in Ontario, Canada (Taylor and Csagoly 1979). Initially, the stress-laminated system was externally retrofitted to longitudinally nail-laminated slab decks by attaching high-strength steel bars in a transverse orientation (top and bottom of deck) at intervals along the bridge length and anchoring them with steel channels and plates to maintain compressive forces. After dramatic improvements in load distribution characteristics under static truck loading were made, the stress-laminated system was adapted for new longitudinal deck timber bridges.

The configuration of a stress-laminated deck bridge consists of nominal 2- to 4-in.-thick deck laminations that are placed on edge and are effectively “laminated” together with a high degree of compressive force, or stress, provided by high-strength steel bars that pass through mid-depth of the deck in pre-bored holes (Fig. 1). Mechanical fasteners such as nails or adhesive are not required in the deck system, and the use of lamination butt joints allows deck laminations to be shorter in length than the bridge span. The span of the longitudinal deck slab system is effectively limited by the availability of wide-width dimension lumber. Engineered wood products such as glued-laminated timber (glulam), laminated veneer lumber (LVL), and parallel strand lumber (PSL) beams can be used alternatively as the deck laminations in the stress-laminated deck configuration. These products can be manufactured to the required sizes for longer spans, which eliminates the need for butt joints in the stress-laminated deck system.

The first known U.S. stress-laminated bridge was constructed in 1987 along Trout Road in Centre County, Pennsylvania, but it was designed according to Canadian highway bridge standards. The superstructure measured 48 ft long, 26 ft wide, and 16 in. deep and consisted of 4-in.-thick Douglas-fir laminations. This bridge was monitored during its first year by Pennsylvania State University (Mozingo and DiCarlantonio 1988) and experienced minor problems, including deck sag and lamination crushing beneath the bar anchorage plates.

The bridges in the Pennsylvania Demonstration Hardwood Timber Bridge program were constructed with three types of decks: stress-laminated lumber decks, stress-laminated lumber/steel composite decks, and glulam beam with transverse decks. The stress-laminated lumber decks were similar to the Trout Road bridge but were designed according to more stringent design standards determined by PennDOT. The stress-laminated lumber/steel composite deck was developed at Pennsylvania State University (Mozingo and Taylor 1989) to overcome superstructure sag and stiffness problems observed with the Trout Road bridge and involved adding a steel sandwich plate between every three or four wood deck laminations.

In 1991, the first-known glulam red oak timber bridge was built near Baileyville, Pennsylvania. It consisted of glulam stringers with a transverse glulam deck measuring 36 ft long and 28 ft wide (Manbeck and others 1991). Hardwood species included in the Pennsylvania demonstration program were red oak, red maple, beech, and yellow poplar. The primary grades of these species are used extensively in the furniture and millwork industries. However, the secondary grade hardwoods are used only somewhat in the railroad tie industry and have been underutilized to a great extent in Pennsylvania. The secondary grade hardwoods are readily adaptable to stress-laminated timber bridges.

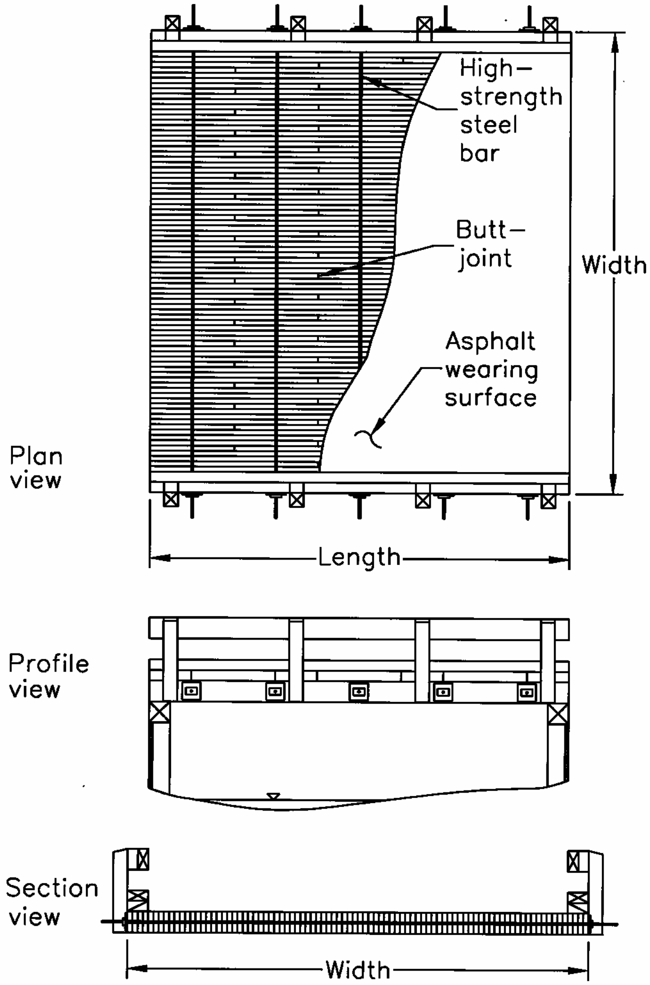


Figure 1—General configuration of stress-laminated deck bridge superstructure.

Additional work was completed to investigate and optimize the glulam process for hardwood timber bridge applications. Material and design specifications (Manbeck and Shaffer 1994) and standardized plans (PennDOT 2001) were developed for Pennsylvania hardwood glulam timber highway bridges.

In addition to the bridges in Pennsylvania, stress-laminated deck bridges have been designed and constructed using hardwood lumber at several other locations in northeastern United States. The Tumbling Rock Run stress-laminated deck bridge in the Monongahela National Forest in West Virginia was built in 1990 using grade No. 1, 4- by 14-in. red oak deck laminations. Its performance was compared with that of a similar bridge in the proximity constructed from Southern Pine lumber and was judged satisfactory for a 3-year period after construction (Wacker and Ritter 1995). The field performance of a red oak stress-laminated bridge in Rhode Island was monitored for 15 months (Dober–Young and Tsiatas 1995).

The West Virginia Department of Transportation, in conjunction with West Virginia University, funded an extensive timber bridge program that resulted in the construction of 15 hardwood stress-laminated deck timber bridges in 1990 as part of the national WIT program (GangaRao and others 1991). Red oak lumber was the predominant species used for the bridges. The West Virginia effort included the development of longer span designs, such as the stress-laminated T-section and stress-laminated box-section bridge configurations.

Objective and Scope

The objective of this research project was to evaluate the long-term structural performance of seven hardwood stress-laminated bridges in Pennsylvania over a 4-year period. Each bridge had been in service for approximately 5 years when this project commenced. The project scope included data collection and analysis related to deck moisture content, stressing bar force, static load test behavior, and general bridge condition. In addition, thermal and relative humidity conditions in the vicinity of the bridge were monitored. Results of these field monitoring efforts will be used in conjunction with similar studies to formulate recommendations for design and construction specifications for future stress-laminated timber deck bridges.

Design and Construction

The design and construction of the Pennsylvania hardwood timber bridges were administered by PennDOT through contractual arrangements with local bridge design consultants and construction contractors.

Design

All seven bridges were designed in accordance with the American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges, 14th edition (AASHTO 1989) as supplemented by Part 4 (structures) of the PennDOT design manual (inclusive of September 1989 revisions). Superstructure components relating to the stress-laminating system were designed in accordance with the Ontario Highway Bridge Design Code (MTC 1983). In addition, the "composite" deck superstructures that incorporate thin steel plates into the lumber slab deck were developed and designed in conjunction with Pennsylvania State University (Mozingo and Taylor 1989).

Superstructure dimensions for all seven simple-span bridges are summarized in Table 2. The bridge length (out–out) ranged from 23 to 46 ft and the bridge width (out–out) from 20 to 32 ft. The deck thickness, or superstructure depth, was 14, 15, or 16 in. The superstructures were designed to meet AASHTO HS25–44 and ML80 live loading conditions.

Table 2—Bridge superstructure dimensions

Name of bridge	Superstructure dimensions Length (ft)	Width (ft)	Depth (in.)
Dutch Hill Road[a]	24	32	15
Brookston Road[a]	35	20	14
Laurel Run	40	24	16
Jacobs[a]	46	26	16
Millcross Road	23	30	16
Dogwood Lane	36	26	15
Birch Creek[b]	25	26	16

[a]Superstructure is skewed 16 to 17 degrees.
[b]Integrated deck sidewalk (not included in width dimension).

In addition, static live load deflections were limited to 1/500th of the bridge span. Dead load deflections were offset with camber at three times the anticipated dead load deflection based upon beam theory.

The hardwood lumber deck laminations for the superstructures are described in Table 3. Deck laminations were typically 3 in. thick and 15 to 16 in. wide, with the exception of the Brookston Road bridge. Red oak lumber was used for six of the seven bridge decks; beech was used for the Birch Creek bridge. Visual grading (No. 2 and better) in accordance with the Northeast Lumber Manufacturer Association (NELMA) was used for the hardwood lumber. Repetitive butt-joint patterns were used in all seven superstructures with only slight variation in the transverse frequency and longitudinal spacing. Butt-jointed deck laminations allow the use of board lengths significantly shorter than the bridge span, but they reduce the strength and stiffness properties of the deck and must be accounted for in the design process.

The galvanized steel components used in the superstructure are described in Table 4. The deck laminations were stress-laminated together by nominal 1-in.-diameter high strength steel threaded bars with an ultimate strength of 150×10^3 lbf/in^2, meeting the requirements of ASTM A722 (ASTM 1986).

The high-strength steel bars were tensioned and anchored with steel plates or continuous steel channels, meeting the requirements of ASTM A36 (ASTM 2002). In addition, the "composite" deck superstructures utilized 3/8-in.-thick welded steel plates with an ultimate strength of 50×10^3 lbf/in^2, meeting the requirements of ASTM A572 (ASTM 2003). The deck superstructures were "stress-laminated" together by tensioning the high-strength steel bars to the design forces and corresponding interlaminar compression levels listed in Table 5.

The curb and rail system for all seven bridges consisted of red oak sawn lumber members meeting the requirements of the AASHTO 10×10^3 lbf/in^2 static load design criteria. Typical dimensions for rail posts were 10 by 12 by 51 in. and for rail members 6 by 8 in. with a center splice connection.

Creosote pressure treatment according to American Wood Preservers' Association C1–84 (AWPA 1984) was used for the deck and rail components of all seven bridges.

Construction

Construction of six of the seven hardwood lumber stress-laminated bridges was completed in 1992; the Dogwood Lane bridge (Schuylkill County) was completed in October 1993 (Table 1). Concrete abutments were cast in place to support five of the seven bridge decks; the Dutch Hill Road (Crawford County) and Brookston Road (Forest County) bridges have creosote-treated red oak lumber and pile abutments. Most of the stress-laminated deck superstructures were prefabricated into partial-width panels that were initially prestressed in the assembly plant.

After delivery to the bridge site, the partial-width panels were lifted onto the abutments and were interconnected by a series of alternating bar couplers along the centerline of the bridge. Other bridges were assembled adjacent to the site and lifted into place by an overhead crane. For all bridges, asphalt concrete wearing surface was applied to the lumber deck and approach roadways.

Evaluation Methodology

The multi-year monitoring plan called for performance monitoring of deck moisture content, stressing bar force, static load test behavior, and general bridge condition. The plan also included evaluation of thermal and relative humidity conditions in the vicinity of the bridges. The evaluation methodology used procedures and equipment previously developed for monitoring similar structures (Davalos and others 1992, Eslyn and Clark 1979, Ritter and others 1991).

Field Data Collection

A data acquisition system, a CR10X datalogger manufactured by Campbell Scientific, Inc. (Logan, Utah), was used to monitor stressing bar force (via load cells), ambient and internal deck temperatures, and relative humidity levels automatically at 2-h intervals. Figure 2 shows the general configuration of the data acquisition system along with the load cells and thermocouples. During periodic site visits by FPL personnel, alkaline batteries for the 12-volt power supply were replaced and data were downloaded from the datalogger with an optical interface device and a laptop computer (Fig. 3).

Table 3—Description of creosote-treated lumber deck laminations

Name of bridge	Size (in.)	Species group[b]	Visual grade[c]	Butt-joint pattern: Transverse frequency	Butt-joint pattern: Longitudinal spacing (in.)
Dutch Hill Road	3 x 15	Northern Red Oak	No. 2 & better	1 in 4[d]	36
Brookston Road[a]	3 x 14	Northern Red Oak	No. 2 & better	1 in 4	36
Laurel Run[a]	3 x 16	Northern Red Oak	No. 2 & better	1 in 4	36
Jacobs[a]	3 x 16	Northern Red Oak	No. 2 & better	1 in 4	36
Millcross Road	3 x 16	Northern Red Oak	No. 2 & better	1 in 3[d]	48
Dogwood Lane[a]	3 x 15	Northern Red Oak	No. 2 & better	1 in 4[e]	48
Birch Creek	3 x 16	Beech–Birch–Hickory	No. 2 & better	1 in 3[e]	42

Lumber deck laminations: columns Size through Longitudinal spacing.

[a]Composite deck consisting of 3/8-in.-thick welded steel plate laminations placed between every 4 to 6 lumber laminations.
[b]Based on the Supplement to the 1986 National Design Specification (NDS) for Wood Construction (June 1988).
[c]Following Northeastern Lumber Manufacturers Association grading rules.
[d]Significant portions with 1 in 2 transverse frequency were detected in inspection of deck underside.
[e]Inspection of deck underside revealed no butt-joints for an area of 5 ft on either side of centerspan.

Table 4—Description of galvanized steel components used in superstructure

	Galvanized steel components				
	Nominal 1-in.-diameter high strength steel bar[a]				
Name of bridge	Number of bars	Spacing interval (in.)	Manufacturer	Bar anchor-age type[b]	3/8-in. steel lamination plates[c]
Dutch Hill Road	13 total; 7 full-width	36	Dywidag Systems Int'l	Discrete steel plates	None
Brookston Road	15 total; 11 full-width	36	Williams Form Co.	Discrete steel plates	1 after every 6 wood laminations
Laurel Run	13	36	Dywidag Systems Int'l	Continuous steel channel	1 after every 4 wood laminations
Jacobs	18 total; 14 full-width	36	Dywidag Systems Int'l	Discrete steel plates	1 after every 4 wood laminations
Millcross Road	6	48	Williams Form Co.	Continuous steel channel	None
Dogwood Lane	13	32	Dywidag Systems Int'l	Continuous steel channel	1 after every 4 wood laminations
Birch Creek	8	38	Dywidag Systems Int'l	Continuous steel channel	None

[a]150×10^3 in^2 high-strength steel bars meet requirements of ASTM A–722 (ASTM 1986).
[b]Steel anchorages meet requirements of ASTM A–36 (ASTM 2002).
[c]50×10^3 in^2 welded steel plates meet requirements of ASTM A–572 (ASTM 2003).

Table 5—Deck prestress and bar forces

Name of bridge	Design prestress level[a] (lb/in^2)	Bar force (×10^3 lbf) at various prestress levels: Design prestress	100 lb/in^2 prestress	40 lb/in^2 prestress
Dutch Hill Road	—[b]	—[b]	54	22
Brookston Road	159	80	50	20
Laurel Run	139	80	58	23
Jacobs	139	80	58	23
Millcross Road	—[b]	—[b]	77	31
Dogwood Lane	—[b]	—[b]	48	19
Birch Creek	119	72	61	24

[a]Prestress based upon tributary area (deck depth × bar spacing); see Tables 2 and 4.
[b]Information not available.

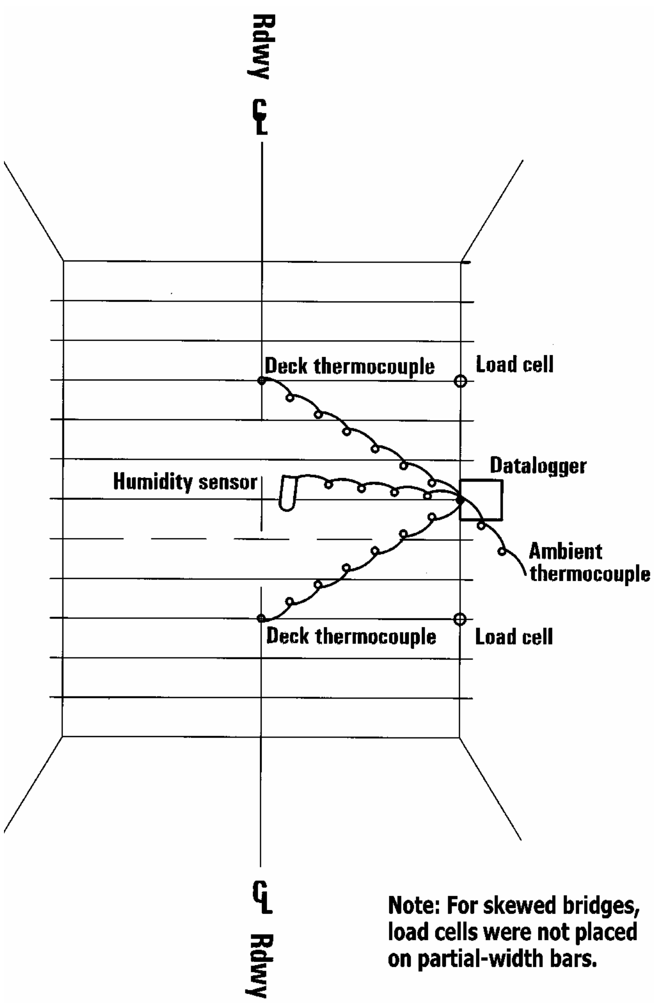


Figure 2—Schematic of field data acquisition setup.

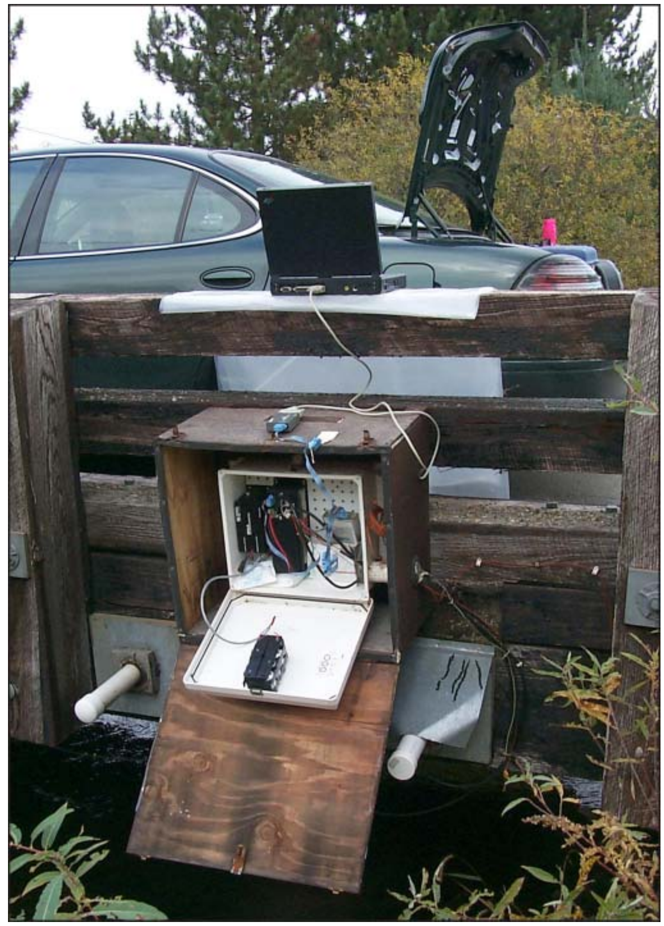


Figure 3—Laptop computer downloads data from Brookston Road bridge through an optical interface device.

Moisture Content

A conductance moisture meter (Delmhorst Instrument Company, Model RC–1D, Towaco, New Jersey) was used to collect moisture content data in accordance with ASTM D4444–92 (ASTM 2000). Insulated 3-in.-long probe pins were hammer-driven into the deck underside at several locations at various depths to gather raw meter readings. Corrections for temperature and wood species were made to the meter readings as required (Pfaff and Garrahan 1984). Moisture content was measured at the initiation and conclusion of the monitoring period. For each meter reading corrected for temperature and species, the 95% confidence interval for predicting the true moisture content between the electrode pins is approximately 7% relative error (±0.5% to 2% moisture content).

Prestressing Bar Force

To measure stressing bar forces, hollow-core steel load cells, fabricated at the FPL Engineering Mechanics Laboratory, were placed on at least two bars at each bridge (see Table 6).

Table 6—Location of load cells for measuring stressing bar force

Name of bridge	Load cell location[a]	
	Position relative to bars	Position relative to bridge
Dutch Hill Road	4th and 7th bars from west end (nearest Hwy 8)	Downstream
Brookston Road	3rd and 5th bars from south end	Downstream
Laurel Run	1st and 13th bars from north end (nearest Hwy 26)	Downstream
Jacobs	3rd and 13th bars from west end (towards Cassville)	Upstream
Millcross Road	3rd and 4th bars from either bridge end	Upstream
Dogwood Lane	6th and 10th bars from east end (nearest Hwy 895)	Upstream
Birch Creek	2nd and 6th bars from south end (nearest Hwy 487)	Downstream

[a]Placement of load cells was limited because several bar ends were trimmed.

A protective rainfall cover (usually sheet metal) was placed over the load cells to prevent moisture from accumulating in the PVC casing and shorting the electronics. Each load cell was calibrated with a test compression machine at FPL prior to use and was field calibrated during the monitoring period. On several occasions during the monitoring period, prestressing bar force (of prestress bars with load cells installed) was measured by a hydraulic hand pump system and/or separate calibrated load cells to verify load cell accuracy (Fig. 4). Prestress bars without load cells were measured by hydraulic pressure gauges to verify that all prestress forces for a single bridge were essentially uniform. At the conclusion of monitoring, the load cells were removed and recalibrated to verify the stressing bar force data.

Deck Temperature

To measure both ambient and internal deck temperatures, copper-constantine thermocouple wires manufactured by Omega Engineering (Stamford, Connecticut) were used. Ambient temperatures were measured by suspending thermocouple wires within 18 in. from the underside of the deck superstructure. Internal deck temperatures were measured by embedding thermocouple wires into the deck at mid-depth from the underside at two locations approximately where the stressing bars (with load cells) intersected with the roadway centerline of the bridge. Accuracy of the thermocouple temperatures was verified on several occasions by a hand-held thermometer.

Figure 4—Hydraulic equipment and independent load cell used to check accuracy of monitoring load cell in measuring bar forces (Laurel Run bridge).

Relative Humidity

To measure relative humidity levels, an Intercap capacitive humidity sensor (Vaisala, Woburn, Massachusetts) was suspended within 18 in. from the underside of the deck superstructure. A custom-made PVC container with mesh screening was used to protect the sensor from insect-related problems. Within the relative humidity range of 10% to 90%, the accuracy of the humidity readings was reported to be ±3% and was dependent upon periodic replacement of calibration chips.

Behavior Under Static Load

Static load testing was conducted to determine the structural response of the various bridge superstructures to highway truck loading. Fully loaded trucks were placed on each bridge deck and the resulting deflections were measured from calibrated rulers suspended from the deck underside at 2-ft intervals along the centerspan cross-section using an optical surveying level (Fig. 5). In addition, predicted deflections based upon analytical modeling were determined for each static load test.

Static Load Testing

Static load tests were conducted at each bridge site on two separate occasions during the 4-year monitoring period (Table 7). Readings were recorded prior to testing (unloaded), after placement of the test truck for each load case (loaded), and at the conclusion of testing (unloaded). Measurement precision was ±0.04 in. No bridge support movement was detected during static load tests.

Figure 5—Typical setup for conducting static load tests with suspended rulers at midspan and an optical level instrument (Brookston Road bridge).

Table 7 summarizes the static load tests conducted at all seven bridges. Either three or six transverse load cases were used depending upon the bridge roadway width. In the longitudinal direction, the midpoint of the truck rear axles or the truck center-of-gravity was placed over the midspan cross-section. For the Laurel Run bridge (Huntingdon County) load test in June 1998, only one truck was available for testing and load case 3 was approximated by the superposition of deflections from load cases 1 and 2.

Table 8 summarizes the truck axle weights and truck configurations used in static load testing. Actual truck weights were obtained at a local certified truck scale or by a weighmaster who used individual scales under each wheel. For all static load tests, two trucks with a total of three axles were used, with one exception. For the 1998 testing of the Brookston Road bridge (Forest County), the trucks had only two axles. In general, the gross vehicle weight (GVW) of the trucks used for testing ranged from 47 to 67 $\times 10^3$ lbf with an average of 52 $\times 10^3$ lbf.

Analytical Evaluation

Predicted deflections based on analytical modeling were also determined for comparison with static load test results. An orthotropic plate computer program adapted for highway bridges (Murphy 1993) was used to simulate the deck behavior of each bridge under actual test truck axle loads and AASHTO HS25–44 truck axle loads. The key orthotropic plate input values used for analyses are listed in Table 9. The effects of edge stiffening caused by the curb and rail systems were not included in these analyses. Orthotropic variables for transverse stiffness and transverse shear were derived using the following equations:

$$E_{\text{transverse}} = 168\,(F_{\text{p}}) + 15{,}749 \text{ (lb/in}^2\text{)}$$

$$G_{\text{transverse}} = 234\,(F_{\text{p}}) + 37{,}879 \text{ (lb/in}^2\text{)}$$

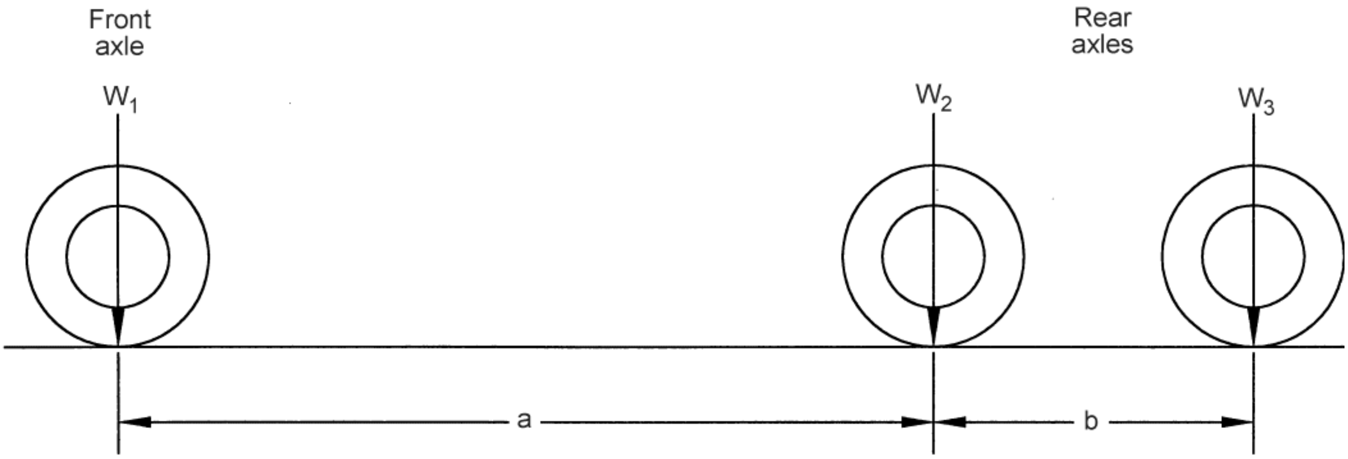
where F_{p} = interlaminar deck prestress level (lb/in^2).

Table 7—Summary of static load tests

Name of bridge	Date of test	Trucks (number)	Load cases (number)	Transverse position offset (ft) [a]	Longitudinal position at midspan[b]
Dutch Hill Road	16 Sep 1998	2	6	6	Rear axles
	17 Apr 2001	2	6	6	Rear axles
Brookston Road	16 Sep 1998	2	3	—	Rear axles
	18 Apr 2001	2	3	—	Rear axles
Laurel Run	2 Jun 1998	1	3	—	Center of gravity
	2 May 2001	2	3	—	Center of gravity
Jacobs	3 Jun 1998	2	6	4	Center of gravity
	1 May 2001	2	6	5	Center of gravity
Millcross Road	4 Jun 1998	2	6	6	Rear axles
	24 May 2001	2	6	6	Rear axles
Dogwood Lane	29 Jun 1998	2	6	5	Rear axles
	19 Jun 2001	2	6	5	Rear axles
Birch Creek	30 Jun 1998	2	3	—	Rear axles
	20 Jun 2001	2	3	—	Rear axles

[a]See Appendix for photos of bridges.
[b]Rear axles: the truck was placed so that the midspan cross-section of the bridge bisected the two rear axles; if the truck had only one rear axle, it was placed directly over midspan. Center of gravity: the truck was placed with its center of gravity over the midspan cross-section.

Table 8—Summary of truck axle weights and spacing



Name of bridge		Truck A W1 (×10^3 lbf)	Truck A a (ft)	Truck A W2 (×10^3 lbf)	Truck A b (ft)	Truck A W3 (×10^3 lbf)	Truck A GVW[a] (×10^3 lbf)	Truck B W1 (×10^3 lbf)	Truck B a (ft)	Truck B W2 (×10^3 lbf)	Truck B b (ft)	Truck B W3 (×10^3 lbf)	Truck B GVW[a] (×10^3 lbf)
Dutch Hill Road	09/98	13.00	13.55	19.75	4.25	19.75	52.70	13.9	13.40	20.75	4.20	20.75	55.40
	04/01	14.65	13.40	18.83	4.20	18.83	52.30	14.25	13.05	18.50	4.65	18.50	51.25
Brook-ston Road	09/98	12.22	13.55	25.30	—	—	37.52	13.02	13.55	24.84	—	—	37.86
	04/01	15.55	13.50	18.68	4.20	18.68	52.90	16.30	13.45	18.80	4.25	18.80	53.90
Laurel Run	06/98	13.46	13.35	17.77	4.55	17.77	49.10	—	—	—	—	—	—
	05/01	12.45	12.3	22.15	4.60	21.90	56.50	15.15	13.45	21.65	4.20	21.85	58.65
Jacobs	06/98	13.46	13.35	17.77	4.55	17.77	49.00	12.52	13.50	18.08	4.20	18.08	48.82
	05/01	12.30	12.3	22.40	4.60	22.00	56.70	15.00	13.45	21.50	4.20	21.40	57.90
Millcross Road	06/98	13.82	13.25	17.22	4.55	17.22	48.26	13.76	13.25	16.66	4.55	16.66	47.08
	05/01	13.20	13.20	17.20	4.55	17.20	47.60	14.30	13.60	17.20	4.20	17.20	48.70
Dogwood Lane	06/98	14.40	12.80	18.10	4.40	17.65	50.15	12.70	12.50	17.70	4.50	17.70	48.10
	06/01	13.00	13.50	16.65	4.20	16.45	46.10	12.85	13.50	17.55	4.10	17.40	47.80
Birch Creek	06/98	15.80	13.50	24.65	4.20	24.85	65.30	13.30	12.20	26.85	4.65	26.70	66.85
	06/01	14.00	13.40	21.50	4.20	21.85	57.35	13.90	13.50	19.55	4.20	19.80	53.25

[a]GVW is truck gross vehicle weight.

Table 9—Key input values for orthotropic plate analysis

Name of bridge	Test date (month/ year)	F_p (lb/in^2)	Span (in.)	½ width (in.)	Deck thickness (in.)	Analysis input values (×10^6 lb/in^2)				C_{bj}
						E_L	E_{comp}	E_{ts}	G_{ts}	
Dutch Hill Road	09/98	87	281	188	15	1.6	NA	30,336	58,255	0.70
	04/01	76						28,492	55,681	
Brook-ston Road	09/98	75	413	120	14	1.6	2.43	28,324	55,447	0.85
	04/01	67						26,983	53,575	
Laurel Run	06/98	73	467	137	16	1.6	2.84	27,989	54,979	0.90
	05/01	75						28,324	55,447	
Jacobs	06/98	64	530	157	16	1.6	2.43	26,480	52,873	0.90
	05/01	57						25,306	51,235	
Millcross Road	06/98	42	260	177	15	1.6	NA	22,791	47,725	0.75
	05/01	66						26,815	53,341	
Dogwood Lane	06/98	71	412	155	16	1.6	2.83	27,654	54,511	0.90
	06/01	63						26,312	52,639	
Birch Creek	06/98	63	272	191	15.6	1.7	NA	26,312	52,639	0.75
	06/01	58						25,474	51,469	

F_p is interlaminar deck average prestress; E_L, elastic modulus in longitudinal (parallel to traffic) direction; E_{comp}, elastic modulus in longitudinal direction based on transformed section of wood and steel laminations; E_{ts}, elastic modulus in transverse (perpendicular to traffic) direction; G_{ts}, transverse shear modulus; and C_{bj}, butt-joint factor for given pattern of transverse frequency and longitudinal spacing (see Table 3).

Butt-joint (C_{bj}) factors varied from 0.70 to 0.90 and were based on recent FPL laboratory tests of stress-laminated decks with various butt-joint patterns. The butt-joint factor of 0.85 or 0.90 was used for the composite bridge decks, because of the continuous steel plates adjacent to most butt joints. The butt-joint factor of 0.70 or 0.75 was used for those bridges (without continuous steel sandwich plates) where the transverse frequency was more than 1 in every 4 laminations.

For the composite bridge decks, where thin steel plates were used in conjunction with hardwood lumber laminations, a transformed section approach was used to compute an equivalent elastic modulus.

Actual test truck positions along with measured axle load and spacings were used as input to generate predicted deflections for comparison with measured deflections.

The PC Bridge computer software program (Murphy 1990) was used to generate maximum moment and deflection envelopes based upon beam theory. The longitudinal truck position producing maximum moment and standard HS25–44 truck axle loads and axle spacing were used to predict maximum HS25–44 deflection.

Condition Assessment

The general condition of the bridges was assessed during site visits including the initiation and conclusion of the monitoring period. These assessments involved visual inspection, measurements, and photographic documentation of the condition of the bridge. Of specific interest were the condition of the treated wood components and asphalt wearing surface, deck distortion, and the stress-laminated system.

Results and Discussion

Performance of the seven stress-laminated deck hardwood timber bridges was continuously monitored for 4 years, from August 1997 to July 2001. The following results are based on an analysis of the data collected at each bridge site. Relative humidity data are not presented because readings were unreliable and most sensors were damaged by vandalism or flooding.

Field Data Collection

At the initiation of monitoring, our intent was to re-tension all prestress bars to the design interlaminar compression level to compare losses at all bridge sites more easily.

However, during initial site visits, we observed that most prestress bars had been trimmed back to within 2 or 3 in. of the anchor nut. Although this may have slightly improved bridge aesthetics, it caused several problems from a structural monitoring viewpoint. At some bridges, the placement of load cells was less than optimal because some prestress bars in the critical zone near midspan were too short to accommodate the load cells. We determined that the best approach was to not re-tension any bridges at the initiation of monitoring since the forces were adequate and re-tensioning could not be easily accomplished at most sites. During the monitoring period, flooding affected several remote data acquisition systems, as reported by local residents and visually confirmed by debris on the upstream side of the bridge. Flooding submerged the decks of the Brookston Road, Laurel Run, and Dogwood Lane bridges. The floods apparently submerged sensors including thermocouples, load cells, and humidity probes, causing only minor damage. However, the datalogger may have been submerged at the Brookston Road bridge since it is attached to the side of the deck superstructure; in the other bridges, the datalogger is attached to the outside of the upper rail.

Moisture Content

The average moisture content level is reported at various pin penetrations in Table 10. Based on only 1-in. penetration values recorded near the initiation of monitoring, average moisture content was 27% for all bridges; moisture content of three bridges (Brookston Road, Millcross Road, and Dogwood Lane) was in excess of fiber saturation. Based on 1-, 2-, and 3-in. penetration values recorded near the end of the monitoring period, average moisture content was 19%, 26%, and 27%, respectively. In addition, average moisture content levels adjacent to the curb line were found to be at or exceeding fiber saturation.

For many bridges, average moisture content of the deck laminations was near fiber saturation after approximately 9 years in service. Average moisture content for 1 in. of penetration decreased from 27% to 19% during the 4-year monitoring period, indicating a slow drying trend; drying was possibly retarded by the oily surface from the creosote preservative treatment. However, average moisture content for the 2- and 3-in. penetration levels was 27% near the end of the monitoring period. For the Millcross Road and Dogwood Lane bridges, average moisture content for the 2- and 3-in. penetration levels was above fiber saturation near the end of the monitoring period. These data suggest that these bridges were installed with a moisture content much greater than 20%. Moisture content has been moving towards the equilibrium for timber bridges of less than 20% (Gutkowski and McCutcheon 1987), and the creosote oil-type preservative may be retarding the drying process. Elevated moisture content in the deck laminations has been shown to accelerate bar force loss in similar bridges and should be monitored during routine bridge inspections.

Prestressing Bar Force and Deck Temperature

Prestressing bar force and internal deck temperature histories for each bridge are provided in Figures 6 through 12. Prestressing bar force levels experienced seasonal fluctuations but were relatively steady for most bridges during the 4-year monitoring period. However, bar force of the Millcross Road bridge decreased at a steady rate throughout the monitoring period, and the bars were re-tensioned near the end of the monitoring period. Several bridges (Jacobs, Dogwood Lane, and Birch Creek) experienced prestressing bar force losses during the winter that dropped slightly below the re-tensioning threshold level of 40 lb/in^2 interlaminar prestress force set by AASHTO (1991). These seasonal prestressing bar force losses were typically 5 to 10 $\times 10^3$ lbf in magnitude and were fully recovered as the internal deck temperature exceeded 32ºF.

Table 10—Average moisture content readings[a]

	Average moisture content (%)										Related site conditions	
	1997 Penetration at deck underside (in.)					2001 Penetration at deck underside (in.)						
Name of bridge	Date	No. readings	1	2	3	Date	No. readings	1	2	3	Sunlight	Height above water (ft)
Dutch Hill Rd	8/7	3	18	—	—	4/17		18	21	25	Shaded	9–10
Brookston Rd	8/6	3	>30	—	—	4/18	3	19	26	25	Shaded	5–6
Laurel Run	8/18	6	25	—	—	5/2	4	21	25	27	Exposed	4–5
Jacobs	8/18	6	26	—	—	5/1	4	12	15	16	Shaded	6–7
Millcross Rd	8/20	6	>30	—	—	5/24	4	22	>30	>30	Exposed	4–5
Dogwood Lane	8/19	6	30	—	—	6/19	7	25	>30	>30	Shaded	4–5
Birch Creek	8/8	3	18	—	—	6/20	3	14	22	24	Shaded	5–6
Average value			27	—	—			19	26	27		

[a] Average moisture content of >30 in. indicates moisture content above fiber saturation, assumed as 35% for averaging.

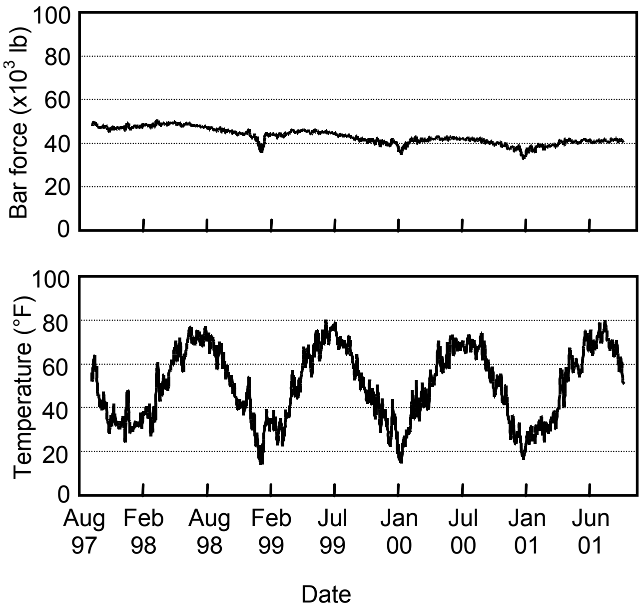


Figure 6—Average bar force and temperature histories for Dutch Hill Road bridge (Crawford County).

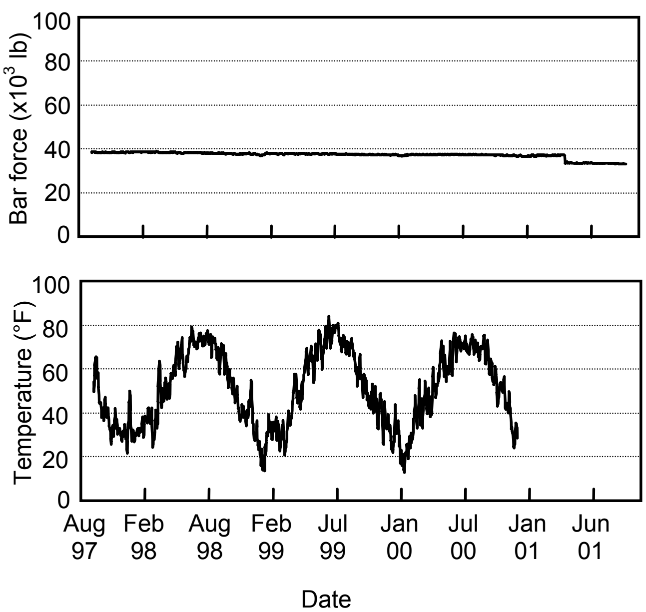


Figure 7—Average bar force and temperature histories for Brookston Road bridge (Forest County).

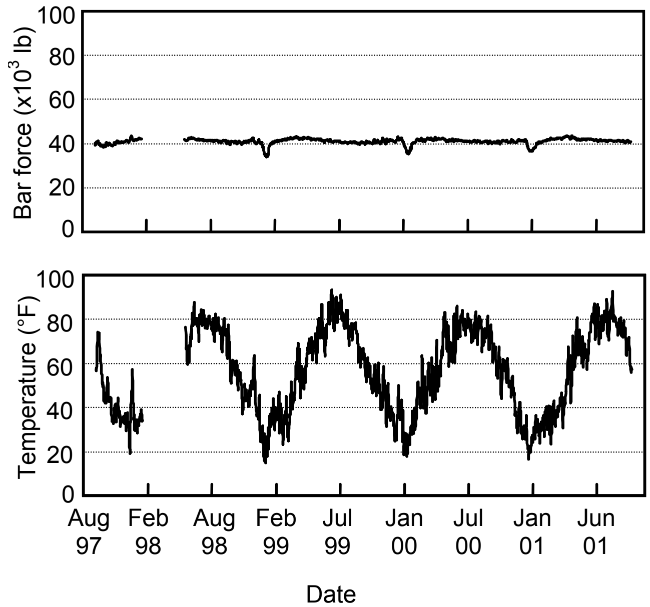


Figure 8—Average bar force and temperature histories for Laurel Run bridge (Huntingdon County).

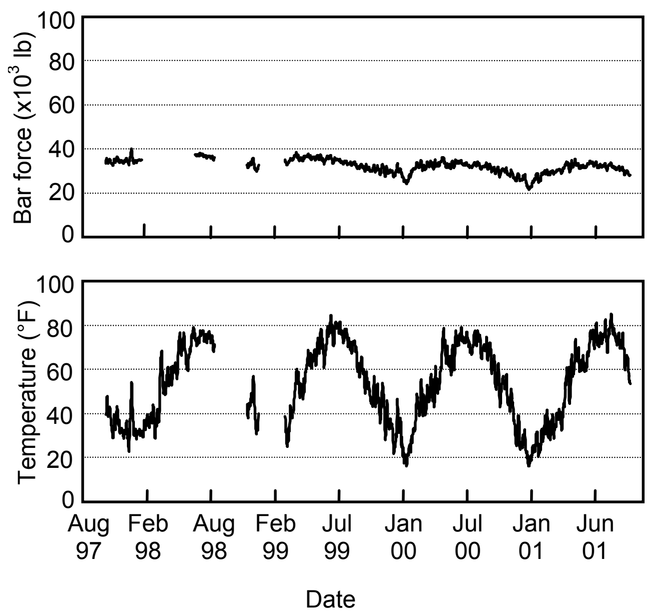


Figure 9—Average bar force and temperature histories for Jacobs bridge (Huntingdon County).

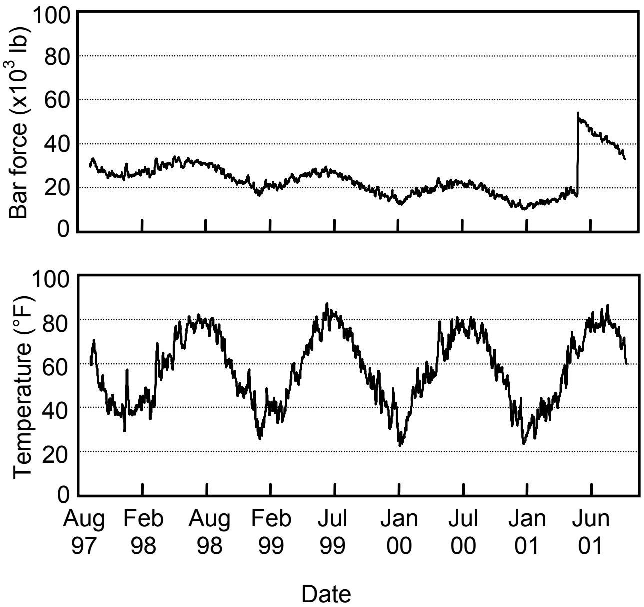


Figure 10—Average bar force and temperature histories for Millcross Road bridge (Lancaster County).

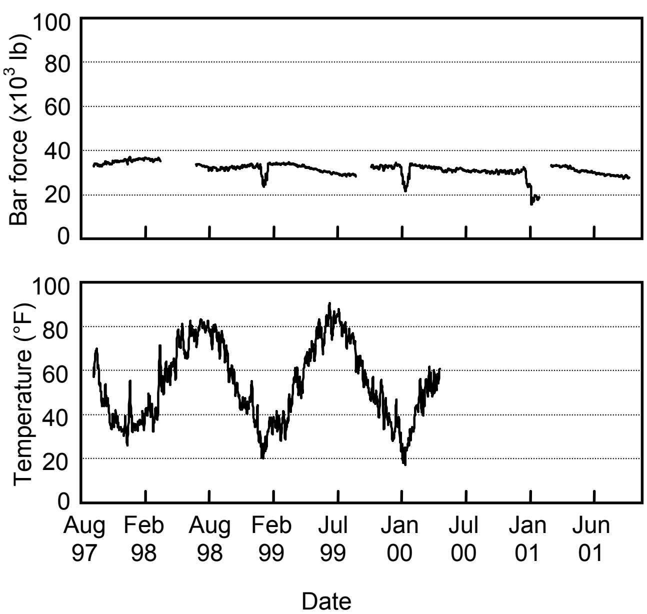


Figure 11—Average bar force and temperature histories for Dogwood Lane bridge (Schuylkill County).

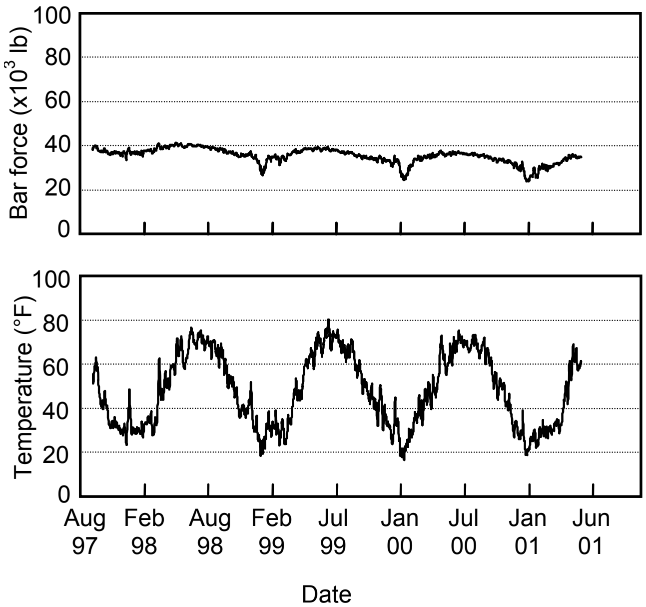


Figure 12—Average bar force and temperature histories for Birch Creek bridge (Sullivan County).

To ensure that prestressing bar force remains above the AASHTO threshold level, we recommend re-tensioning the prestressing bars of the following bridges to meet or exceed 100 lb/in^2 interlaminar prestress force: Brookston Road (Forest County), Jacobs (Huntingdon County), Millcross Road (Lancaster County), Dogwood Lane (Schuylkill-County), and Birch Creek (Sullivan County). Prestressing bar force should also be checked with hydraulic equipment (Ritter and Lee 1996) as part of routine bridge inspection.

The prestressing bar force data from load cell and hydraulic measurements at the Brookston Road bridge were confusing and we recommend further field evaluation. The decreasing prestressing bar force levels measured at the Millcross Road bridge are most likely attributed to a combination of the relatively high moisture content of the deck laminations and high compressive force (highest of all bridges), resulting from the 48-in. prestressing bar spacing and 16-in.-deep laminations. Elevated moisture content can accelerate stress–relaxation (i.e., creep) in the lumber laminations of stress-laminated decks. Therefore, we recommend further field evaluation of the Millcross Road bridge to monitor prestressing bar loss until bar force stabilizes as a result of the recommended bar-tensioning.

The internal deck temperature seems to correlate with prestressing bar force, except for the Brookston Road bridge. The strong correlation between temperature and bar force with regard to stress-laminated bridge decks was extensively studied in the laboratory (Kainz and others 2001, Wacker 2003), where moisture content was determined to be the

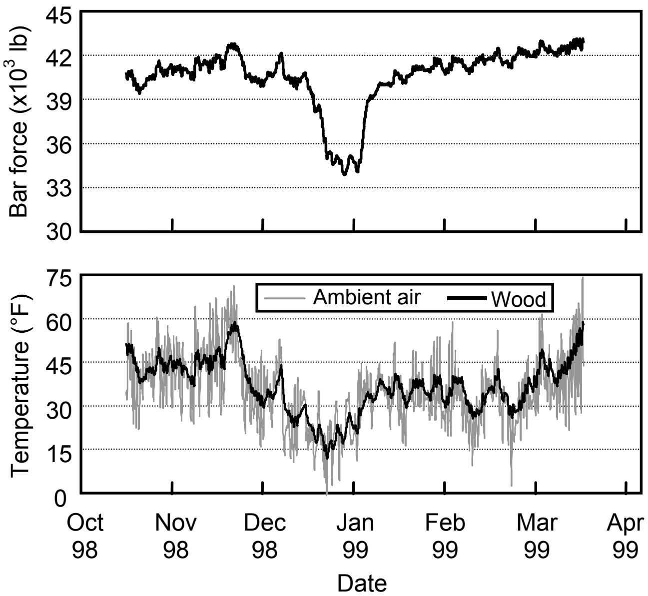


Figure 13—Typical plot showing 2-h interval data during 1998–1999 winter at Laurel Run bridge (Huntingdon County).

major factor governing the magnitude of bar force loss. A mechanosorptive effect takes place within the microstructure of the wood laminations such that their cumulative rate of thermal contraction accelerates beyond that of the steel prestressing bars under sustained sub-freezing ambient conditions, which can result in significant temperature-induced prestressing bar force loss. When the internal temperature of the bridge deck remains above 32ºF, prestressing bar force slightly fluctuates with temperature variation. However, when the internal temperature of the bridge deck drops below 32ºF, prestressing bar force rapidly decreases and does not recover until the temperature rises above freezing. Since the moisture content of most bridges in our study approached fiber saturation at the end of the monitoring period, potential prestressing bar force loss was great. However, the relatively mild temperatures and short-duration sub-freezing temperatures common to Pennsylvania winters helped to control prestressing bar force loss during the monitoring period.

Figure 13 shows the actual 2-h interval data from the Laurel Run bridge during the winter of 1998–1999. Significant prestressing bar force loss occurred for only a short period in January 1999 when internal deck temperature remained below 32ºF for several weeks; prestressing bar force was fully recovered later that month as temperatures rose. The variation in ambient air temperature is typically much greater than that in the internal deck temperature, primarily as a result of the insulating properties of wood.

Behavior Under Static Load

The maximum measured deflections for all load cases are presented in Table 11 for each bridge. The corresponding deflection plots of the static load tests conducted at each bridge site are provided in the Appendix. The lowest maximum measured deflection was 0.197 in. at the Millcross bridge (shortest span length), and the highest maximum measured deflection was 1.247 in. at the Jacobs bridge (longest span length). As expected, load case 3 (where both trucks were placed adjacent to each other near the roadway centerline) produced the largest deflection for each static load test because the truck axle loads were concentrated near the center of the bridge. As demonstrated in the deflection plots, the bridges exhibited the transverse load distribution characteristic of the orthotropic behavior of stress-laminated bridge decks (AASHTO 1991).

The measured maximum deflections were less than the L/500 live load deflections limit, with the exception of the Brookston Road (Forest County) and Jacobs (Huntingdon County) bridges. For the Brookston Road bridge, the width of the roadway limits vehicle traffic to a single lane and consequently results in significantly lower actual deflections than those measured during testing. For the Jacobs bridge, the very wide and skewed deck may have an effect on the midspan deflection.

Analytical Evaluation

The results of the analytical analysis predicting maximum midspan deflections for load cases 3 and 6 are presented in Table 12 for each bridge. Maximum measured deflection, maximum predicted deflection, and maximum predicted deflection for HS25–44 design loading are presented in the Appendix for all load cases and both load tests. In general, the maximum predicted deflections for load cases 3 and 6 were close approximations of the maximum measured deflections. Some significant differences in deflection are attributed to edge stiffening effects of the curb and rail system, where the measured deflections are less than the predicted deflections, and are most noticeable on a very narrow bridge like the Brookston Road bridge (Forest County). Other significant differences in deflection are attributed to skew effects; three of the bridges are skewed slightly greater than the maximum of 15° permitted by the AASHTO Guide Specifications for Stress-Laminated Wood Bridges (AASHTO 1991). The orthotropic plate program assumes a rectangular deck for analysis purposes, and differences between measured and predicted deflections would be most noticeable on a very wide skewed bridge like the Dutch Hill Road bridge (Crawford County).

Table 11—Measured maximum centerspan deflections from static load tests conducted at all bridges

	Maximum measured centerspan deflection (in.)											
	1998 load test, load cases 1 to 6						2001 load test, load cases 1 to 6					
Name of bridge	1	2	3	4	5	6	1	2	3	4	5	6
Dutch Hill Rd	0.24	0.28	0.36	0.21	0.25	0.25	0.20	0.24	0.31	0.21	0.25	0.25
Brookston Rd	0.61	0.56	0.73	—	—	—	0.73	0.67	0.98	—	—	—
Laurel Run	0.51	0.53	0.75	—	—	—	0.63	0.69	0.92	—	—	—
Jacobs	0.67	0.73	1.04	0.81	0.80	0.83	0.83	0.87	1.25	1.18	1.19	1.18
Millcross Rd	0.24	0.24	0.28	0.20	0.24	0.21	0.20	0.22	0.28	0.20	0.20	0.20
Dogwood Ln	0.34	0.34	0.49	0.39	0.35	0.39	0.31	0.35	0.51	0.35	0.39	0.39
Birch Creek	0.28	0.28	0.44	—	—	—	0.22	0.22	0.33	—	—	—

Table 12—Comparison of measured, predicted, and predicted HS25-44 centerspan deflections for load case 3 (centered loading) and load case 6 (eccentric loading) for 1998 and 2001 load tests

	L/500 deflection level	Maximum centerspan deflection (in.)											
		1998 load test						2001 load test					
		Load case 3			Load case 6			Load case 3			Load case 6		
Name of bridge	(in.)	Meas.	Pred.	HS25	Meas.	Pred.	HS25	Meas.	Pred.	HS25	Meas.	Pred.	HS25
Dutch Hill Rd	0.56	0.36	0.46	0.54	0.25	0.35	0.42	0.32	0.43	0.55	0.25	0.34	0.42
Brookston Rd	0.83	0.73	0.72	1.66	—	—	—	0.98	1.02	1.67	—	—	—
Laurel Run	0.93	0.75	0.76	1.28	—	—	—	0.92	0.91	1.28	—	—	—
Jacobs	1.06	1.04	1.26	2.16	0.83	1.10	1.88	1.25	1.50	2.17	1.18	1.53	1.88
Millcross Rd	0.52	0.28	0.30	0.33	0.21	0.26	0.32	0.28	0.30	0.32	0.20	0.26	0.28
Dogwood Ln	0.82	0.50	0.51	0.86	0.39	0.54	0.90	0.51	0.48	0.86	0.39	0.52	0.91
Birch Creek	0.54	0.44	0.43	0.38	—	—	—	0.34	0.34	0.38	—	—	—

The predicted HS25–44 maximum deflection exceeded the L/500 deflection level at the Brookston Road, Laurel Run, and Jacobs bridges. Large differences, on the order of 100%, were noted for the Brookston Road and the Jacobs bridges, most likely because the analysis did not take into account the skewed configuration of the deck. Minor differences, of less than 40%, were noted at the Laurel Run and the Dogwood Lane bridges and may be attributed to uncertainty about the properties of the Red Oak lamination material. For three bridges (Dutch Hill Road, Millcross Road, and Birch Creek), predicted HS25–44 maximum deflection was less than the L/500 deflection set in the original design and recommended by AASHTO (1991).

Condition Assessment

The general condition of the bridges was acceptable after several years in service. However, several maintenance areas were identified that need attention to prolong the service life of these stress-laminated hardwood bridges.

Treated Wood Components

End and surface checking was visible on most rail, curb, and edge deck lamination members. In some cases, the checking caused 1-in.-wide and 4-in.-deep crevices in the hardwood rail members (Fig. 14). We recommend application of suitable field treatments to bridges with large surface and end checking and any damaged wood components to prevent problems with moisture penetration and decay (Ritter 1990). Deep checking can penetrate the preservative envelope, exposing untreated interior wood and providing avenues for moisture and decay organisms. One method to reduce end checking is to embed mechanical fasteners, such as metal-plate-connectors or S-irons, into the end grain of each rail member, as at the Birch Creek bridge (Sullivan County) (Fig. 15). Creosote preservative bleeding was visible on several bridges, including the Birch Creek bridge (Fig. 16). More efforts are needed to reduce preservative bleeding from highway bridges by enforcing the appropriate American Wood Preservers' Association (AWPA) treatment standards, with special emphasis on the post-treatment cleaning

Figure 14—Large end-check and split in rail member of Laurel Run bridge (Huntingdon County).

Figure 15—Metal-plate-connector embedded into rail member end grain of Birch Creek bridge (Sullivan County) to limit checking.

Figure 16—Noticeable creosote preservative bleeding at Birch Creek bridge.

techniques included in the *Best Management Practices for the Use of Treated Wood in Aquatic Environments* (WWPI 1996).

Asphalt Wearing Surface

The general condition of the asphalt wearing surface was good at all seven bridge sites. However, large amounts of debris (including plant growth) were observed on most bridge decks, especially adjacent to the scupper/curb area (Fig. 17). Removal of accumulated surface debris is recommended semi-annually, or as warranted, to allow good drainage of the wearing surface and scupper/curb areas of the bridge. Asphalt surface cracking was minimal and typically occurred transversely where the end of the bridge connects with the approach roadway. No longitudinal surface cracking was evident. However, recent application of asphalt overlays, prior to initiation of field monitoring, made visual inspection of the original asphalt surface difficult at some bridges.

Stress-Laminating System

The galvanized steel components of the stressing system were in good condition. However, corrosion was visible on the exposed ends of the high-strength steel prestressing bars at several bridges. Removal of corrosion and application of a suitable field galvanizing treatment are recommended for corroded bar ends. No crushed wood was visible in the vicinity of the discrete steel bearing plate or continuous steel channel bar anchorages. The use of concrete abutment cheek-walls (Fig. 18) is not recommended as it prevents bar re-tensioning and, in some cases, the deck can expand and cause abutment cracking. Several bars were trimmed for aesthetic reasons prior to the monitoring period, which will make future bar re-tensioning more difficult. Figure 19 shows an alternative method to externally prestress stress-laminated decks when the existing bars cannot be coupled. In this case, a pair of external prestressing bars (top and bottom) are placed on each side of a particular bar for re-tensioning. After tensioning the external bars to the required tension level, the anchor nut of the internal bar is hand-tightened to lock-off the prestressing force, and the tension forces are then released from the external prestressing bars. The process is repeated on successive bars until the entire bridge deck is completed.

Bridge Deck and Railing Distortions

The stress-laminated slab-type deck was distorted in relation to the horizontal plane at the Brookston Road (Forest County) bridge such that the ends of the bridge curled upward at the corners and did not evenly bear upon the abutments across the entire bridge width. This kind of deck distortion has been observed at other stress-laminated decks in West Virginia (Dickson 1995) and Iowa (Lee and others 1997). Although the cause of distortion is not clear,

Figure 17—Significant plant growth (indicating moisture accumulation near scupper block openings) at Laurel Run bridge (Huntingdon County).

Figure 18—Concrete abutment "cheek-wall," which prevents access to end bars for re-tensioning.

Figure 19—One alternative method to re-tension stress-laminated bridges with limited bar extension is to use external prestressing, with one bar above and one below the deck.

Figure 20—Large bowing of rail member at Laurel Run bridge (Huntingdon County).

distortion does not seem to have an adverse effect on the structural performance of the bridge deck.

The condition of the bridge curb and rail systems is poor at three of the seven bridges. At the Brookston Road, Laurel Run, and Jacobs bridges, the bridge rail posts are leaning outward (away from the bridge), apparently as a result of transverse bowing of the deck. Bowing is possibly the result of deck expansion caused by excessively high lumber moisture content in the scupper/curb zone. These rail post and deck distortions also cause the rail members to bow outward and are especially noticeable at the longer span bridges (Fig. 20). Similar rail post and deck distortions observed at several hardwood bridges in West Virginia (Dickson 1995) are possibly due to the tendency of the curb and scupper zone to accumulate moisture. While these distortions do not reduce the structural integrity of the bridge deck, the geometry of the vehicle rail and curb system may be inadequate for safe vehicle impact. Shimming the rail posts to the vertical position is recommended to maintain the critical geometric design of the rail and curb system.

Conclusions

The following conclusions are based on data collected during the 4-year monitoring period from August 1997 to July 2001.

- Field performance of the seven stress-laminated hardwood lumber deck bridges has been unsatisfactory. Several items related to serviceability and maintenance need immediate attention to achieve satisfactory field performance. See future recommendations for details.

- Moisture content should be monitored during routine bridge inspection. Average moisture content of deck laminations of many bridges was near fiber saturation after approximately 9 years in service. Average moisture content at 1 in. of deck penetration decreased from 27% to 19% during the 4-year monitoring period. However, average moisture content at 2 and 3 in. of deck penetration was 27% near the end of the monitoring period. For the Millcross Road and Dogwood Lane bridges, average moisture content at the 2- and 3-in. levels was above fiber saturation near the end of the monitoring period. These data suggest that the moisture content of these bridges was much greater than 20% at time of installation, and it has been moving towards the equilibrium of less than 20% for timber bridges. Moreover, the creosote oil-type preservative may be retarding the drying process. Elevated moisture content in deck laminations has been shown to accelerate bar force loss in similar bridges.
- Prestressing bar force should be checked with hydraulic equipment and the bars re-tensioned when necessary, as part of routine bridge inspection. For most bridges, bar force was relatively steady during the 4-year monitoring period. However, bar force of the Millcross Road bridge decreased at a steady rate throughout the monitoring period, and the bars were re-tensioned near the end of the monitoring period. During the winter, the prestressing bar force at several bridges (Jacobs, Dogwood Lane, and Birch Creek) dropped slightly below the re-tensioning threshold 40-lb/in^2 interlaminar prestress level set by AASHTO.
- Ambient and internal deck wood temperature data demonstrate the strong insulating properties of wood. The internal temperature of the deck varied over a smaller range of maximum and minimum temperatures as compared with that of the ambient air temperatures and changed at a slower rate. When the internal wood temperature dropped below the freezing point of water, a temporary loss of prestressing bar force occurred. The magnitude of this "temperature induced" loss is related to the duration of the sub-freezing internal wood temperature and lamination moisture content. The temperature-induced loss was typically 5 to 10 $\times 10^3$ lbf in magnitude and was fully recovered as the internal wood temperature rose above the freezing point of water. Relative humidity data collected underneath the bridge superstructures were unreliable. Alternative methods to gather reliable data are being explored.
- Static load tests performed at all seven bridges demonstrated the satisfactory structural performance of the stress-laminated bridge decks under typical highway loading conditions. In general, the bridges exhibited transverse load distribution characteristic of the orthotropic behavior of stress-laminated bridge decks. The live load deflection limitation of 1/500 of the bridge span was not exceeded for four of the seven bridges (Dutch Hill Road, Millcross Road, Dogwood Lane, and Birch Creek), based on predicted deflections using AASHTO HS25–44 design loading in conjunction with an orthotropic plate analysis program. However, the deflection of the remaining bridges (Brookston Road, Laurel Run, and Jacobs) exceeded the live load deflection limitation of 1/500 of the bridge span. The assumed stiffness value for red oak lumber (1.6×10^3 lb/in^2) may be different than the actual value and may have accounted for some differences between measured and predicted deflections.
- Condition assessments indicated several maintenance areas that need immediate attention. End checking of lumber rail and curb members was observed at several bridges and can be reduced by embedding metal fasteners into the end grain. Creosote preservative leaching was evident at several bridges, and more efforts are needed to prevent problems in the future. The corners of the stress-laminated deck superstructure curled upward at the Brookston Road bridge. In addition, the condition of the bridge curb and rail systems was poor at three bridges. Shimming the rail posts to the vertical position is recommended to maintain the critical geometric design of the rail and curb system.

Future Recommendations

The following recommendations regarding serviceability and maintenance issues will be vital to prolonging the service life of stress-laminated deck bridges.

- Re-tension prestressing bars of the following bridges in the near future to at least the 100-lb/in^2 interlaminar prestress level listed in Table 5:

  Brookston Road (Crawford County),
  Jacobs (Huntingdon County),
  Millcross Road (Lancaster County),
  Dogwood Lane (Schuylkill County), and
  Birch Creek (Sullivan County).
- After re-tensioning prestressing bars, monitor prestressing bar forces at the Brookston Road and Millcross Road bridges to ensure that they stabilize above the 40-lb/in^2 interlaminar prestress level (see Table 5).
- Treat areas affected by surface and end checking as well as damaged wood components to prevent moisture penetration and decay problems.
- Rehabilitate rail post and rail member distortions by shimming rail posts to the vertical position and further straightening the bridge rails.
- Remove debris accumulation on the wearing surface, especially along the curb and shoulder zones, at least twice per year. Efforts to improve drainage and eliminate pockets of high moisture content along curb lines and underneath scupper openings will also be very beneficial.

- For future hardwood stress-laminated deck bridges, we also propose the following recommendations:
  - Improve the retention of prestressing bar forces and reduce the need for repeated bar re-tensioning by specifying and enforcing deck lamination drying to less than 15% moisture content at installation. In addition, consider using glulam beams for the deck laminations, a design option with many advantages for stress-laminated decks.
  - Any trimming of prestressing bars after construction should preserve a minimum of 8 in. of bar extension beyond the anchor nut to facilitate the use of bar couplings for re-tensioning purposes.
  - Reduce lamination moisture content to less than 20% at installation to improve overall field performance for all timber bridges. Even though sawn lumber members are limited to less than 20% moisture content in most bridge contract specifications, bridge owners typically do not verify moisture content of the treated lumber components they receive from their suppliers. For hardwood lumber, the drying process is typically longer because of the high density of this wood, and is sometimes not performed by suppliers. In addition, temperature induced bar force losses during cold weather seasons can become insignificant when the lamination moisture content is below 20%.
  - The use of concrete "cheek wall" abutments (see Fig. 18) is not recommended as they can prevent access to end bars for tensioning purposes. In some instances, the expansion of the deck width can also lead to concrete cracking at the "cheek walls" where water can accumulate and lead to major substructure problems.
  - For large hardwood timbers used for the rail and curb system, embed mechanical fasteners such as metal-plate-connectors or S-irons into the end grain of each member to reduce checking, which can provide avenues for moisture to penetrate the preservative "envelope" and lead to decay problems.

Acknowledgments

We express gratitude to the following individuals for contributing to the success of this project.

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Appendix—Bridge Specifications and Load Test Analyses

Dutch Hill Road Bridge

General
Name: Dutch Hill Road bridge
Location: Crawford County, Pennsylvania
Date of construction: December 1992
Owner: City of Titusville

Design Configuration
Structure type: Stress-laminated deck with butt joints
Butt joint frequency: 1 in 4 laminations transversely, spaced 3 ft longitudinally
Length (out-out): 24 ft
Width (out-out): 32 ft
Skew: 16 degrees
Design loading: AASHTO HS25-44

Material and Configuration
Lumber deck laminations:
- Species: Red Oak
- Size: 3 by 15 in.
- Grade: No. 2, Northern Red Oak
- Preservative: Creosote

Stressing elements:
- Type: High strength steel threaded bar, conforming to ASTM A722, Type II
- Diameter: 1 in. (nominal)
- Spacing: 36 in.
- Anchorage Type: Discrete steel bearing plates

Abutment type: Timber pile with lumber cap

Dutch Hill Road bridge: views of bridge, test sensors, and load test.

Dutch Hill Road Bridge (Crawford County, PA)
Summary of 1998 Load Test Analysis with Orthotropic Plate Computer Program

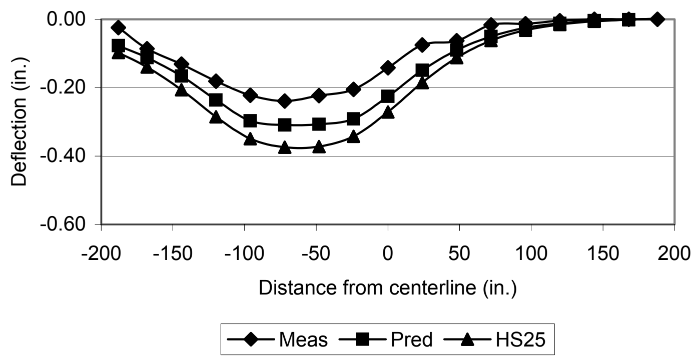
L = 280.9 in.	t = 15 in.	(~87 lb/in^2 prestress)	(~17 DEG. SKEW)	(NO STEEL PLATES)
b/2 = 188 in.	Ewood = 1,600,000 lb/in^2	Ets = 30,336 lb/in^2	Gts = 58,255 lb/in^2	Cbj = 0.7

Plot Coordinates (in.)

(@140.5)	Meas	Pred	HS25
-188	-0.02	-0.08	-0.10
-168	-0.09	-0.11	-0.14
-144	-0.13	-0.17	-0.21
-120	-0.18	-0.24	-0.29
-96	-0.22	-0.30	-0.35
-72	-0.24	-0.31	-0.37
-48	-0.22	-0.31	-0.37
-24	-0.21	-0.29	-0.34
0	-0.14	-0.23	-0.27
24	-0.08	-0.15	-0.19
48	-0.06	-0.09	-0.11
72	-0.02	-0.05	-0.06
96	-0.01	-0.03	-0.03
120	0.00	-0.01	-0.02
144	0.00	0.00	-0.01
168	0.00	0.00	0.00
188	0.00	0.00	0.00

Program input for truck axle weight and position
(3 0 13 13.55 19.75 4.25 19.75) & (328.5 60)
(3 0 10 14 40 14 40) & (395.6 60)

Load Case 1



Plot Coordinates (in.)

(@140.5)	Meas	Pred	HS25
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-168	0.00	0.00	0.00
-144	-0.01	-0.01	-0.01
-120	-0.02	-0.01	-0.02
-96	-0.04	-0.03	-0.03
-72	-0.06	-0.05	-0.06
-48	-0.11	-0.10	-0.11
-24	-0.15	-0.16	-0.19
0	-0.22	-0.24	-0.27
24	-0.27	-0.31	-0.34
48	-0.28	-0.32	-0.37
72	-0.28	-0.33	-0.37
96	-0.27	-0.31	-0.35
120	-0.21	-0.25	-0.29
144	-0.15	-0.18	-0.21
168	-0.09	-0.12	-0.14
188	-0.03	-0.08	-0.10

Program input for truck axle weight and position
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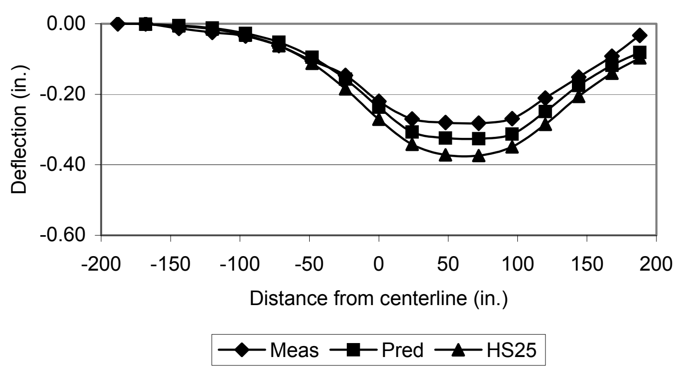
(3 0 10 14 40 14 40) & (395.6 -60)

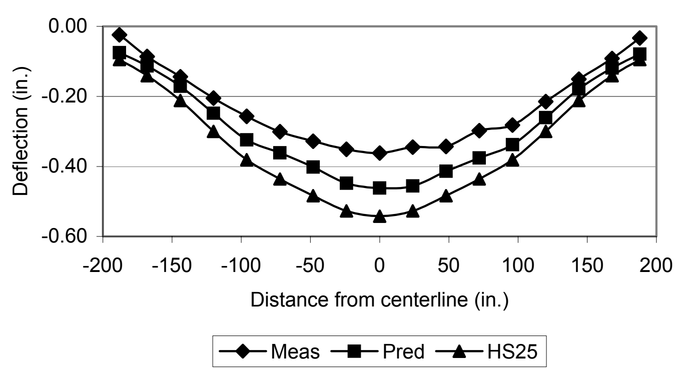
Load Case 2



Plot Coordinates (in.)

(@140.5)	Meas	Pred	HS25
-188	-0.02	-0.08	-0.10
-168	-0.09	-0.11	-0.14
-144	-0.14	-0.17	-0.21
-120	-0.21	-0.25	-0.30
-96	-0.26	-0.32	-0.38
-72	-0.30	-0.36	-0.44
-48	-0.33	-0.40	-0.48
-24	-0.35	-0.45	-0.53
0	-0.36	-0.46	-0.54
24	-0.35	-0.46	-0.53
48	-0.34	-0.41	-0.48
72	-0.30	-0.38	-0.44
96	-0.28	-0.34	-0.38
120	-0.22	-0.26	-0.30
144	-0.15	-0.18	-0.21
168	-0.09	-0.12	-0.14
188	-0.03	-0.08	-0.10

Load Case 3



Dutch Hill Road Bridge (Crawford County, PA)
Summary of 1998 Load Test Analysis with Orthotropic Plate Computer Program

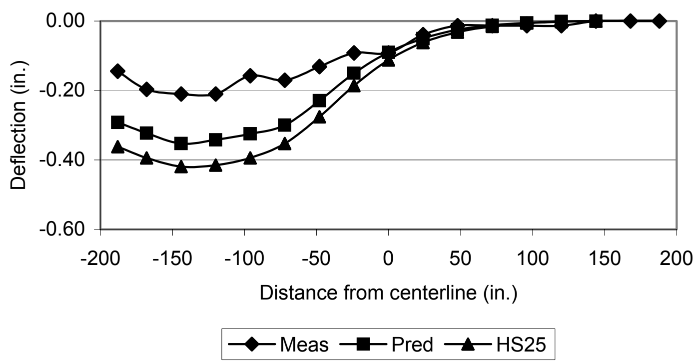
L = 280.9 in.	t = 15 in.	(~87 lb/in^2 prestress)	(~17 DEG. SKEW)	(NO STEEL PLATES)
b/2 = 188 in.	Ewood = 1,600,000 lb/in^2	Ets = 30,336 lb/in^2	Gts = 58,255 lb/in^2	Cbj = 0.7

Plot Coordinates (in.)

(@140.5)	Meas	Pred	HS25
-188	-0.14	-0.29	-0.36
-168	-0.20	-0.32	-0.39
-144	-0.21	-0.35	-0.42
-120	-0.21	-0.34	-0.42
-96	-0.16	-0.33	-0.39
-72	-0.17	-0.30	-0.35
-48	-0.13	-0.23	-0.28
-24	-0.09	-0.15	-0.19
0	-0.09	-0.09	-0.11
24	-0.04	-0.05	-0.06
48	-0.01	-0.03	-0.03
72	-0.01	-0.01	-0.02
96	-0.01	-0.01	-0.01
120	-0.01	0.00	0.00
144	0.00	0.00	0.00
168	0.00	0.00	0.00
188	0.00	0.00	0.00

Program input for truck axle weight and position
(3 0 13 13.55 19.75 4.25 19.75) & (328.5 108)
(3 0 10 14 40 14 40) & (395.6 108)

Load Case 4



Plot Coordinates (in.)

(@140.5)	Meas	Pred	HS25
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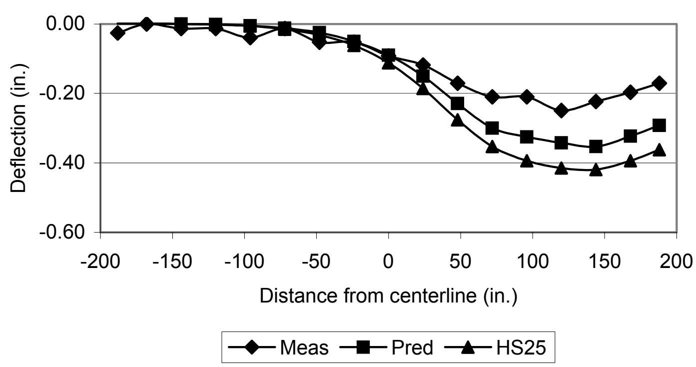
-168	0.00	0.00	0.00
-144	-0.01	0.00	0.00
-120	-0.01	0.00	0.00
-96	-0.04	-0.01	-0.01
-72	-0.01	-0.01	-0.02
-48	-0.05	-0.03	-0.03
-24	-0.05	-0.05	-0.06
0	-0.09	-0.09	-0.11
24	-0.12	-0.15	-0.19
48	-0.17	-0.23	-0.28
72	-0.21	-0.30	-0.35
96	-0.21	-0.33	-0.39
120	-0.25	-0.34	-0.42
144	-0.22	-0.35	-0.42
168	-0.20	-0.32	-0.39
188	-0.17	-0.29	-0.36

Program input for truck axle weight and position
(3 0 13.9 13.4 20.8 4.2 20.8) & (328.5 -108)
(3 0 10 14 40 14 40) & (395.6 -108)

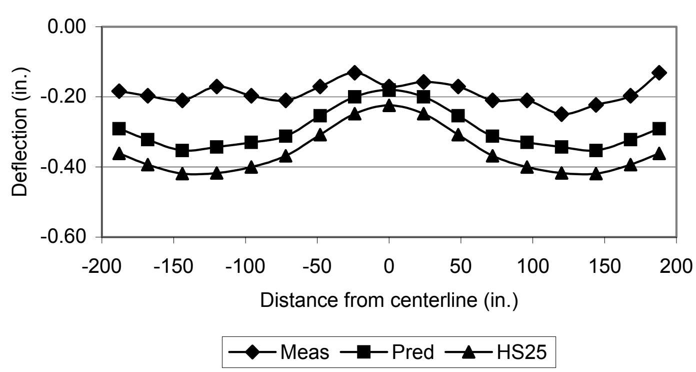
Load Case 5



Plot Coordinates (in.)

(@140.5)	Meas	Pred	HS25
-188	-0.18	-0.29	-0.36
-168	-0.20	-0.32	-0.39
-144	-0.21	-0.35	-0.42
-120	-0.17	-0.34	-0.42
-96	-0.20	-0.33	-0.40
-72	-0.21	-0.31	-0.37
-48	-0.17	-0.25	-0.31
-24	-0.13	-0.20	-0.25
0	-0.17	-0.18	-0.22
24	-0.16	-0.20	-0.25
48	-0.17	-0.25	-0.31
72	-0.21	-0.31	-0.37
96	-0.21	-0.33	-0.40
120	-0.25	-0.34	-0.42
144	-0.22	-0.35	-0.42
168	-0.20	-0.32	-0.39
188	-0.13	-0.29	-0.36

Load Case 6



Dutch Hill Road Bridge (Crawford County, PA)
Summary of 2001 Load Test Analysis with Orthotropic Plate Computer Program

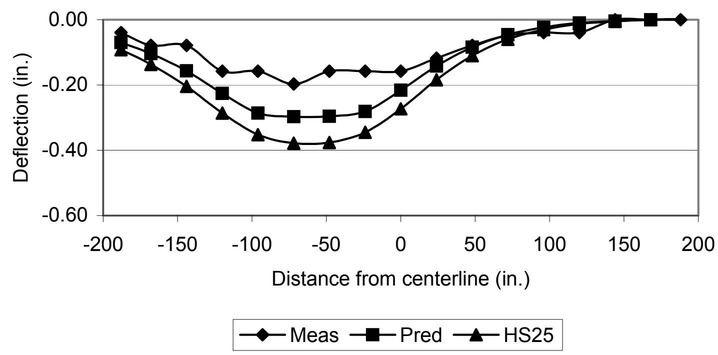
L = 280.9 in.	t = 15 in.	(~87 lb/in^2 prestress)	(~17 DEG. SKEW)	(NO STEEL PLATES)
b/2 = 188 in.	Ewood = 1,600,000 lb/in^2	Ets = 28,492 psi	Gts = 55,681 lb/in.^2	Cbj = 0.7

Load Case 1

Program input for truck axle weight and position
(3 0 14.65 13.40 18.83 4.20 18.83) & (327.7 60)
(3 0 10 14 40 14 40) & (395.6 60)

Plot Coordinates (in.)

(@140.5)	Meas	Pred	HS25
-188	-0.04	-0.07	-0.09
-168	-0.08	-0.10	-0.14
-144	-0.08	-0.16	-0.20
-120	-0.16	-0.23	-0.29
-96	-0.16	-0.29	-0.35
-72	-0.20	-0.30	-0.38
-48	-0.16	-0.30	-0.38
-24	-0.16	-0.28	-0.35
0	-0.16	-0.22	-0.27
24	-0.12	-0.14	-0.18
48	-0.08	-0.08	-0.11
72	-0.05	-0.05	-0.06
96	-0.04	-0.02	-0.03
120	-0.04	-0.01	-0.01
144	0.00	0.00	-0.01
168	0.00	0.00	0.00
188	0.00	0.00	0.00

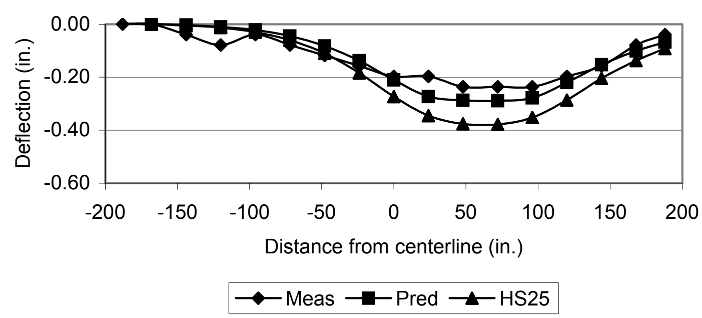


Load Case 2

Program input for truck axle weight and position
(3 0 14.25 13.05 18.50 4.65 18.50) & (327.7 -60)
(3 0 10 14 40 14 40) & (395.6 60)

Plot Coordinates (in.)

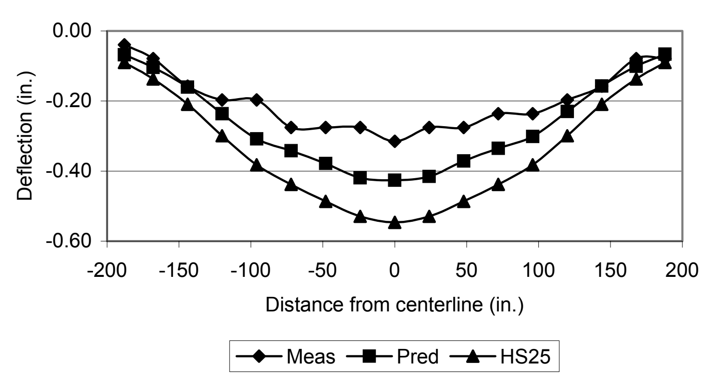
(@140.5)	Meas	Pred	HS25
-188	0.00	0.00	0.00
-168	0.00	0.00	0.00
-144	-0.04	0.00	-0.01
-120	-0.08	-0.01	-0.01
-96	-0.04	-0.02	-0.03
-72	-0.08	-0.05	-0.06
-48	-0.12	-0.08	-0.11
-24	-0.16	-0.14	-0.18
0	-0.20	-0.21	-0.27
24	-0.20	-0.27	-0.35
48	-0.24	-0.29	-0.38
72	-0.24	-0.29	-0.38
96	-0.24	-0.28	-0.35
120	-0.20	-0.22	-0.29
144	-0.16	-0.15	-0.20
168	-0.08	-0.10	-0.14
188	-0.04	-0.07	-0.09



Load Case 3

Plot Coordinates (in.)

(@140.5)	Meas	Pred	HS25
-188	-0.04	-0.07	-0.09
-168	-0.08	-0.10	-0.14
-144	-0.16	-0.16	-0.21
-120	-0.20	-0.24	-0.30
-96	-0.20	-0.31	-0.38
-72	-0.28	-0.34	-0.44
-48	-0.28	-0.38	-0.49
-24	-0.28	-0.42	-0.53
0	-0.31	-0.43	-0.55
24	-0.28	-0.42	-0.53
48	-0.28	-0.37	-0.49
72	-0.24	-0.34	-0.44
96	-0.24	-0.30	-0.38
120	-0.20	-0.23	-0.30
144	-0.16	-0.16	-0.21
168	-0.08	-0.10	-0.14
188	-0.08	-0.07	-0.09



Dutch Hill Road Bridge (Crawford County, PA)
Summary of 2001 Load Test Analysis with Orthotropic Plate Computer Program

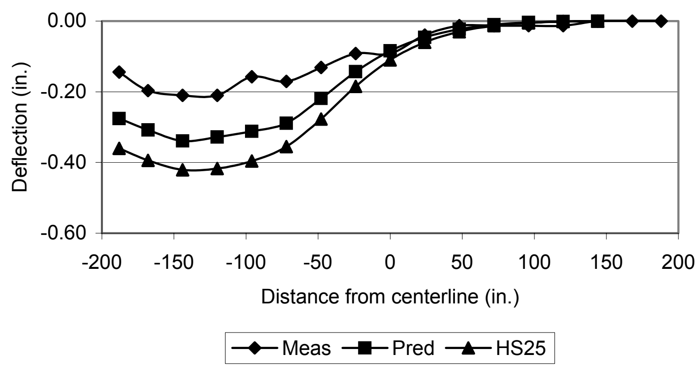
L = 280.9 in.	t = 15 in.	(~87 lb/in^2 prestress)	(~17 DEG. SKEW)	(NO STEEL PLATES)
b/2 = 188 in.	Ewood = 1,600,000 lb/in^2	Ets = 28,492 psi	Gts = 55,681 lb/in.^2	Cbj = 0.7

Load Case 4

Program input for truck axle weight and position
(3 0 14.65 13.40 18.83 4.20 18.83) & (327.7 108)
(3 0 10 14 40 14 40) & (395.6 108)

Plot Coordinates (in.)

(@140.5)	Meas	Pred	HS25
-188	-0.14	-0.28	-0.36
-168	-0.20	-0.31	-0.39
-144	-0.21	-0.34	-0.42
-120	-0.21	-0.33	-0.42
-96	-0.16	-0.31	-0.40
-72	-0.17	-0.29	-0.36
-48	-0.13	-0.22	-0.28
-24	-0.09	-0.14	-0.19
0	-0.09	-0.08	-0.11
24	-0.04	-0.05	-0.06
48	-0.01	-0.02	-0.03
72	-0.01	-0.01	-0.01
96	-0.01	0.00	-0.01
120	-0.01	0.00	0.00
144	0.00	0.00	0.00
168	0.00	0.00	0.00
188	0.00	0.00	0.00

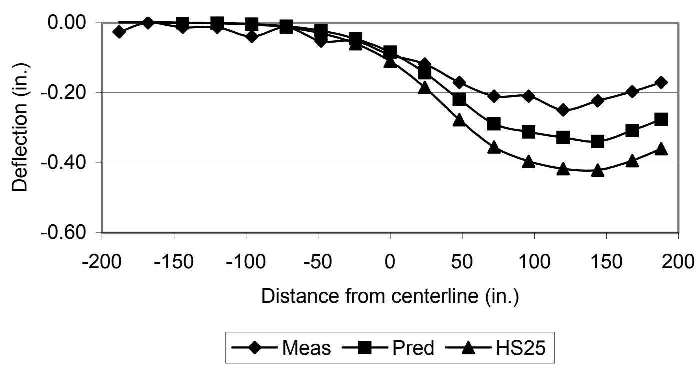


Load Case 5

Program input for truck axle weight and position
(3 0 14.25 13.05 18.50 4.65 18.50) & (327.7 -108)
(3 0 10 14 40 14 40) & (395.6 -108)

Plot Coordinates (in.)

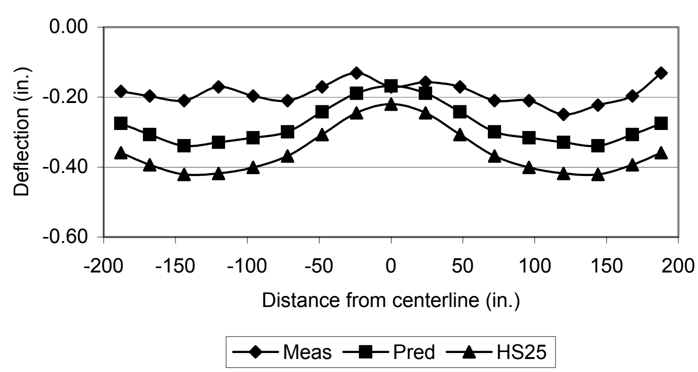
(@140.5)	Meas	Pred	HS25
-188	-0.03	0.00	0.00
-168	0.00	0.00	0.00
-144	-0.01	0.00	0.00
-120	-0.01	0.00	0.00
-96	-0.04	0.00	-0.01
-72	-0.01	-0.01	-0.01
-48	-0.05	-0.02	-0.03
-24	-0.05	-0.05	-0.06
0	-0.09	-0.08	-0.11
24	-0.12	-0.14	-0.19
48	-0.17	-0.22	-0.28
72	-0.21	-0.29	-0.36
96	-0.21	-0.31	-0.40
120	-0.25	-0.33	-0.42
144	-0.22	-0.34	-0.42
168	-0.20	-0.31	-0.39
188	-0.17	-0.28	-0.36



Load Case 6

Plot Coordinates (in.)

(@140.5)	Meas	Pred	HS25
-188	-0.18	-0.28	-0.36
-168	-0.20	-0.31	-0.39
-144	-0.21	-0.34	-0.42
-120	-0.17	-0.33	-0.42
-96	-0.20	-0.32	-0.40
-72	-0.21	-0.30	-0.37
-48	-0.17	-0.24	-0.31
-24	-0.13	-0.19	-0.25
0	-0.17	-0.17	-0.22
24	-0.16	-0.19	-0.25
48	-0.17	-0.24	-0.31
72	-0.21	-0.30	-0.37
96	-0.21	-0.32	-0.40
120	-0.25	-0.33	-0.42
144	-0.22	-0.34	-0.42
168	-0.20	-0.31	-0.39
188	-0.13	-0.28	-0.36



Brookston Road Bridge

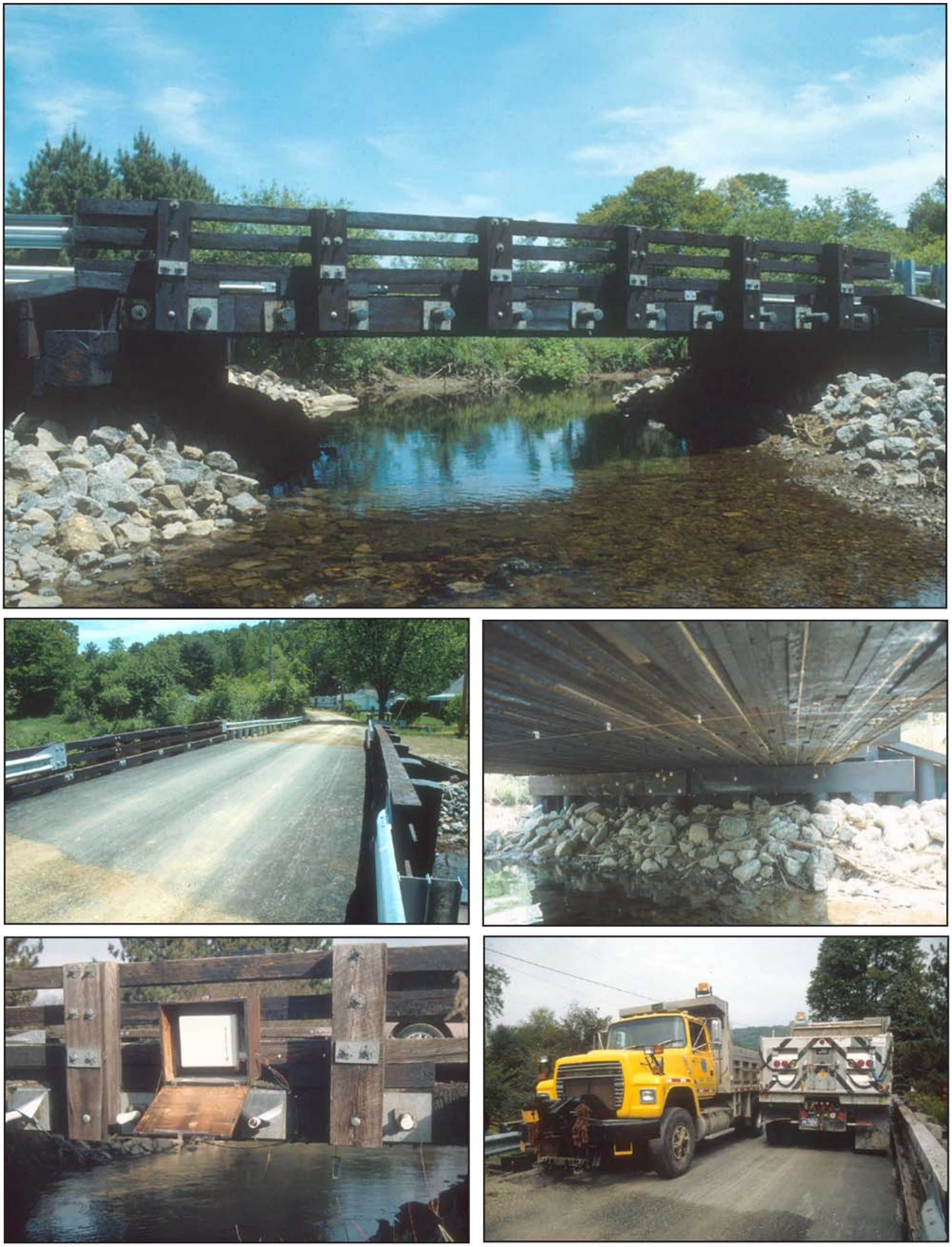
General
Name: Brookston Road bridge
Location: Forest County, Pennsylvania
Date of construction: June 1992
Owner: Howe Township

Design Configuration
Structure type: Stress-laminated deck with butt joints (composite with steel plates)
Steel plate frequency: 1 after every 6 lumber laminations transversely
Butt joint frequency: 1 in every 4 laminations transversely, spaced 3 ft longitudinally
Length (out-out): 35 ft
Width (out-out): 20 ft
Skew: 16 degrees
Design loading: AASHTO HS25-44

Material and Configuration
Lumber deck laminations:
- Species: Red Oak
- Size: 3 by 14 in.
- Grade: No. 2, Northern Red Oak
- Preservative: Creosote

Stressing elements:
- Type: High strength steel threaded bar, conforming to ASTM A722, Type II
- Diameter: 1 in. (nominal)
- Spacing: 36 in.
- Anchorage Type: Discrete steel bearing plates

Abutment type: Timber pile with lumber cap



Brookston Road bridge: views of bridge, test instrumentation, and load test.

Brookston Road bridge (Forest County, PA)
Summary of 1998 Load Test Analysis with Orthotropic Plate Computer Program

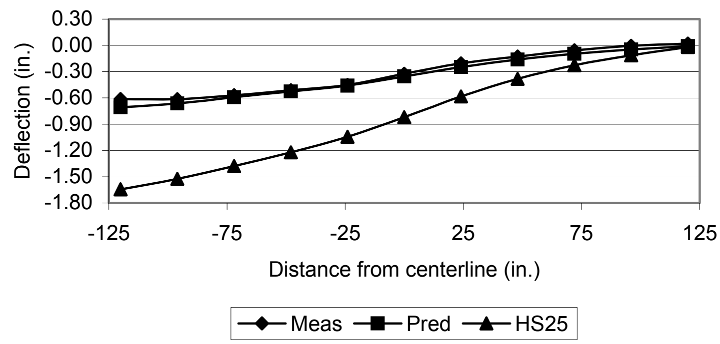
L = 413 in.	t = 14 in.	(~75 lb/in^2 prestress)	(~16 DEG. SKEW)	(E is 2.43 WOOD/STEEL)
b/2 = 120 in.	Ewood = 1,600,000 lb/in^2	Ets = 28,325 lb/in^2	Gts = 55,447 lb/in^2	Cbj = 0.85

Plot Coordinates (in.)

(@206.5)	Meas	Pred	HS25
-120	-0.61	-0.71	-1.64
-96	-0.62	-0.67	-1.53
-72	-0.57	-0.59	-1.38
-48	-0.51	-0.53	-1.22
-24	-0.45	-0.46	-1.05
0	-0.32	-0.36	-0.82
24	-0.21	-0.25	-0.58
48	-0.13	-0.16	-0.38
72	-0.06	-0.10	-0.23
96	-0.01	-0.05	-0.11
120	0.02	-0.01	-0.02

Program input for truck axle weight and position
(2 0 12.22 13.55 25.30) & (369.1 60)
(3 0 10 14 40 14 40) & (455 60)

Load Case 1

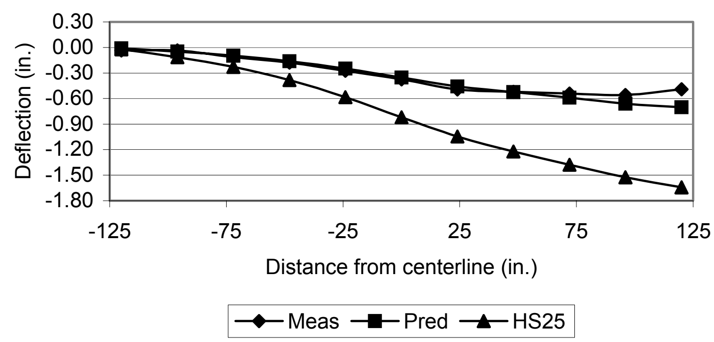


Plot Coordinates (in.)

(@206.5)	Meas	Pred	HS25
-120	-0.03	-0.01	-0.02
-96	-0.03	-0.05	-0.11
-72	-0.11	-0.10	-0.23
-48	-0.18	-0.16	-0.38
-24	-0.27	-0.25	-0.58
0	-0.37	-0.35	-0.82
24	-0.49	-0.46	-1.05
48	-0.52	-0.52	-1.22
72	-0.54	-0.59	-1.38
96	-0.56	-0.66	-1.53
120	-0.49	-0.70	-1.64

Program input for truck axle weight and position
(2 0 13.02 13.55 24.84) & (369.1 -60)
(3 0 10 14 40 14 40) & (455 -60)

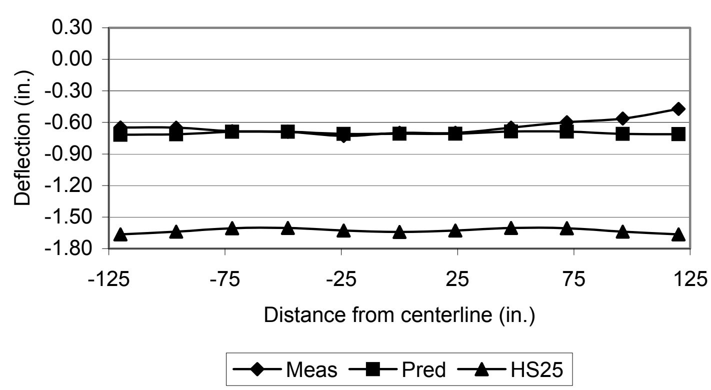
Load Case 2



Plot Coordinates (in.)

(@206.5)	Meas	Pred	HS25
-120	-0.65	-0.72	-1.67
-96	-0.65	-0.71	-1.64
-72	-0.68	-0.69	-1.61
-48	-0.69	-0.69	-1.60
-24	-0.73	-0.71	-1.63
0	-0.70	-0.71	-1.64
24	-0.70	-0.71	-1.63
48	-0.65	-0.69	-1.60
72	-0.60	-0.69	-1.61
96	-0.56	-0.71	-1.64
120	-0.47	-0.71	-1.67

Load Case 3



Brookston Road bridge (Forest County, PA)
Summary of 2001 Load Test Analysis with Orthotropic Plate Computer Program

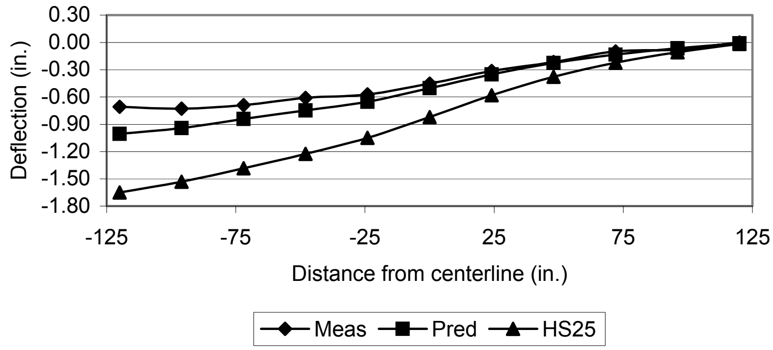
L = 413 in.	t = 14 in.	(~75 lb/in^2 prestress)	(~16 DEG. SKEW)	(E is 2.43 WOOD/STEEL)
b/2 = 120 in.	Ewood = 1,600,000 lb/in^2	Ets = 26,983 lb/in^2	Gts = 53,575 lb/in^2	Cbj = 0.85

Plot Coordinates (in.)

(@206.5)	Meas	Pred	HS25
-120	-0.71	-1.00	-1.65
-96	-0.73	-0.94	-1.53
-72	-0.69	-0.84	-1.38
-48	-0.61	-0.75	-1.23
-24	-0.57	-0.65	-1.05
0	-0.45	-0.50	-0.82
24	-0.31	-0.35	-0.58
48	-0.22	-0.23	-0.38
72	-0.10	-0.13	-0.22
96	-0.08	-0.06	-0.11
120	0.00	-0.01	-0.02

Program input for truck axle weight and position
(3 0 15.55 13.50 18.68 4.20 18.68) & (393.7 60)
(3 0 10 14 40 14 40) & (455 60)

Load Case 1

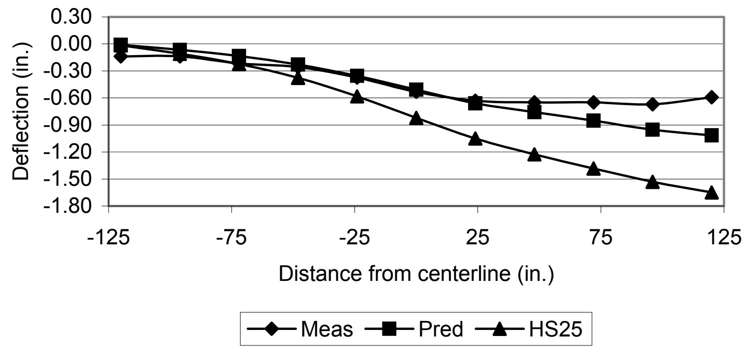


Plot Coordinates (in.)

(@206.5)	Meas	Pred	HS25
-120	-0.14	-0.01	-0.02
-96	-0.14	-0.07	-0.11
-72	-0.22	-0.13	-0.22
-48	-0.26	-0.23	-0.38
-24	-0.37	-0.35	-0.58
0	-0.53	-0.51	-0.82
24	-0.63	-0.66	-1.05
48	-0.65	-0.76	-1.23
72	-0.65	-0.85	-1.38
96	-0.67	-0.95	-1.53
120	-0.59	-1.02	-1.65

Program input for truck axle weight and position
(3 0 16.30 13.45 18.80 4.25 18.80) & (393.4 -60)
(3 0 10 14 40 14 40) & (455 -60)

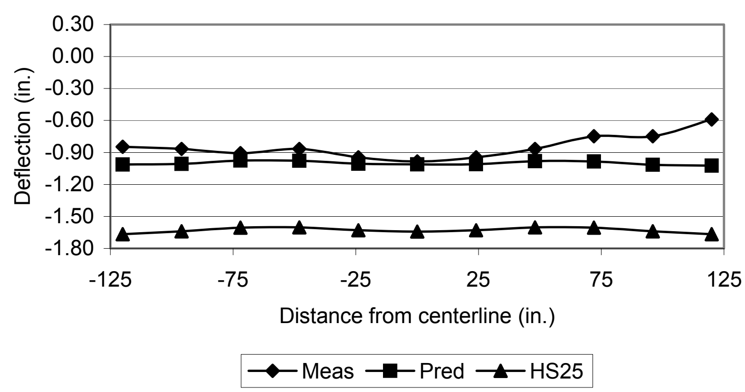
Load Case 2



Plot Coordinates (in.)

(@206.5)	Meas	Pred	HS25
-120	-0.85	-1.01	-1.67
-96	-0.87	-1.01	-1.64
-72	-0.91	-0.98	-1.61
-48	-0.87	-0.98	-1.60
-24	-0.94	-1.01	-1.63
0	-0.98	-1.01	-1.64
24	-0.94	-1.01	-1.63
48	-0.87	-0.98	-1.60
72	-0.75	-0.98	-1.61
96	-0.75	-1.02	-1.64
120	-0.59	-1.02	-1.67

Load Case 3



Laurel Run Bridge

General
Name: Laurel Run bridge
Location: Huntingdon County, Pennsylvania
Date of construction: August 1992
Owner: Jackson Township

Design Configuration
Structure type: Stress-laminated deck with butt joints (composite with steel plates)
Steel plate frequency: 1 after every 4 lumber laminations transversely
Butt joint frequency: 1 in 4 laminations transversely, spaced 3 ft longitudinally
Length (out-out): 40 ft
Width (out-out): 24 ft
Skew: 0 degrees
Design loading: AASHTO HS25-44

Material and Configuration
Lumber deck laminations:
- Species: Red Oak
- Size: 3 by 16 in.
- Grade: No. 2, Northern Red Oak
- Preservative: Creosote

Stressing elements:
- Type: High strength steel threaded bar, conforming to ASTM A722, Type II
- Diameter: 1 in. (nominal)
- Spacing: 36 in.
- Anchorage Type: Continuous steel channel and bearing plates

Abutment type: Cast-in-place reinforced concrete

Laurel Run bridge: views of bridge, test instrumentation, and load tests.

Laurel Run bridge (Huntingdon County, PA)
Summary of 1998 Load Test Analysis with Orthotropic Plate Computer Program

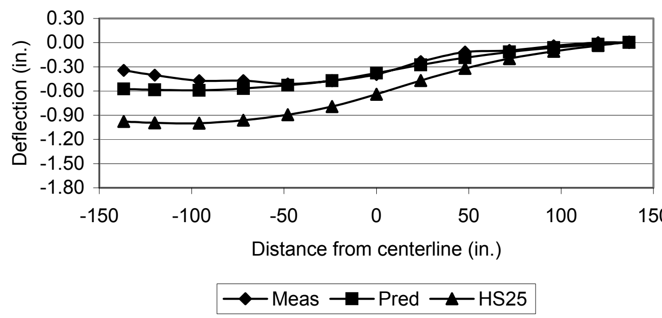
L = 466.6 in.	t = 16 in.	(~73 lb/in^2 prestress)	(no SKEW)	(E is 2.43 WOOD/STEEL)
b/2 = 136.8 in.	Ewood = 1,600,000 lb/in^2	Ets = 27,989 lb/in^2	Gts = 54,979 lb/in^2	Cbj = 0.90

Plot Coordinates (in.)

(@233.3)	Meas	Pred	HS25
-136.8	-0.34	-0.57	-0.98
-120	-0.40	-0.59	-0.99
-96	-0.47	-0.59	-1.00
-72	-0.47	-0.57	-0.96
-48	-0.51	-0.53	-0.89
-24	-0.47	-0.47	-0.79
0	-0.39	-0.38	-0.64
24	-0.24	-0.28	-0.47
48	-0.12	-0.19	-0.32
72	-0.10	-0.12	-0.20
96	-0.04	-0.06	-0.11
120	0.00	-0.02	-0.04
136.8	0.00	0.00	0.01

Program input for truck axle weight and position
(3 0 13.46 13.35 17.77 4.55 17.77) & (369.26 60)
(3 0 10 14 40 14 40) & (457.3 60)

Load Case 1

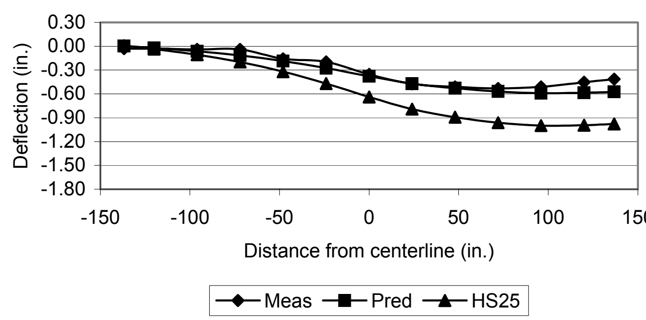


Plot Coordinates (in.)

(@233.3)	Meas	Pred	HS25
-136.8	-0.03	0.00	0.01
-120	-0.03	-0.02	-0.04
-96	-0.04	-0.06	-0.11
-72	-0.04	-0.12	-0.20
-48	-0.16	-0.19	-0.32
-24	-0.20	-0.28	-0.47
0	-0.35	-0.38	-0.64
24	-0.47	-0.47	-0.79
48	-0.51	-0.53	-0.89
72	-0.53	-0.57	-0.96
96	-0.51	-0.59	-1.00
120	-0.45	-0.59	-0.99
136.8	-0.41	-0.57	-0.98

Program input for truck axle weight and position
(3 0 13.46 13.35 17.77 4.55 17.77) & (73.1 -60)
(3 0 10 14 40 14 40) & (457.3 -60)

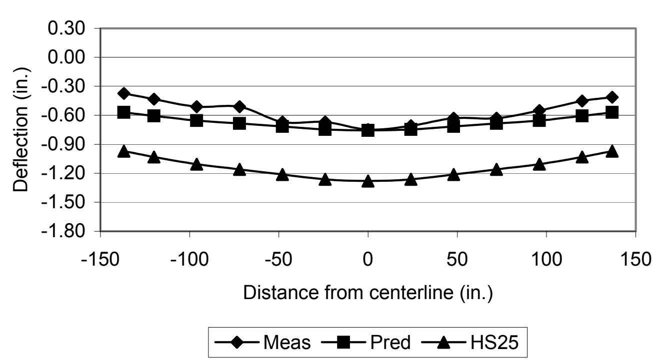
Load Case 2



Plot Coordinates (in.)

(@233.3)	Meas	Pred	HS25
-136.8	-0.37	-0.57	-0.97
-120	-0.43	-0.61	-1.03
-96	-0.51	-0.66	-1.11
-72	-0.51	-0.68	-1.16
-48	-0.67	-0.72	-1.21
-24	-0.67	-0.75	-1.26
0	-0.75	-0.76	-1.28
24	-0.71	-0.75	-1.26
48	-0.63	-0.72	-1.21
72	-0.63	-0.68	-1.16
96	-0.55	-0.66	-1.11
120	-0.45	-0.61	-1.03
136.8	-0.41	-0.57	-0.97

Load Case 3



Laurel Run bridge (Huntingdon County, PA)
Summary of 2001 Load Test Analysis with Orthotropic Plate Computer Program

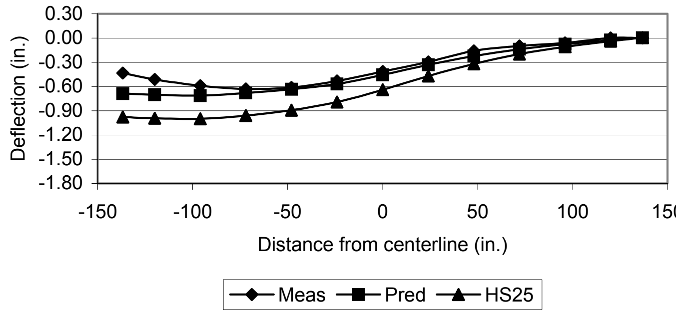
L = 466.6 in.	t = 16 in.	(~75 lb/in^2 prestress)	(no SKEW)	(E is 2.43 WOOD/STEEL)
b/2 = 136.8 in.	Ewood = 1,600,000 lb/in^2	Ets = 28,324 lb/in^2	Gts = 55,447 lb/in^2	Cbj = 0.90

Plot Coordinates (in.)

(@233.3)	Meas	Pred	HS25
-136.8	-0.43	-0.69	-0.98
-120	-0.51	-0.70	-0.99
-96	-0.59	-0.71	-1.00
-72	-0.63	-0.68	-0.96
-48	-0.61	-0.63	-0.89
-24	-0.53	-0.57	-0.79
0	-0.41	-0.46	-0.64
24	-0.30	-0.33	-0.47
48	-0.16	-0.22	-0.32
72	-0.10	-0.14	-0.20
96	-0.06	-0.08	-0.11
120	0.00	-0.03	-0.04
136.8	0.00	0.00	0.01

Program input for truck axle weight and position
(3 0 12.45 12.3 22.15 4.60 21.90) & (380.9 60)
(3 0 10 14 40 14 40) & (457.3 60)

Load Case 1

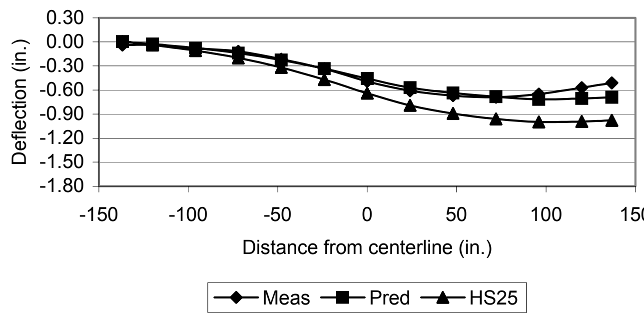


Plot Coordinates (in.)

(@233.3)	Meas	Pred	HS25
-136.8	-0.04	0.00	0.01
-120	-0.04	-0.03	-0.04
-96	-0.08	-0.08	-0.11
-72	-0.12	-0.14	-0.20
-48	-0.22	-0.23	-0.32
-24	-0.33	-0.33	-0.47
0	-0.49	-0.46	-0.64
24	-0.61	-0.57	-0.79
48	-0.67	-0.64	-0.89
72	-0.69	-0.69	-0.96
96	-0.65	-0.72	-1.00
120	-0.57	-0.71	-0.99
136.8	-0.51	-0.69	-0.98

Program input for truck axle weight and position
(3 0 15.15 13.45 21.65 4.20 21.85) & (394.7 -60)
(3 0 10 14 40 14 40) & (457.3 -60)

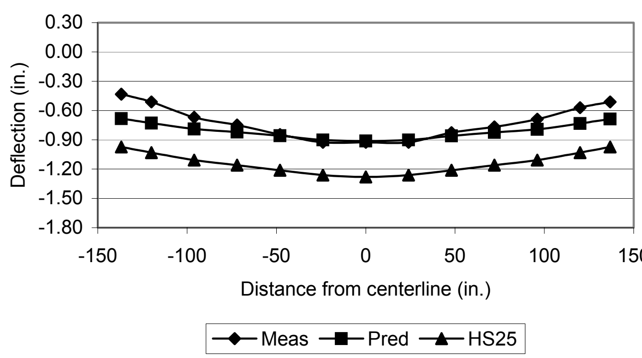
Load Case 2



Plot Coordinates (in.)

(@233.3)	Meas	Pred	HS25
-136.8	-0.43	-0.68	-0.97
-120	-0.51	-0.73	-1.03
-96	-0.67	-0.79	-1.11
-72	-0.75	-0.82	-1.16
-48	-0.85	-0.86	-1.21
-24	-0.93	-0.90	-1.26
0	-0.93	-0.91	-1.28
24	-0.93	-0.90	-1.26
48	-0.83	-0.86	-1.21
72	-0.77	-0.82	-1.16
96	-0.69	-0.79	-1.11
120	-0.57	-0.73	-1.03
136.8	-0.51	-0.69	-0.97

Load Case 3



Jacobs Bridge

General
Name: Jacobs bridge
Location: Huntingdon County, Pennsylvania
Date of construction: November 1991
Owner: Todd Township

Design Configuration
Structure type: Stress-laminated deck with butt joints (composite with steel plates)
Steel plate frequency: 1 after every 4 lumber laminations transversely
Butt joint frequency: 1 in 4 laminations transversely, spaced 3 ft longitudinally
Length (out-out): 46 ft
Width (out-out): 27 ft
Skew: 16 degrees
Design loading: AASHTO HS25-44

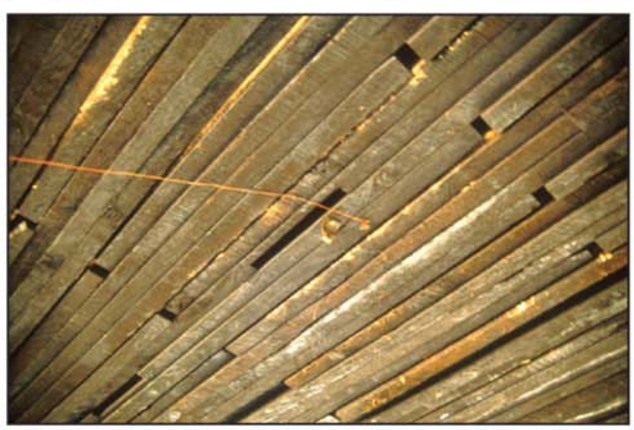
Material and Configuration
Lumber deck laminations:
- Species: Red Oak
- Size: 3 by 16 in.
- Grade: No. 2, Northern Red Oak
- Preservative: Creosote

Stressing elements:
- Type: High strength steel threaded bar, conforming to ASTM A722, Type II
- Diameter: 1 in. (nominal)
- Spacing: 36 in.
- Anchorage Type: Discrete steel bearing plates

Abutment type: Cast-in-place reinforced concrete







Jacobs bridge: views of bridge and test instrumentation.

Jacobs bridge (Huntingdon County, PA)
Summary of 1998 Load Test Analysis with Orthotropic Plate Computer Program

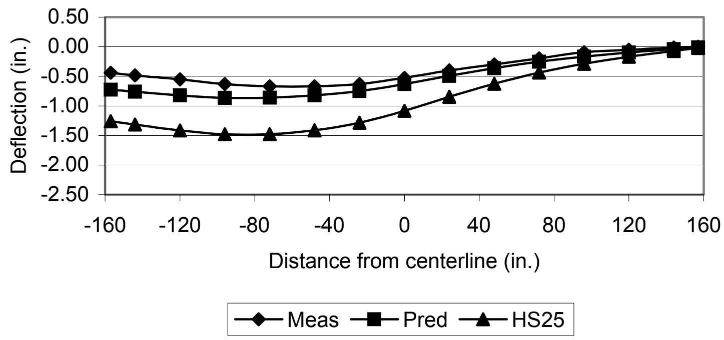
L = 530 in.	t = 16 in.	(~64 lb/in.^2 prestress)	(16 DEG. SKEW)	(E is 2.43 WOOD/STEEL)
b/2 = 157 in.	Ewood = 1,600,000 lb/in^2	Ets = 26,480 lb/in^2	Gts = 52,873 lb/in^2	Cbj = 0.90

Plot Coordinates (in.)

(@265)	Meas	Pred	HS25
-157	-0.44	-0.73	-1.26
-144	-0.49	-0.76	-1.31
-120	-0.55	-0.82	-1.41
-96	-0.63	-0.86	-1.48
-72	-0.67	-0.86	-1.48
-48	-0.67	-0.82	-1.41
-24	-0.63	-0.75	-1.28
0	-0.52	-0.63	-1.08
24	-0.40	-0.49	-0.85
48	-0.30	-0.36	-0.63
72	-0.20	-0.25	-0.44
96	-0.09	-0.17	-0.29
120	-0.05	-0.10	-0.17
144	-0.01	-0.04	-0.07
157	0.00	-0.01	-0.02

Program input for truck axle weight and position
(3 0 13.46 13.35 17.77 4.55 17.77) & (403 60)
(3 0 10 14 40 14 40) & (492 60)

Load Case 1

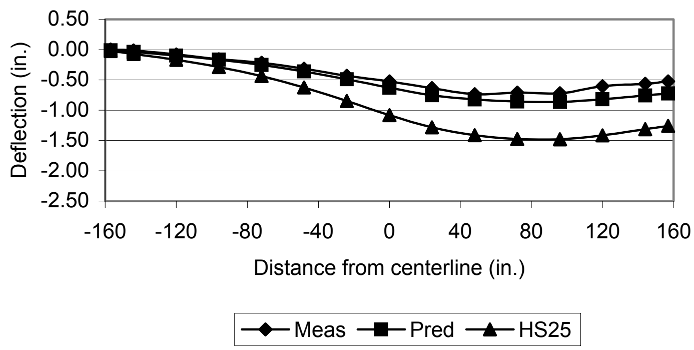


Plot Coordinates (in.)

(@265)	Meas	Pred	HS25
-157	0.00	-0.01	-0.02
-144	-0.01	-0.04	-0.07
-120	-0.08	-0.10	-0.17
-96	-0.16	-0.17	-0.29
-72	-0.22	-0.25	-0.44
-48	-0.31	-0.36	-0.63
-24	-0.43	-0.49	-0.85
0	-0.52	-0.63	-1.08
24	-0.64	-0.75	-1.28
48	-0.73	-0.82	-1.41
72	-0.71	-0.86	-1.48
96	-0.72	-0.87	-1.48
120	-0.60	-0.82	-1.41
144	-0.56	-0.76	-1.31
157	-0.52	-0.72	-1.26

Program input for truck axle weight and position
(3 0 12.52 13.50 18.08 4.20 18.08) & (428.6 -60)
(3 0 10 14 40 14 40) & (492 -60)

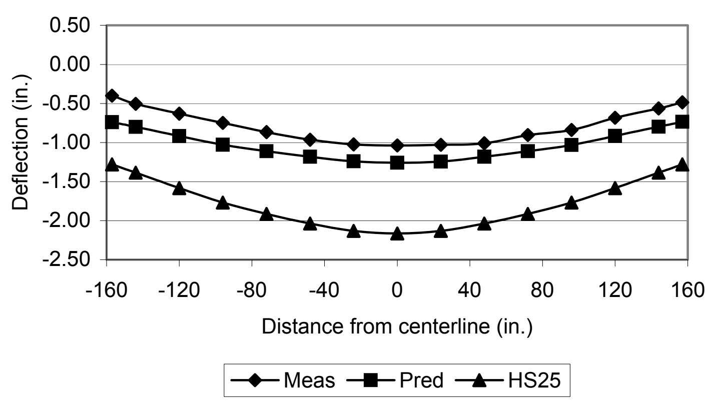
Load Case 2



Plot Coordinates (in.)

(@265)	Meas	Pred	HS25
-157	-0.40	-0.74	-1.28
-144	-0.51	-0.80	-1.39
-120	-0.63	-0.92	-1.58
-96	-0.75	-1.03	-1.77
-72	-0.87	-1.11	-1.91
-48	-0.96	-1.18	-2.04
-24	-1.02	-1.24	-2.13
0	-1.04	-1.26	-2.16
24	-1.03	-1.24	-2.13
48	-1.01	-1.18	-2.04
72	-0.91	-1.11	-1.91
96	-0.84	-1.03	-1.77
120	-0.68	-0.92	-1.58
144	-0.56	-0.80	-1.39
157	-0.49	-0.74	-1.28

Load Case 3



Jacobs bridge (Huntingdon County, PA)
Summary of 1998 Load Test Analysis with Orthotropic Plate Computer Program

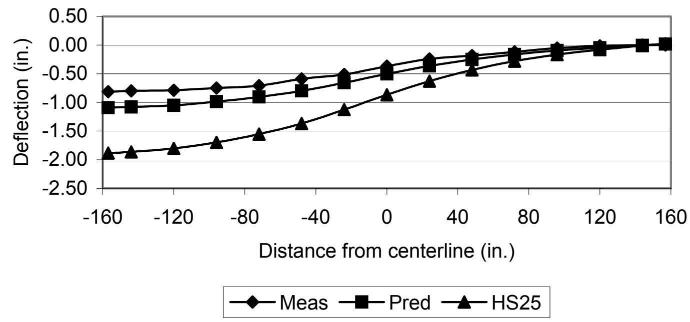
L = 530 in.	t = 16 in.	(~64 lb/in.^2 prestress)	(16 DEG. SKEW)	(E is 2.43 WOOD/STEEL)
b/2 = 157 in.	Ewood = 1,600,000 lb/in^2	Ets = 26,480 lb/in^2	Gts = 52,873 lb/in^2	Cbj = 0.90

Plot Coordinates (in.)

(@265)	Meas	Pred	HS25
-157	-0.81	-1.09	-1.88
-144	-0.80	-1.08	-1.86
-120	-0.79	-1.05	-1.80
-96	-0.75	-0.99	-1.70
-72	-0.71	-0.90	-1.55
-48	-0.59	-0.80	-1.37
-24	-0.51	-0.66	-1.13
0	-0.37	-0.50	-0.87
24	-0.24	-0.36	-0.63
48	-0.18	-0.25	-0.43
72	-0.12	-0.16	-0.28
96	-0.05	-0.10	-0.17
120	-0.01	-0.05	-0.08
144	0.00	0.00	-0.01
157	0.00	0.02	0.03

Program input for truck axle weight and position
(3 0 13.46 13.35 17.77 4.55 17.77) & (403 84)
(3 0 10 14 40 14 40) & (492 84)

Load Case 4

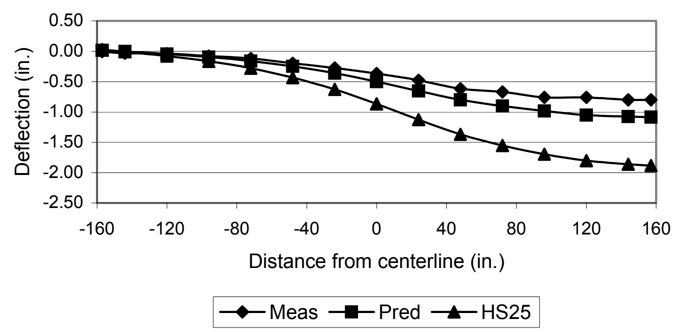


Plot Coordinates (in.)

(@265)	Meas	Pred	HS25
-157	-0.01	0.02	0.03
-144	-0.03	0.00	-0.01
-120	-0.04	-0.05	-0.08
-96	-0.08	-0.10	-0.17
-72	-0.12	-0.16	-0.28
-48	-0.20	-0.25	-0.43
-24	-0.28	-0.36	-0.63
0	-0.37	-0.50	-0.87
24	-0.48	-0.66	-1.13
48	-0.62	-0.80	-1.37
72	-0.67	-0.90	-1.55
96	-0.76	-0.98	-1.70
120	-0.76	-1.05	-1.80
144	-0.80	-1.08	-1.86
157	-0.80	-1.09	-1.88

Program input for truck axle weight and position
(3 0 12.52 13.50 18.08 4.20 18.08) & (428.6 -84)
(3 0 10 14 40 14 40) & (492 -84)

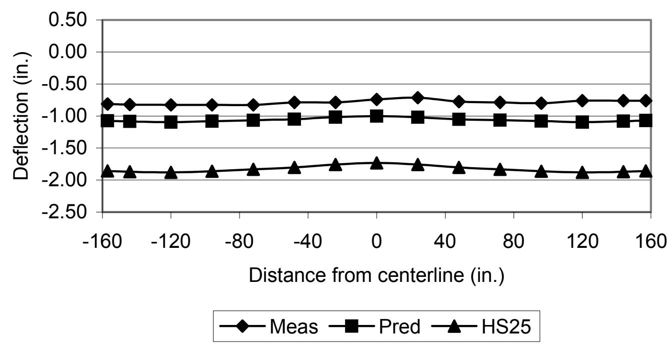
Load Case 5



Plot Coordinates (in.)

(@265)	Meas	Pred	HS25
-157	-0.81	-1.07	-1.86
-144	-0.82	-1.08	-1.87
-120	-0.83	-1.10	-1.88
-96	-0.83	-1.08	-1.86
-72	-0.83	-1.07	-1.83
-48	-0.79	-1.05	-1.80
-24	-0.79	-1.02	-1.76
0	-0.74	-1.00	-1.73
24	-0.72	-1.02	-1.76
48	-0.77	-1.05	-1.80
72	-0.79	-1.06	-1.83
96	-0.80	-1.08	-1.86
120	-0.76	-1.10	-1.88
144	-0.76	-1.08	-1.87
157	-0.76	-1.07	-1.86

Load Case 6



Jacobs bridge (Huntingdon County, PA)
Summary of 2001 Load Test Analysis with Orthotropic Plate Computer Program

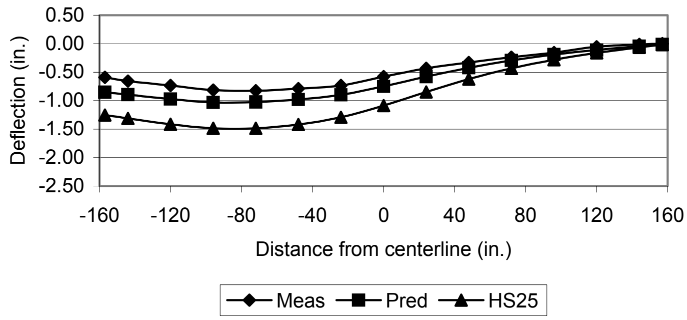
L = 530 in.	t = 16 in.	(~57 lb/in^2 prestress)	(16 DEG. SKEW)	(E is 2.43 WOOD/STEEL)
b/2 = 157 in.	Ewood = 1,600,000 lb/in^2	Ets = 25,306 lb/in^2	Gts = 51,235 lb/in^2	Cbj = 0.90

Plot Coordinates (in.)

(@265)	Meas	Pred	HS25
-157	-0.59	-0.85	-1.25
-144	-0.66	-0.89	-1.31
-120	-0.73	-0.97	-1.42
-96	-0.81	-1.03	-1.49
-72	-0.83	-1.02	-1.48
-48	-0.79	-0.98	-1.42
-24	-0.73	-0.90	-1.29
0	-0.58	-0.75	-1.09
24	-0.43	-0.58	-0.85
48	-0.33	-0.42	-0.62
72	-0.24	-0.29	-0.43
96	-0.16	-0.19	-0.28
120	-0.05	-0.11	-0.16
144	-0.01	-0.04	-0.06
157	0.00	-0.01	-0.02

Program input for truck axle weight and position
(3 0 12.3 12.3 22.40 4.60 22.00) & (440.2 60)
(3 0 10 14 40 14 40) & (492 60)

Load Case 1

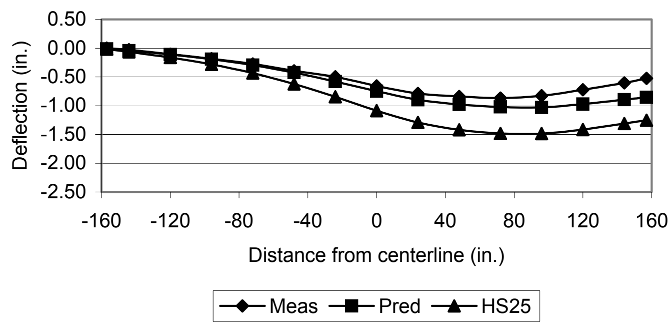


Plot Coordinates (in.)

(@265)	Meas	Pred	HS25
-157	0.00	-0.01	-0.02
-144	-0.03	-0.04	-0.06
-120	-0.10	-0.11	-0.16
-96	-0.18	-0.19	-0.28
-72	-0.28	-0.29	-0.43
-48	-0.39	-0.42	-0.62
-24	-0.50	-0.58	-0.85
0	-0.66	-0.75	-1.09
24	-0.79	-0.90	-1.29
48	-0.84	-0.98	-1.42
72	-0.87	-1.02	-1.48
96	-0.83	-1.03	-1.49
120	-0.72	-0.97	-1.42
144	-0.60	-0.89	-1.31
157	-0.52	-0.85	-1.25

Program input for truck axle weight and position
(3 0 15.00 13.45 21.50 4.20 21.40) & (451.6 -60)
(3 0 10 14 40 14 40) & (492 -60)

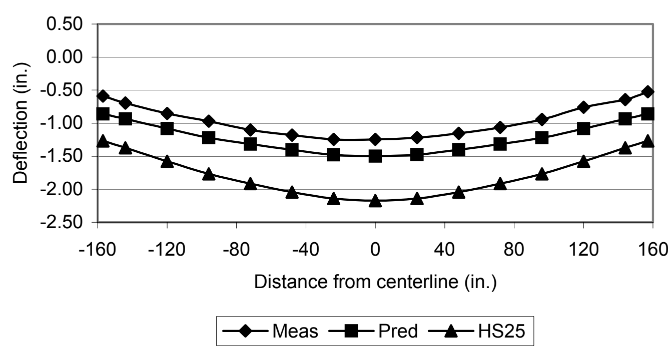
Load Case 2



Plot Coordinates (in.)

(@265)	Meas	Pred	HS25
-157	-0.59	-0.86	-1.27
-144	-0.70	-0.94	-1.37
-120	-0.85	-1.08	-1.58
-96	-0.97	-1.22	-1.77
-72	-1.10	-1.32	-1.92
-48	-1.18	-1.40	-2.04
-24	-1.25	-1.48	-2.14
0	-1.25	-1.50	-2.17
24	-1.22	-1.48	-2.14
48	-1.15	-1.40	-2.04
72	-1.06	-1.32	-1.92
96	-0.94	-1.22	-1.77
120	-0.76	-1.08	-1.58
144	-0.64	-0.94	-1.37
157	-0.52	-0.86	-1.27

Load Case 3



Jacobs bridge (Huntingdon County, PA)
Summary of 2001 Load Test Analysis with Orthotropic Plate Computer Program

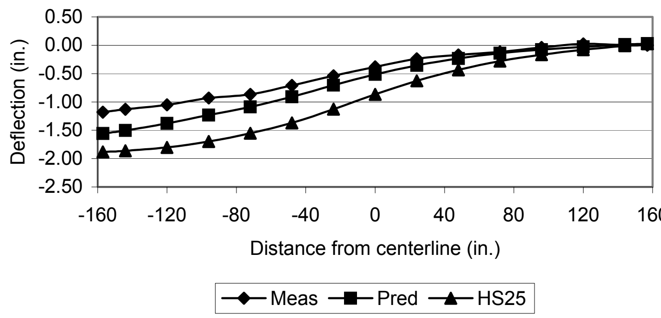
L = 530 in.	t = 16 in.	(~57 lb/in^2 prestress)	(16 DEG. SKEW)	(E is 2.43 WOOD/STEEL)
b/2 = 157 in.	Ewood = 1,600,000 lb/in^2	Ets = 25,306 lb/in^2	Gts = 51,235 lb/in^2	Cbj = 0.90

Plot Coordinates (in.)

(@265)	Meas	Pred	HS25
-157	-1.18	-1.56	-1.88
-144	-1.13	-1.50	-1.86
-120	-1.05	-1.38	-1.80
-96	-0.93	-1.23	-1.70
-72	-0.87	-1.09	-1.55
-48	-0.71	-0.91	-1.37
-24	-0.54	-0.70	-1.13
0	-0.38	-0.51	-0.87
24	-0.24	-0.36	-0.63
48	-0.17	-0.23	-0.43
72	-0.12	-0.14	-0.28
96	-0.04	-0.08	-0.17
120	0.03	-0.03	-0.08
144	0.00	0.01	-0.01
157	0.00	0.03	0.03

Program input for truck axle weight and position
(3 0 12.3 12.3 22.40 4.60 22.00) & (440.2 96)
(3 0 10 14 40 14 40) & (492 84)

Load Case 4

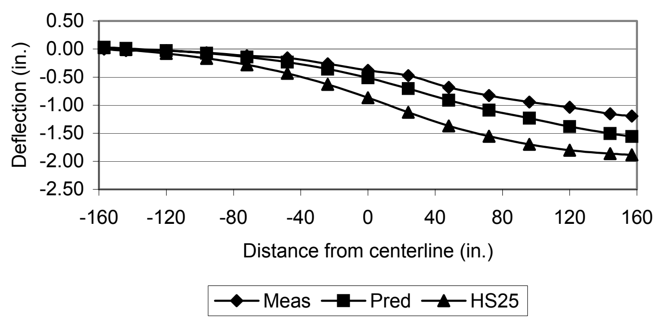


Plot Coordinates (in.)

(@265)	Meas	Pred	HS25
-157	0.00	0.03	0.03
-144	-0.03	0.01	-0.01
-120	-0.03	-0.03	-0.08
-96	-0.07	-0.08	-0.17
-72	-0.12	-0.14	-0.28
-48	-0.16	-0.23	-0.43
-24	-0.26	-0.36	-0.63
0	-0.38	-0.51	-0.87
24	-0.47	-0.70	-1.13
48	-0.68	-0.91	-1.37
72	-0.83	-1.09	-1.55
96	-0.94	-1.23	-1.70
120	-1.04	-1.38	-1.80
144	-1.15	-1.50	-1.86
157	-1.19	-1.56	-1.88

Program input for truck axle weight and position
(3 0 15.00 13.45 21.50 4.20 21.40) & (451.6 -96)
(3 0 10 14 40 14 40) & (492 -84)

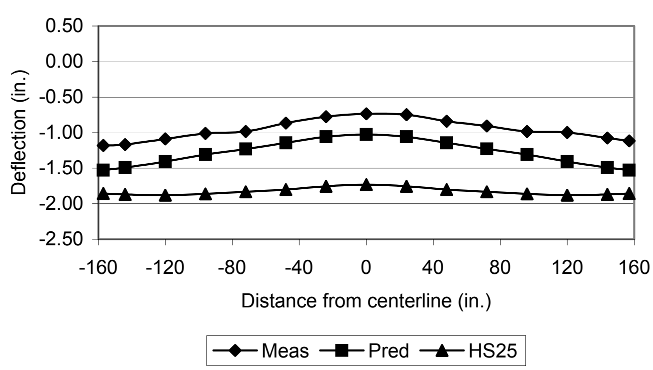
Load Case 5



Plot Coordinates (in.)

(@265)	Meas	Pred	HS25
-157	-1.18	-1.53	-1.86
-144	-1.17	-1.49	-1.87
-120	-1.09	-1.41	-1.88
-96	-1.01	-1.31	-1.86
-72	-0.98	-1.23	-1.83
-48	-0.87	-1.14	-1.80
-24	-0.77	-1.06	-1.76
0	-0.73	-1.03	-1.73
24	-0.75	-1.06	-1.76
48	-0.84	-1.14	-1.80
72	-0.91	-1.23	-1.83
96	-0.98	-1.31	-1.86
120	-1.00	-1.41	-1.88
144	-1.08	-1.49	-1.87
157	-1.12	-1.53	-1.86

Load Case 6



Millcross Road Bridge

General
Name: Millcross Road bridge
Location: Lancaster County, Pennsylvania
Date of construction: July 1992
Owner: East Lampeter Township

Design Configuration
Structure type: Stress-laminated deck with butt joints
Butt joint frequency: 1 in 3 laminations transversely, spaced 4 ft longitudinally
Length (out-out): 21 ft
Width (out-out): 30 ft
Skew: 0 degrees
Design loading: AASHTO HS25-44

Material and Configuration
Lumber deck laminations:
- Species: Red Oak
- Size: 3 by 16 in.
- Grade: No. 2, Northern Red Oak
- Preservative: Creosote

Stressing elements:
- Type: High strength steel threaded bar, conforming to ASTM A722, Type II
- Diameter: 1 in. (nominal)
- Spacing: 48 in.
- Anchorage Type: Continuous steel channel and bearing plates

Abutment type: Cast-in-place reinforced concrete

Millcross Road bridge: views of bridge, test sensor and load test.

Millcross Road Bridge (Lancaster County, PA)
Summary of 1998 Load Test Analysis with Orthotropic Plate Computer Program

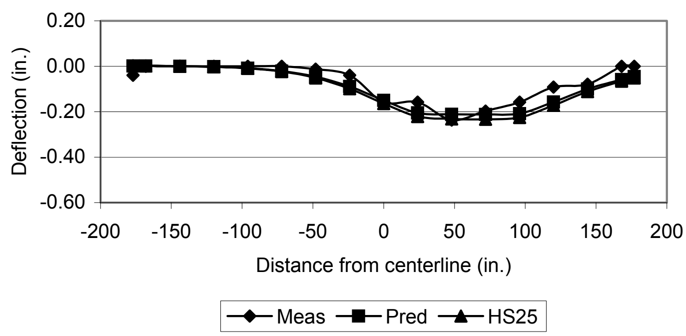
L = 260 in.	t = 15 in.	(~42 lb/in^2 prestress)	(NO SKEW)	(NO STEEL PLATES)
b/2 = 177 in.	Ewood = 1,600,000 lb/in^2	Ets = 22,791 lb/in^2	Gts = 47,725 lb/in^2	Cbj = 0.75

Plot Coordinates (in.)

(@130)	Meas	Pred	HS25
-177	-0.04	0.00	0.00
-168	0.00	0.00	0.00
-144	0.00	0.00	0.00
-120	0.00	0.00	0.00
-96	0.00	-0.01	-0.01
-72	0.00	-0.02	-0.02
-48	-0.01	-0.05	-0.05
-24	-0.04	-0.09	-0.10
0	-0.16	-0.15	-0.16
24	-0.16	-0.21	-0.22
48	-0.24	-0.21	-0.23
72	-0.20	-0.21	-0.23
96	-0.16	-0.21	-0.23
120	-0.09	-0.16	-0.17
144	-0.08	-0.10	-0.11
168	0.00	-0.06	-0.07
177	0.00	-0.05	-0.05

Program input for truck axle weight and position
(3 0 13.82 13.25 17.22 4.55 17.22) & (316.3 60)
(3 0 10 14 40 14 40) & (336 60)

Load Case 1

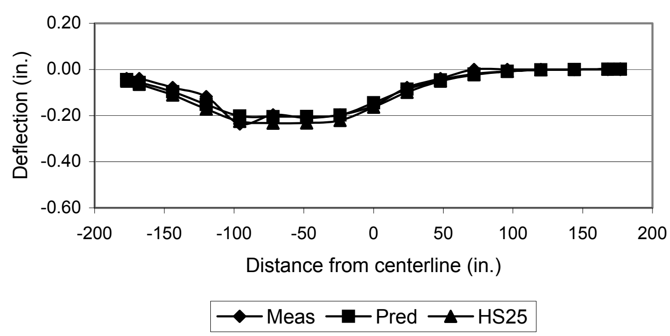


Plot Coordinates (in.)

(@130)	Meas	Pred	HS25
-177	-0.04	-0.04	-0.05
-168	-0.04	-0.06	-0.07
-144	-0.08	-0.10	-0.11
-120	-0.12	-0.15	-0.17
-96	-0.24	-0.20	-0.23
-72	-0.20	-0.21	-0.23
-48	-0.21	-0.20	-0.23
-24	-0.20	-0.20	-0.22
0	-0.16	-0.15	-0.16
24	-0.08	-0.09	-0.10
48	-0.04	-0.05	-0.05
72	0.00	-0.02	-0.02
96	0.00	-0.01	-0.01
120	0.00	0.00	0.00
144	0.00	0.00	0.00
168	0.00	0.00	0.00
177	0.00	0.00	0.00

Program input for truck axle weight and position
(3 013.76 13.25 16.66 4.55 16.66) & (316.3 -60)
(3 0 10 14 40 14 40) & (336 -60)

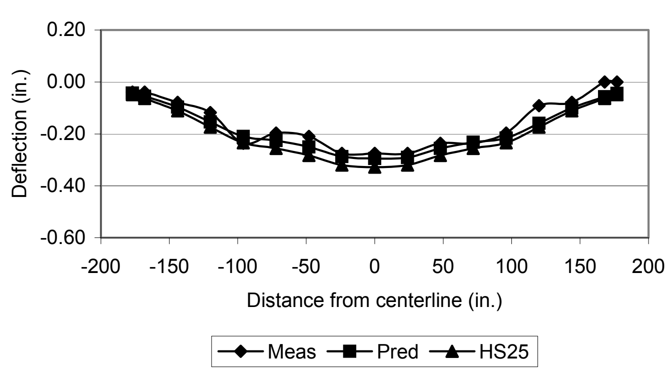
Load Case 2



Plot Coordinates (in.)

(@130)	Meas	Pred	HS25
-177	-0.04	-0.04	-0.05
-168	-0.04	-0.06	-0.06
-144	-0.08	-0.10	-0.11
-120	-0.12	-0.15	-0.17
-96	-0.24	-0.21	-0.23
-72	-0.20	-0.23	-0.26
-48	-0.21	-0.25	-0.28
-24	-0.28	-0.29	-0.32
0	-0.28	-0.30	-0.33
24	-0.28	-0.29	-0.32
48	-0.24	-0.26	-0.28
72	-0.24	-0.23	-0.26
96	-0.20	-0.22	-0.23
120	-0.09	-0.16	-0.17
144	-0.08	-0.10	-0.11
168	0.00	-0.06	-0.06
177	0.00	-0.04	-0.05

Load Case 3



Millcross Road Bridge (Lancaster County, PA)
Summary of 1998 Load Test Analysis with Orthotropic Plate Computer Program

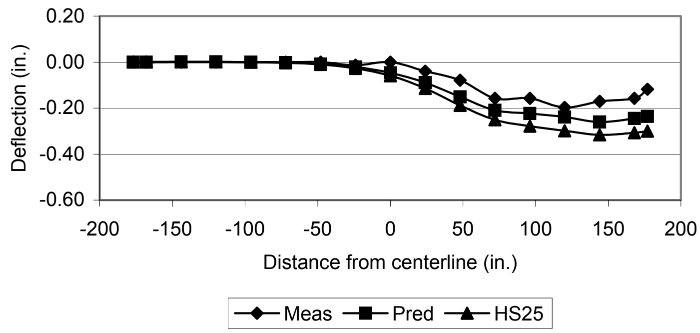
L = 260 in.	t = 15 in.	(~42 lb/in^2 prestress)	(NO SKEW)	(NO STEEL PLATES)
b/2 = 177 in.	Ewood = 1,600,000 lb/in^2	Ets = 22,791 lb/in^2	Gts = 47,725 lb/in^2	Cbj = 0.75

Plot Coordinates (in.)

(@130)	Meas	Pred	HS25
-177	0.00	0.00	0.00
-168	0.00	0.00	0.00
-144	0.00	0.00	0.00
-120	0.00	0.00	0.00
-96	0.00	0.00	0.00
-72	0.00	0.00	0.00
-48	0.00	-0.01	-0.01
-24	-0.01	-0.02	-0.03
0	0.00	-0.05	-0.06
24	-0.04	-0.09	-0.11
48	-0.08	-0.15	-0.19
72	-0.16	-0.21	-0.25
96	-0.16	-0.22	-0.28
120	-0.20	-0.24	-0.30
144	-0.17	-0.26	-0.32
168	-0.16	-0.25	-0.31
177	-0.12	-0.24	-0.30

Program input for truck axle weight and position
(3 0 13.82 13.25 17.22 4.55 17.22) & (316.3 108)
(3 0 10 14 40 14 40) & (336 108)

Load Case 4

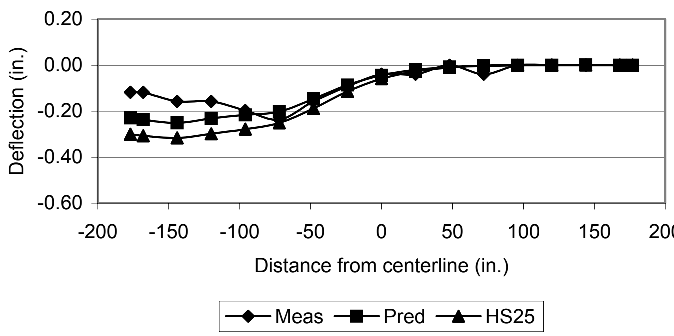


Plot Coordinates (in.)

(@130)	Meas	Pred	HS25
-177	-0.12	-0.23	-0.30
-168	-0.12	-0.24	-0.31
-144	-0.16	-0.25	-0.32
-120	-0.16	-0.23	-0.30
-96	-0.20	-0.22	-0.28
-72	-0.24	-0.20	-0.25
-48	-0.16	-0.15	-0.19
-24	-0.09	-0.09	-0.11
0	-0.04	-0.04	-0.06
24	-0.04	-0.02	-0.03
48	0.00	-0.01	-0.01
72	-0.04	0.00	0.00
96	0.00	0.00	0.00
120	0.00	0.00	0.00
144	0.00	0.00	0.00
168	0.00	0.00	0.00
177	0.00	0.00	0.00

Program input for truck axle weight and position
(3 013.76 13.25 16.66 4.55 16.66) & (316.3 -108)
(3 0 10 14 40 14 40) & (336 -108)

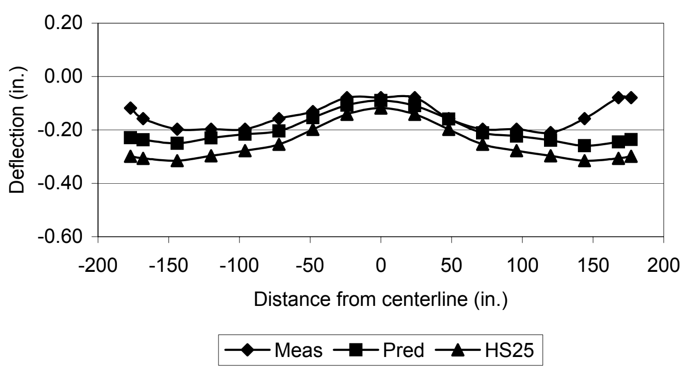
Load Case 5



Plot Coordinates (in.)

(@130)	Meas	Pred	HS25
-177	-0.12	-0.23	-0.30
-168	-0.16	-0.24	-0.31
-144	-0.20	-0.25	-0.32
-120	-0.20	-0.23	-0.30
-96	-0.20	-0.22	-0.28
-72	-0.16	-0.20	-0.25
-48	-0.13	-0.15	-0.20
-24	-0.08	-0.11	-0.14
0	-0.08	-0.09	-0.12
24	-0.08	-0.11	-0.14
48	-0.16	-0.16	-0.20
72	-0.20	-0.21	-0.25
96	-0.20	-0.22	-0.28
120	-0.21	-0.24	-0.30
144	-0.16	-0.26	-0.32
168	-0.08	-0.25	-0.31
177	-0.08	-0.24	-0.30

Load Case 6



Millcross Road Bridge (Lancaster County, PA)
Summary of 2001 Load Test Analysis with Orthotropic Plate Computer Program

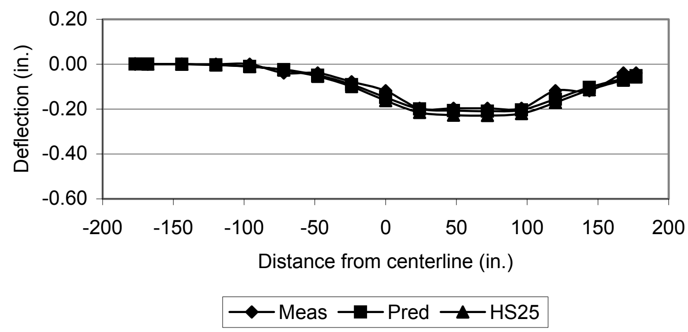
L = 260 in.	t = 15 in.	(~66 lb/in^2 prestress)	(NO SKEW)	(NO STEEL PLATES)
b/2 = 177 in.	Ewood = 1,600,000 lb/in^2	Ets = 26,815 lb/in^2	Gts = 53,341 lb/in^2	Cbj = 0.75

Plot Coordinates (in.)

(@130)	Meas	Pred	HS25
-177	0.00	0.00	0.00
-168	0.00	0.00	0.00
-144	0.00	0.00	0.00
-120	0.00	0.00	0.00
-96	0.00	-0.01	-0.01
-72	-0.04	-0.02	-0.03
-48	-0.04	-0.05	-0.05
-24	-0.08	-0.09	-0.10
0	-0.12	-0.15	-0.16
24	-0.20	-0.20	-0.22
48	-0.20	-0.21	-0.23
72	-0.20	-0.21	-0.23
96	-0.20	-0.20	-0.22
120	-0.12	-0.16	-0.17
144	-0.12	-0.10	-0.11
168	-0.04	-0.06	-0.07
177	-0.04	-0.05	-0.06

Program input for truck axle weight and position
(3 0 13.20 13.20 17.20 4.55 17.20) & (315.7 60)
(3 0 10 14 40 14 40) & (336 60)

Load Case 1

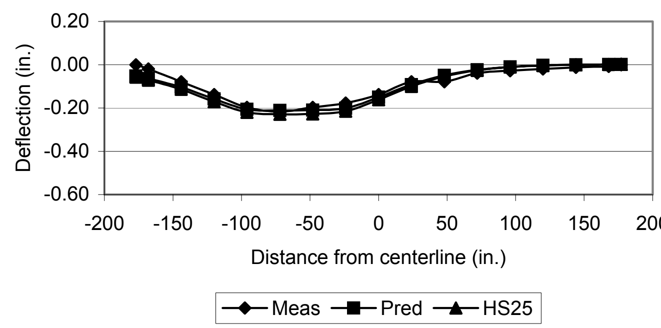


Plot Coordinates (in.)

(@130)	Meas	Pred	HS25
-177	0.00	-0.05	-0.06
-168	-0.02	-0.06	-0.07
-144	-0.08	-0.10	-0.11
-120	-0.14	-0.16	-0.17
-96	-0.20	-0.21	-0.22
-72	-0.22	-0.21	-0.23
-48	-0.20	-0.21	-0.23
-24	-0.18	-0.20	-0.22
0	-0.14	-0.15	-0.16
24	-0.08	-0.09	-0.10
48	-0.08	-0.05	-0.05
72	-0.04	-0.02	-0.03
96	-0.03	-0.01	-0.01
120	-0.02	0.00	0.00
144	-0.01	0.00	0.00
168	-0.01	0.00	0.00
177	0.00	0.00	0.00

Program input for truck axle weight and position
(3 0 14.30 13.60 17.20 4.20 17.20) & (319.6 -60)
(3 0 10 14 40 14 40) & (336 -60)

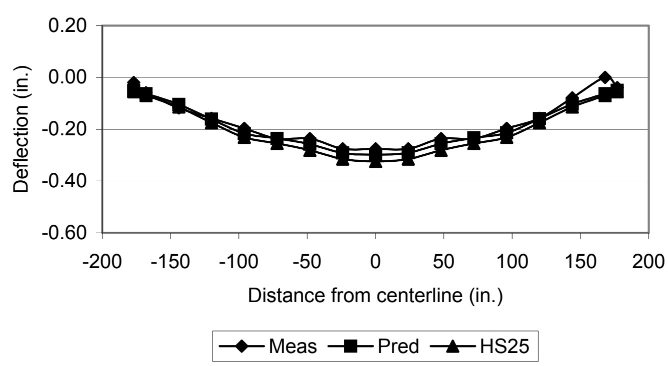
Load Case 2



Plot Coordinates (in.)

(@130)	Meas	Pred	HS25
-177	-0.02	-0.05	-0.06
-168	-0.06	-0.06	-0.07
-144	-0.12	-0.10	-0.11
-120	-0.16	-0.16	-0.18
-96	-0.20	-0.22	-0.23
-72	-0.24	-0.24	-0.26
-48	-0.24	-0.26	-0.28
-24	-0.28	-0.29	-0.32
0	-0.28	-0.30	-0.32
24	-0.28	-0.29	-0.32
48	-0.24	-0.26	-0.28
72	-0.24	-0.23	-0.26
96	-0.20	-0.21	-0.23
120	-0.16	-0.16	-0.18
144	-0.08	-0.10	-0.11
168	0.00	-0.06	-0.07
177	-0.04	-0.05	-0.06

Load Case 3



Millcross Road Bridge (Lancaster County, PA)
Summary of 2001 Load Test Analysis with Orthotropic Plate Computer Program

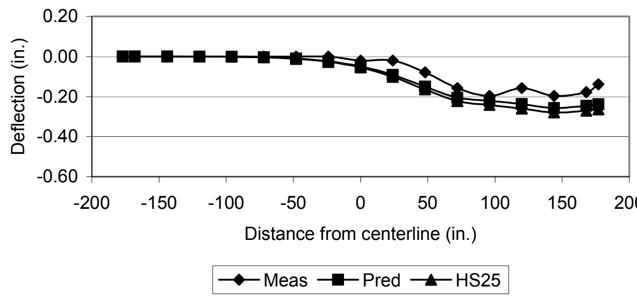
L = 260 in.	t = 15 in.	(~66 lb/in^2 prestress)	(NO SKEW)	(NO STEEL PLATES)
b/2 = 177 in.	Ewood = 1,600,000 lb/in^2	Ets = 26,815 lb/in^2	Gts = 53,341 lb/in^2	Cbj = 0.75

Plot Coordinates (in.)

(@130)	Meas	Pred	HS25
-177	0.00	0.00	0.00
-168	0.00	0.00	0.00
-144	0.00	0.00	0.00
-120	0.00	0.00	0.00
-96	0.00	0.00	0.00
-72	0.00	0.00	0.00
-48	0.00	-0.01	-0.01
-24	0.00	-0.02	-0.03
0	-0.02	-0.05	-0.05
24	-0.02	-0.09	-0.10
48	-0.08	-0.15	-0.16
72	-0.16	-0.21	-0.22
96	-0.20	-0.22	-0.24
120	-0.16	-0.24	-0.26
144	-0.20	-0.26	-0.28
168	-0.18	-0.25	-0.27
177	-0.14	-0.24	-0.26

Program input for truck axle weight and position
(3 0 13.20 13.20 17.20 4.55 17.20) & (315.7 108)
(3 0 10 14 40 14 40) & (336 108)

Load Case 4

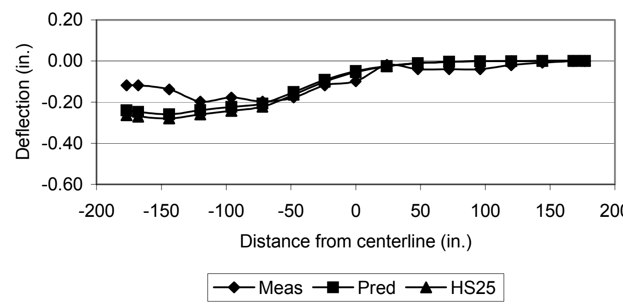


Plot Coordinates (in.)

(@130)	Meas	Pred	HS25
-177	-0.12	-0.24	-0.26
-168	-0.12	-0.25	-0.27
-144	-0.14	-0.26	-0.28
-120	-0.20	-0.24	-0.26
-96	-0.18	-0.22	-0.24
-72	-0.20	-0.21	-0.22
-48	-0.18	-0.15	-0.16
-24	-0.12	-0.09	-0.10
0	-0.10	-0.05	-0.05
24	-0.02	-0.02	-0.03
48	-0.04	-0.01	-0.01
72	-0.04	0.00	0.00
96	-0.04	0.00	0.00
120	-0.02	0.00	0.00
144	-0.01	0.00	0.00
168	0.00	0.00	0.00
177	0.00	0.00	0.00

Program input for truck axle weight and position
(3 0 14.30 13.60 17.20 4.20 17.20) & (319.6 -108)
(3 0 10 14 40 14 40) & (336 -108)

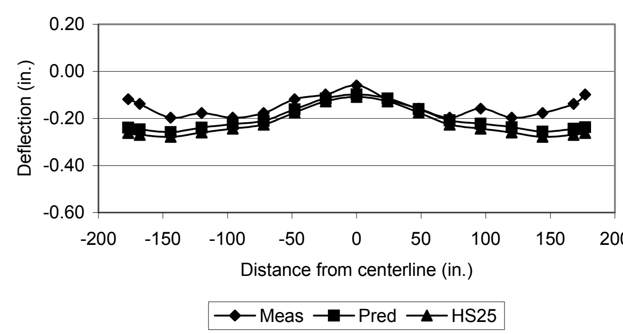
Load Case 5



Plot Coordinates (in.)

(@130)	Meas	Pred	HS25
-177	-0.12	-0.24	-0.26
-168	-0.14	-0.25	-0.27
-144	-0.20	-0.26	-0.28
-120	-0.18	-0.24	-0.26
-96	-0.20	-0.22	-0.24
-72	-0.18	-0.21	-0.23
-48	-0.12	-0.16	-0.18
-24	-0.10	-0.12	-0.13
0	-0.06	-0.10	-0.11
24	-0.12	-0.12	-0.13
48	-0.16	-0.16	-0.18
72	-0.20	-0.21	-0.23
96	-0.16	-0.22	-0.24
120	-0.20	-0.24	-0.26
144	-0.18	-0.26	-0.28
168	-0.14	-0.24	-0.27
177	-0.10	-0.24	-0.26

Load Case 6



Dogwood Lane Bridge

General
Name: Dogwood Lane bridge
Location: Schuylkill County, Pennsylvania
Date of construction: October 1993
Owner: West Brunswick Township

Design Configuration
Structure type: Stress-laminated deck with butt joints (composite with steel plates)
Steel plate frequency: 1 after every 4 lumber laminations transversely
Butt joint frequency: 1 in 4 laminations transversely, spaced 4 ft longitudinally
Length (out-out): 36 ft
Width (out-out): 26 ft
Skew: 0 degrees
Design loading: AASHTO HS25-44

Material and Configuration
Lumber deck laminations:
- Species: Red Oak
- Size: 3 by 15 in.
- Grade: No. 2, Northern Red Oak
- Preservative: Creosote

Stressing elements:
- Type: High strength steel threaded bar, conforming to ASTM A722, Type II
- Diameter: 1 in. (nominal)
- Spacing: 32 in.
- Anchorage Type: Continuous steel channel and bearing plates

Abutment type: Cast-in-place reinforced concrete

Dogwood Lane bridge: views of bridge, load cell, and load test.

Dogwood Lane bridge (Schuylkill County, PA)
Summary of 1998 Load Test Analysis with Orthotropic Plate Computer Program

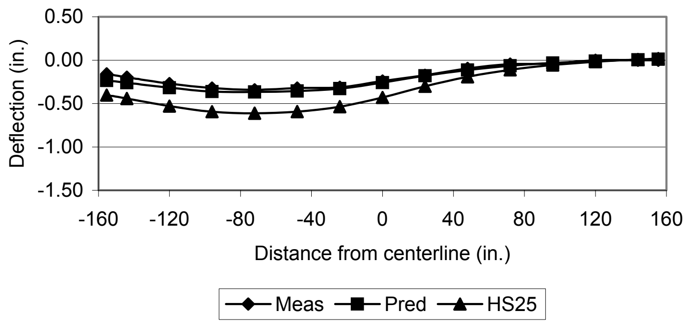
L = 412 in.	t = 16 in.	(~71 lb/in^2 prestress)	(NO SKEW)	(E is 2.83 WOOD/STEEL)
b/2 = 155.4 in.	Ewood = 1,600,000 lb/in^2	Ets = 27,654 lb/in^2	Gts = 54,511 lb/in^2	Cbj = 0.90

Plot Coordinates (in.)

(@206)	Meas	Pred	HS25
-155.4	-0.16	-0.23	-0.40
-144	-0.20	-0.26	-0.44
-120	-0.27	-0.32	-0.53
-96	-0.32	-0.36	-0.59
-72	-0.34	-0.37	-0.61
-48	-0.32	-0.36	-0.59
-24	-0.31	-0.33	-0.54
0	-0.24	-0.26	-0.43
24	-0.17	-0.18	-0.30
48	-0.10	-0.11	-0.19
72	-0.05	-0.06	-0.11
96	-0.04	-0.03	-0.05
120	0.00	-0.01	-0.02
144	0.00	0.01	0.01
155.4	0.00	0.01	0.02

Program input for truck axle weight and position
(3 0 14.40 12.80 18.10 4.40 17.65) & (386 60)
(3 0 10 14 40 14 40) & (458 60)

Load Case 1

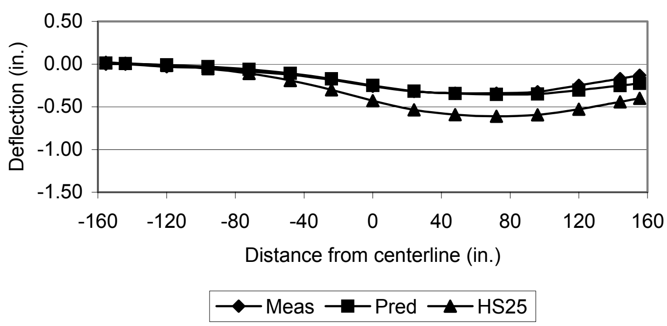


Plot Coordinates (in.)

(@206)	Meas	Pred	HS25
-155.4	0.00	0.01	0.02
-144	0.00	0.01	0.01
-120	-0.03	-0.01	-0.02
-96	-0.05	-0.03	-0.05
-72	-0.09	-0.06	-0.11
-48	-0.12	-0.11	-0.19
-24	-0.18	-0.17	-0.30
0	-0.26	-0.25	-0.43
24	-0.32	-0.32	-0.54
48	-0.34	-0.34	-0.59
72	-0.34	-0.36	-0.61
96	-0.32	-0.35	-0.59
120	-0.25	-0.31	-0.53
144	-0.17	-0.25	-0.44
155.4	-0.13	-0.23	-0.40

Program input for truck axle weight and position
(3 0 12.70 12.50 17.70 4.50 17.70) & (383 -60)
(3 0 10 14 40 14 40) & (458 -60)

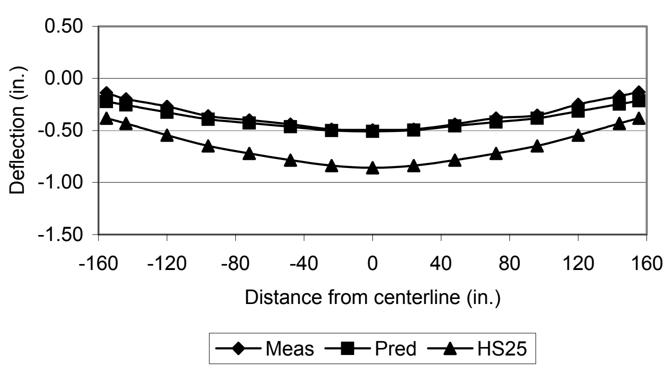
Load Case 2



Plot Coordinates (in.)

(@206)	Meas	Pred	HS25
-155.4	-0.14	-0.22	-0.38
-144	-0.20	-0.26	-0.43
-120	-0.27	-0.33	-0.55
-96	-0.36	-0.39	-0.65
-72	-0.40	-0.43	-0.72
-48	-0.44	-0.46	-0.79
-24	-0.49	-0.50	-0.84
0	-0.50	-0.51	-0.86
24	-0.49	-0.50	-0.84
48	-0.44	-0.46	-0.79
72	-0.38	-0.42	-0.72
96	-0.35	-0.38	-0.65
120	-0.25	-0.32	-0.55
144	-0.17	-0.25	-0.43
155.4	-0.13	-0.22	-0.38

Load Case 3



Dogwood Lane bridge (Schuylkill County, PA)
Summary of 1998 Load Test Analysis with Orthotropic Plate Computer Program

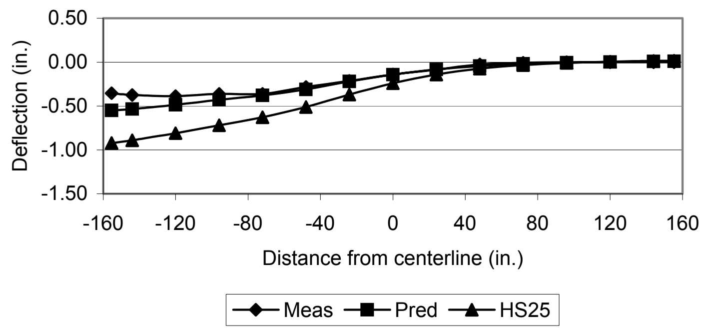
L = 412 in.	t = 16 in.	(~71 lb/in^2 prestress)	(NO SKEW)	(E is 2.83 WOOD/STEEL)
b/2 = 155.4 in.	Ewood = 1,600,000 lb/in^2	Ets = 27,654 lb/in^2	Gts = 54,511 lb/in^2	Cbj = 0.90

Plot Coordinates (in.)

(@206)	Meas	Pred	HS25
-155.4	-0.35	-0.55	-0.92
-144	-0.37	-0.53	-0.89
-120	-0.39	-0.49	-0.81
-96	-0.36	-0.43	-0.72
-72	-0.36	-0.38	-0.63
-48	-0.28	-0.31	-0.51
-24	-0.21	-0.22	-0.37
0	-0.14	-0.14	-0.24
24	-0.09	-0.08	-0.14
48	-0.03	-0.04	-0.07
72	-0.01	-0.02	-0.03
96	0.00	-0.01	-0.01
120	0.00	0.00	0.01
144	0.00	0.01	0.01
155.4	0.00	0.01	0.02

Program input for truck axle weight and position
(3 0 14.40 12.80 18.10 4.40 17.65) & (386 96)
(3 0 10 14 40 14 40) & (458 96)

Load Case 4

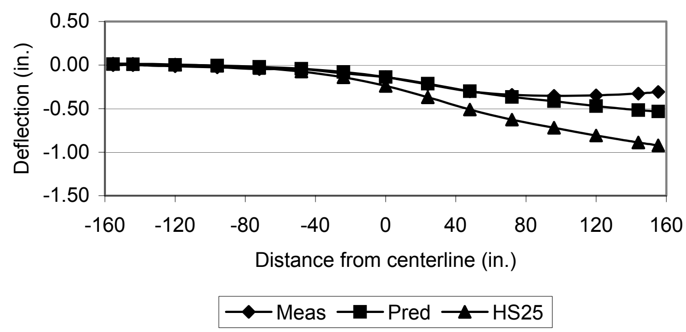


Plot Coordinates (in.)

(@206)	Meas	Pred	HS25
-155.4	0.00	0.01	0.02
-144	0.00	0.01	0.02
-120	-0.01	0.00	0.01
-96	-0.03	-0.01	-0.01
-72	-0.05	-0.02	-0.03
-48	-0.05	-0.04	-0.07
-24	-0.10	-0.08	-0.14
0	-0.14	-0.14	-0.24
24	-0.22	-0.21	-0.37
48	-0.30	-0.30	-0.51
72	-0.34	-0.37	-0.63
96	-0.35	-0.42	-0.72
120	-0.35	-0.47	-0.81
144	-0.33	-0.52	-0.89
155.4	-0.31	-0.53	-0.92

Program input for truck axle weight and position
(3 0 12.70 12.50 17.70 4.50 17.70) & (383 -96)
(3 0 10 14 40 14 40) & (458 -96)

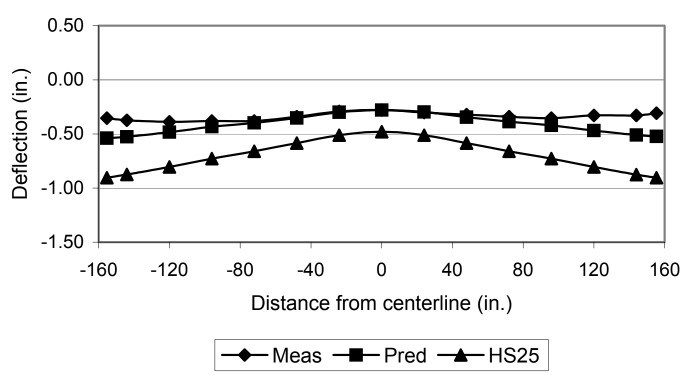
Load Case 5



Plot Coordinates (in.)

(@206)	Meas	Pred	HS25
-155.4	-0.35	-0.54	-0.91
-144	-0.37	-0.53	-0.88
-120	-0.39	-0.48	-0.81
-96	-0.38	-0.43	-0.73
-72	-0.38	-0.40	-0.66
-48	-0.34	-0.35	-0.59
-24	-0.29	-0.30	-0.51
0	-0.28	-0.28	-0.48
24	-0.30	-0.30	-0.51
48	-0.32	-0.35	-0.59
72	-0.34	-0.39	-0.66
96	-0.35	-0.42	-0.73
120	-0.33	-0.47	-0.81
144	-0.33	-0.51	-0.88
155.4	-0.31	-0.52	-0.91

Load Case 6



Dogwood Lane bridge (Schuylkill County, PA)
Summary of 2001 Load Test Analysis with Orthotropic Plate Computer Program

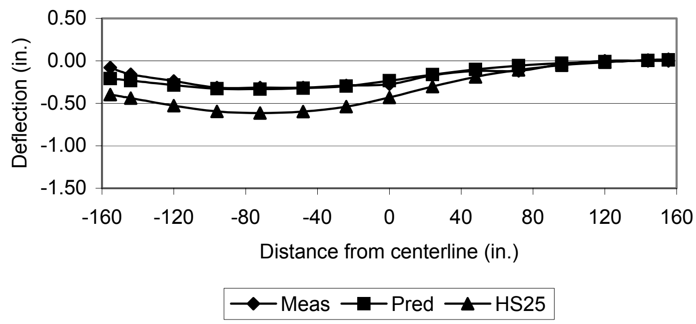
L = 412 in.	t = 16 in.	(~63 lb/in^2 prestress)	(NO SKEW)	(E is 2.83 WOOD/STEEL)
b/2 = 155.4 in.	Ewood = 1,600,000 lb/in^2	Ets = 26,312 lb/in^2	Gts = 52,639 lb/in^2	Cbj = 0.90

Plot Coordinates (in.)

(@206)	Meas	Pred	HS25
-155.4	-0.08	-0.21	-0.40
-144	-0.16	-0.23	-0.44
-120	-0.24	-0.29	-0.53
-96	-0.31	-0.33	-0.60
-72	-0.31	-0.33	-0.62
-48	-0.31	-0.32	-0.60
-24	-0.29	-0.30	-0.54
0	-0.28	-0.23	-0.43
24	-0.17	-0.16	-0.30
48	-0.12	-0.10	-0.19
72	-0.12	-0.06	-0.11
96	-0.04	-0.03	-0.05
120	0.00	-0.01	-0.02
144	0.00	0.01	0.01
155.4	0.00	0.01	0.02

Program input for truck axle weight and position
(3 0 13.00 13.50 16.65 4.20 16.45) & (394.4 60)
(3 0 10 14 40 14 40) & (458 60)

Load Case 1

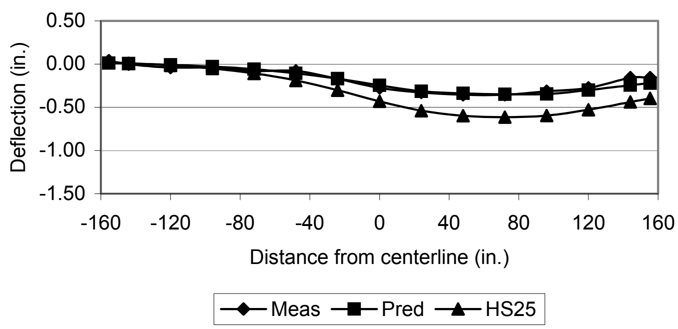


Plot Coordinates (in.)

(@206)	Meas	Pred	HS25
-155.4	0.04	0.01	0.02
-144	0.00	0.01	0.01
-120	-0.04	-0.01	-0.02
-96	-0.04	-0.03	-0.05
-72	-0.08	-0.06	-0.11
-48	-0.08	-0.11	-0.19
-24	-0.17	-0.17	-0.30
0	-0.28	-0.25	-0.43
24	-0.33	-0.31	-0.54
48	-0.35	-0.34	-0.60
72	-0.35	-0.35	-0.62
96	-0.31	-0.35	-0.60
120	-0.28	-0.30	-0.53
144	-0.16	-0.24	-0.44
155.4	-0.16	-0.22	-0.40

Program input for truck axle weight and position
(3 0 12.85 13.50 17.55 4.10 17.40) & (392.6 -60)
(3 0 10 14 40 14 40) & (458 -60)

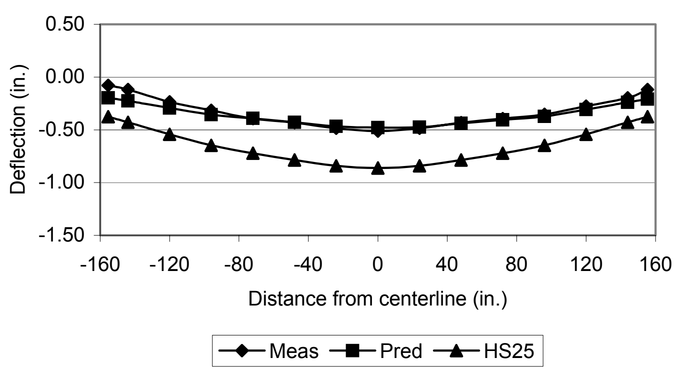
Load Case 2



Plot Coordinates (in.)

(@206)	Meas	Pred	HS25
-155.4	-0.08	-0.20	-0.38
-144	-0.12	-0.23	-0.43
-120	-0.24	-0.29	-0.54
-96	-0.31	-0.36	-0.65
-72	-0.39	-0.39	-0.72
-48	-0.43	-0.43	-0.79
-24	-0.49	-0.47	-0.84
0	-0.51	-0.48	-0.86
24	-0.49	-0.48	-0.84
48	-0.43	-0.44	-0.79
72	-0.39	-0.41	-0.72
96	-0.35	-0.37	-0.65
120	-0.28	-0.31	-0.54
144	-0.20	-0.24	-0.43
155.4	-0.12	-0.21	-0.38

Load Case 3



Dogwood Lane bridge (Schuylkill County, PA)
Summary of 2001 Load Test Analysis with Orthotropic Plate Computer Program

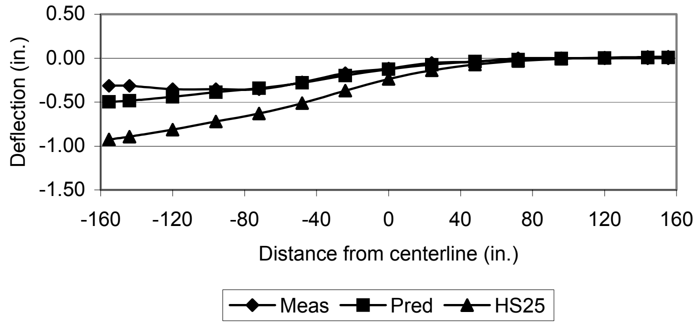
L = 412 in.	t = 16 in.	(~63 lb/in^2 prestress)	(NO SKEW)	(E is 2.83 WOOD/STEEL)
b/2 = 155.4 in.	Ewood = 1,600,000 lb/in^2	Ets = 26,312 lb/in^2	Gts = 52,639 lb/in^2	Cbj = 0.90

Plot Coordinates (in.)

(@206)	Meas	Pred	HS25
-155.4	-0.31	-0.50	-0.93
-144	-0.31	-0.48	-0.89
-120	-0.35	-0.44	-0.81
-96	-0.35	-0.39	-0.72
-72	-0.35	-0.34	-0.63
-48	-0.28	-0.28	-0.51
-24	-0.17	-0.20	-0.37
0	-0.12	-0.13	-0.24
24	-0.05	-0.07	-0.14
48	-0.04	-0.04	-0.07
72	0.00	-0.02	-0.03
96	0.00	0.00	-0.01
120	0.00	0.00	0.01
144	0.00	0.01	0.01
155.4	0.00	0.01	0.02

Program input for truck axle weight and position
(3 0 13.00 13.50 16.65 4.20 16.45) & (394.4 96)
(3 0 10 14 40 14 40) & (458 96)

Load Case 4

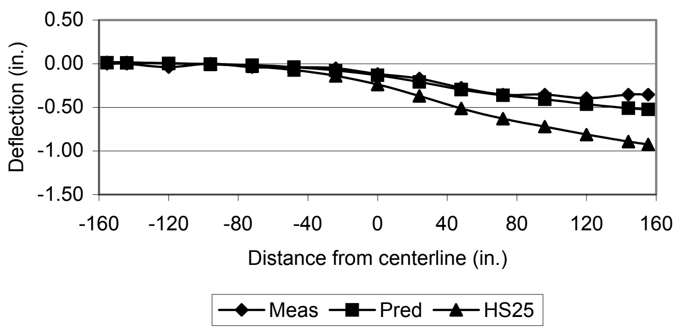


Plot Coordinates (in.)

(@206)	Meas	Pred	HS25
-155.4	0.00	0.01	0.02
-144	0.00	0.01	0.01
-120	-0.04	0.00	0.01
-96	0.00	0.00	-0.01
-72	-0.04	-0.02	-0.03
-48	-0.04	-0.04	-0.07
-24	-0.05	-0.08	-0.14
0	-0.12	-0.13	-0.24
24	-0.17	-0.21	-0.37
48	-0.28	-0.30	-0.51
72	-0.35	-0.36	-0.63
96	-0.35	-0.41	-0.72
120	-0.39	-0.46	-0.81
144	-0.35	-0.51	-0.89
155.4	-0.35	-0.52	-0.93

Program input for truck axle weight and position
(3 0 12.85 13.50 17.55 4.10 17.40) & (392.6 -96)
(3 0 10 14 40 14 40) & (458 -96)

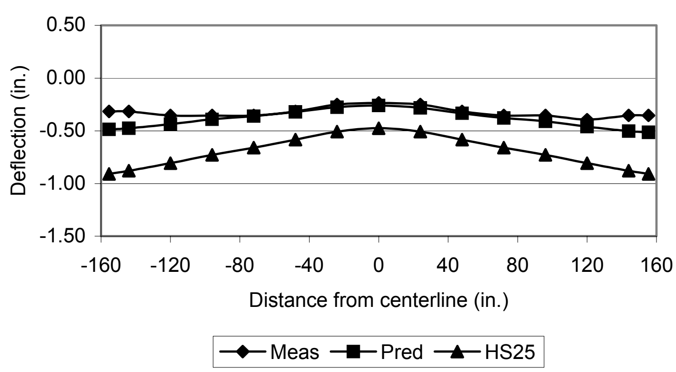
Load Case 5



Plot Coordinates (in.)

(@206)	Meas	Pred	HS25
-155.4	-0.31	-0.49	-0.91
-144	-0.31	-0.48	-0.88
-120	-0.35	-0.44	-0.81
-96	-0.35	-0.39	-0.73
-72	-0.35	-0.36	-0.66
-48	-0.31	-0.32	-0.58
-24	-0.25	-0.28	-0.51
0	-0.24	-0.26	-0.48
24	-0.25	-0.28	-0.51
48	-0.31	-0.33	-0.58
72	-0.35	-0.38	-0.66
96	-0.35	-0.41	-0.73
120	-0.39	-0.46	-0.81
144	-0.35	-0.50	-0.88
155.4	-0.35	-0.52	-0.91

Load Case 6



Birch Creek Bridge

General
Name: Birch Creek bridge
Location: Sullivan County, Pennsylvania
Date of construction: March 1992
Owner: Cherry Township

Design Configuration
Structure type: Stress-laminated deck with butt joints
Butt joint frequency: 1 in 3 laminations transversely, spaced 3.5 ft longitudinally
Length (out-out): 25 ft
Width (out-out): 26 ft
Skew: 16 degrees
Design loading: AASHTO HS25-44

Material and Configuration
Lumber deck laminations:
- Species: Beech
- Size: 3 by 16 in.
- Grade: No. 2, Beech, Birch, & Hickory
- Preservative: Creosote

Stressing elements:
- Type: High strength steel threaded bar, conforming to ASTM A722, Type II
- Diameter: 1 in. (nominal)
- Spacing: 38 in.
- Anchorage Type: Continuous steel channel and bearing plates

Abutment type: Cast-in-place reinforced concrete

Birch Creek bridge: views of bridge and load test.

Birch Creek bridge (Sullivan County, PA)
Summary of 1998 Load Test Analysis with Orthotropic Plate Computer Program

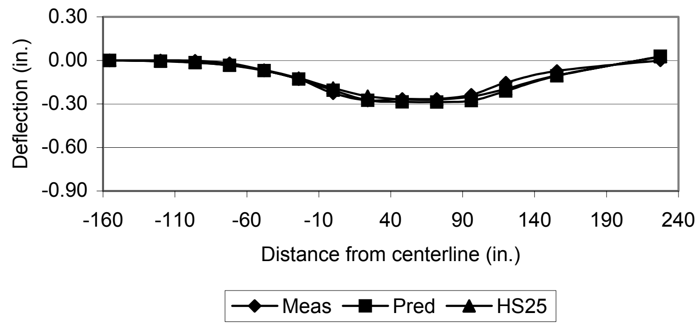
L = 272 in.	t = 15.6 in.	(~63 lb/in^2 prestress)	(NO SKEW)	(NO STEEL PLATES)
b/2 = 191 in.	E = 1,700,000 lb/in^2	Ets = 26,312 lb/in^2	Gts = 52,639 lb/in^2	Cbj = 0.75

Load Case 1

Program input for truck axle weight and position
(3 0 15.80 13.50 24.65 4.20 24.85) & (324.4 60)
(3 0 10 14 40 14 40) & (388 60)

Plot Coordinates (in.)

(@136)	Meas	Pred	HS25
-155.5	0.00	0.00	0.00
-120	0.00	-0.01	-0.01
-96	0.00	-0.02	-0.01
-72	-0.02	-0.03	-0.03
-48	-0.07	-0.07	-0.07
-24	-0.13	-0.13	-0.12
0	-0.23	-0.21	-0.19
24	-0.28	-0.28	-0.25
48	-0.27	-0.29	-0.27
72	-0.27	-0.29	-0.27
96	-0.24	-0.28	-0.25
120	-0.15	-0.21	-0.20
155.5	-0.07	-0.11	-0.10
227.5	0.00	0.03	0.03

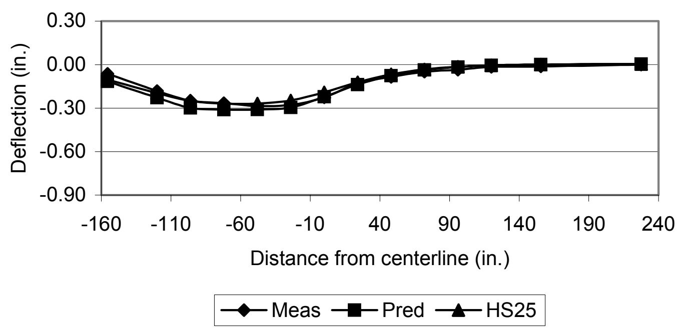


Load Case 2

Program input for truck axle weight and position
(3 0 13.30 12.20 26.85 4.65 26.70) & (310.3 -60)
(3 0 10 14 40 14 40) & (388 -60)

Plot Coordinates (in.)

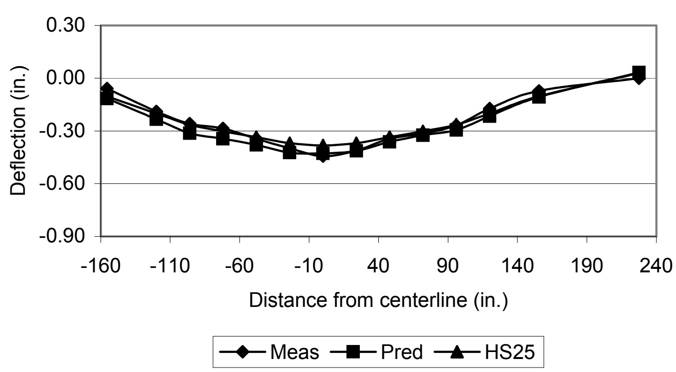
(@136)	Meas	Pred	HS25
-155.5	-0.06	-0.12	-0.10
-120	-0.18	-0.23	-0.20
-96	-0.25	-0.30	-0.25
-72	-0.27	-0.31	-0.27
-48	-0.29	-0.31	-0.27
-24	-0.28	-0.30	-0.25
0	-0.23	-0.22	-0.19
24	-0.13	-0.14	-0.12
48	-0.08	-0.08	-0.07
72	-0.05	-0.04	-0.03
96	-0.04	-0.02	-0.01
120	-0.02	-0.01	-0.01
155.5	-0.01	0.00	0.00
227.5	0.00	0.00	0.00



Load Case 3

Plot Coordinates (in.)

(@136)	Meas	Pred	HS25
-155.5	-0.06	-0.12	-0.10
-120	-0.19	-0.23	-0.20
-96	-0.26	-0.31	-0.26
-72	-0.29	-0.34	-0.30
-48	-0.34	-0.38	-0.34
-24	-0.40	-0.42	-0.37
0	-0.44	-0.43	-0.38
24	-0.41	-0.41	-0.37
48	-0.34	-0.36	-0.34
72	-0.31	-0.32	-0.30
96	-0.27	-0.29	-0.26
120	-0.17	-0.22	-0.20
155.5	-0.07	-0.11	-0.10
227.5	0.00	0.03	0.03



Birch Creek bridge (Sullivan County, PA)
Summary of 2001 Load Test Analysis with Orthotropic Plate Computer Program

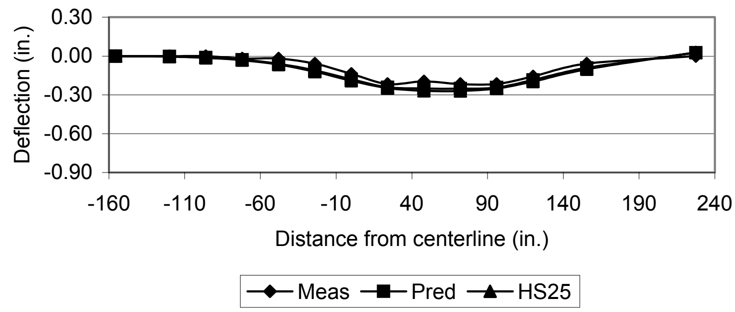
L = 272 in.	t = 15.6 in.	(~58 lb/in^2 prestress)	(NO SKEW)	(NO STEEL PLATES)
b/2 = 191 in.	E = 1,700,000 lb/in^2	Ets = 25,474 lb/in^2	Gts = 51,469 lb/in^2	Cbj = 0.75

Plot Coordinates (in.)

(@136)	Meas	Pred	HS25
-155.5	0.00	0.00	0.00
-120	0.00	0.00	-0.01
-96	0.00	-0.01	-0.01
-72	-0.02	-0.03	-0.03
-48	-0.02	-0.06	-0.07
-24	-0.06	-0.11	-0.12
0	-0.14	-0.18	-0.19
24	-0.22	-0.24	-0.25
48	-0.20	-0.25	-0.27
72	-0.22	-0.25	-0.27
96	-0.22	-0.24	-0.25
120	-0.16	-0.19	-0.20
155.5	-0.06	-0.09	-0.10
227.5	0.00	0.03	0.03

Program input for truck axle weight and position
(3 0 14.00 13.40 21.50 4.20 21.85) & (322 60)
(3 0 10 14 40 14 40) & (388 60)

Load Case 1

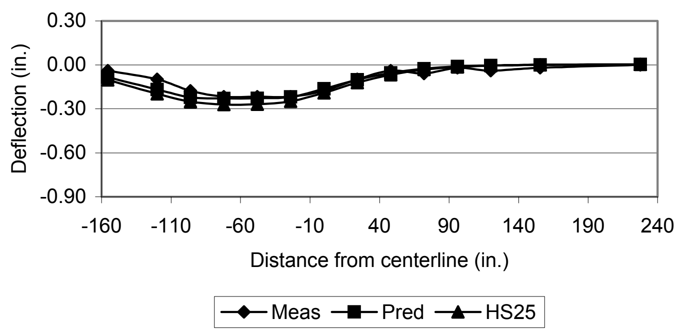


Plot Coordinates (in.)

(@136)	Meas	Pred	HS25
-155.5	-0.04	-0.08	-0.10
-120	-0.10	-0.17	-0.20
-96	-0.18	-0.22	-0.25
-72	-0.22	-0.23	-0.27
-48	-0.22	-0.23	-0.27
-24	-0.22	-0.22	-0.25
0	-0.18	-0.16	-0.19
24	-0.10	-0.10	-0.12
48	-0.04	-0.06	-0.07
72	-0.06	-0.03	-0.03
96	-0.02	-0.01	-0.01
120	-0.04	0.00	-0.01
155.5	-0.02	0.00	0.00
227.5	0.00	0.00	0.00

Program input for truck axle weight and position
(3 0 13.90 13.50 19.55 4.20 19.80) & (324.4 -60)
(3 0 10 14 40 14 40) & (388 -60)

Load Case 2



Plot Coordinates (in.)

(@136)	Meas	Pred	HS25
-155.5	-0.04	-0.08	-0.10
-120	-0.14	-0.17	-0.20
-96	-0.18	-0.23	-0.27
-72	-0.22	-0.26	-0.30
-48	-0.26	-0.29	-0.34
-24	-0.30	-0.33	-0.37
0	-0.33	-0.34	-0.38
24	-0.33	-0.34	-0.37
48	-0.28	-0.31	-0.34
72	-0.26	-0.28	-0.30
96	-0.26	-0.25	-0.27
120	-0.16	-0.19	-0.20
155.5	-0.06	-0.09	-0.10
227.5	0.00	0.03	0.03

Load Case 3