

SESSION 25

**COMPOSITE BRIDGES: A CIVIL
INFRASTRUCTURE SOLUTION**

A Systematic Design Approach for FRP Bridges

JULIO F. DAVALOS and PIZHONG QIAO

ABSTRACT

There is a concern with worldwide deterioration of highway bridges. In the U.S. over 40% of the approximately 600,000 highway bridges are in need of repair or replacement. The favorable advantages of fiber reinforced polymer (FRP) composites over conventional materials motivate their use in highway bridges for rehabilitation and replacement of structures. In this paper, a systematic approach for analysis and design of all FRP deck/stringer bridges is presented. The analyses of structural components include: (1) constituent materials and ply properties, (2) laminated panel engineering properties, (3) stringer stiffness properties, and (4) apparent stiffnesses for composite cellular decks and their equivalent orthotropic material properties. For design analysis of FRP deck/stringer bridge systems, an approximate series solution for orthotropic plates, including first-order shear deformation, is used to develop simplified design equations, which account for wheel load distribution factors for various load cases. A bridge system consisting of an FRP cellular deck placed transversely on FRP wide-flange beams is tested under static loads for various load conditions, and the experimental results are correlated with proposed design equations. The present simplified design analysis method can be used to design FRP highway bridge decks and deck/stringer systems and to develop new efficient FRP bridge components.

INTRODUCTION

The commercial development and implementation of new advanced and low-cost high-performance materials can alleviate major problems adversely contributing to infrastructure deterioration worldwide. The U.S. Infrastructure received the "grade" of D by the American Society of Civil Engineers, who estimated rehabilitation costs of 1.3 trillion dollars over the next five years; in particular, over 40%

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of the approximately 600,000 highway bridges in the U.S. are in need of repair or replacement, and fiber-reinforced polymer (FRP) composite materials offer great potential for application to highway bridges, particularly for bridge decks in combination with steel or concrete stringers.

A critical obstacle to widespread use and applications of FRP structures in construction is the lack of simplified and practical design guidelines. Unlike standard materials, FRP composites are typically orthotropic or anisotropic, and their analyses are much more difficult. In addition, shear deformations in FRP composites are usually significant, and therefore, the modeling of FRP structural components should account for shear effects. For applications to pedestrian and vehicular FRP bridges, there is a need to develop simplified design equations and procedures, which should provide relatively accurate predictions of bridge behavior and be easily implemented by practicing engineers.

In this paper, a systematic approach for analysis and design of all FRP deck/stringer bridges is presented. This approach (Figure 1) is based on analyses at micro-level (material), macro-level (structural component), and system level (structure) to design all FRP deck/stringer bridge systems. First, based on manufacturer's information and material lay-up, ply properties are predicted by micromechanics. Once the ply stiffnesses are obtained, macromechanics is applied to compute the panel mechanical properties. Beam or stringer stiffness properties are then evaluated from mechanics of thin-walled laminated beams (MLB). Using elastic equivalence, apparent stiffnesses for composite cellular decks are formulated in terms of panel and single-cell "beam-like" stiffness properties, and their equivalent orthotropic material properties are further obtained. For design analysis of FRP deck/stringer bridge systems, an approximate series solution for first-order shear deformation orthotropic plate theory is applied to develop simplified design equations, which account for wheel load distribution factors for various load cases. As illustrated in Figure 1, the present systemic approach, that accounts for the microstructure of composite materials and geometric orthotropy of a bridge system, can be used to design and optimize efficient FRP deck and deck/stringer systems.

PANEL AND BEAM ANALYSES

Extensive research has been conducted in the area of analysis and design of composite materials at micro- and macro-levels. The analysis of FRP beams from micro/macromechanics to beam response has been presented in [1]. Most commonly used FRP structural shapes are manufactured by the pultrusion process, and although pultruded FRP shapes are not laminated structures in a rigorous sense, they exhibit material architectures that can be simulated as laminated configurations. A typical pultruded section mainly includes the following three types of layers [1] (see Figure 2): (1) Continuous Strand Mats (CSM); (2) Stitched Fabrics (SF); and (3) rovings or unidirectional fiber bundles. The fiber volume fraction (V_f) of individual layers can be evaluated and used to compute the ply stiffnesses from micromechanics models [1]. Once the ply stiffnesses for each laminate or panel, are

computed, the stiffnesses of a laminated panel can be computed from macromechanics [1].

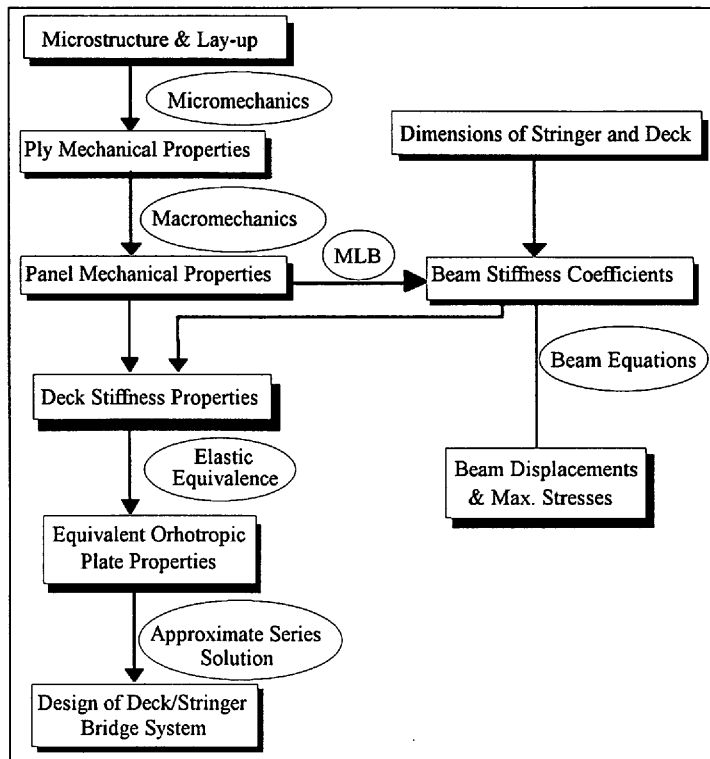


Figure 1. Systematic analysis protocol for FRP Bridge Systems

The response of FRP shapes in bending is evaluated using the Mechanics of thin-walled Laminated Beams (MLB) [2]. In MLB, the stiffness coefficients (axial, A ; bending, D ; axial-bending coupling, B ; and shear, F) of a beam are computed by adding the contributions of the stiffnesses of the component panels. The beam stiffness equations can be easily adopted by practicing engineers and composite manufacturers for the analysis, design, and optimization of structural FRP beams and for evaluating the stiffness properties and response of bridge stringers. The panel and beam properties obtained above by micro/macromechanics and MLB can be efficiently implemented in deck and deck/stringer system design, as described next.

ANALYSIS OF FRP CELLULAR DECKS: ELASTIC EQUIVALENCE

A multi-cellular FRP composite bridge deck can be modeled as an orthotropic plate, with equivalent stiffnesses that account for the size, shape, and constituent

materials of the cellular deck. Thus, the complexity of material anisotropy of the panels and structural orthotropy of the deck system can be reduced to an equivalent orthotropic plate with global elastic properties in two orthogonal directions: parallel and transverse to the longitudinal axis of the deck cell. These equivalent orthotropic plate properties can be directly used in design and analysis of deck/stringer bridge system, as presented in the next section, and they can also serve to simplify modeling procedures either in numerical or explicit formulations.

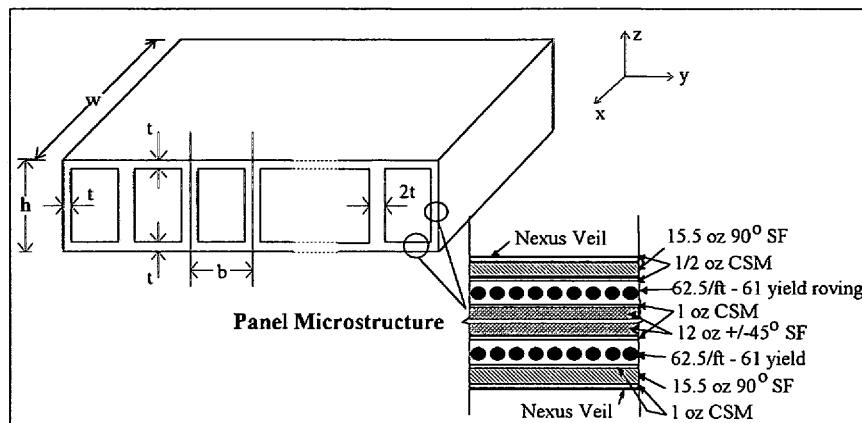


Figure 2. Geometric parameters of multicell box deck

In this study, the elastic equivalence approach [3] is used to derive the deck stiffness properties and account for out-of-plane shear effects. For example, the bending, shear and torsional equivalent stiffnesses for a deck composed of multiple box sections (Figure 2) are:

$$\text{Longitudinal bending stiffness: } D_x = n_c E_x h t (h^2 + t^2 + 3hb) / 6 \quad (1)$$

$$\text{Longitudinal shear stiffness: } F_x = 2n_c G_{xy} t h \quad (2)$$

$$\text{Transverse bending stiffness: } D_y = E_y w t h^2 / 2 \quad (3)$$

$$\text{Transverse shear stiffness: } F_y = 2E_y w t^3 / (b^2 + bh / 4) \quad (4)$$

$$\text{Torsional stiffness: } GJ = 2n_c G_{xy} b^2 h^2 t / (n_c b + h) + 2(n_c b + h) G_{xy} t^3 / 3 \quad (5)$$

where, E_x , E_y , and G_{xy} are the panel moduli computed by micro/macromechanics [1], and n_c is the number of cells (Figure 2). To verify the accuracy of the above deck stiffness equations, a finite element analysis of the deck system was performed [4], and a good correlation was obtained. Once the stiffness properties of an actual deck are obtained, it is a simple matter to calculate effective material properties E_x^p , E_y^p , G_{xz}^p , G_{yz}^p , and G_{xy}^p , where the superscript "p" indicates properties related to the equivalent orthotropic plate [3].

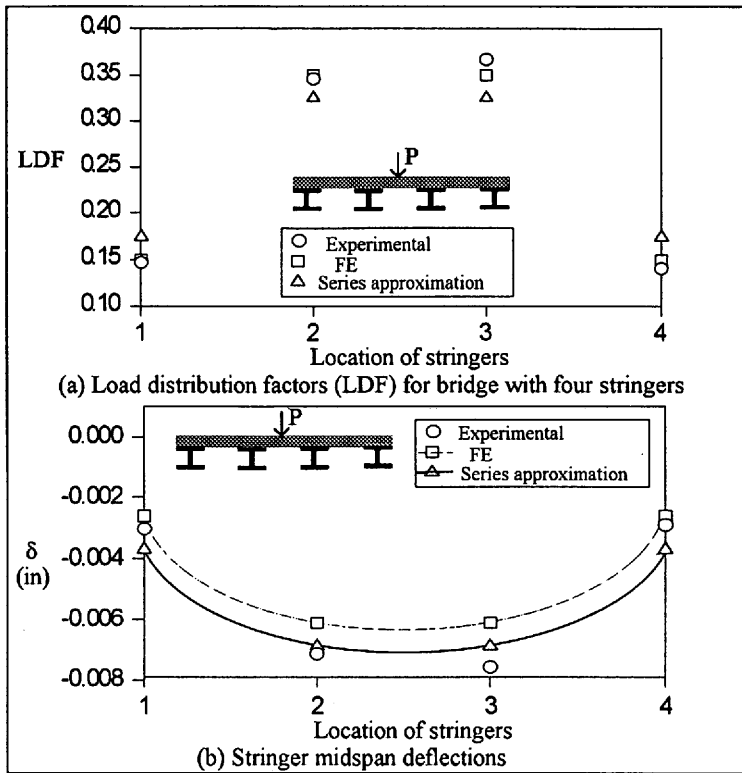


Figure 3. Comparison for deck/stringer bridge system

ANALYSIS AND DESIGN OF FRP DECK/STRINGER BRIDGE SYSTEM

The equivalent orthotropic properties for cellular decks (E_x^p , E_y^p , G_{xz}^p , G_{yz}^p , and G_{xy}^p) and stiffnesses for FRP beams (D and F), obtained as described above, can be efficiently used to analyze and design deck/stringer systems. Based on first-order shear deformation theory and transverse interaction of forces between the deck and the stringers, a series solution [5] for stiffened orthotropic plates is applied to obtain wheel load distribution factors (LDF) for design of bridge systems. For example, the general expression of LDF for any stringer at any location r in terms of the number of stringers m for symmetric loads is:

$$LDF(r) = \frac{\sin\left(\frac{r-1}{m-1}\pi\right) + W_0}{\frac{2}{\pi}(m-1) + mW_0} \quad (6)$$

where the constant W_0 is the bridge system displacement coefficient, which depends on the dimensions and stiffness properties of deck and stringers and the distribution

of loads [4]. The solutions for both symmetric and asymmetric load cases are given in [5]. The approximate series solution is verified by testing a 10' x 10' x 8" multi-box-beam deck supported by WF 12" x 12" x 1/2" FRP beams (Figure 3); this system is also analyzed by the finite element method [4].

Based on the LDF obtained above, the number of stringers necessary for a given bridge deck can be determined. First, the dimensions of the bridge are used to evaluate the maximum allowable moment per lane (M_{max}) according to AASHTO, and then, an equivalent concentrated load (P_e) is calculated [5]. Second, the equivalent deck properties and the stringer bending and shear stiffnesses are used to calculate the edge deflection coefficient W_o . Third, a design load (P_d) is defined for the maximum LDF as a function of number of stringers (m). Finally, based on a bridge deflection limit (e.g., $\delta \leq L/800$) and beam deflection equation for the design load (P_d), the required number of stringers (m) can be determined for a given bridge system.

CONCLUSIONS

As described in this paper, a systematic approach for design analysis of FRP deck/stringer bridge systems is proposed, and the constitutive material properties and micro/macrostructure of a composite bridge system are accounted for in the design. This relatively simple and systematic concept accounts for the complexity of composite materials and geometry of the bridge system. The approximate series solution, which is used to obtain the LDFs for symmetric and asymmetric loading, is an efficient way to analyze and design single-span FRP deck/stringer systems. The present design analysis approach can be efficiently used to design bridge systems and also develop new design concepts for single-span FRP bridges.

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Review of Field Data on the All-Composite Highway Bridge, *TECH 21*

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DOUG THOMSON⁴ and CHRIS DUMLAO⁵

ABSTRACT

This paper will review the field test data that has been gathered on the first all composite bridge in Ohio called *TECH 21*. The bridge is in Butler County, Ohio and was installed in July of 1997. *TECH 21* is ~ 10.1 meters (33 ft.) long, ~ 7.3 meters (24 ft.) wide, and ~ 838 mm (33 in.) deep. *TECH 21* has two monitoring systems gathering data from the structure. One system is basic in reading strains and temperatures with conventional sensors. This system is connected to a phone line and provides constant data on the bridge to the Butler County Engineer's Office. The structural parameters are set to limits that will alert the County Engineer if the limits are exceeded. The second system is a fiber optic system that duplicates some of the structural parameters being registered by the first system. This system provides measurements of the field bond line for moisture absorption and degradation. Data such as this has never been compiled for the in situ monitoring of a composite bridge.

Field Testing

Live load tests have been generated to determine the short-term response to loading beyond AASHTO requirements. The main purpose of the test is to quantify the Tech 21 performance capabilities and set the benchmark for future bridges. The end result

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of the testing was to develop an analytical model to determine the load distribution characteristics for the bridge.

Several different tests have been performed during both summer and winter to characterize the bridge performance under different ambient conditions. This particular set of data reflects the testing that was performed on August 11, 1998. The temperature was around 80 degrees. Other tests were performed on September of 1997 and January of 1998. A total of 28 strain transducers and 4 Linear Varying Displacement Transducers (LVDTs) were installed. The data in this report reflects the strains at the midspan of the beams from the gages that lie parallel to the truck path. Deflection data is also examined for transducers that are located across the midspan of the bridge perpendicular to the truck path.

Figure 1 shows a diagram of the trucks used in the August testing. During the test two trucks with different axle configurations and weights are driven across the bridge at crawl speed (@ 5 mph). The trucks traversed across each lane and then the two trucks traveled side by side across the bridge. Note that the average combined dual axle weight of 50.4 kips was approximately 58% higher than the HS20 design axle weight of 32 kips.

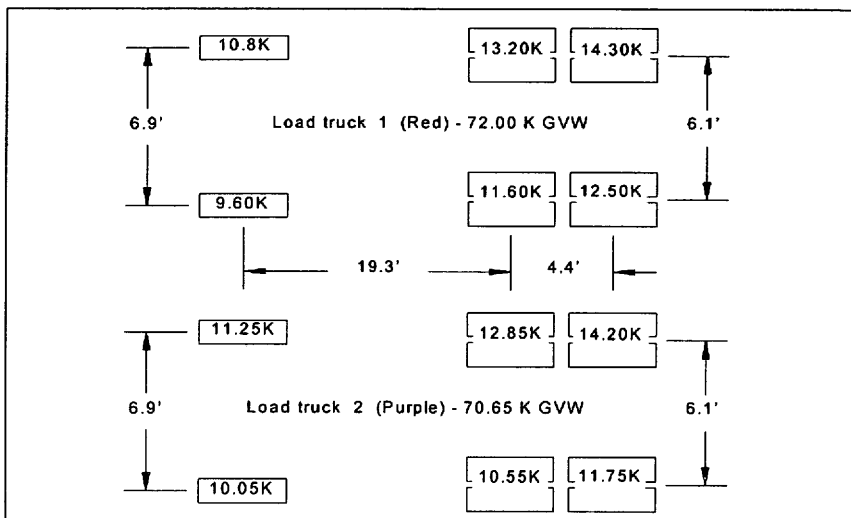


Figure 1. Truck Wheel Loads

Gage Layout

The next set of figures shows the strain gage and LVDT layout (figures 2 and 3) for live load testing. Each strain transducer has a 3" gage length and is NIST-calibrated to an accuracy of $\pm 2\%$. The LVDT transducers are model number DCT-1000A DC from RDP Group with a $\pm 15V$ DC power supply and a range of $\pm 1"$. The resolution and accuracy are around 0.001".

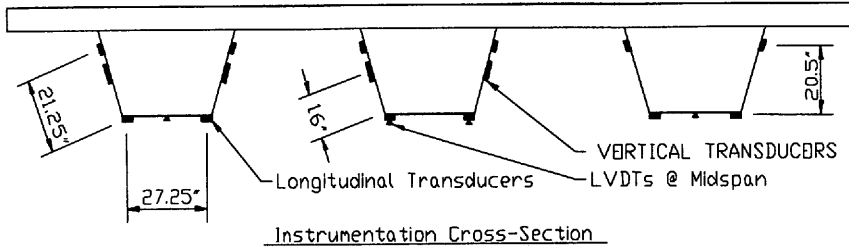


Figure 2. Cross Section of Gage Layout

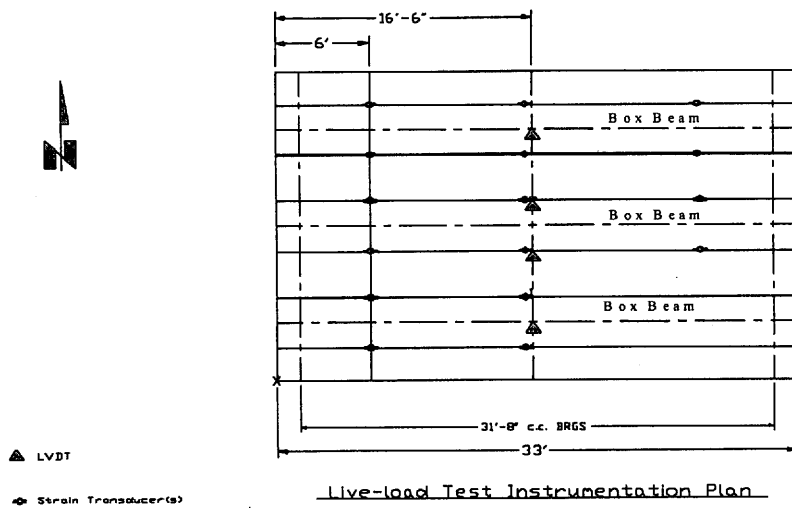


Figure 3. Strain Gage and LVDT Layout

Deflection

As expected, the highest deflection during testing was experienced when both trucks were driven side by side across the bridge. It can be seen in Figure 4 that the maximum deflection of 0.45" occurred at the midspan between the bearings. It should be noted that even with much greater wheel loads than the standard HS 20 design criteria, the *span/deflection* ratio is still well within the $L/800$ limit that is specified by AASHTO.

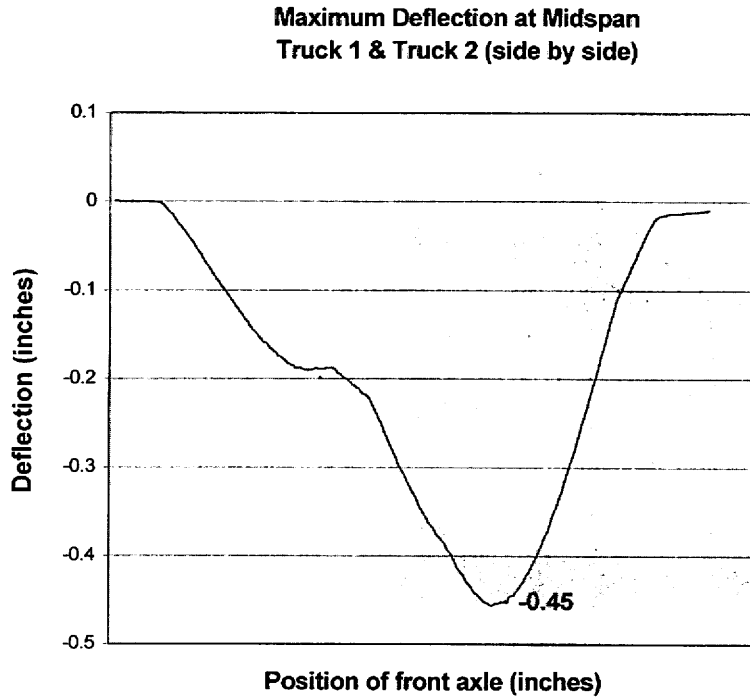


Figure 4. Maximum Deflection

Strain

Similar to the LVDT data, the highest strain during testing was experienced when both trucks traveled across the bridge at the same time. As shown in figure 5, a

maximum measured microstrain of 732 occurred at the midspan between bearings. The design concept used was to limit the maximum allowable strain for the FRP material to be 20 % of the ultimate strain. The maximum measured strain experienced during testing is ~ 14 % of the ultimate strain.

**Maximum Strain at Midspan
Truck 1 & Truck 2 (side by side)**

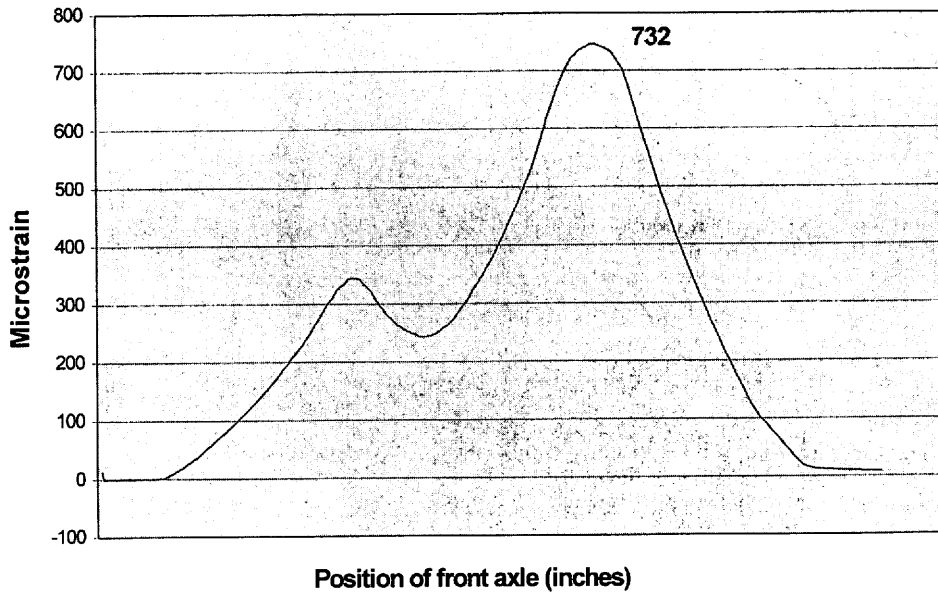


Figure 5. Maximum Strain

Bondline Sensors

Sapphire chemical sensors were installed to monitor the two field bondlines in the bridge deck. The sensors utilize infrared spectroscopy to track chemical changes in the material. They enable cure monitoring of the epoxy as well as detection of any degradation or moisture present in the bondline. Slots for the sensors were cut into the two bondline flanges before installation. The center twelve feet of each bondline were monitored using two sensors. Unfortunately, two of the four sensors were damaged during installation. Therefore the data is representative of the two sensors on the northern bondline.

Data from the bondline sensors has been taken on several different occasions during installation and testing. The first two readings were taken in 1997 on July 8th (installation date) and November 17th. As can be seen in Figure 6, the bondline cured significantly between this time. It can also be seen that between November 17th, 1997 and August 11th, 1998, the percent absorbance changed insignificantly. This proves that no further curing took place and no moisture or foreign chemicals were getting into the bondline.

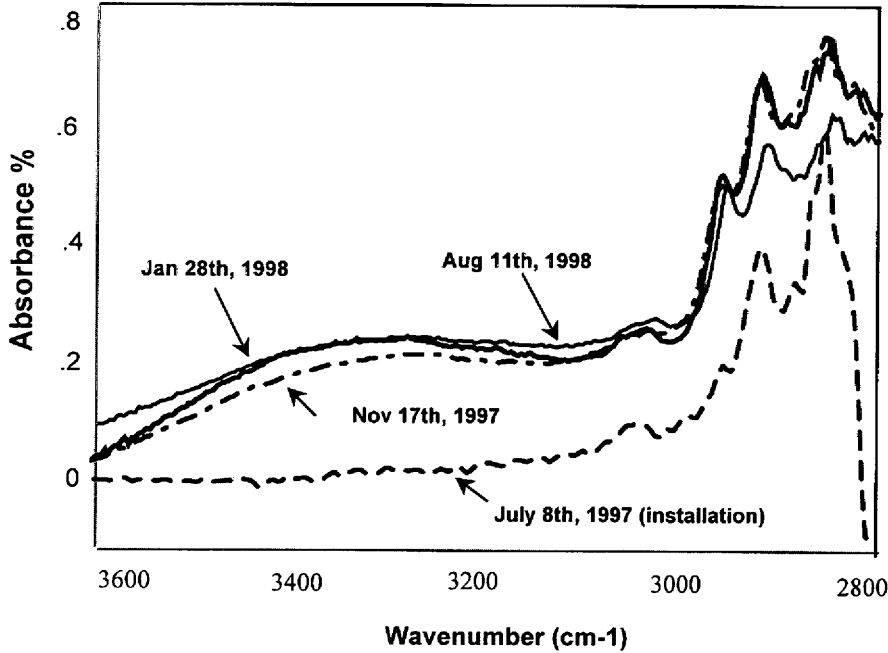


Figure 6. Bondline Sensor Data

Summary

Field test data has been gathered and analyzed for the *TECH 21 Bridge*, thus accomplishing two main objectives. First, to compare the actual strains and deflections to finite element modeling. Second, to monitor the long term “health” of the bridge. The deflections and strains matched the predicted values and proved to be well within the design limits. Also, the Sapphire bondline sensors showed minimal change in absorbance after the initial cure stage of the epoxy. This shows that no degradation or moisture has been present in the bondline since installation and the system is performing as expected.

Design and Construction of FRP Pedestrian Bridges Subjected to Extreme Snow Load Conditions

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ABSTRACT

The design and construction of fiberglass reinforced plastic (FRP) pedestrian bridges by E.T. Techtonics, Inc. subjected to heavy snow load conditions has been investigated in this study. The advanced composite material system is constructed of FRP tubes, channels and decking. The investigation is being conducted in conjunction with the Federal Highway Administration and the U.S. Forest Service. Two bridges, a 45'-6" span and a 22'-0" span, were designed and constructed in early 1998 with design engineers from the Eastern Federal Lands Highway Division (EFLHD) of FHWA. In May 1998, the structures were sent to the main U.S. Forest Service Testing Laboratory located in Madison, WI where the bridges were instrumented and currently being load tested for heavy sustained load conditions. Successful performance of the bridges will result in the installation of the 45'-6" span at the base of Mt. Ranier (outside Seattle, WA) on the Falls Creek Trail in the Gifford Pinchot National Forest and the 22'-0" span bridge in western Oregon. Design criteria for the bridges developed by USFS was very stringent due to the recent collapse of several bridges in these areas due to snow load. A three dimensional computer analysis was developed for both bridges to demonstrate the feasibility of the proposed designs. Full scale sustained load tests were conducted to determine creep behavior under extreme snow load conditions. Advantages derived from using FRP in comparison to traditional materials such as wood, concrete and steel were evaluated.

DESIGN CRITERIA

The design criteria used in the evaluation of the proposed bridges was determined by the USFS as follows:

Live Load (pedestrian):	-	85 psf
Snow Load (45'-6" span)	-	250 psf
(22'-0" span)	-	125 psf
Wind Load:	-	100 mph
Seismic Zone:	-	2

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The FRP Design Criteria assumed the use of isophthalic polyester resin components.

FRP Ultimate Strength (psi)

Compression: 30,000 (F.S. = 3)
Tension: 30,000 (F.S. = 3)
Bending: 30,000 (F.S. = 3)
Shear: 5,500 (F.S. = 3)

FRP Young's Modulus

C8x2-3/16"x3/8": 3000 ksi
C6x1-11/16"x3/8": 3000 ksi
2"x2"1/4" Square Tube: 2500 ksi
1-1/2" Solid 6000 ksi
2" Square Tube + 1-1/2" Solid (approx.) 4000 ksi

The serviceability criteria established for the project was as follows:

Assume initial camber would eliminate any initial dead load deflection and joint slippage.

Live load deflection: L/360

Time dependent deflection due to sustained load (6 months): L/720

Total recovery of bridge structure after unloading (no downward deflection)

Minimum Frequency: 5 cycles/sec.(vertical/pedestrian loading)
3 cycles/sec. (horizontal/wind or seismic loading)

TESTING/CONCLUSIONS

Testing of the bridges is currently being conducted at the U.S. Forest Service Testing Laboratory located in Madison, WI. On September 29, 1998 the 45'-6" span was loaded to approximately 250 psf and the 22'-0" span was loaded to approximately 125 psf. After 4000 hrs. (6 months) of sustained loading, there has been an increase in deflection of approximately 30% for each bridge. This satisfies the above criteria established by USFS. The bridges will be unloaded in May/June, 1999 and recovery behavior will be studied before shipment to the sites. Given previous long term testing conducted by E.T. Techtonics, Inc. , total recovery of the bridge system is expected. After installation, the USFS will continue environmental studies on the bridges evaluating freeze/thaw issues as well as overall maintenance characteristics. Given the heavy loading conditions the bridges will be subjected to on a yearly basis, successful long term performance will help to establish FRP components as viable alternatives to traditional members constructed in wood, steel and concrete.

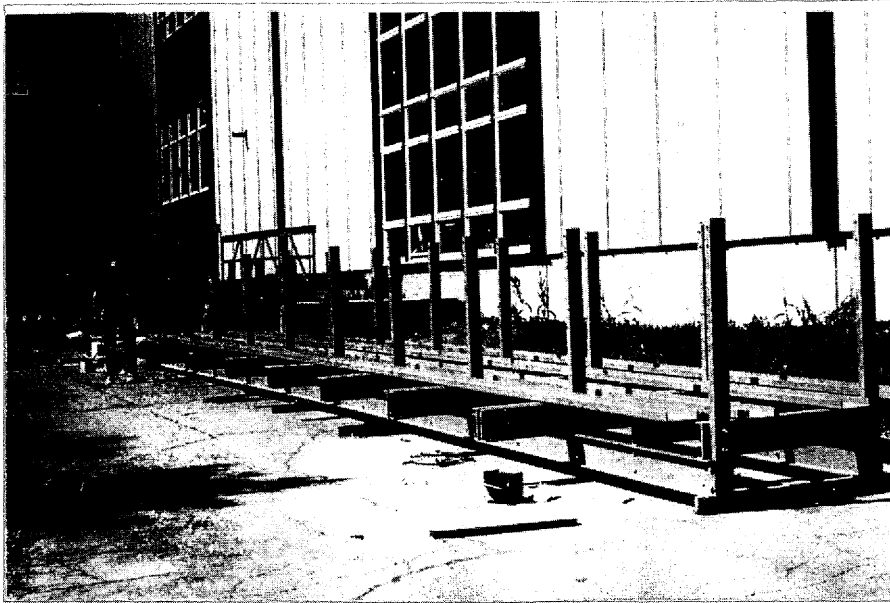


Figure 1 - Construction of 45'-6" Bridge at USFS Testing Lab - Madison, WI

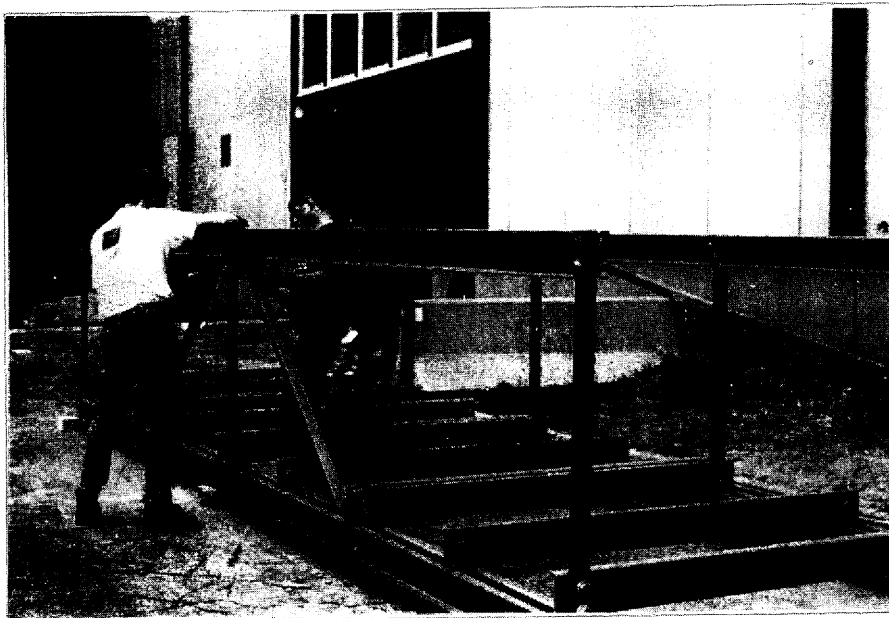


Figure 2- Construction of 22'-0" Bridge

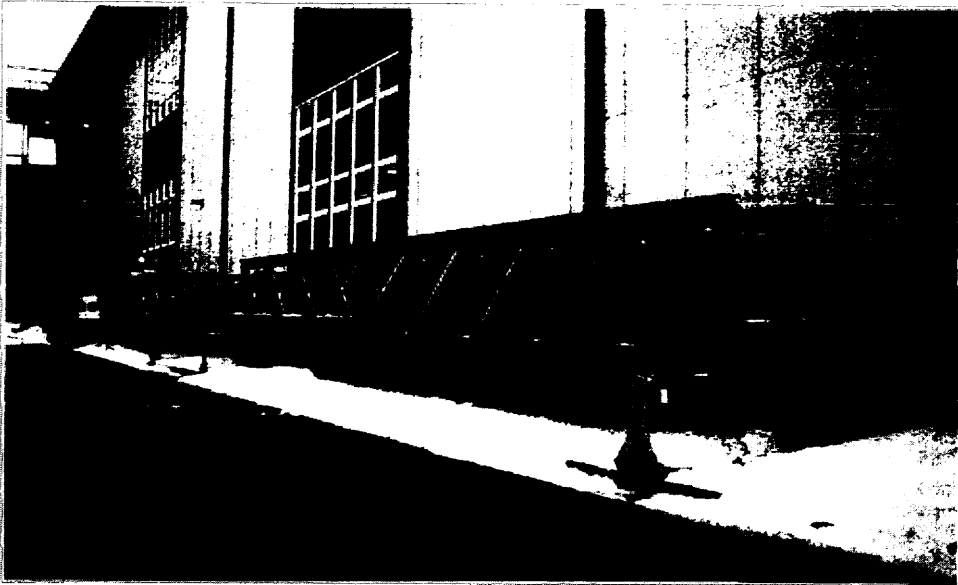


Figure 3- 2 Bridges Under Sustained Load Condition



Figure 4- Typical Sustained Load on 45'-6" Span

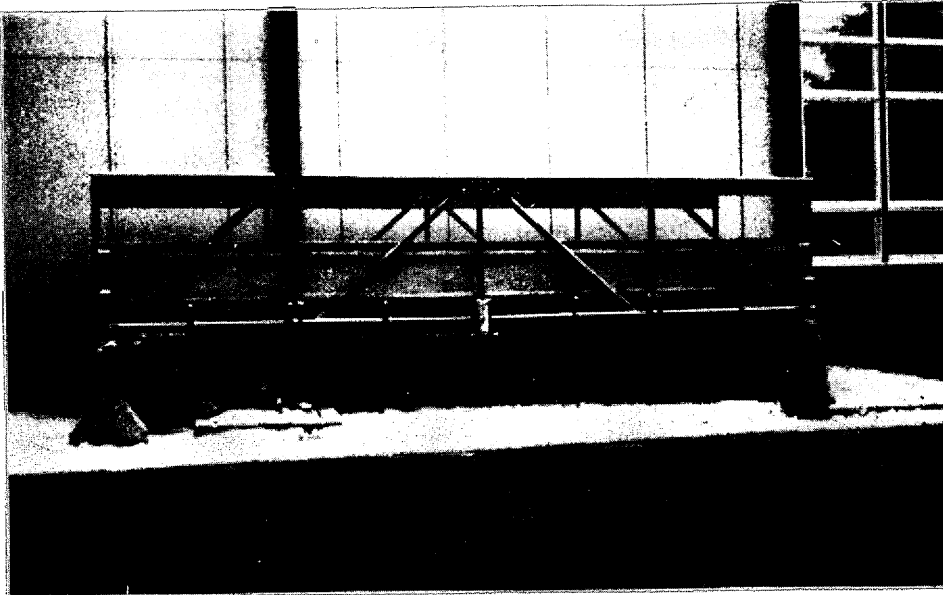


Figure 5 - Testing Arrangement on 22'-0" Span

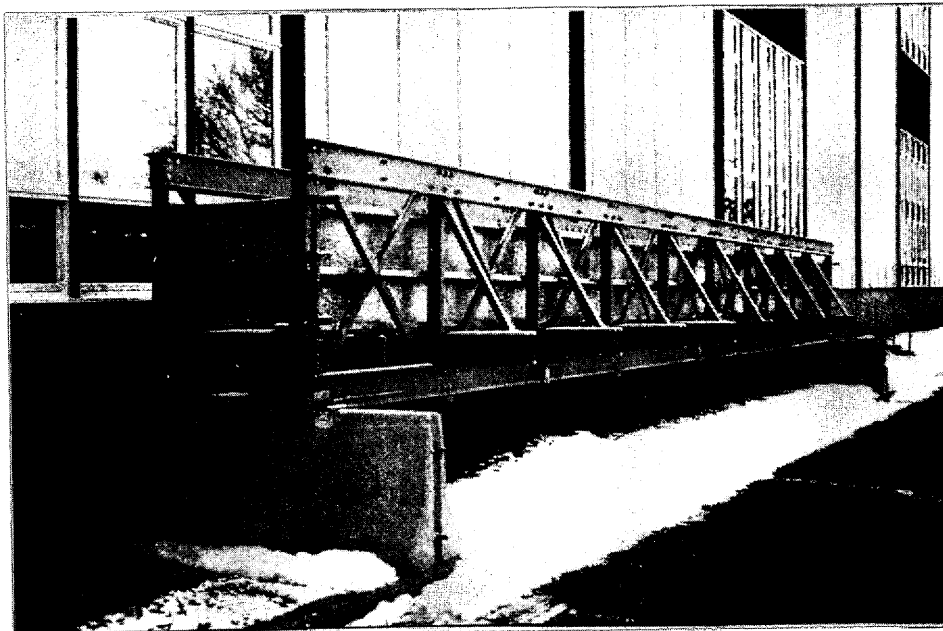


Figure 6 - Testing Arrangement on 45'-6" Span

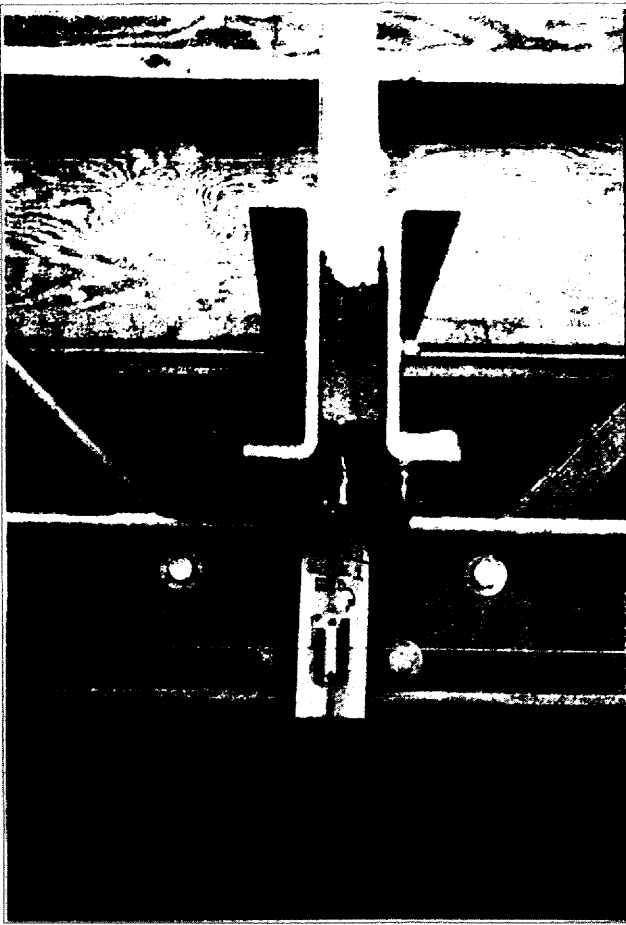


Figure 7 - Instrumentation for Deflection Readings

BIOGRAPHY

Dr. G. Eric Johansen and Roy Wilson are owners of the engineering/architecture firm, **E.T. Techtonics, Inc.**, Philadelphia, PA which specializes in the design of advanced composite material structures.

Gary Jakovich and Scott Wallace are bridge engineers for **Eastern Federal Lands Highway Division of the Federal Highway Administration.**

Merv Eriksson is a lead structural engineer with the **U.S. Forest Service.**

James Guest is a doctoral candidate in structural engineering at **Princeton University.**

West Seboeis Stream FRP-Glulam Highway Bridge

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Abstract

Glue-laminated wood beams, commonly known as Glulam, have been used in bridge construction for many years. The addition of glass fiber reinforced plastic (GFRP) to glulam beams has been shown to significantly increase beam bending strength. GFRP reinforced glulam beams can potentially be structurally and economically competitive with unreinforced glulam and traditional materials. The West Seboeis Stream bridge was designed and built using GFRP reinforced red pine glulam girders, with a conventional red pine glulam deck. The bridge was designed as a prefabricated "kit", which provided for the short construction time and low cost of the bridge erection. GFRP glulam provided a bridge capable of carrying a live load 25% greater than the standard HS25 truck load.

Introduction

The West Seboeis Stream Bridge provides vehicular access to state-owned timberland that is maintained for recreational and forestry use by the Maine Department of Conservation Bureau of Public Lands. In 1995, the United States Department of Agriculture (USDA) Forest Service approved a grant under the Wood in Transportation Program to help pay for construction of a new bridge over the West Seboeis Stream. This project would demonstrate how locally grown Maine timber reinforced with the Fiber Reinforced Polymer (FRP) technology developed at the University of Maine Advanced Engineered Wood Composites (AEWC) Center could be used in a medium-span vehicular bridge.

FRP-Reinforced Glulams Developed at UMaine AEW C

Research at the University of Maine AEW C has shown that the addition of small amounts of glass fiber reinforced polymer (GFRP) reinforcement to the tension face of glulam beams can increase beam allowable bending strength (F_b) by over

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100% [Dagher et al. (1998)]. Over the past six years, these studies have proven that the reinforcement of glulam with FRP is technically feasible in terms of short-term strength and stiffness, as well as long term durability.

Extensive laboratory testing (ASTM D905, ASTM D2559) has been performed to verify the durability of the FRP-to-wood bond. However, little information exists on the performance of FRP-reinforced glulams under “real-world” conditions. One goal of the West Seboeis Stream Bridge Project, therefore, was to evaluate the performance of FRP-glulam beams under extreme conditions in a real-world environment.

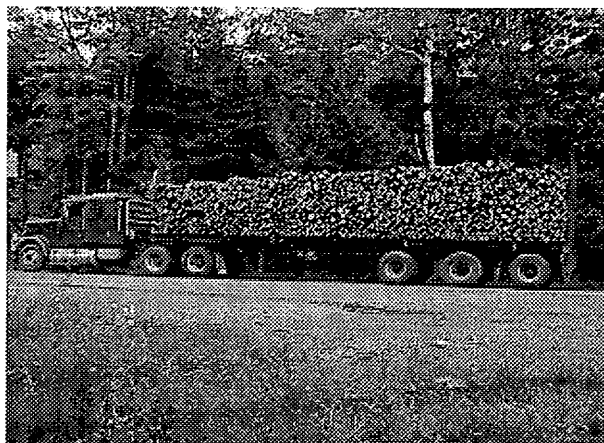


Figure 1: Typical Truck Load for West Seboeis Stream Bridge

Bridge Description and Site Conditions

The West Seboeis Stream Bridge is located approximately 60 miles north of Bangor, Maine. Air temperatures at the bridge site can range from 90°F (32°C) during the summer to -40°F (-40°C) during the winter. Relative Humidity at the site can typically range from 52 to 87%. The bridge is located on an unpaved access road used primarily for recreational and logging traffic. While the traffic counts over the bridge are low (typically less than 30 cars per day), the bridge was designed to carry heavily loaded logging trucks. The live load used in the bridge design was a six-axle, 172,000 lbs. standard live load truck used by the Maine Bureau of Public Lands (see Figures 1 and 2).

The FRP-glulam bridge has a single span of 41 ft. (c/c bearings) and a total length of 44 ft. The bridge carries a single lane of traffic, with a total width of 16 ft. (fascia to fascia). For the span length of 41 ft. the bending moment from the 172,000 lbs. live load truck is approximately 25% greater than an AASHTO HS25 live load moment (live load shear at the supports is approximately 20% greater than HS25 shear). The proposed bridge superstructure consists of seven FRP-reinforced

Red Pine glulam beams spaced 2 ½ ft. on center, with an unreinforced Red Pine glulam deck lag-screwed to the girders (see Figures 3 and 4). The bridge abutments consist of precast concrete segmental "T-Walls" assembled on site.

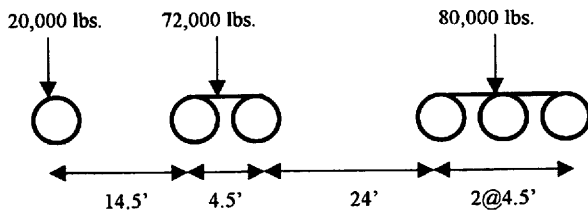


Figure 2: Maine Bureau of Public Lands 172,000 lbs. Live Load Truck

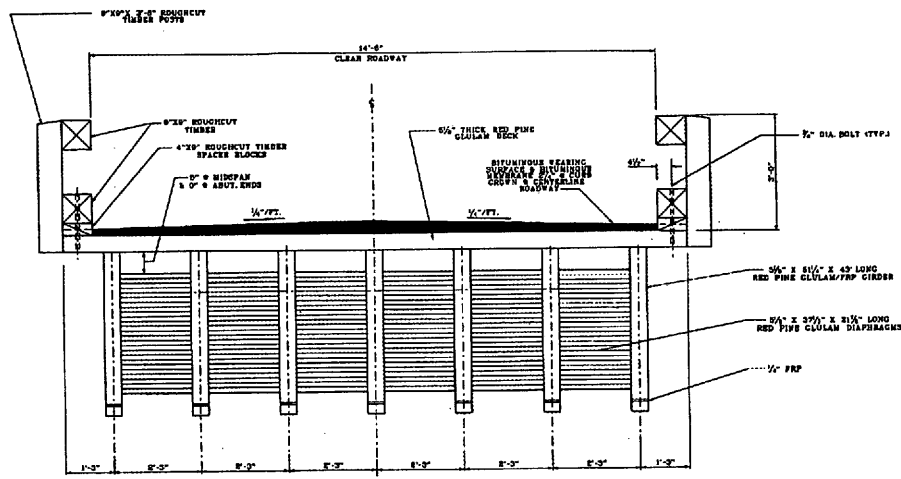


Figure 3: Superstructure Cross Section

Design of FRP-Reinforced Glulam Girders

The West Seboeis Stream Bridge was designed using the AASHTO Bridge Specification (1996). The main girders were designed as unreinforced glulams under the ASTM D3737 *Standard Test Method for Establishing Stresses for Structural Glue Laminated Timber (Glulam)* (1996). Under ASTM D3737, it was determined that the Red Pine unreinforced glulams had an allowable bending stress (F_b) of 1450 psi, and a bending Modulus of Elasticity (MOE) of 1,500,000 psi. Using these

bending strength and stiffness values, the girders were sized to be 5.125" wide by 49.5" deep. Added to the bottom of the unreinforced glulam girder were 2 layers of 0.125" thick x 4.75" wide pultruded E-Glass/Phenolic resin FRP sheets manufactured by Strongwell. In order to protect the FRP during fabrication and shipping, a 1.5" thick wood "bumper-lam" was placed on the bottom of the beam, bringing the total beam depth to 51.25".

The FRP reinforcement was not accounted for in the bridge's structural capacity because of the lack of durability performance data under "real-world" bridge conditions. The FRP was added to the Red Pine girder to evaluate how the FRP and FRP-wood bond perform under extreme environmental and loading conditions. However, if the additional strength of the FRP reinforcement had been accounted for, the allowable bending strength (F_b) would be doubled, and the bending MOE would increase by 20%.

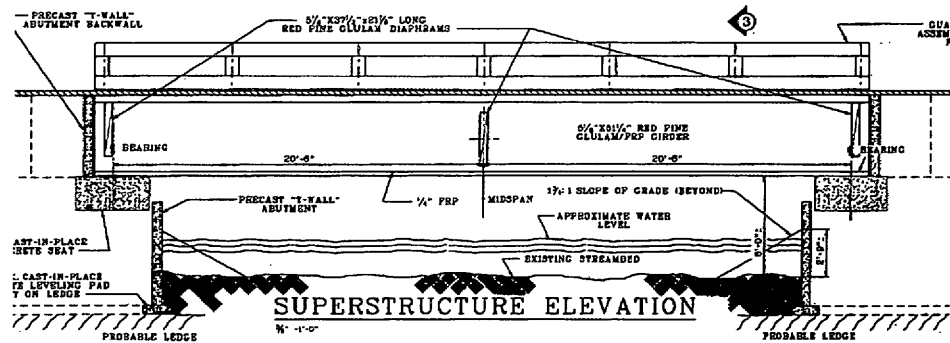


Figure 4: Superstructure Elevation

All of the superstructure components were laminated, with all connection holes predrilled, prior to preservative treatment. The main girders, deck panels, and laminated wood diaphragms were all preservative treated with Pentachlorophenol.

Construction

Bridge construction began in late August 1998 with removal of the existing bridge and site preparation for installation of the segmental concrete abutments. All of the bridge superstructure components were delivered to the site on a single flatbed truck.

After completion of the bridge abutments, the main girders were lifted into place one at a time, and spaced using the laminated wood diaphragms (see Figures 5 and 6). After all of the girders were in place and securely bolted together via the diaphragms, the wood deck panels were installed. The actual time spent in assembly of the superstructure was approximately 3 to 4 days.

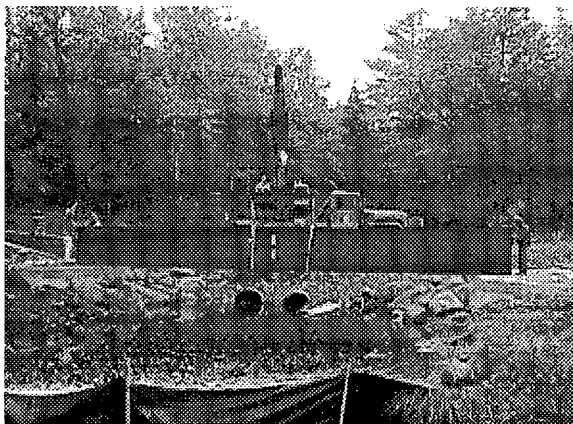


Figure 5: Main Girder Being Lowered into Place

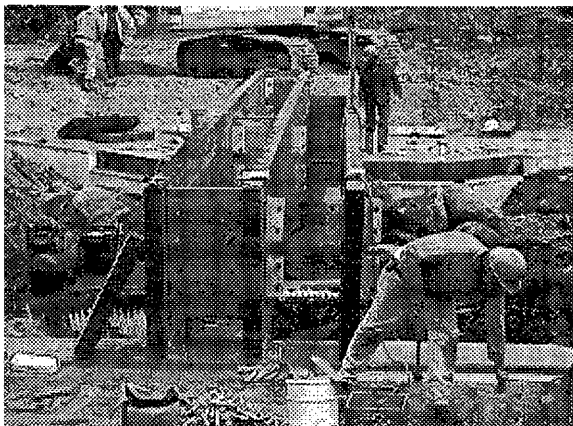


Figure 6: Installation of Subsequent Girders with Diaphragms

Monitoring

In order to monitor the long-term performance of the FRP-wood bond, strain gages were mounted on the FRP through holes drilled in the bumper-lam prior to lamination. As part of the monitoring program, the bridge will be load-tested on a

yearly basis, measuring deflection under load and strain in the FRP to evaluate the integrity of the FRP and FRP-wood bond.

Bridge Costs

The superstructure cost was approximately \$60,000, or \$85/ft². The average superstructure cost of a bridge built in New England in 1995 was approximately \$75/ft² [James (1995)]. In order to make an accurate comparison however, the total cost of the West Seboeis Stream Bridge should be adjusted to account for the following factors:

1. The live load moment was 25% greater than an HS25 moment, which is the standard for bridges designed in Maine.
2. The FRP-reinforcement was not accounted for in design, meaning that the design did not benefit from the strength gains of FRP reinforcement.
3. Excessive transportation costs were incurred in the fabrication and preservative treatment of the beams due to the fact that there are no wood laminators or penta treaters in New England.

When redesigned using an HS25 live load and full utilization of the FRP reinforcement, it was found that approximately 25% savings could potentially be realized on both the raw material and fabrication costs. If transportation costs were also decreased 25% (in the event that a laminator existed in New England), the total bridge costs would be reduced to approximately \$67/ft², or 11% less than the average bridge in New England in 1995.

Conclusions

The following conclusions can be drawn from this demonstration project:

- It is technically feasible to build a medium span vehicular bridge using low-grade underutilized Red Pine lumber.
- The addition of FRP-reinforcement can potentially reduce superstructure costs enough to make FRP-glulam competitive with traditional bridge materials.
- The West Seboeis Stream Bridge will be monitored and load tested yearly to evaluate the long-term durability of the FRP and FRP-wood bond.

References

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