INEL/EXT-97-00359

April 1997

Idaho National Engineering Laboratory

Test and Evaluation Plan for the Composite Bridge

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Prepared for the
U.S. Department of Transportation, Federal Highway Administration
and the U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-94ID13223

ABSTRACT

Polymer matrix composites (PMC) are entering the nation's infrastructure as alternatives to conventional materials. Working with the Federal Highway Administration and Department of Energy, the Idaho National Engineering and Environmental Laboratory is testing and evaluating a PMC structure for use in bridge rehabilitation and replacement. A 30-foot PMC bridge, designed and built by Lockheed Martin Missile and Space, will be field tested in Idaho. The design of this bridge represents simple support bridges in the 120-foot span category. This report describes the construction, transportation, installation, testing, and material properties for this PMC structure.

ACKNOWLEDGMENTS

The authors acknowledge the support of the U.S. Department of Transportation, Federal Highway Administration, and the Department of Energy in the advancement of composite materials for the nation's bridges. Special thanks goes to all project participants, to David George of National Oceanic and Atmospheric Administration Air Resource Laboratories, Grant Godwin of Martin Marietta Materials, and to all the researchers and operations personnel, especially Nancy Carlson, at the Idaho National Engineering and Environmental Laboratory that made this project possible.

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INTRODUCTION

The Composite Bridge Demonstration Project is evaluating the performance of a composite bridge structure to determine its safety and suitability for standard highway construction. While composite structures are in use as pedestrian bridges and column reinforcements on vehicular bridges, large-scale use of structural composites has been limited. This project, funded by the U.S. Department of Transportation, Federal Highway Administration (FHWA), is a major step towards enabling routine use of composite bridges for rehabilitation projects, new construction, and temporary structures during highway construction. The testing and evaluation of the composite bridge structure will provide the information necessary to characterize its performance with respect to design predictions and loads.

The maintenance needs of the nation's transportation infrastructure, especially bridges, is of growing concern. A cost-effective, lightweight, easily transported composite structure that can be rapidly erected and placed in service as a temporary bridge would dramatically improve efficiency and safety during highway construction. And a universal composite structure for general bridge applications would be a valuable tools for state transportation departments. However, composite structures are not widely used because of perceived high costs and a lack of engineering experience with the technology. To address these issues, a partnership was formed to install and test a composite bridge at the Idaho National Engineering and Environmental Laboratory (INEEL). The participants in the Composite Bridge Demonstration Project are Lockheed Martin Idaho Technologies Company (INEEL), Lockheed Martin Missile Advance Technology Center (LMMS), Martin Marietta Materials, the Idaho Transportation Department (ITD), the University of Idaho (U of I), and Construction Technology Laboratories, Inc. (CTL).

The objectives of the Composite Bridge Demonstration Project are to characterize performance of the bridge structure with respect to design predictions and loads and to evaluate its performance with respect to safety and suitability for standard construction. To this end, the bridge design and materials will meet American Association of State Highway and Transportation Officials (AASHTO) guidelines. In addition, the project will assess transportation of the bridge structure from Palo Alto, California to Idaho Falls, Idaho, and its erection at INEEL, evaluate the bridge's performance under static and dynamic loading, and evaluate the composite structure's resistance to weather extremes and environmental effects as well as aging. The results of this project can be used to develop acceptance testing procedures for composite bridges, based upon load resistance factor design (LRFD), that will meet AASHTO specifications.

The schedule for this project is shown in Table 1.

Table 1. Project schedule.

Task	Anticipated Start	Anticipated Completion
1. Test & Evaluation Plan	August 1996	April 1997
2. Installation Requirement	November 1996	February 1996
3. Testing Requirements	December 1996	April 1996
4. Test Procedure and sensor selection	November 1996	May 1997
5. Bridge Transported to INEEL	October 1996	April 1997
6. Bridge Installed	April 1997	June 1997
7. Roadway Modifications for Bridge Installation	March 1997	May 1997
8. Sensor Installation	May 1997	June 1997
9. Data Collection and Analysis	June 1997	June 1998
10. Test Report	August 1998	September 1998
11. Bridge removal and road modification	September 1998	TBD

Note: This schedule is contingent upon the bridge being installed at the INEEL as indicated above.

COMPOSITE BRIDGE DESIGN

The orthotropic bridge design chosen uses two essentially repeating components–traffic-bearing road deck plates and deep, U-shaped, support beams. Both components are made entirely of fiberglass-reinforced polymer matrix composite (PMC) materials. Some attractive features of the orthotropic design, from the fabrication and field assembly points of view, include:

- Redundant load paths between deck and support beams lower risk of failure
- Open section design reduces tooling and fabrication cost
- Flexible design is tolerant of manufacturing flaws, i.e., twisting and small warpage can be corrected at assembly
- Easy to visually inspect
- Modularity
    - Stackable units occupy less space
    - Half section of 60-ft bridge can be carried by one truck
- Stitched fiberglass fabric/polyester or vinylester resin is light weight
    - Single pieces weigh <3600 lb.
    - 30 ft. by 18 ft. unit weighs less than 25,000 lb.
    - Half sections can be pre-assembled, then hoisted over abutments.

The demonstration bridge is one-lane wide and 30 ft. long, representing one quarter of a two-lane, 60 ft. long traffic bridge. Figure 1 shows the bridge assembled on the static test fixture. It has three deck plates and three longitudinal beams and can be transported on one truck (Figure 2). Either precast concrete parapets ("Jersey barriers") or metal guard railing meeting the current Idaho Transportation Department standards will be placed along the edges of the structure to protect traffic during testing at INEEL.

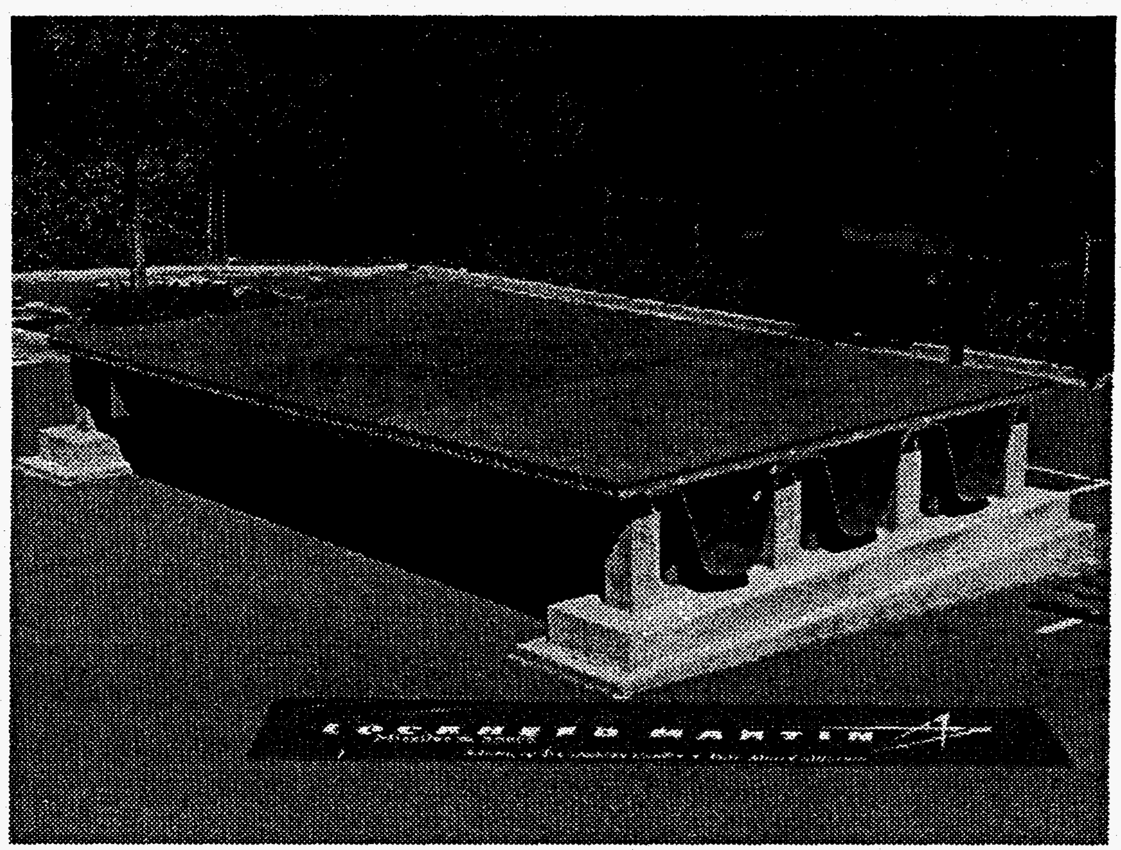


Figure 1. Composite bridge on the static test fixture.

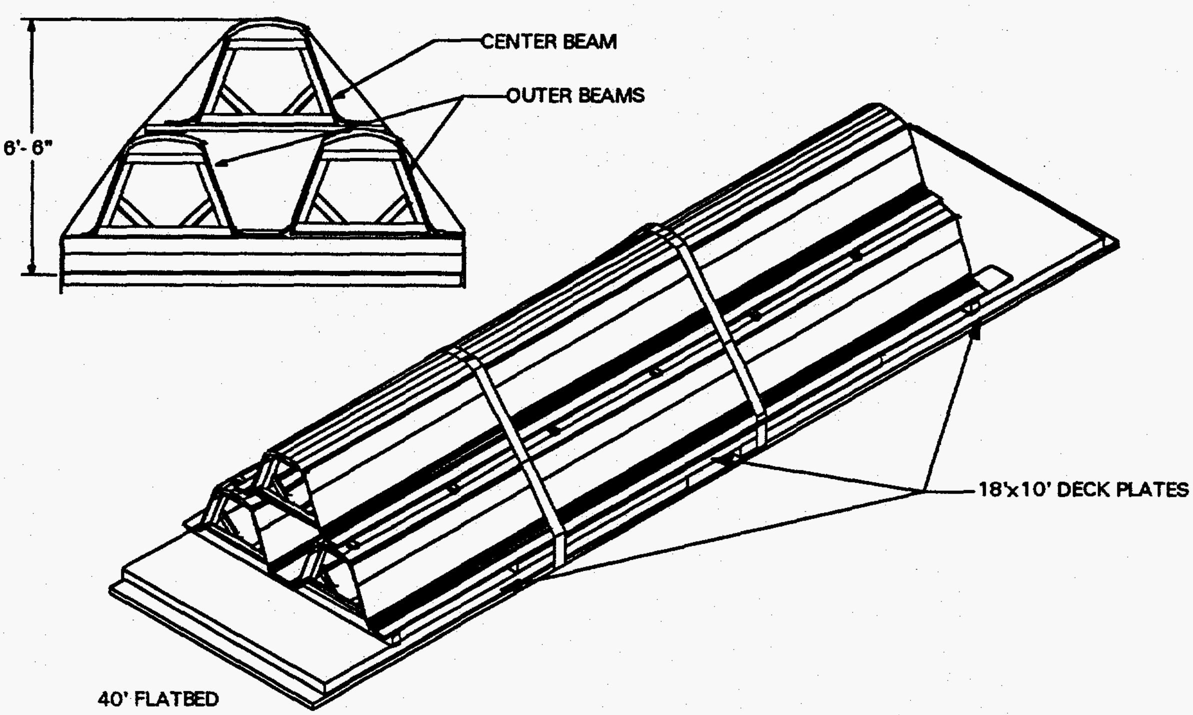


Figure 2. Components of disassembled bridge stowed for transport.

Design Requirements

The bridge was designed to AASHTO specifications for a 60-foot span vehicular traffic bridge. AASHTO bridge design specifications generally limit the deflection of bridge girders to 1/800 of the span length. The specification states that flexural members of bridge structures shall be designed to have adequate stiffness to limit deflections or any deformations that may adversely affect the strength or serviceability of the structure. General AASHTO specifications as well as assumptions used to determine laminate allowables are summarized below.

Loading

- One AASHTO HS20-44 truck (72,000 lb.) in center of each traffic lane
- From California guidelines for simple spans, <145 ft. HS loads produce higher moment and deflection than lane or alternative loading
- The deck is assumed be a continuous plate over longitudinal beams because there are no stringers
- The live load distribution is based on a uniform flat plate model subject to wheel loads across three axles in a 32/32/8 Kips distribution.

Performance

- Maximum deflection under live load < Span/800
- Allowable deflection for 60-ft span < 0.9 in. or 0.45 in. for 30-ft span.

Strength

- Maximum stress / first-ply failure criterion
- Factor of safety of 4.0 applied to material strengths to account for neglected loading, load multipliers, and material strength reduction factors.

Buckling

- al/FS > 1.0, where a = knockdown factor; l = buckling load factor; FS = factor of safety
- Buckling margin of safety = al/FS - 1.0.

A conservative safety factor of 4.0 was used for the design of the composite bridge. Table 2 provides expected margins of safety based on analyses and tests described later (page 15).

Table 2. Allowables and margins of safety.

	80,000 lb. Load	Margin of Safety
Beam Strain	385 με	32
Deck Strain	208 με	53
Deflection	0.95 in.	–
Bolt Shear Load	4000 lb.	1
Bond Shear Stress	150 psi	9

Deck

The road deck consists of three plates, described in Table 3. The only difference among the three deck plates is that Plates One and Two are made with a polyester matrix resin and Plate Three with a vinyl ester resin. No structural performance difference between the two resins is expected.

Support Beams

The support beams are designed to simplify fabrication and handling, yet transfer loads efficiently from the deck to the abutments. The tapered side walls and curved bottom of the U-shaped beams provided dimensional stability during forming and improve load transfer from the top deck, across the shear walls, to the end frames, and into the abutments. Flanges are provide for bolting the top deck panels to the beam. Specifications for the support beams are given in Table 4.

Table 3. Specifications for fiberglass PMC deck plates.

Geometry	10 ft. x 18 ft. panels; 5.5 in. thick sandwich construction
Materials	Upper and lower face sheets of 56 oz. knitted fiberglass fabric, $[0°/45°/90°/-45°/mat]_8$ layup, with unsaturated polyester (2 plates) or vinylester (1 plate) resins.
	Cobonded core made from 18 ft. x 4 in. x 4 in. square pultruded tubes; C-channels at ends for polymer-filled shear joints
Process	Hand layup, room temperature cure

Table 4. Specifications for fiberglass PMC longitudinal support beams.

Geometry	U-shaped, 30 ft. x 6 ft. x 36 in., open cross section, 0.75 in. thick wall
Materials	Quasi-isotropic wall of 56 oz. knitted fiberglass fabric $[0°/45°/90°/-45°]_8$ layup throughout beam
	0.95 in. buildup of 0° fiberglass reinforcement at bottom (1.7 in. total thickness)
	0.96 HYDREX polyester-vinylester blend resin
Process	Hand layup, room temperature cure

Abutments

The bridge will be placed on concrete abutments prepared with molded contours conforming to the curvature of the beams as shown in Figure 3. The abutments meet AASHTO and ITD standards. The footings are embedded to a sufficient depth to provide adequate bearing and frost heave protection during the testing of the structure. The main beams, which are seated with 1 in. thick elastomeric bearing pads, have full bearing on the abutments.

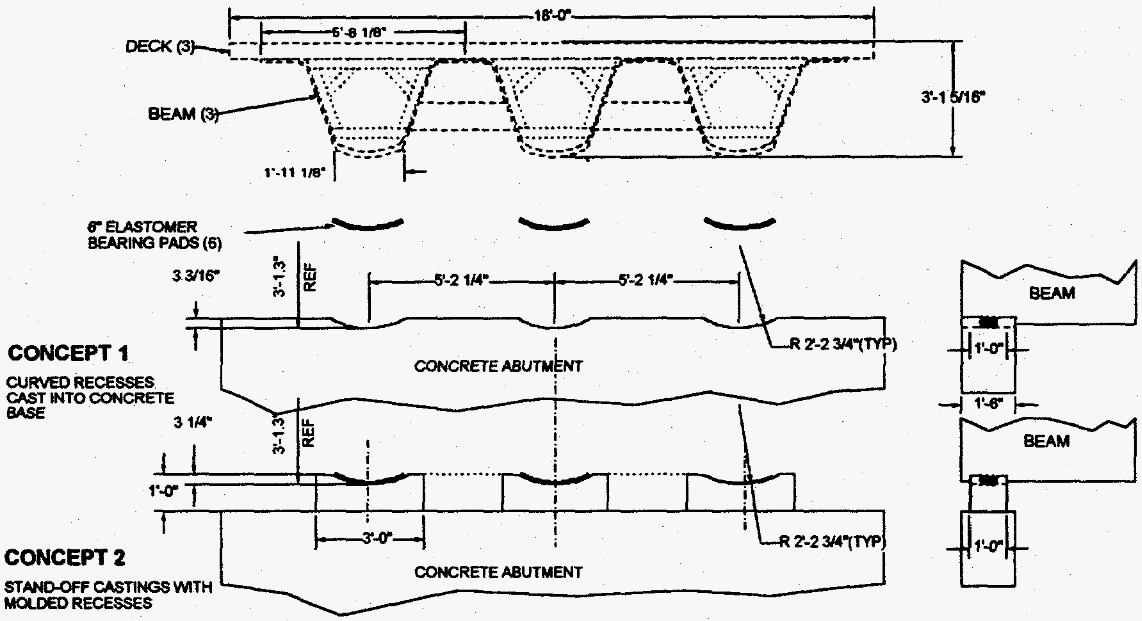


Figure 3. Abutment interfaces. Concept 2 was selected.

Wear Surface

Protecting the deck from moisture and contaminants was a major consideration in selecting the wear surface. Based upon the preliminary research, a variety of wear surfaces could be used to protect the deck. However, trials at LMMS indicated that a standard asphalt overlay can be applied without damaging the surface of the polymer composite deck and it is anticipated that a standard asphalt wear surface will be used. The wear surface will be at least 1.25 in. thick. The asphalt will be applied according to INEEL and ITD specifications. Height differences between the road surface and the bridge surface will be minimized using the asphalt wear surface; the transition to and from the bridge will meet the design specification prepared by the INEEL.

FABRICATION AND ERECTION

Component Fabrication

The bridge components were manufactured by commercial fiberglass fabricators from commercially stocked raw materials. Tag pieces were tested to verify the laminate properties and fabrication quality of each part.

To fabricate the deck's sandwich panels, thick face sheets were laminated onto cobonded pultruded tubes (standard catalog items purchased from Morrison Molded Fiberglass, Bristol, VA). The face sheets were hand laid using 50 in. roles of 56 oz. knitted, four-ply, quasi-isotropic fiberglass fabric. (Part of the reason for using a quasi-isotropic layup was concern for warping from non-uniform shrinkage during fabrication, which did not occur.) The laminate was cured to avoid exothermic buildup. Next, the pultruded tubes were coated with the same polyester/vinylester resin and bonded to the lower face sheets (Figure 4). Finally, the top face sheet was laminated onto the partially finished deck and the completed panel left to cure at room temperature (Figure 5). Each deck weighed 3400 lb.

Each beam was hand laid using heavy-weight knitted fiberglass fabric, as shown in Figure 6. Layers of four-ply quasi-isotropic fabric and a polyester resin matrix were used to fabricate a wall approximately 0.75 in. thick. Unidirectional reinforcements (additional 0.9 in.) were added to the bottom of the beams (interspersed between quasi-isotropic fabric layers) to further increase their bending stiffness. The weight of a finished beam was under 3500 lb.

Bridge assembly

The PMC demonstration bridge was first assembled at Lockheed Martin's Palo Alto Research facility shortly after the major components were delivered to the test site. The major structural members weighed less than 3500 pounds each, so handling and most of the assembly was performed with a three-man crew and a forklift, as shown in Figure 7. The original plans for assembly called for both bonding and bolting the bridge deck panels to the bottom support beams. Because the site was only a temporary location, the bridge was assembled as an all-bolted structure to permit disassembly afterwards.

The beams were individually lifted into place over the test fixture (Figure 7). Because the individual beams were susceptible to twisting due to the natural flexibility of their open cross-section, internal transverse struts were bolted onto the beams prior to assembly to provide the necessary handling stability and to maintain wall straightness during installation.

The deck plates were hoisted into position by a light-duty crane (Figure 8). Once the three decks were installed, they were secured by a shear key connection (Figure 9). A solid metal-wood insert served as the temporary key. For assembly at the INEEL, this key will be a polymer insert. Half-inch diameter steel bolts spaced 2 ft apart were used to fasten the deck panels to the lower support beams. Near the shear joints and at the beam ends the spacing was reduced to 1 ft. Finally, welded internal steel frames were bolted inside the ends of the beams to provide end rigidity for load transfer (Figure 10).

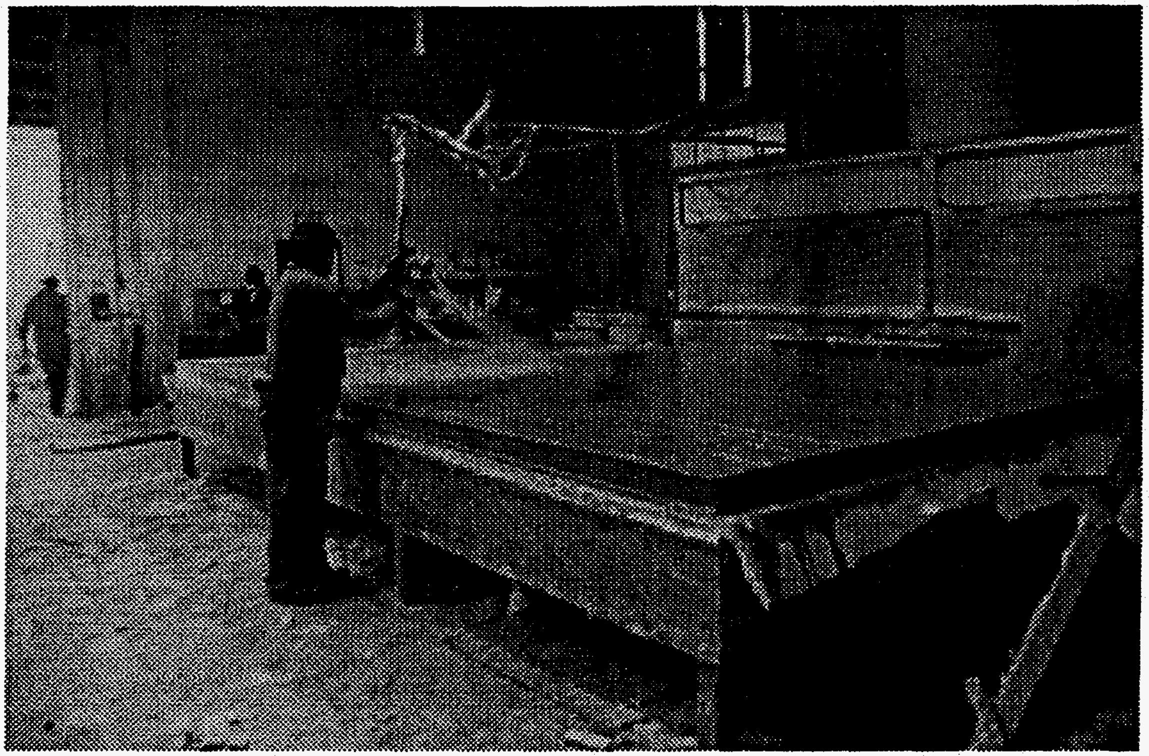


Figure 4. The core of the deck was saturated with resin prior to laying the top face sheet.

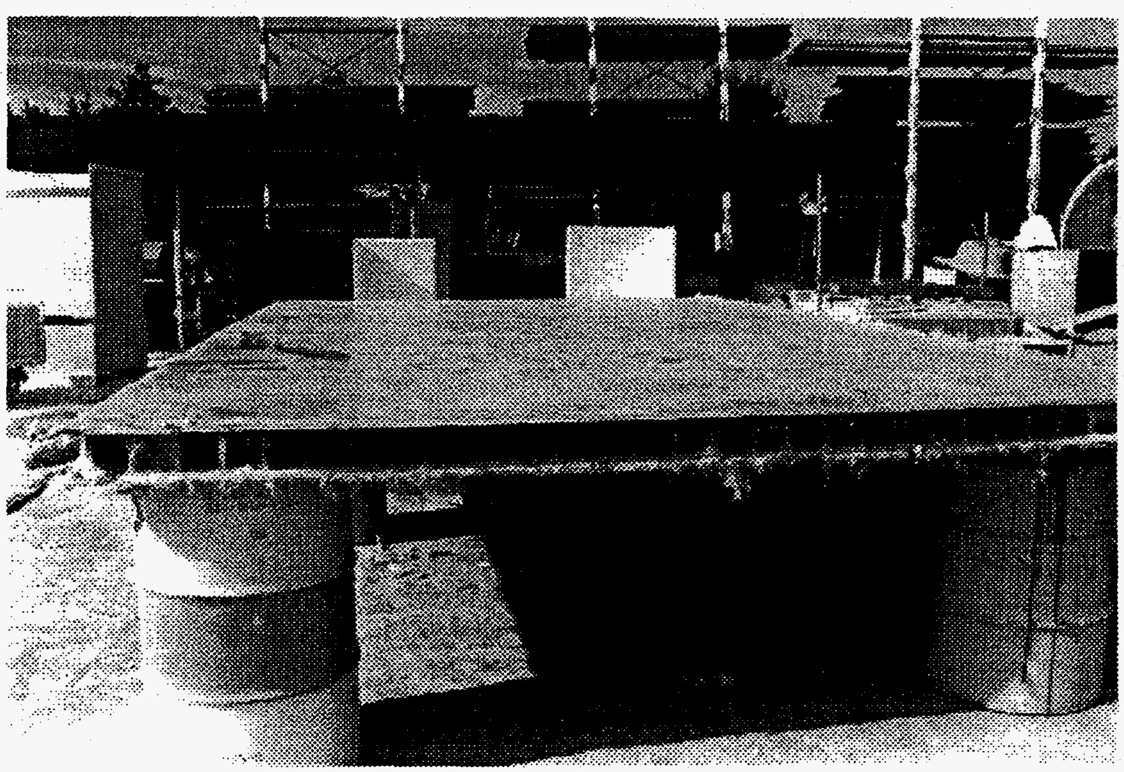


Figure 5. Completed deck panel before final trimming.

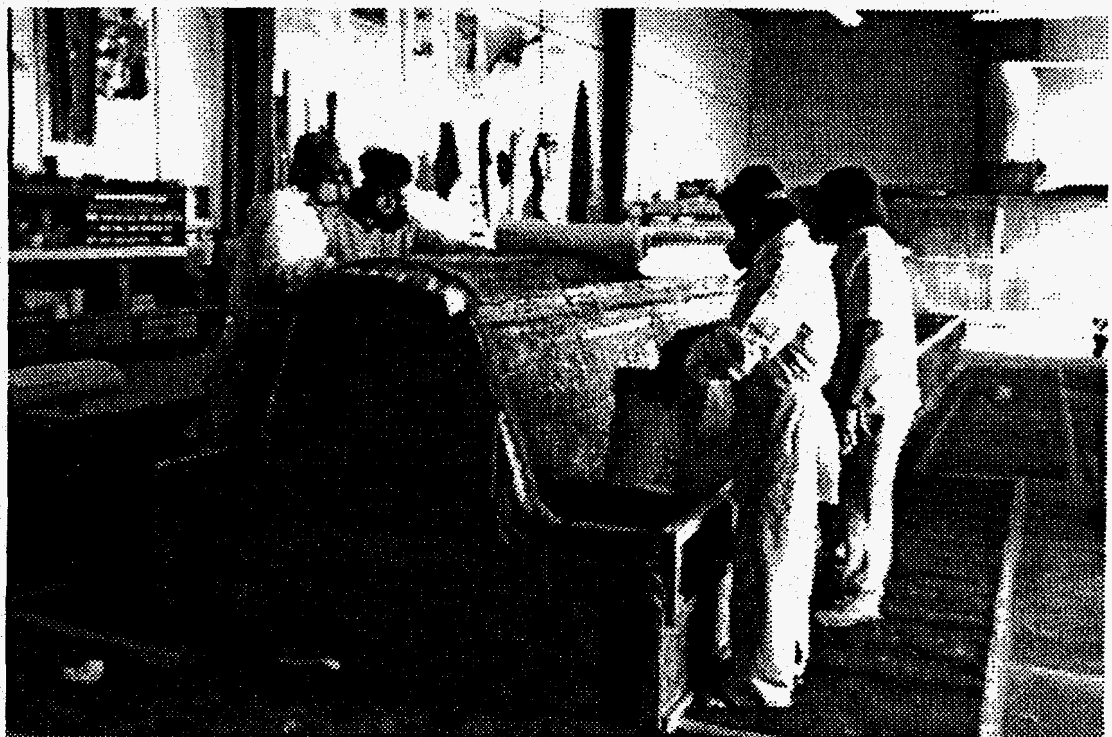


Figure 6. Support beam fabrication.

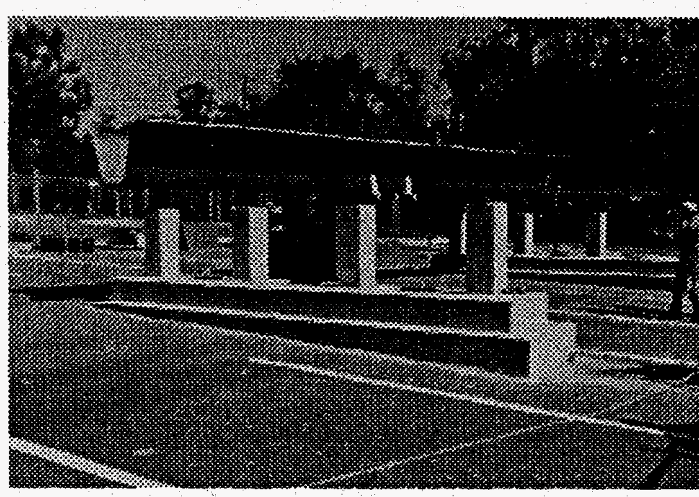


Figure 7. Forklift is used to place 30 ft. long support beams on static test fixture.

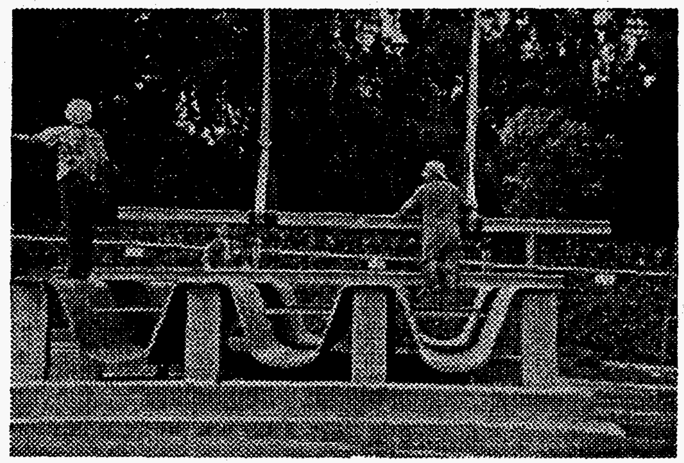


Figure 8. Deck plates are hoisted onto support beams.

Figure 9. Shear keys transmit loads between adjacent deck plates.

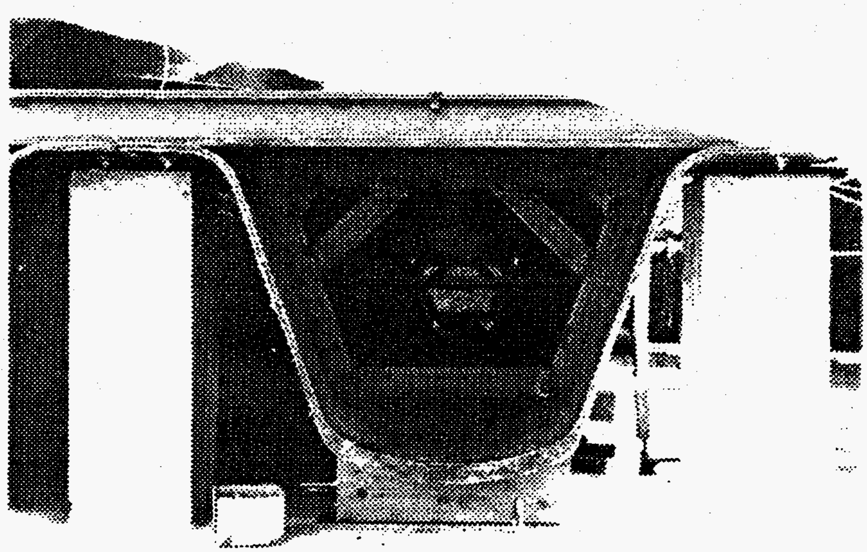


Figure 10. Steel frames reinforce beam ends.

INEEL Test Site Location

For dynamic and field testing, the composite bridge will be installed at the INEEL Transportation Complex located approximately 45 miles west of Idaho Falls. The Transportation Complex is in a restricted access area where only government vehicles are allowed. A section of parking area will be removed and the bridge placed across the hole. INEEL buses will be able to travel across the composite bridge structure in both directions.

It should be noted that after completion of testing the parking area will need to be restored. INEEL is requesting all participants in this and future bridge testing projects to include restoration in their costs.

TESTING AND EVALUATION

The purpose of the testing is to verify that the composite bridge meets all the design requirements established by AASHTO for short span bridges. Before developing the test plan, the literature was surveyed by the University of Idaho to identify existing data for the bridge materials, including failure modes and environment effects, and to determine the weight, speed, and number of cycles of trucks needed for dynamic and fatigue testing of the bridge. Testing, instrumentation, and analysis of the composite bridge has been selected to verify analytical calculations in areas where existing information is lacking or nonexistent.

In static testing, the bridge was found to meet the primary length/800 maximum deflection requirements. After installation at INEEL, the bridge will be instrumented to monitor strains, deflections, acoustic signatures, ambient temperature, and deck and girder temperature, movement, and length under actual highway loads (static and dynamic) in field service conditions for one year to further verify its structural performance.

Evaluation and analysis will include data collected at the INEEL installation location, INEEL research labs, CTL, and from the literature. One aspect of the analysis will be identifying appropriate testing procedures for composite bridges and recommending these to AASHTO.

Structural Analysis and Prior Static Tests

Finite element analyses were conducted to evaluate the performance of a 60 ft. span composite bridge. However, the demonstration bridge is one-lane wide and 30 ft. long, representing one quarter of a two-lane wide, 60 ft. long traffic bridge. For this 30 ft. length, the front end of a HS20-44 truck would just be exiting from the bridge as the rear is entering. Consequently, a more severe load case was simulated, with a full truck load applied as close to the center of the bridge as possible. In the field test this static loading was simulated with water tanks placed on the bridge and filled to generate loads exceeding 80,000 lb.

The deformed shape of the bridge is shown in Figure 11. The maximum deflection under this load is 0.95 in., which exceeds the design goal of 0.45 in. However, this loading is much more severe than an actual truck load and, when adjusted to reflect realistic truck loading, the deflection should satisfy the L/800 requirement for the same design bridge with a 60 ft. span.

Shear loads are transmitted from the deck plates to the beam flanges. Two coupling methods were considered, bolting only and bonding as well as bolting. For bolting only, the maximum expected bolt shear load is about 4000 lb., while the capacity exceeds 8000 lb. (Capacity was determined experimentally by bolt bearing tests in both torqued and untorqued configurations. A typical experimental load deformation curve is shown in Figure 12 for the untorqued condition. The deformation and fracture behavior appear ductile, leading to load redistribution to surrounding bolts rather than catastrophic failure.) For bonding as well as bolting, the shear stress in the bond is about 150 psi, while the strength exceeds 1500 psi. as determined from lap shear tests.

The material properties used in the analyses are summarized in Table 5. These properties were obtained from manufacturers' data in combination with experimental coupon data and laminate analysis programs. Material properties were substantiated by mechanical tests performed on large bridge component specimens, such as the beam bending experiment (the load deflection response for this experiment is given in Figure 13). Results from the component tests were used to validate the analytical models and calculate the margins of safety presented in Table 2.

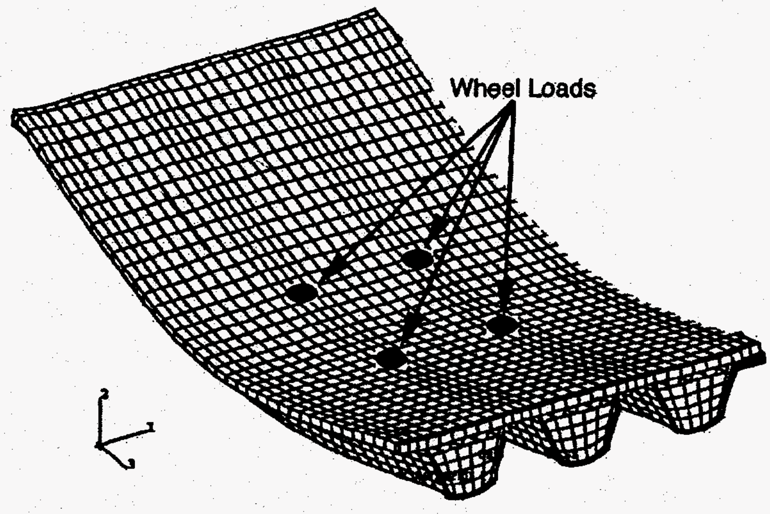


Figure 11. Finite element model of bridge showing deformation under four 20,000 lb. wheel loads (80,000 lb. total load).

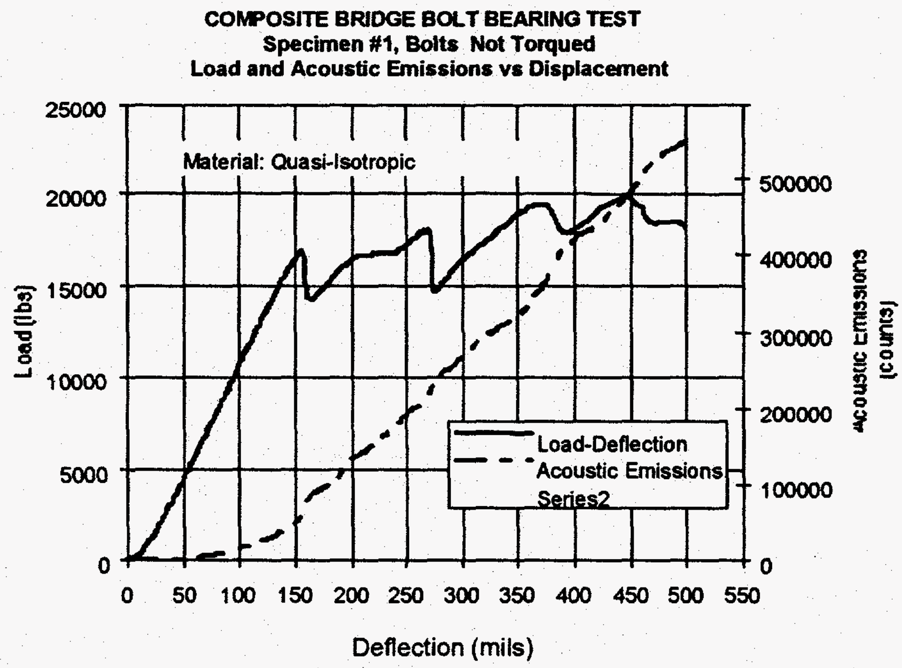


Figure 12. Load vs. deflection for pin bearing test of 1/2" diameter bolt in a quasi-isotropic plate.

Table 5. Material Property Data.

Property		Uni-directional Ply	Flange	Cap	Deck	Deck Core
Fiber volume by cross-sectional area	Fiber Volume (%)	34	34	34	50	N/A
Laminate longitudinal tension modulus	E_x (*10^6 psi)	4.00	1.92	3.17	2.62	0.100
Laminate transverse tension modulus	E_y (*10^6 psi)	0.95	1.92	1.38	2.62	0.5859
Laminate through-thickness tension modulus (est.)	E_z (*10^6 psi)	0.95	1.04	1.01	1.35	0.100
Laminate longitudinal-transverse shear modulus	G_{xy} (*10^6 psi)	0.34	0.727	0.493	0.93	0.055
Laminate longitudinal-thickness shear modulus	G_{xz} (*10^6 psi)	–	0.337	0.337	0.434	0.100
Laminate transverse-thickness shear modulus	G_{yz} (*10^6 psi)	–	0.337	0.337	0.434	0.055
Laminate longitudinal-transverse Poisson's ratio	n_{xy}	0.30	0.322	0.316	0.322	0.33
Laminate longitudinal-thickness Poisson's ratio	n_{xz}	–	0.303	0.304	0.302	0.33
Laminate transverse-thickness Poisson's ratio	n_{yz}	–	0.303	0.387	0.302	0.058
Percent laminate longitudinal compression strain to failure	X_c (% strain)	1.24	1.23	1.24	1.24	—
Percent laminate longitudinal tension strain to failure	X_t (% strain)	1.27	1.28	1.27	1.13	—
Percent laminate transverse compression strain to failure	Y_c (% strain)	1.97	1.23	1.22	1.24	—
Percent laminate transverse tension strain to failure	Y_t (% strain)	1.35	1.28	1.25	1.13	—
Percent laminate in-plane shear strain to failure	S (% strain)	2.53	2.53	2.53	2.53	—

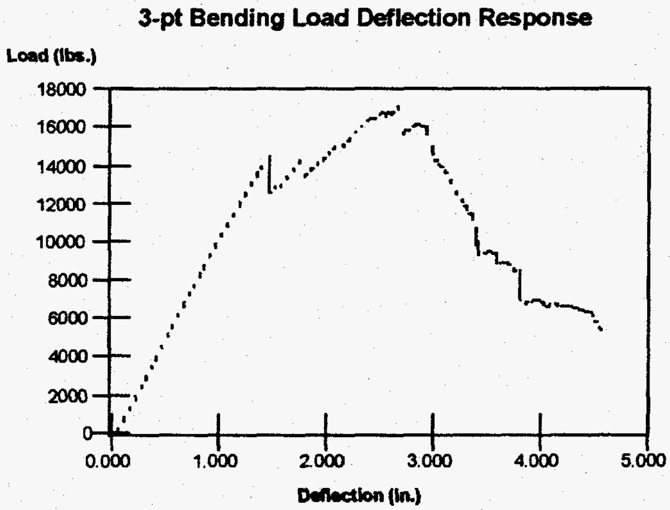


Figure 13. Load vs. deflection for 3-pt bend test of 2-inch deep glass/polyester support beam component tested with 3 ft span.

Composite Bridge Testing at INEEL

INEEL vehicles will be used to repeatedly load the composite bridge structure during the 12-month testing phase. During this 12 months the INEEL is expecting to maintain a constant pattern of traffic over the composite structure under a variety of weather conditions. This test phase is expected to include 31,000 repetitions of a 22,000 lb. axle load.[a] Additionally, the bridge will be subjected to static load testing on a quarterly basis to compare stresses and deflections calculated in design with *in situ* structural behavior. The load tests will also serve as a periodic measure of potential changes in the structure's stiffness due to environmentally or live-load induced degradation. At the end of the test interval, an additional load test to failure may be performed. Although this test would provide useful design performance information, funding for this effort has not been identified. The INEEL will try to identify additional project participants during the testing period to perform additional testing. Any additional testing identified during this project will be coordinated with the bridge owner, Martin Marietta Materials.

The bridge's response will be monitored with remotely-positioned electronic instrumentation, periodic load test events, and frequent, detailed, visual inspections. The purpose of the visual inspections will be to evaluate the presence and extent of aging deterioration phenomena, such as abrasion of deck wearing surface, impact/snow plow damage, connection integrity, environmentally-induced deterioration, and other phenomena not practically measured by sensors.

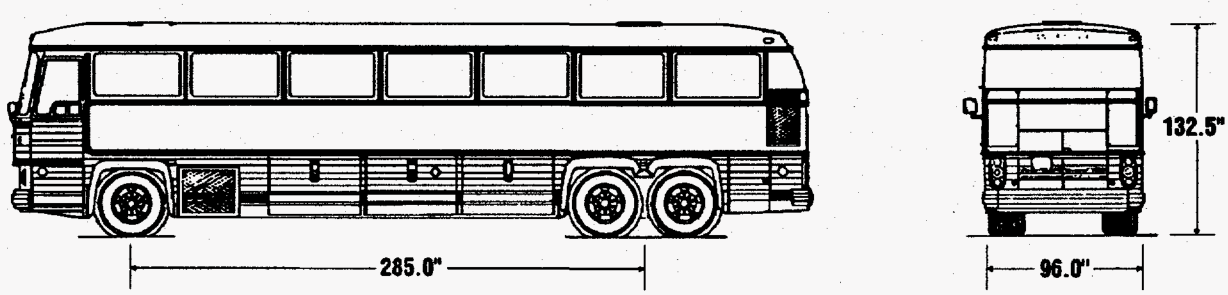
a. It should be noted that the fatigue limit for composite materials is defined as the strain below which the matrix cracks remain non-propagating at 10^6 cycles. Thus, any testing for fatigue should consist of at least that many cycles (Talreja, 1987). However, for unidirectional composites, this limit will be lower for strains out of direction of the composite fibers. The failure mechanism of laminated composite material is typically as follows. The 90° layer fails in transverse fiber debonding. This is followed by the delamination of the 45° layer. The 0° layer becomes overstressed leading to the failure of the composite (Talreja, 1987). Composite materials are especially sensitive to the rate or frequency of loading due to material heating and high damping effects. At frequencies over a few hertz, this becomes a problem. Composite materials are insulators so they do not dissipate the heat absorbed during cyclical loading.

INEEL Vehicle Information

Access to the composite bridge is limited to INEEL buses and other government vehicles owned and operated by the INEEL. The majority of the bridge traffic will be buses, but H- and HS-type loading vehicles will be used for specific testing purposes. The specifications for these vehicles are given in Table 6. Vehicles will maintain a constant speed of 15 miles per hour across the bridge.

Table 6. INEEL Vehicle Specification

	Buses		Trucks	
Vehicle Type	96A3	102A3	H20-44/H15-44	HS20-44/HS15-44
Vehicle length	40' 6 5/8"	40' 6 5/8"	—	—
Wheel Base (see drawing below)	285"	285"	168"	168" plus trailer
Weight Front Axle	13,340 lb.	14,000 lb.	8,000 lb/6,000	8,000 lb/6,000
Weight Drive Axle	22,000 lb.	22,000 lb.	N/A	32,000/24,000
Weight Tag Axle	6,000 lb.	6,000 lb.	32,000/24,000	32,000/24,000
Radius	45'	45'	—	—



Data Collection

The INEEL will collect data from the bridge using a variety of sensors mounted to the composite structure. As a minimum, data will be collected after 25 vehicle crossings. Measurement frequency may change based upon weather conditions or traffic volumes. An instrument cabinet at the bridge installation site will be used to terminate sensor cables from the bridge. Communications from the instrument cabinet to a local area computer will be required for data storage and processing. The parameters to be measured are listed in Table 7.

Table 7. Instrumentation Measurement Matrix.

Parameter	Instrumentation	Resolution	Measurement Interval
Strain	—	—	At least every 25th vehicle and more than once per day
Web	4 Strain Gauge Rosettes	5 με	—
Beam	4 Strain Gauge Rosettes	5 με	—
Deck	8 Strain Gauge Rosettes	1 με	—
Bolt	4-8 Strain Gauges	—	—
Deflection	—	1/100 inch	At least every 25th vehicle and more than once per day
Support	8 Position Sensors	—	—
Centerline	7 Position Sensors	—	—
Longitudinal	2 Position Sensors	—	—
Deck/Beam	3 Position Sensors	—	—
Deck/Flange	4 Position Sensors	—	—
Deck/Deck	4 Position Sensors	—	—
Reaction Forces	—	—	At least every 25^{th} vehicle and more than once per day
Beam	6 Load Cells	—	—
Acoustic Emission	—	—	Continuous
Deck	2 AE Sensors	15 - 35 kHz	—
Environmental	—	—	Hourly
Temperature	Thermistor	1/10 Degree F	—
Humidity	Thermistor	1/10 Degree F	—
Solar Radiation	Pyranometer	1/1000 W/m^2	—
Ultra Violet	Pyranometer	1/1000 W/m^2	—
Thermal	—	—	Hourly
Deck	X Thermocouple	1 Degree F	—
Top of Wear Surface	X Thermocouple	1 Degree F	—
Underside of Deck Between Beams	X Thermocouple	1 Degree F	—
Optional Thermal Measurements	—	—	Hourly
Abutment	X Thermocouple	1 Degree F	—
Web	X Thermocouple	1 Degree F	—
Bridge Length	Extensometer	1/100 inch	—
Vehicle	—	—	Continuous
Axles	Vehicle Counter	1 Axle	—
Axle Spacing	Vehicle Counter	0.5 ft	—
Axle Weight	Vehicle Counter	500 lb.	—
Vehicle Speed	Vehicle Counter	2 mph	—

Strain Measurements

Strain measurements will be made on the composite structure at the sensor locations indicated in Figure 14. The mathematical model developed by Lockheed Martin Missile and Space for the composite structure will be used to determine the material's modeled behavior relative to the measured parameters. The data collected during the test period will be used to refine the mathematical analysis for this structure.

Web Shear Strain. Measurement of the shear strain on each beam web requires four strain gauge rosettes. One rosette will be mounted on the inner surface of the center beam near the neutral axis of the section at the centerline, and three more along one of the bridge quarter points (see Figure 14).

Beam Cap Strain. Measurement of the direct strain in the beam cap requires four strain gauges, one on the inner surface of each of the three beam caps at the centerline, and one at the quarter point of the bridge along the center beam.

Deck Strain. Measurement of the direct strains in the deck plate will require eight strain gauges. Pairs of strain gauges will be used to measure the longitudinal and transverse strains at the four points where the beam cap strain is measured.

Bolt Strain. Due to the overdesign of the composite bridge, a change in bolt strain may indicate a change in bridge health. As part of an INEEL long-term research initiative, a bolt on the center beam flange at either the forward or aft end will be instrumented to measure axial and bending strains in the shank of the bolt. This will provide information on the clamping and bending forces to which the bolt is subjected. Correlation of the bolt data with other strain values should provide insight into the merit of using instrumented bolts for dynamic in-service monitoring as well as periodic inspection to determine bridge health.

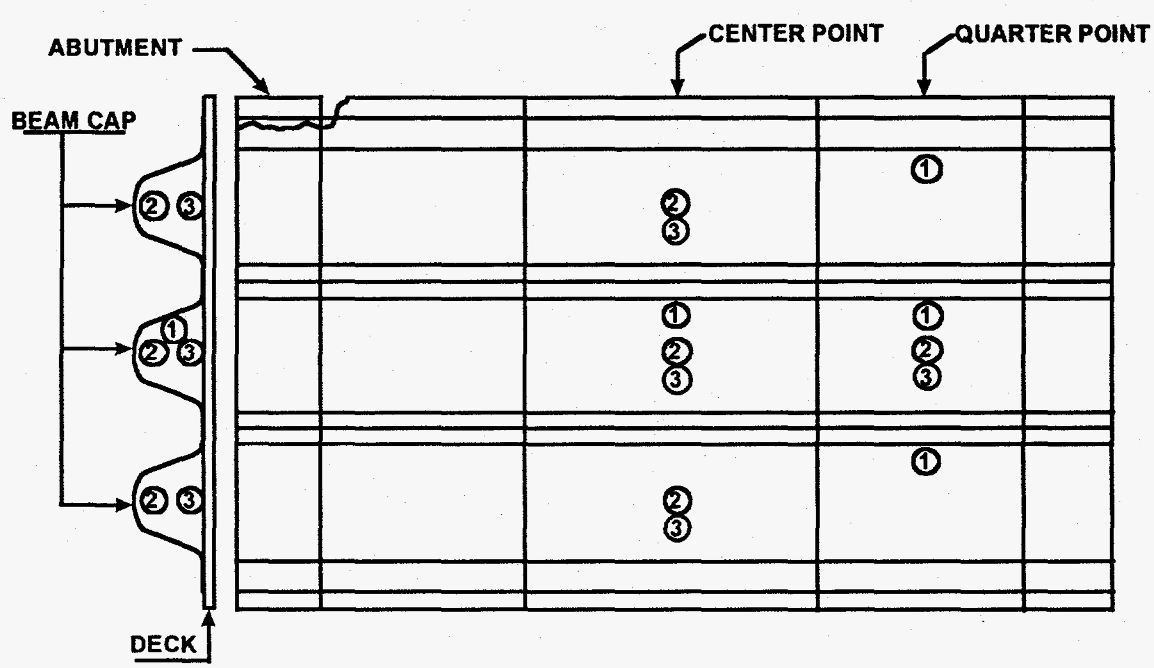


Figure 14. Strain Transducer Locations. Locations identified "1" are to measure web shear strain, "2" beam cap strain, and "3" deck strain.

Deflection Measurement

Deflection measurements are to made on the composite structure at the locations indicated in Figure 15.

Support Deflection. Measurement of the vertical deflection of the bridge relative to the abutment supports requires eight position sensors with a maximum range of ±1 in. Four sensors will be placed on each end of the bridge, positioned outside and between the three support beams, and grounded to the abutments.

Centerline Deflection. Measurement of the deflection of the bridge centerline requires seven position sensors with a maximum range of ±2 in. Three sensors will measure the deflection of the beam caps relative to the ground, and four sensors will measure the beam flange deflection relative to the ground.

Longitudinal Deflection. Measurement of the quarter point deflection of the center beam to develop the longitudinal deflection profile requires two position sensors with maximum range of ±2 in.

Deck/Beam Deflection. Measurement of the relative deflection of the bottom of the deck and the inside of a beam requires three position sensors with a maximum range of ±1 in. Sensors will be positioned inside each beam at centerline or, alternatively, under the loading points.

Deck/Flange Deflection. Measurement of the relative deflection between the deck and the beam flanges requires four position sensors with a maximum range of ±0.25 in. Sensors will be mounted to the beam flange and the deck in the 0.75 in. gap between flanges on the inner beam.

Deck/Deck Deflection. Measurement of the relative normal and shear deflection between the deck plates requires four position sensors with a maximum range of ±0.25 in. Two sensors will be located along the longitudinal centerline and two over the inner beam flange at one of the deck/deck interfaces.

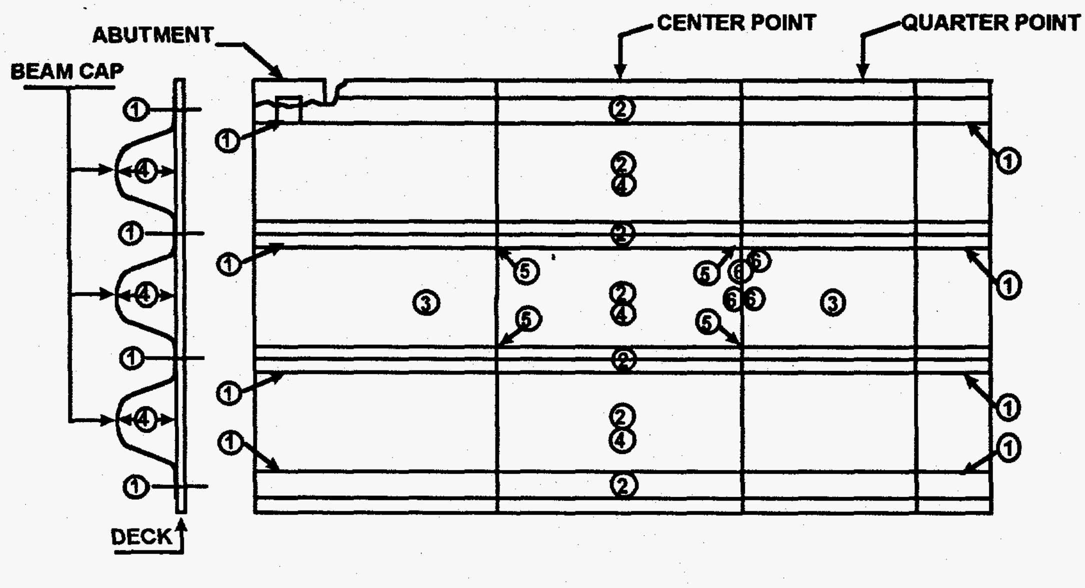


Figure 15. Deflection Transducer Locations. Locations identified "1" are to measure support deflection, "2" centerline deflection, "3" longitudinal deflection, "4" deck/beam deflection, "5" deck/flange deflection, and "6" deck/deck deflection.

Acoustic Emission

Acoustic emission (AE) is due to the energy released to mechanical waves during progressive stressing of materials. AE is used as a nondestructive tool in acceptance testing, design analysis, and material characterization. Composite materials are typically considered "noisy" materials from the standpoint of AE because of the many energy release sources in their interfacial boundaries. Some degree of AE is present during testing, either from the materials themselves or from external sources, that is displayed as sporadic or continuous low-level noise. However, the sudden release of energy due to major structural events such as impact loading, joint movements, or material damage would be indicated by abnormal spikes in the AE. Acoustic sensors would thus serve as a warning system for abnormal events. At least one AE pickup should be mounted on the bottom face of the first and third decks, within the center beam, to monitor the joint interface at the forward and aft ends of the bridge.

Environmental Monitoring and Thermal Measurements

The material properties and performance of the composite structure will be correlated to temperature during the testing phase. The INEEL, in southeastern Idaho, is subject to temperature extremes of over 50°F during the winter. The National Oceanic and Atmospheric Administration (NOAA) has over 31 atmospheric measuring stations in and around the INEEL. One of these monitoring stations is located near the bridge site. This monitoring station will used to monitor air temperature, solar radiation, wind speed and direction, relative humidity, and rainfall. Data collected from this weather station will be used to determine the freeze/thaw cycles during the testing phase.

Continuous or intermittent measurements of material temperatures will be made at key points on the bridge; areas currently identified include the deck, web, and abutment. These data will be coupled with deflection measurements to determine temperature dependent deflections over time. (The nominal coefficient of thermal expansion for the composite bridge is 6.0×10^{-6} in/in/°F, which is comparable to that of concrete.) Monitoring before, during, and after critical static and dynamic loading will allow changes due to thermal and mechanical loading to be distinguished. Thermocouples will be placed adjacent to strain and displacement gauges if possible; at least one thermocouple will be placed in each of the following locations:

1. On top of the wear surface and free from shadows, preferably at the center of the bridge near one edge

2. Embedded under the wearing surface directly below Location 1 and in contact with the top of the deck

3. On the underside of the deck between the support beams (probably mounted to the flange of the center beam at mid-span.

An ambient temperature gauge will be used to monitor air temperature.

Other Tests

Research on composite materials has been identified as a critical need amongst the transportation community. Some of the measurement requirements that have been identified by this community are durability, creep, ultraviolet deterioration, alkaline reactions, bonding, environmental impact, and galvanic reaction between composite materials and connection hardware, i.e., fasteners, metal frames, etc. As part of this project, ultraviolet coatings will be tested and accelerated aging tests will be performed.

Ultraviolet Coatings

The main environmental concern when using composite materials is ultraviolet degradation. The exposed face of untreated composite materials may experience significant loss of resin, exposing the fibers. While the modulus of elasticity does not change with exposure, strength can be affected. This is more significant on the tension face of the material as it may result in loss of tensile strength. However, a surface coating can prevent fiber exposure and ultraviolet inhibitors can be added to the composite to help prevent degradation (Trabocco, et al., 1975).

While composite materials are more corrosion resistant than steel, they still display some loss of strength when exposed to moisture. This effect may not be permanent. Salt spray in combination with ultraviolet exposure has been shown to increase degradation of the material and decrease impact resistance (ASCE, 1984). The effect of corrosive chemicals is temperature dependent, with elevated temperatures increasing the corrosion activity.

To address some of these concerns, INEEL will, as part of its internally funded research and development effort, evaluate the environmental factors related to ultraviolet coatings. The INEEL will prepare, test, and evaluate coupons of polyester resin PMC beam material with various coatings. The INEEL will work directly with the bridge and coating manufacturers in selecting coatings for this evaluation. It is anticipated that the following coatings will be used.

- Coated with ultraviolet protective coating used on bridge, with the bridge pigment color
- Coated with ultraviolet protective coating used on bridge, with color different than bridge (to be chosen)
- A more rugged ultraviolet coating (color pigment to be determined). Specifications for this more rugged coating will be based upon manufacturer's environmental protection properties.
- A third ultraviolet coating (color pigment to be determined).

An additional category will be "uncoated with one year of California sun exposure". At least two coating thicknesses will be used, the nominal coating application thickness and half of that thickness. Samples of each thickness will be exposed to dirt and sand erosion (mild sandblast).

Samples will be exposed to a combination of UV, moisture, and water erosion while in an environmental test chamber. The time-of-wetness, UV exposure cycle, and duration of water spray for water erosion will be selected in collaboration with the environmental chamber manufacturer. Samples will be evaluated on a set interval to determine change in gloss and color using ASTM-accepted techniques. The samples will also be evaluated using visual inspection techniques. A duplicate set of samples will be placed in an outdoor exposure rack at the bridge installation location and evaluated using the same monitoring techniques. These samples will be ranked following a year of outdoor exposure. Coating performance in the outdoor exposure will be compared to performance in the environmental chamber. Based on environmental chamber and initial outdoor exposure results, additional samples may be added to test sample suite. Factors that may need to be considered include additional UV coatings, other candidate pigments in the UV coating, and additional chemical assessments such as acid rain solutions.

Another set of samples will be used to test the effects of salt spray. Some samples will be exposed only to a salt spray environment while others will be exposed to salt spray followed by UV exposure to determine the interaction of these environmental factors. The UV environmental chamber is not equipped to provide salt spray; therefore, the samples will be exposed to alternating cycles of salt spray in one chamber followed by UV exposure in another chamber. The chambers' manufacturer will be consulted regarding the optimum intervals for the salt spray-UV sequence.

The results of the UV testing series will be included in the final report. Although a direct correlation cannot be made between the outdoor and environmental chamber exposure results, it is anticipated that the rankings will provide a basis for selection of appropriate UV coatings and pigment colors in future composite bridge fabrication.

Accelerated Aging Test

Accelerated aging tests will be conducted at Construction Technology Laboratories, Inc. to evaluate the durability of the bridge deck compared to traditional construction materials. The test procedure, which will meet the requirements of ASTM Test Method C 666, will expose a specimen to between six and eight daily alternating cycles of temperature between 0 and 40°F in a saturated condition with a target of attaining 300 cycles. Testing will be coordinated between project participants and may vary depending upon the availability of small test sections from Lockheed Martin Missile and Space.

DATA EVALUATION AND REPORTING

Evaluation and analysis will include data collected at the INEEL installation location, CTL test results, and historic information. These results will provide a basis for further composite development and evaluation. Data collected during this project will be stored by the INEEL and distributed at the discretion of the project sponsors; a copy will be provided to FHWA with the final report.

The INEEL will provide additional material property information from research and development sponsored by Lockheed Martin Idaho on environmental factors associated with the bridge material and ultraviolet coatings (the scope of this project does not include this material property testing). The quantitative and qualitative results of the environmental testing, and the identification of the mechanisms responsible for coating and material degradation, will be the basis for recommendations on appropriate criteria for selection of a protective coating.

The final report will describe the construction, transportation, installation, testing, and material properties of the composite bridge and the performance of the composite structure relative to design specifications. Conclusions on the performance of the composite bridge will be provided by the project participants. Recommendations will be made for the development of testing and monitoring requirements for composite structures.

REFERENCES

ASCE, 1984, *Structural Plastics Design Manual*, American Society of Civil Engineers, New York, NY.

Talreja, R., 1987, *Fatigue of Composite Materials*, Technomic Publishing Co., Inc., Lancaster, PA.

Trabocco, R. E. and M. Stander, 1975, "Effect of Natural Weathering on the Mechanical Properties of Graphite/ Epoxy Composite Material," *Environmental Effects on Advanced Composite Materials*, American Society for Testing and Materials, Philadelphia, PA, pp. 67-84.