United States
Department of
Agriculture

Forest Service

Forest
Products
Laboratory

General
Technical
Report
FPL–GTR–195

Development of a Smart Timber Bridge—A Five-Year Plan

Brent M. Phares
Terry J. Wipf
Ursula Deza
James P. Wacker

Abstract

This paper outlines a 5-year research plan for the development of a structural health monitoring system for timber bridges. A series of studies identify and evaluate various sensing technologies for measurement of structural adequacy and/or deterioration parameters. The overall goal is to develop a turn-key system to analyze, monitor, and report on the performance and condition of timber bridges. The introduction of structural health monitoring technologies for timber bridges should result in improved safety, longer service life, and improved load ratings.

Keywords: structural health monitoring, deterioration, long-term performance, timber bridge, glulam, sensors

SI conversion factors

Inch–pound unit	Conversion factor	SI unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)

March 2011

Phares, Brent M.; Wipf, Terry J.; Deza, Ursula; Wacker, James P. 2011. Development of a smart timber bridge—A five-year plan. General Technical Report FPL-GTR-195. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 10 p.

A limited number of free copies of this publication are available to the public from the Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726–2398. This publication is also available online at www.fpl.fs.fed.us. Laboratory publications are sent to hundreds of libraries in the United States and elsewhere.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

Contents

Development of a Smart Timber Bridge—A Five-Year Plan

Brent M. Phares, Associate Manager
Terry J. Wipf, Director
Ursula Deza, Graduate Student
Bridge Engineering Center, Institute for Transportation—Iowa State University, Ames, Iowa

James P. Wacker, Research General Engineer
Forest Products Laboratory, Madison, Wisconsin

Background

The critical deterioration of bridges nationwide has initiated the search for new methods to rehabilitate, repair, manage, and construct bridges. In this context, smart structures have recently emerged as a new technology to help improve future management. This approach can be thought of as a potential replacement for, or complementary to, on-site inspections currently specified by the National Bridge Inspection Program. In general, research on smart structures involves materials, structural mechanics, electronics, signal processing, communication, and control (ISIS 2001, Bruhwiler 2003). In practice, a smart structure would typically incorporate the use of sensors, data reduction techniques, and remote systems that allow for monitoring of the structure (Maalej and others 2002, Muthumani and Sreekala 2003, Koh and others 2003). With these elements, the smart structure is able to monitor the in situ behavior of the structure, to assess its performance under service loads, to detect damage and deterioration, and to determine its current condition (Udd and others 2000, Li and others 2004).

To date, fiber optic sensors (FOSs) have been used in concrete and steel structures (Merzbacher and others 1996, Doornink and others 2005, Kim and Cho 2004, Ansari 2005, Sumant and Maiti 2005). Fiber Bragg Gratings (FBGs), a type of diffraction grating of an optical fiber that filters out particular wavelengths of light, have many advantages over other FOS types. Besides being absolute, linear in response, interrupt immune, and readily multiplexed, these sensors have the ability to be both embedded and surface mounted. In laboratory and field tests, good agreement with foil strain gages has been demonstrated in both steel and concrete structures.

In recent research efforts involving existing steel and concrete bridges, health monitoring systems have been applied with the purpose of detecting early damage and deterioration and prolonging service life. Health monitoring systems have also been applied in newly constructed bridges with the goal of reducing the total life maintenance cost and improving bridge management (Koh and others 2003). The purpose of using structural health monitoring (SHM) systems is to provide real-time monitoring of various structural and serviceability changes through measurement metrics such as strain and temperature, among others. In the case of bridge structures, the data provided by these sensors are usually transmitted to remote data acquisition centers. Thus, an active structural control based on the collected information is possible.

In the past, timber bridge evaluation and maintenance efforts have principally focused on the internal integrity of timber components and improving day-to-day performance (Ritter 1992, FPL 1999, Kainz and others 2001). The goal of the research plan that is the subject of this report is to develop a smart timber bridge that improves the long-term performance, maintenance, and management of timber bridges through the development of smart timber bridge concepts. The development of the smart timber bridge will utilize current and new sensors, health monitoring technologies, and bridge management approaches that will be integrated in one turn-key SHM system. Thus, the work described herein is to develop a system to monitor, analyze, and report on the performance and condition of the most commonly constructed timber bridge. This work will be accomplished over a 5-year period.

Conceptual Smart Timber Bridge

Conceptual Structural System

Not surprisingly, the material used in the smart timber bridge will be glued-laminated timber (glulam) members (Ritter 1992, FPL 1999, Russell 1997). In contrast to the variable range of solid wood, glulam is an engineered wood product that provides distinct advantages over solid-sawn timber. Glulam consists of (2-in. nominal) lumber laminations that are bonded together on their wide faces with structural adhesive. Fundamentally, glulam members can be manufactured from any softwood or hardwood lumber. In the United States, glulam has been applied successfully in buildings and bridges since the 1930s.

The superstructure of the conceptual bridge is composed of a series of transverse glulam deck panels supported by longitudinal glulam girders. In general, these superstructures can span 20 to 80 ft. Based on the *Standard Plans for Timber Bridge Superstructures* (Wacker and Smith 2001), the baseline smart timber bridge considered during development will be a simply supported 60-ft-long span with a 24-ft roadway width with zero skew supported on concrete abutments.

The baseline superstructure system consists of three primary components: seven girders spaced at 44 in., four sets of diaphragms spaced at 18 ft, and bearings (Figure 1). The girders will be assumed to be Southern Pine 24F-V3 designed for a HS25-44 truck loading. The resulting girder cross section is 8-1/2 in. wide and 45-3/8 in. deep. The diaphragms are glulam sections 5-3/8 in. thick, 37-3/8 in. deep, and 35-1/2 in. long with the same denomination as the deck panels and beams (Southern Pine combination 48), and placed perpendicular to the girders. The diaphragms are attached to the girders with 7/8-in.-diameter tie rods that extend through the diaphragms at the third glue line from the top and bottom of the diaphragm. The bearing connections for the glulam beams are fixed to prevent longitudinal movement. The bearing shoe consists of two 4- by 8- by 1/2-in. steel angles that connect the beams to the substructure (concrete backwall) with 3/4-in.-diameter anchor bolts and to the glulam beams with 3/4-in.-diameter through bolts. A 3/4-in.-thick bearing pad made of elastomeric rubber will also be assumed.

The baseline bridge deck consists of transverse glulam deck panels with vertical laminations (Figure 2). The glulam deck panels are 5-1/8 in. thick. All standard interior and end panels are 4 ft wide. The panels are attached to the beams with 5/8-in.-diameter dome head bolts and cast aluminum alloy deck brackets. The deck brackets are connected to the glulam beam sides in 3/4- by 8-in. slots. For the interior panels, two brackets per beam side are connected to the deck panel with bolts placed 6 in. from the panel edge and spaced at 2 ft and not coincident with the other side. In the end panels, the brackets are connected to the deck panel with bolts placed 6 in. from the panel edges.

Measurement Attributes of the Smart Timber Bridge

Development of the smart timber bridge focuses first on understanding bridge-specific behaviors and deterioration modes (Ritter 1992, FPL 1999, NFPA 2005) and then designing an instrumentation and data processing plan that allows extraction of the needed information. Assessment of structural adequacy and deterioration of a structure is key to the success of a smart timber bridge. The needed variables thought to define the attributes of the smart timber bridge constructed with glued laminates are described below.

Structural Adequacy

Structural behavior attributes, which are related to the load side of structural capacity, will be evaluated with respect to three engineering metrics: lateral load distribution, dynamic load allowance, and fatigue life usage (Hosteng 2004, Le and others 1998, Ansell 2003, Clorius and others 2000, Davids and others 2005). Lateral load distribution obtained from the live loads is an important parameter that indicates how loads are being resisted by the structure and may be an indicator of changes in stiffness and possible deterioration of the bridge over time. Also, quantification of the dynamic load allowance will give a similar indicator. Finally, fatigue life usage (which can be used in bridge management and in other ways) of critical members (such as girder-to-deck and girder-to-bearing connections) will be assessed through stress cycle counting.

Another structural adequacy requirement is serviceability of the structure, which focuses on ensuring functionality and appearance of the structure. In the smart timber bridge, live load deflection, or measurements related to deflection (such as strain) will be monitored to investigate functionality and changes in stiffness of the bridge superstructure. Somewhat related, a technique to assess configuration and loading of vehicles will be obtained from measurement responses. Evaluation of all assessed parameters, in the light of the actual response of the structure, would provide information about usage of the structure and could be used to predict remaining service life of the smart timber bridge.

Structural damage is an equally important characteristic of timber bridges. The SHM system would need to assess changes in stiffness resulting from factors, such as delamination, vehicular collision, and other sources. This will most

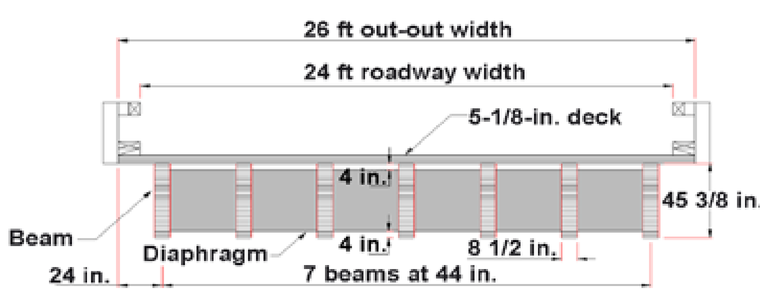

Figure 1. Cross-sectional view of the baseline bridge, with a 24-ft roadway width.

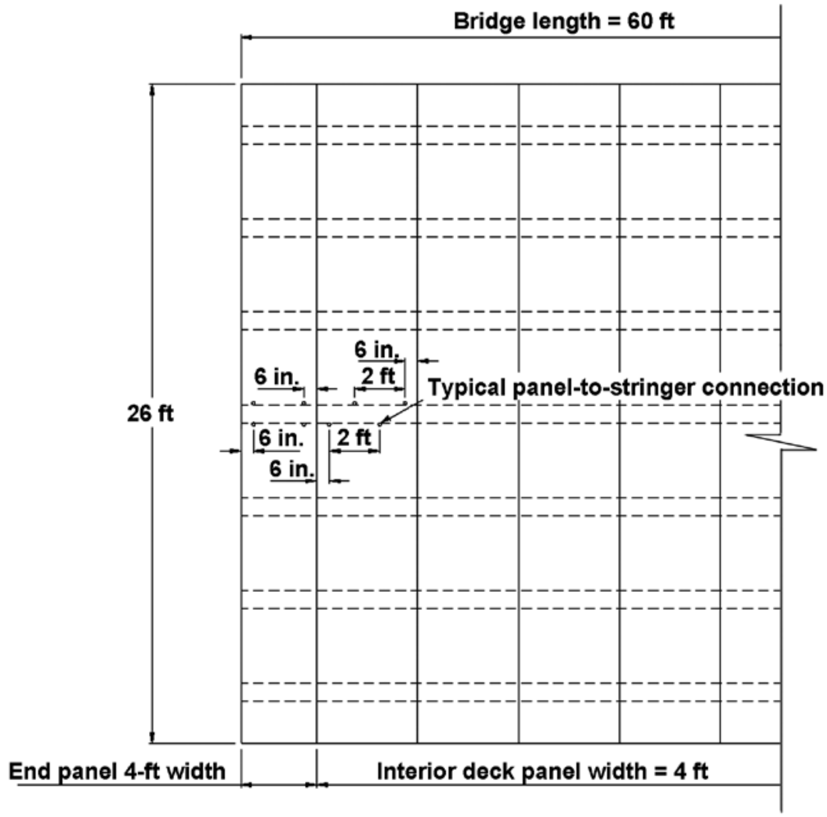

Figure 2. Plan view of baseline bridge, showing the transverse glulam deck panel layout for a 60-ft-long bridge.

likely be accomplished through statistical evaluation of the above parameters.

Deterioration

When properly engineered throughout the design, fabrication, and installation process, wood is a durable bridge material (Ritter 1992, FPL 1999, NFPA 2005). However, over extended periods under service, wood may decay due to exposure to biologics and other deleterious environment factors. To preserve the utility of the bridge and to ensure the safety of road users, the smart timber bridge will need to assess the condition of the structure by measuring factors that are associated with decay and deterioration. Moisture content, corrosion, and ultraviolet light degradation are the primary metrics to be monitored by the smart timber bridge. Proactive maintenance measures triggered by monitoring these metrics may prevent future problems related to performance and integrity of the structure.

Moisture has a detrimental influence on the service life of many structures, especially in wood, causing several deterioration processes. In the presence of water, the microstructure of wood swells until the fiber saturation point, which can make the cellulose more accessible to fungal enzymes, thereby enhancing rate of decay. Repeated wetting and drying or continuous exposure to moisture can result in leaching of toxic heartwood extractives and some preservatives, reducing resistance to decay (Ritter 1992). Currently, early assessment of moisture content and resulting preventive maintenance have proven to effectively control and prevent decay in timber bridges. Thus, moisture content monitoring will aid in the development of an active management program.

Ultraviolet light is a source of deterioration often found in timber bridges. Ultraviolet light chemically degrades the lignin near the wood surface of members such as deck edges, exterior girders, and barriers. Continued removal of the damaged wood eventually reduces member dimensions, affecting both stiffness and strength parameters. Wood lignin degradation will be detected by FOSs in exposed smart timber bridge members.

Finally, wood degradation due to metal corrosion will be assessed. Corrosion in timber bridges is an extreme case of bridge deterioration. Marine environments and deicing of roadways may cause deterioration in exposed bolts and other steel components such as diaphragms and truss ties. Early detection of corrosion in exposed bolted connections, steel trusses, and diaphragms will be monitored by detecting ferric ions in susceptible areas.

Anticipated Sensor Types To Be Used

In light of their attractive attributes, the sensors of choice for the smart-timber bridge are likely to be FOSs. In particular, FOS based on FBG technology, which can measure different parameters such as strain, temperature, pressure, vibrations, acceleration, and potentially other metrics (Swart and others 2001, Wiese and others 1999, Yeo and others 2006, Furh and Houston 1998, Maalej and others 2002), will be the primary focus of investigation. In a properly designed FBG sensor, a change in the desired parameter will induce a change in the wavelength measured by the sensor. In comparison with electrical sensors, FBG sensors are free from electromagnetic interference and time-related drift typically encountered with electrical sensors. FBG sensors are lightweight and small and can be embedded and integrated in virtually any structure (Kuang and others 2001, Measures and others 1995, Ritdumrongkul and others 2003). Also, only a limited number of lead wires are needed to transmit data obtained from a large number of FBG sensors.

Communication and Reporting

After the raw data are collected and cleansed, they are ready for processing, storage, and interpretation (ISIS 2001, Bruhwiler 2003). Data collected during continuous monitoring activities of the smart timber bridge will need to be processed before being stored. The developed performance algorithm would not only cleanse but process the obtained data (such as strain, temperature, moisture content, deflection, delamination, truck loads, ultraviolet light exposure, and corrosion). Following interpretation, a simple report would be developed by the smart timber bridge. The behavior of the superstructure would be summarized in the report, which would integrate all responses related to attributes of the smart timber bridge described in this section and report on overall bridge condition. This report would also serve as an alert to early damage or deterioration. This information would need to be translated into a clear language that the owner can interpret for prompt evaluation and programming of routine maintenance and/or rehabilitation of the bridge.

Problem Statements

Problem statements required to achieve the overall objective are summarized in Table 1. Sensor development tasks are in progress. The data processing and software development tasks can be accomplished concurrently. Field demonstration does not include costs for design, construction, or installation of a new bridge. Detailed project descriptions for each problem statement are provided in the following sections.

Development of FBG Sensors to Detect Moisture Content in Timber

Background: Moisture plays an important role in determining the life of wood and is known to cause several deterioration processes (Ritter 1992). Moisture can both reduce the decay resistance of wood and cause severe degradation of material properties. Also, moisture can accelerate fatigue life usage in compression members. Currently, several

Table 1—Summary of research problem statements

Phase	Project focus	Estimated cost (thousand dollars)	Total cost (thousand dollars)
Research plan	Develop 5-year plan for development of a smart glulam bridge	—	Done
Development of reliable sensors for timber bridge performance monitoring	Embed sensors during manufacture of glulam bridge components (2 years)	100	
	Develop new sensors for measuring in situ moisture contents (1-1/2 years)	200	
	Develop new sensors for detecting ferric ions caused by metal fastener corrosion (1-1/2 years)	200	
	Develop new sensors for detecting lignin loss caused by UV degradation (1-1/2 years)	250	750
Development of an efficient structural health monitoring system	Data processing techniques for structural adequacy parameters (1 year)	125	
	Data processing techniques for detecting systemic changes in stiffness (1 year)	125	
	Data processing for determining truck loading characteristics (1-1/2 years)	175	
	Bridge management software development (1 year)	100	525
Field demonstration	Construct a new “smart bridge” with embedded sensors and 1 year data collection (1 year)	125	125
Total			1,400

techniques to evaluate moisture are used during regular inspections. This practice has demonstrated that detection of pockets of elevated moisture content along with associated preventive maintenance of timber bridges can effectively control and prevent decay in timber bridges.

Objectives: To develop a FBG sensor that can reliably measure moisture content in timber over a range of 10% to approximately 30%.

Task 1: Develop FBG sensors capable of detecting moisture content in timber members. Recent studies have demonstrated that fiber-optic-based humidity sensors can measure moisture absorption in concrete by using FBG sensors with a moisture-sensitive polymer, indicating their potential use in timber members. The developed sensors should have accuracy levels similar to currently used technologies and should be able to be embedded within timber members.

Task 2: Test FBG sensors under various moisture and ambient temperature conditions including wetting and drying cycles. Small and full-scale glulam members are to be fabricated and instrumented with the developed FBG moisture sensor. The specimens should be exposed to accelerated environmental conditions and the FBG moisture sensor readings compared with traditional moisture content probe readings.

Task 3: Develop a final report that summarizes the work related to sensor development and laboratory tests. This report will include details on the FBG sensor materials and specifications for future installation.

Duration: Estimated project time is 18 months.

Cost: Estimated project cost is $200,000.

Development of FBG Sensors to Detect Ferric Ions

Background: Wood degradation due to metal corrosion is a type of timber bridge deterioration that is often observed in marine environments. A similar effect can also result from the application of deicing chemicals to a bridge roadway. In the presence of moisture, fasteners made of iron corrode and release ferric ions, which deteriorate wood cell walls. This occurs because acidity at the anode causes cellulose hydrolysis, which decreases wood strength.

Objective: To develop a FBG sensor that indirectly measures corrosion activity by detecting the presence of ferric ions.

Task 1: Develop FBG sensors that detect ferric ions released from bolts and other metal fasteners. A limited amount of documented research indicates that multi-parameter FBG sensors are capable of indirectly measuring steel reinforcement corrosion in reinforced concrete roadways and bridges by detecting changes in chemical composition or simply changes in material color. Such a sensor is to be developed; it is desirable that the developed sensor be able to detect both corrosion initiation and growth rate.

Task 2: Test FBG ferric ion sensors in typical saline environments, including marine water and in the presence of chloride-based deicing chemicals. Testing of the developed sensor should be conducted on small-scale specimens with a variety of fastener types. When possible, comparisons with electromechanical methods will be made.

Task 3: Prepare a final report that summarizes the FBG sensor development and testing. This report will include details on the FBG sensor materials and specifications for future installation.

Duration: Estimated project time is 18 months.

Cost: Estimated project cost is $200,000.

Development of Sensors to Detect Degradation in Wood Lignin

Background: Chemical degradation of wood lignin can be caused by ultraviolet sunlight exposure. This deterioration typically affects the surface and, over time, results in a reduction in member physical dimensions, which in turn reduces the associated member strength and stiffness. This deterioration becomes critical when the continued removal of material reduces the member capacity below the required demand or compromises the protective outer layer of preservative-treated material.

Objectives: To detect wood deterioration associated with ultraviolet light exposure, FBG sensors will be developed to detect the initial loss of wood lignin.

Task 1: Develop FBG sensors that detect the breakdown of wood lignin associated with ultraviolet light exposure. The developed sensor could be either surface mounted or embedded. In either case, it is desirable to detect the initiation of the breakdown and, if possible, to determine the rate of deterioration.

Task 2: Evaluate the performance of the developed FBG sensors under controlled ultraviolet light. The amount of exposure should be varied to simulate varying degrees of exposure and should be used to study the sensitivity of the sensor to deterioration. When possible, correlations to conventional detection techniques are to be made.

Task 3: Develop a final report that documents the sensor development and laboratory testing. The final report will detail the sensor materials and specifications.

Duration: Estimated project time is 18 months.

Cost: Estimated project cost is $250,000.

Evaluation of Techniques for Embedding and Attaching FBG Sensors to New Glulam Bridge Members

Background: FBG sensors have been embedded and attached to structural materials such as steel and reinforced concrete with proven success. These deployed systems are currently working under harsh climatic conditions and are reporting on the health condition of highway bridges around the world. However, no such applications exist for timber members.

Objectives: To measure the desired physical attributes of the smart timber bridge, techniques for embedding and attaching FBG sensors to timber members need to be developed and evaluated under static, cyclic, and sustained loads.

Task 1: Collect information on available structural adhesives for adhering FBG sensor to timber members. Existing and emerging adhesives for glulam are to be investigated. The most promising adhesives for attaching and embedding FOS sensors to timber will be selected for further evaluation.

Task 2: Develop potential techniques (such as packaging, configurations) for embedding and attaching FBG sensors to timber members. These techniques need to include designs for sensors that require structural adhesion as well as those sensors that need to be isolated from the structural behavior.

Task 3: Evaluate the performance of attached and embedded sensors within tension members under static loads. Prepare and test small-scale glulam specimens with various adhesives and attachment methods. Select adhesive types that show the best agreement with conventional instrumentation.

Task 4: Evaluate the performance of embedded and attached sensors within tension members under cyclic loads. Prepare small-scale glulam specimens with candidate adhesives and packaging. Determine the fatigue life of the adhesive and compare responses with conventional instrumentation.

Task 5: Evaluate adhesive responses under sustained tensile load and temperature variations. Prepare small-scale glulam specimens and test them under different sustained loads with temperature and humidity variations. Analyze failure modes, effect of the applied variables, and bond-slip behavior based on effects of adhesive thickness and protective coating materials.

Task 6: Select the embedment and attachment methods with best performance.

Task 7: Evaluate sensor and adhesive performance in full-scale laboratory specimens under static and cyclic loads. Where possible, make comparisons under both static and cyclic loads with conventional instrumentation.

Task 8: Prepare a final report that will document the developed techniques for embedding and attaching FBG sensors to timber members.

Duration: Estimated project time is 24 months.

Cost: Actual project cost was $93,000, as this study is funded and currently in progress.

Development of Data Processing Techniques for Determining Structural Adequacy Parameters

Background: Lateral load distribution between girders and dynamic load allowance, as defined in current bridge standards, are engineering metrics that indicate how loads are resisted by bridge superstructures. Processing techniques and associated instrumentation are needed to extract this information. In addition, fatigue life usage, when combined with other information (such as moisture content), gives a bridge owner a sense of how much usage a bridge has seen.

Objective: The objective of this work is to develop data processing techniques to determine lateral load distribution, dynamic load allowance, and fatigue life usage.

Task 1: Identify FBG strain sensor locations in the conceptual smart timber bridge that are needed for determining structural adequacy parameters. Identify alternative sensor locations in other possible positions.

Task 2: Review currently developed data processing techniques for determining structural adequacy (such as fatigue life usage in real-time). Select tools that may be implemented to the data processing techniques.

Task 3: Collect data from a selected highway timber bridge subjected under ambient traffics load for a period of time to be used in the beta testing of data processing techniques for evaluating structural adequacy. These data should be collected using conventional instrumentation.

Task 4: Develop data processing techniques for determining lateral load distribution characteristics in real time. These techniques should identify vehicle position such that the lateral load distribution factors may be “normalized.” The developed techniques should be tested with the data collected in Task 3.

Task 5: Develop data processing techniques for determining dynamic load allowance characteristics in real time. The developed techniques should be tested with the data collected in Task 3.

Task 6: Develop data processing techniques for determining fatigue life usage in real time. The developed techniques should be tested with the data collected in Task 3.

Task 7: Prepare a final report summarizing the data processing techniques for lateral load distribution, dynamic load allowance, and fatigue life usage.

Duration: Estimated project time is 12 months.

Cost: Estimated project cost is $125,000.

Development of Data Processing Techniques for Determining Changes in Structural Stiffness

Background: In general, changes in structural stiffness imply that a change in member properties has occurred. Techniques for identifying both instantaneous and gradual changes in stiffness are needed.

Objectives: Develop techniques for assessing changes in structural stiffness through statistical evaluation of measured physical properties.

Task 1: Investigate statistical evaluation methods for evaluating changes in large and diverse population measurements. Select statistical evaluation methods most suitable for processing data of this type for the purpose of identifying statistical differences over short and long periods of time.

Task 2: Modify collected data from a highway timber bridge subjected to ambient traffics load to generate synthetic changes in structural stiffness. These modifications should include both gradual and significant variations in lateral load distribution and dynamic allowance characteristics.

Task 3: Develop techniques for evaluating gradual and significant changes in stiffness through statistical evaluation of lateral load distribution and dynamic allowance. It is desired that the technique will both identify and quantify the level of structural stiffness change. Beta test the developed techniques using the synthetic data obtained in Task 2.

Task 4: Develop data processing techniques and required instrumentation for detecting vehicle collisions. The data processing techniques and needed instrumentation should be capable of detecting collision both on and below the bridge. Validate the technique with analytical modeling.

Task 5: Prepare a final report with the developed data processing techniques for stiffness degradation. This report will document the defined damage levels in each case and the beta test results.

Duration: Estimated project time is 12 months.

Cost: Estimated project cost is $125,000.

Development of Data Processing Techniques to Determine Vehicle Characteristics

Background: Bridges are designed to carry truck traffic, and it is desirable to know the number, geometry, and weight of the passing trucks. By determining vehicle characteristics, it will be possible to better predict usage and induced damage or deterioration.

Objective: Develop a data processing technique for determining vehicle characteristics such as vehicle weight, configuration, and speed.

Task 1: Review previous work for determining vehicle characteristics. Select tools that may be integrated into other data processing technique development.

Task 2: Develop initial conceptual tools to determine vehicle characteristics and an associated instrumentation scheme.

Task 3: With the instrumentation scheme developed in Task 2 in mind, collect response data from a typical timber bridge using conventional instrumentation.

Task 4: Using the data collected in Task 3 and the techniques developed in Task 2, determine the effectiveness of various tools at predicting vehicle characteristics. If required, refine the developed tools to improve overall performance.

Task 5: Prepare a final report that documents the development and resulting data processing tools.

Duration: Estimated project time is 18 months.

Cost: Estimated project cost is $175,000.

Development of Smart Timber Bridge Software Application

Background: Any effective SHM system must integrate data from many sources and evaluate it in a simple, turn-key application. Such a software application is needed for the smart timber bridge.

Objectives: Develop a software application to collect, reduce, extract, analyze, and report on the health condition of the smart timber bridge by using collected data and data processing techniques that evaluate and translate obtained responses in clear formats.

Task 1: Develop software to collect data obtained from FBG sensors. In this task, detection of possible data crossover will be conducted and revised. Also, this software will verify sensor performance and collected data consistency.

Task 2: Develop tools to cleanse the collected data from noise and undesired data record characteristics.

Task 3: Develop tools to preprocess the obtained data by extracting data related to loading events and discarding other insignificant data. Selected data will be saved in compressed form so that they may be retrieved and used for near-real-time analysis.

Task 4: Develop an application that analyzes the stored data. This analysis should include converting measured wavelengths to engineering parameters. The software should integrate all applications and procedures developed under separate work. The software should develop various bridge condition reports on a daily, weekly, monthly, and yearly basis that are clear and understandable to bridge owners.

Task 5: Prepare a final report that documents the developed software application.

Duration: Estimated project time is 1 year.

Cost: Estimated project cost is $100,000.

Demonstration of the Smart Timber Bridge

Background: Work conducted separately has resulted in the development of several new sensor types for measuring engineering parameters such as moisture content, degradation due to corrosion and ultraviolet exposure, and others. Further other work has led to the development of data processing techniques for evaluating collected behavior data in real time.

Objectives: Demonstrate all the developed components of the smart timber bridge in a field application.

Task 1: Prepare detailed construction plans and specifications for the assembly of the smart timber bridge members and installation of FBG sensors. Also, design the data acquisition system, including sensor positions, cabling routes, and storage cabinets.

Task 2: Work with selected construction contractors, equipment manufacturers, and timber fabricators to fabricate and construct the smart timber bridge.

Task 3: Test the SHM system under ambient traffic loading. Verify the performance of all sensors and calculations with known loads. Where possible, validate the performance of sensors and algorithms with conventional sensors and loading tests.

Task 4: Monitor the smart timber bridge and the monitoring system for 1 year. Complete any needed revisions to the system.

Task 5: Prepare a final report that documents the performance of the smart timber bridge. The report should include detailed construction specifications for future smart timber bridges.

Duration: Estimated project time is 12 months.

Cost: Estimated project cost is $125,000 plus bridge costs.

Concluding Remarks

This report outlines a 5-year research plan to develop a smart glulam timber bridge. New-sensor technologies will be developed to measure structural performance and deterioration parameters. A turnkey system will be developed that is capable of monitoring, analyzing, and reporting on the performance and condition of a timber bridge. This comprehensive effort will result in the first fully automated structural health monitoring system for timber bridges.

Literature Cited

Ansari, F. 2005. Fiber-optic health monitoring of civil structures using long gage and acoustic sensors. Chicago, IL: University of Illinois. pp. S1–S8. http://iopscience.iop.org/0964-1726/14/3/001/pdf/sms5_3_001.pdf. Last accessed August 2010.

Ansell, M. 2003. Fatigue of wood and wood panel products. In: Fatigue en Composites. United Kingdom: University of Bath. pp. 339–360

Bruhwiler, E. 2003. Conceptual design of a monitoring system. In: Wu; Abe, eds. Proceedings, Structural Health Monitoring and Intelligent Infrastructure (SHMII). MCS-CONF-2007-048. Tokyo, Japan. November 13–15. Vol. CD-Rom, Num. 2003.

Clorius, C.; Pedersen, M.; Hoffmeyer, P.; Damkilde, L. 2000. Compressive fatigue in wood. Germany: Springer–Berlin/Heidelberg. Wood Science and Technology. 34(1): 21–37.

Davids, W.; Dagher, H.; Richie, M.; Sanchez, O. 2005. Fatigue of glulam beams with fiber-reinforced polymer tension reinforcing. Forest Products Journal. 55(1): 93–101.

Doornink, J.; Phares, B.; Zhou, Z.; Ou, J.; Graver, T.; Xu, Z. 2005. Fiber Bragg grating sensing for structural health monitoring of civil structures. In: International symposium on advances and trends in fiber optics and applications. October 11–14, 2004. China. 4 pp. http://www.micronoptics.com/uploads/library/documents/FBGsensingSHMcivil.pdf. Last accessed August 2010.

FPL. 1999. Wood handbook—wood as an engineering material. Gen. Tech. Rep. FPL–GTR–113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 463 p.

Fuhr, P.; Houston, D. 1998. Corrosion detection in reinforced concrete roadways and bridges via embedded fiber optic sensors. Smart Materials and Structures. 7: 217–228.

Hosteng, T. 2004. Live load deflection criteria for glue-laminated timber bridges. Ames, IA: Iowa State University. M.S. thesis. 300 p.

ISIS. 2001. Guidelines for structural health. monitoring – Design manual No. 2. Intelligent Sensing for Innovative Structures ISIS Canada, University of Manitoba, Winnipeg, Manitoba 2001, 127 p.

Kainz, J.; Wacker, J.; Ritter, M.; Bishop, S. 2001. Field performance of timber bridges—Humphrey stress-laminated T-beam bridge. Res. Pap. FPL–RP–597. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 16 p.

Kim, N.; Cho, N. 2004. Estimating deflection of a simple beam model using fiber optic Bragg grating sensors. Journal of Sound and Vibration. 305(3): 534–542.

Koh, H.; Choo, J.; Kim, S.; Kim, C. 2003. Recent application and development of structural health monitoring systems and intelligent structures in Korea. In: Wu; Abe, eds.

Proceedings, Structural Health Monitoring and Intelligent Infrastructure (SHMII). November 13–15. Tokyo, Japan.

Kuang, K.; Kenny, R.; Whelan, M.; Cantwell, W.; Chalker, P. 2001. Residual strain measurement and impact response of optical fibre Bragg grating sensors in fibre metal laminates. Smart Materials and Structures. 10: 338–246. Institute of Physics Publishing.

Le, X.; Kainz, J.; Peterson, M.L.; Landisic, E.N. 1998. Smart timber bridges for in-situ evaluation. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 8 p. http://www.fpl.fs.fed.us/documnts/pdf1998/le98a.pdf. Last accessed August 2010.

Li, H.N.; Li, D.S.; Song, G.B. 2004. Recent applications of fiber optic sensors to health monitoring in civil engineering. Engineering Structures 2004, Vol. 26, pp. 1647–1657.

Maalej, M.; Karasaridis, A.; Pantazopoulou, S.; Hatzinakos, D. 2002. Structural health monitoring of smart structures. Smart Materials and Structures. 11(4): 581–589. Institute of Physics Publishing.

Measures, M.; Alavie, A.; Maaskant, R.; Ohn, M.; Karr, S.; Huang, S. 1995. A structurally integrated Bragg grating laser sensing system for a carbon fiber prestressed concrete highway bridge. Smart Materials and Structures. 4: 20–30.

Merzbacher, C.; Kersey, A.; Friebele, E. 1996. Fiber optic sensors in concrete structures: a review. Smart Materials and Structures. 5: 96–208.

Muthumani, K.; Sreekala, R. 2003. Structural application of smart materials. In: Smart Materials. Mel Shwartz, Ed. CRC Press 2009. pp. 4-1–4-4. http://www.crcnetbase.com/doi/pdfplus/10.1201/9781420043730.ch4. Last accessed August 2010.

NFPA. 2005. National design specification: wood construction—structural lumber, glue laminated timber, timber piling, fastenings. Washington, DC: National Forest Products Association. 1,000 p.

Ritdumrongkul, S.; Abe, M.; Fujino, Y. 2003. Experimental study on bolted joints using piezoceramic and LDV. In: Wu, A., ed. Structural Health Monitoring and Intelligent Infrastructure (SHMII). pp. 825–830.

Ritter, M.A. 1992. Timber bridges: design, construction, inspection and maintenance. EM 7700–8. Washington, DC: U.S. Department of Agriculture, Forest Service. (Approved for reprinting, August 1992). 970 p.

Russel, C. 1997. Glued-laminated timber. In: Engineered Wood Product. Smulki, E., Ed. p. 340.

Sumant, P.; Maiti, S. 2005. Crack detection in a beam using PZT sensors. B Smart Mat. Struct. 5 pp. 695–703. http://iopscience.iop.org/0964-1726/15/3/004/pdf/sms6_3_004.pdf. Last accessed August 2010.

Swart, P.L.; Naude, R.; Lacquet, B.M. 2001. Determining the moisture content in concrete with fibre optic Mach-Zehnder interferometer: a feasibility study. Measurement Science and Technology. 12(2001): 927–931. Institute of Physics Publishing.

Udd, E.; Seim, J.; Schulz, W.; McMahon, R. 2000. Monitoring trucks, cars, and joggers on the Horsetail Falls bridge using fiber optics granting strain sensors. SPIE Proceedings, Vol. 4185, p. 872.

Wacker, J.P.; Smith, M.S. 2001. Standard plans for timber bridge superstructures. Gen. Tech. Rep. FPL–GTR–125. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Product Laboratory. 53 p.

Wiese, S.; Kowalsky, W.; Wichern, J.; Grahn, W. 1999. Fiberoptical sensors for on-line monitoring of moisture in concrete structures. In: Chang, F.K., ed. Structural Health Monitoring and Intelligent Infrastructure (SHMII). pp. 643–650.

Yeo, T.L.; Eckstein, D.; McKinley, B.; Boswell, L.F.; Sun, T.; Grattan, K.T.V. 2006. Demonstration of a fibre-optic sensing technique for the measurement of moisture absorption in concrete. Smart Materials and Structures. 15(2006): N40–N45. Institute of Physics Publishing.

Other References

LaViolette, M.; Vis, J.; Phares, B.; Wipf, T.; Hagan, T.; Murphy, J. 2005. Remote security monitoring of historic covered bridges. Ames, IA: Iowa State University, Bridge Engineering Center—CTRE.

Maalej, M.; Ahmed, S.; Kuang, K.; Paramasivam, P. 2004. Fiber optic sensing for monitoring corrosion-induced damage. Structural Health Monitoring and Intelligent Infrastructure (SHMII). 3(2): 165–176.

Maalej, M.; Karasaridis, A.; Pantazopoulou, S.; Hatzinakos, D. 2003. Structural health monitoring of smart structures. Smart Materials and Structures. Institute of Physics Publishing.

Muragishi, O.; Nihei, K.; Kobayashi, T.; Ohgaki, K.; Kawaguchi, Y.; Umeda, A. 2003. Remaining life evaluation by fatigue detecting sensor. Structural Health Monitoring and Intelligent Infrastructure (SHMII). IIW. Doc XIII-2018-04.

Pakzad, S.; Kim, S.; Fenves, G.; Glaser, S.; Culler, D.; Demmel, J. 2005. Multipurpose wireless accelerometers for civil infrastructure monitoring. Berkeley, CA: University of California.

Phares, B.; Wipf, T.; Greimann, L.F.; Lee, Y. 2005. Health monitoring of bridge structures and components using smart structure technology. Ames, IA: Iowa State University, Bridge Engineering Center—CTRE. 57 p. http://www.intrans.iastate.edu/reports/health_monitor_wi_vol1.pdf. Last accessed August 2010.

Tsuda, H.; Toyama, N.; Urabe, K.; Takatsubo, J. 2004. Impact damage detection in CFRP using fiber Bragg gratings. Smart Materials and Structures. 13(4): 719–724. Institute of Physics Publishing.

Tsutsui, H.; Kawamata, A.; Sanda, T.; Takeda, N. 2004. Detection of impact damage of stiffened composite panels using embedded small-diameter optical fibers. Smart Materials and Structures. 13(6): 1284–1290. Institute of Physics Publishing.

Udd, E.; Schulz, W.; Seim, J. 1998. Advanced fiber optic sensors capable of multiparameter sensing. In: SPIE Proceedings. Gresham, OR: Blue Road Research. Vol. 3489, p. 66.

Wipf, T.; Phares, B. 2005. A 5-year research plan for the development of a smart glue-laminated timber bridge. Ames, IA: Iowa State University, Bridge Engineering Center—CTRE. 2 p. http://www.fpl.fs.fed.us/documnts/rips/fplrip-eml-004-glued-laminated-timber-bridge.pdf. Last accessed August 2010.