Research Proposal

Structural Health Monitoring of Highway Bridges Subjected to Overweight Vehicles
Phase II – Field Deployment

WYDOT Sponsor:

Paul G. Cortez, P.E.
Assistant State Bridge Engineer, Operations

Wyoming Department of Transportation
5300 Bishop Blvd, Cheyenne, Wyoming 82009
Phone: (307) 777-4049; Fax; (307) 777-4279
paul.cortez@wyo.gov

Principal Investigators:

Johnn P. Judd, Ph.D., S.E.
Assistant Professor

Michael G. Barker, Ph.D., P.E.
Professor

Department of Civil and Architectural Engineering
University of Wyoming
Dept. 3295, 1000 E. University Ave., Laramie, Wyoming 82071
Phone: (307) 766-6142; Fax; (307) 766-2221
jjudd5@uwyo.edu

September 26, 2016

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Department of Civil and Architectural Engineering
University of Wyoming

Project Summary

A two-year project is proposed to deploy and operate an optical-fiber sensor structural health monitoring (SHM) system on highway bridges subjected to overweight vehicles. This proposal consists of an overview of Phase I of the project, completed in 2016, and a request for continued funding for Phase II in 2017-2018.

In Phase I, techniques for installation and protection of fiber Bragg grating (FBG)-based optical-fiber sensors on concrete and steel host structures were developed. Instrumentation for interrogating the SHM network was developed, and a radio-frequency identification (RFID) triggering system was explored.

In Phase II, the FBG-based SHM system will be deployed in the field and methods to access and manage the data will be developed. A prototype SHM system will be first deployed on the Laramie River bridge (MP 312.33) on I-80. The Laramie River bridge was selected by the WYDOT and University of Wyoming team based on accessibility, power source, and the wireless network. The Laramie River bridge will be instrumented with mobile diagnostic devices to validate the optical-fiber SHM system using field testing. After validation, the mobile devices will be removed, remote collection of bridge data will be activated, and the resiliency of the field deployed SHM system will be evaluated. The Laramie River bridge will be used to develop the triggering system and the data transmission and data storage system for remote management. The FBG-based SHM system will then be deployed on the Bear River bridge (MP 5.87) on I-80 in Evanston. The Bear River bridge is proposed based on an analysis of non-slab bridges on I-80, and was identified as having the most stringent restrictions for overweight vehicles on I-80. Methods to process bridge response data and to automate the task of examining raw SHM data streams will be developed, along with operational guidelines.

When completed, the proposed research project is expected to improve the ability of bridge engineers to understand and predict traffic load behavior, to estimate bridge load capacity, and to safely route overweight vehicles.

Keywords: bridge engineering, structural health monitoring, mining of massive data sets, fiber optics, instruments for measuring deformation or deflection, structural analysis, load ratings.

Motivation

The impact of overweight vehicles on highway bridges and the appropriate routing for such vehicles are of vital concern to departments of transportation in the United States. State departments of transportation in the West, and WYDOT in particular, have been under increasing pressure to permit and route overweight vehicles that transport machinery and equipment for the energy sector through their state and interstate highway systems. As a result, bridge engineers are frequently called upon to load rate highway bridges for overweight vehicles, to determine the appropriate routing, and to assess the impacts of the vehicles on the safety and durability of the bridge. Many of these overweight vehicles are trucks with nonstandard configurations. This further complicates the load rating and permitting process. Therefore, it is critical that bridge engineers develop confidence that their bridge analysis and load rating software accurately predicts the response of bridges to overweight trucks, especially for bridges on the most frequently traveled routes. This confidence can be gained through the proposed project, in which software analysis and load rating results for overweight vehicles is correlated to direct field measurements of the response of bridges. When completed, the proposed structural health monitoring (SHM) system will also improve the ability of bridge engineers to safely route overweight vehicles.

Overview of Phase I

Three main objectives were accomplished in Phase I of the project: (1) techniques for installation and protection of fiber Bragg grating (FBG)-based sensors on concrete and steel host structures were developed; (2) instrumentation and a FBG-based interrogator for the SHM system was developed; and (3) a radio-frequency identification (RFID) triggering system for managing bridge response data from the sensors was developed. A detailed report of Phase I is provided in Report No. FHWA-WY-16/06F (Schmidt 2016) and is briefly summarized as follows:

Installation and Accuracy of FBG-based Sensors

Experimental and analytical methods were used to determine the strain measurement accuracy of FBG-based sensors attached to concrete or steel.

- Concrete Structures. For sensors bonded to concrete in notches, it was found that finite element analysis slightly over-predicted the strain transfer to the sensor compared to experimental data. For 80 percent of the configurations that were compared, the analytical strain transfer results were 1 percent to 9 percent greater than those observed in the experimental tests. Some configurations provided full strain transfer and some did not.

  The results indicated the equipment and materials required to install a sensor in a notched concrete structural member were effective and feasible for a typical engineering or a construction crew. The embedment notches can be cut in the concrete with a masonry saw or formed as the concrete is placed. The Ultrabond 1300 epoxy was effective: it has a short cure time and is widely available. For overhead or vertical applications, however, a more paste-like adhesive with higher viscosity is recommended.

The analysis results supported several conclusions about how the configuration parameters affect the strain transfer for the notch-embedment sensing method. As epoxy bond length increased, so did the effective strain transfer length for a given configuration. This trend was true for all bond layer thicknesses and epoxy moduli. A second conclusion relates to the effect of epoxy elastic modulus on strain transfer. It was observed that strain transfer increased with an increase in the adhesive elastic modulus. This trend supports the conclusions of previous studies, which suggested that the closer the elastic modulus is to the concrete, the better the strain transfer.

The results suggest an inverse relationship between bond layer thickness and strain transfer. It was observed that smaller bond layer thicknesses provided greater strain transfer. Additionally, the effect of bond layer thickness appears to have more of an impact on the V-notch configuration than the saw-notch configuration. This behavior is likely due to the fact that the V-notch is wider with a tapered shape while the saw-notch geometry is narrower and more uniform. The bigger V-notch provides a greater volume of epoxy for strain loss to occur in. The tapered V-notch shape provides more epoxy between the FBG and the concrete than the saw-notch as the bond layer thickens.

- Steel Structures. FBG-based sensors and traditional foil gages (TG) sensors were installed on an S3x5.7 steel beam. Each sensor type was located at six locations on the beam and the averaged results compared. The modulus of elasticity values recorded were used for comparison, since averaged results were linear and one slope value accurately represented the data set.

  Measured data was within a reasonable range given the assumptions of the tests and additional test properties. Typically, when comparing strain gages on the market to foil gages through laboratory testing, strain results within 5 percent are acceptable. Set 6 displayed this comparison with a 2 percent difference. When considering the additional factors (test properties, for example) results within 15 percent are acceptable.

Interrogation and Instrumentation of the SHM System

Hardware for interrogation and instrumentation of the SHM system was developed using a commercially available FBG network interrogator and a custom designed microcontroller unit.

- FBG network interrogator. A two-channel SmartScan 02 Lite FBG interrogator produced by Smart Fibres was purchased for the laboratory study. The purpose of the interrogator is to collect data from the sensors. The interrogator type was selected based on a study of commercially available FBG network interrogators. Compared to a custom developed interrogator, commercially developed interrogators provide lower cost, more compact form-factor, and are more energy-efficient. Selecting a commercial interrogator also assured that the laboratory instrumentation conformed to the latest industry standards and had the reliability and durability to perform as required. The only other resources required in the laboratory were a standard Windows-based desktop computer and an internet connection.

- Microcontroller Unit. A microcontroller unit was custom designed in collaboration with James Branscomb, P.E., an electrical design engineer at WDOT. The purpose of the mircocontroller unit is to convert serial peripheral interface (SPI) signals back to the Ethernet so that the field strain data can be directed through a cellular network. The microcontroller consists of a printed circuit board containing two Ethernet controllers, a microcontroller, a PDI programming port, voltage supply and regulator, LED indicators, and general purpose input/output pins included for future programming. A detailed description and images of the printed circuit board are provided in Danforth (2015).

  The microcontroller can receive continuous strain data from the FBG interrogator by using the Ethernet controller to form the SPI connection. The microcontroller allows the user to define which parameters will trigger data storage, such as detection of an RFID tag. A second Ethernet controller links the microcontroller unit and the cellular module.

RFID Triggering System
Field tests were conducted to validate the concept of using a RFID triggering system for managing bridge response data from the sensors. The idea is to install RFID transponders at a weigh station at a Wyoming port of entry and at the bridge of interest. At the port of entry, the permitted vehicle (truck) information, including the axle weights and configuration, will be assigned to an RFID tag with an identification code that would be placed on the windshield of the vehicle. Another transponder placed near the bridge will detect the presence of the RFID tag and trigger the SHM system to store data.

The field tests were organized so that the initial positioning of each RFID component was established prior to testing the system at full speed, including positioning of the RFID transponder, RFID tag, and RFID vehicle. Each time the transponder detected the tag, the strain data from three FBG-based sensors were recorded for the allotted 30-second time frame. The field tests showed that that the success of the triggering system depends on the tagged vehicle position, the transponder position (including the height and horizontal position), and the tag position on the vehicle.

Recommendations
Phase I of the project led to the following recommendations:

1. Response data obtained in the laboratory using FBG-based sensors is comparable to traditional foil gages, but field installed sensor data should be validated.

2. Placement of sensors should account for the expected interaction of primary (major-axis) and secondary (minor-axis) bending and any system effects.

3. The data triggering system requires additional development before actual implementation.

4. A secure database must be developed to access and utilize response data.

5. Methods need to be developed to automatically manage the massive amount of data produced by the SHM system, and algorithms need to be established for automatic post-processing.

Research Plan for Phase II

Objective

The preliminary research in Phase I of the project demonstrated that the FBG-based sensor SHM system is a viable concept with the potential to be implemented and to provide valuable data on bridge performance. In Phase II of the project, the FBG-based SHM system will be deployed and operated in the field. *The overarching objective of the proposed project is to establish a proven basis for optical-fiber sensor SHM systems on highway bridges with a focus on bridges that may be subjected to overweight vehicles*.

Implementation

The proposed research will be conducted at the University of Wyoming under the direction of the PI (Johnn Judd) and the co-PI (Michael Barker). The PI is experienced in experimental testing of large-scale structures, advanced structural analysis, and high-performance computing (e.g. Judd et al. 2016; Jarrett, Judd, and Charney 2015; Judd et al. 2012; Judd and Fonseca 2005). The co-PI is an expert in experimental testing of bridges, in-situ field tests, and loading-rating analysis of highway bridges (e.g. Barker 2001). It is anticipated that one graduate student, one electrical engineering consultant, and several undergraduate students will be involved. The University of Wyoming team will coordinate with bridge engineers at WYDOT regarding the installation of sensors in the field, the field testing of bridges, and operation of the SHM system.

The project is organized under five tasks, outlined in Table 1 and described in detail in the following section. The estimated schedule of completion is two years. In the first year, instrumentation equipment will be acquired and prepared for deployment. A prototype SHM system will be installed on the Laramie River bridge (MP 312.33) on I-80 and instrumented with mobile diagnostic devices to validate the optical-fiber SHM system using field testing. The triggering system and the data transmission and storage system will be developed, and the resiliency of the SHM system in a harsh environment will be evaluated. In the second year, the FBG-based SHM system will be deployed on the Bear River bridge (MP 5.87) on I-80 in Evanston. Methods will be developed to process bridge response data and to automate the task of examining raw SHM data. Finally, the research findings will be published in peer-reviewed publications and disseminated in presentations and workshops geared specifically towards WYDOT bridge engineers.

Table 1. Proposed schedule for Phase II

Research Task	Year 1				Year 2			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1. Preparation for Field Deployment	■	■						
2. Deploy SHM System on Laramie River Bridge		■						
3. Field Test and Validation of FBG System			■					
4. Develop Data Triggering and Transmission			■					
5. Evaluate Resiliency of SHM System				■	■	■		
6. Deploy SHM system on Bear River Bridge						■		
7. Develop Data Management Methods							■	■
Publication / Dissemination								■

Detailed Tasks

Task 1 – Preparation for Field Deployment

Equipment will be purchased for field deployment. FBG-based SHM system equipment will be acquired, including the sensors, interrogators, microcontroller units, cellular modems, solar panels and power units, server-grade computer hardware and software for data management (acquisition, transmission, storage and processing).

The type of FBG-based sensors will be selected based on the capability to provide accurate, consistent, and reliable strain measurements, the life span of the sensors, and the central wavelength of the sensors (in order to maximize the number of sensors on a single optical fiber). A practical method to install the optical fiber on a steel beam with epoxy (in order to obtain a specific pretension) will be determined. Since vehicles traverse a highway bridge in a matter of seconds, it is unlikely that temperature effects will be significant and it is expected that special-purpose sensors will not be required.

The mobile diagnostic system to validate the optical-fiber SHM system will be acquired. This includes the strain transducers and the data acquisition system hardware and software. An installation plan will be developed and the instrumentation and data acquisition systems will be tested in the laboratory. Next, the installation of the sensors and the field test of the Laramie River bridge will be scheduled with WYDOT.

Task 2 – Deploy SHM System on Laramie River Bridge

A prototype SHM system will be installed on the Laramie River bridge. It is planned that each of the four steel girders will be instrumented at the critical locations: at the mid-span (maximum positive moment) and at the interior side of the center span support (maximum negative moment). Sensors will be positioned at three elevations along the girder profile (i.e. at the bottom flange, at approximately the mid-depth of the web, and near the top flange), for a total of 24 sensors. The position of the sensors will be close to the minor axis of the girder and the position will be based on an analysis of the bridge during Task 1, in order to minimize minor-axis bending and to account for any intentional or unintentional composite action between the deck and the girder. Potential lateral loads in the bottom flange of a steel girder will be investigated as part of the design process during Task 1 for the sensor location.

Task 3 – Field Test and Validation of FBG System

The Laramie River bridge will be subjected to a field test. A temporary diagnostic system will be mounted parallel to the FBG-based sensors in order to validate the long-term FBG-based sensors. In the field test, a calibrated test vehicle, similar to the HS20 design truck, will traverse the bridge in a predetermined loading pattern, such that each girder is subjected to the maximum live load effects. A preliminary vehicle loading pattern was developed in Phase I of the project (Danforth 2015). The loading pattern will be revised based on input from the WYDOT and University of Wyoming team during Task 1.

Task 4 – Develop Data Triggering and Transmission

A redundant triggering system will be developed. It is anticipated that the primary trigger will utilize the RFID concept explored in Phase I of the project. The port of entry system installation, transponder range, cellular transmission capabilities, and associated software will be developed as part of the primary triggering system. A GPS locator (e.g. using a smart phone app) will be used as a secondary trigger.

The data transmission and storage system will be developed. It is planned that bridge response data will be transmitted from the bridge using the Feeney Wireless Skyus (or equivalent) cellular modem. The data collected will be stored on a server-grade computer temporarily located at the University of Wyoming campus.

Task 5 – Evaluate Resiliency of SHM System

It is anticipated that the SHM system deployment and field test will be conducted before the fall, and that the data triggering system, data transmission, and data storage system will be in place before late fall or early winter. As a consequence, the resiliency of the SHM system in a harsh environment will be evaluated as the project transitions from year 1 to year 2. The wintertime will also provide time to debug the data triggering, transmission, and storage system before implementation on more remote bridge in Task 6.

Task 6 – Deploy SHM system on Bear River Bridge

A refined SHM system will be deployed on the Bear River bridge based on results from Task 5.

Task 7 – Develop Data Management Methods

Methods will be developed to process bridge response data and to automate the task of examining raw SHM data. The SHM system will be capable of recording massive amounts of data. Data that is significant and that should be transmitted and saved will be automatically determined. An algorithm will be established to save data with readings that exceed a certain threshold or that represent the maximum response each day. Extracting a relaxed-state reading will be used to document changes in the bridge and to verify that the SHM system is functioning properly. Software as well as algorithms for automatic post-processing will be developed.

Publication / Dissemination

At the conclusion of Phase II, the research team will hold a training workshop for WDOT bridge engineers. The workshop will introduce the SHM system, the sensor network, data management system, and discuss operation of the SHM system. Guidance will be given on how to use bridge response data for load ratings, for routing overweight vehicles.

Expected Outcomes

Phase II of the research project is expected to make several direct contributions to the WYDOT Center goals of improving, enhancing, and preserving our State's transportation system (described in detail below), and to have a positive impact on the broader goal of preparing the next generation of bridge engineers as student participate in hands-on research and education.

Benefits to WYDOT

The proposed SHM system when completed is expected to improve the ability of bridge engineers to understand and predict traffic load behavior and bridge load capacity. The SHM system is cost effective. The equipment and installation costs are relatively low compared to other sensor systems, and the cost of maintain the system once installed is relatively low. The SHM system is expected to lead to improved predictions of a bridge's longevity. When combined with a triggering system, such as the RFID system, and static weigh-in-motion systems at the port of entries, the SHM system could be used to automatically collect vehicle characteristics and correlated vehicle loads to response data induced by permitted live loads.

Existing highway bridges could be better persevered. Over time, the SHM is expected to improve the ability of bridge engineers to predict the effect that overweight vehicles will have on the condition of bridges that are instrumented. As the SHM system is deployed on additional bridges in the future, the system has the potential to more effectively allocate funds for inspection and repair. Effective scheduling of inspections and maintenance would be facilitated by an accurate and easy-to-use sensing network on a bridge. With suitable experience and calibration of the sensing network, engineers will be able to observe changes in bridge response that might suggest deterioration or damage, thus prompting more timely inspection and maintenance work. As the engineers receive feedback on bridge performance to confirm (or to recalibrate) load rating methods, they will be better able to predict the expected lifespan of bridges.

The safety of highway bridges could be enhanced. The SHM system could assist in helping to quickly and safely re-route overweight vehicles. Real-time monitoring of bridge response will improve the operational safety of highway bridges during overload events by controlling the magnitude of the overload. Long-term safety will also be enhanced by use of the monitoring system to identify and quantify unanticipated overload events. Increased precision in defining the weight distribution in overweight vehicles could reduce the uncertainty in the demand (applied loads) as well as the variability in structural capacity. Aside from the SHM system, the diagnostic system that will be used to validate the FBG-based sensors could be quickly deployed in situations where a bridge must be evaluated due to advanced deterioration or impact damage.

The SHM system could be used to identify illegal loads that are not detected at a weigh-in-motion station. For example, individuals or companies with overweight or oversize vehicles might not file for a permit in an attempt to by-pass permit fees. Strain-level triggers implemented in the sensing network, coupled to RFID tags in trucks entering the State, could be used to detect and identify these types of illegal loads.

The monitoring system will be particularly valuable for assessing the effects of overweight vehicles with unusual configurations, typically trucks with wide cargo. Similarly, road closures on the interstate highway system (I-80 in particular) during inclement weather conditions can cause long back-ups of vehicles. When the closures are lifted, it is common for long trains of trucks to progress nearly bumper to bumper, filling all traffic lanes as travel resumes. Such situations raise serious questions about the possibility of bridge overload and durability under high-density truck traffic with normal configurations and loads. The two-year duration of Phase II of the project is intended to provide an opportunity to observe a sufficient number of overweight trucks or high density traffic events and to refine the operation and resiliency of the SHM network. Continuation of Phase II to incorporate wide-ranging installation of SHM networks on critical bridges could then be pursued.

Broader Impacts

Phase II of the project will elevate the state of the art for evaluating bridge response in real time. The research findings will be disseminated to a national and an international audience, and have the potential to be applied in other regions across our nation. The research will have special applicability to regions departments (such as the western United States) where overweight vehicles are a concern.

Graduate students participating in Phase II of the project will develop advanced technical skills and communication skills that will extend the benefits of the project into the future. Over the long term, the outcomes from this project may be incorporated into a graduate level course (CE 5270 *Highway Bridge Engineering*) at the University of Wyoming. Real-time bridge response data from the Laramie River bridge, for example, could be used to illustrate application of theoretical concepts such as live load distribution.

Additionally, the proposed project could provide a mentored experience for younger students. First-year college students could be introduced to bridge engineering using the College’s mentoring program. The Summer Research Apprentice Program (SRAP) sponsored by the NSF Experimental Program to Stimulate Competitive Research (EPSCoR) could be used to involve high-school students, especially those from Wyoming. In the SRAP program, a group of high school students will be assigned to work with the graduate student during a two-month internship.

Budget

The preliminary budget for Phase II is $220,374. A detailed budget for each year of the project is given in Table 2 and Table 3, respectively. Justification for each section is provided below.

Personnel

One month of summer salary compensation is requested in the proposal budget for the PIs. Time spent during other months is compensated by the PI's organizational salary. The proposed budget includes two years of support for one graduate student and partial support for undergraduate students to assist in the research. Typical graduate student support at the University of Wyoming is for twelve months. The funds requested are based on the University's published rates for graduate stipend and a 2% cost escalation. Undergraduate research assistants will be employed at 20 hours per week, for 20 months total (10 months during year 1, and 10 months during year 2), to assist in deployment of the SHM systems and in field testing. Funds are also requested to contract the services of an electrical engineering consultant.

Fringe Benefits

Costs associated with personnel amount to 49.863% of wages paid to senior personnel, 8.413% of wages paid to undergraduate students and consultants, and to 0.606% of wages paid to graduate students (e.g. worker's comp.), based on the University's published fringe benefit rates.

Equipment

Funds are requested to cover the costs of the SHM system, including the triggering system and the data management system. The equipment includes the sensors, interrogators, microcontroller units, cellular modems, solar panels and power units, server-grade computer hardware and software for data acquisition, data transmission, and data storage and processing. Funds are also requested to contribute towards the cost of the mobile diagnostic system used in the field tests. The PI is contributing $50,000 towards the cost of the system (total cost of $60,000). Accordingly, it is proposed that at the conclusion of Phase II of the project, WYODT will take possession of the SHM system equipment and provide for its maintenance, and the University of Wyoming will retain the diagnostic system equipment and provide for its maintenance.

Travel

The proposal budget includes $1,000 per year for domestic travel for the purpose of conducting field work, meeting with WYDOT, and dissemination and presentation of research findings.

Other Direct Costs

The proposal budget includes tuition, fees, and health insurance for the entire year based on published fees and a 2% cost escalation, and $1,000 per year for materials and supplies associated with preparation and deployment of the SHM system. WYDOT will be responsible for traffic control necessary to complete the research and for a calibrated vehicle for field testing.

Indirect Costs

Indirect costs are based on the University of Wyoming published rate of 20% of total direct costs (excluding equipment over $5,000, and student tuition, fees, and health insurance) through December 31, 2018.

Table 2. Proposed budget for Year 1 of Phase II

A. Senior Personnel		**Calendar Months**		
Name	**Title**	**Academic**	**Summer**	**Funds Requested**
Johnn Judd	PI	0	1	$9,228
Michael Barker	coPI	0	1	$12,163
			Total	$21,391
B. Other Personnel				
Number of Personnel	**Type**	**Academic M**	**Summer M**	**Funds Requested**
1	Graduate Students			$22,828
1	Undergraduate students			$8,000
1	EE consultant			$2,000
			Total	$32,828
C. Fringe Benefits				
				Funds Requested
				$11,645.83
D. Equipment				
Item				**Funds Requested**
1. SHM system equipment				$8,000
2. Diagnostic system equipment				$60,000
UW contribution				-$50,000
			Total	$18,000
E. Travel				
Descirption				**Funds Requested**
Travel Domestic				$1,000
Travel Foreign				$0
			Total	$1,000
F. Participant Support Costs				
Descirption				**Funds Requested**
				$0
G. Other Direct Costs				
Descirption				**Funds Requested**
1. Materials and Supplies				$1,000
2. Publication Costs				$0
3. Consultant Services				$0
4. Computer Services				$0
5. Subcontracts				$0
6. Other	UW student tution and fees, health insurance			$9,149
			Total	$10,149
H. Total Direct Costs				
				A Through G
			Total	$95,014
I. Indrect Costs				
Indirect Cost Item	**Rate %**	**Base**		**Funds Requested**
1. Total direct costs - tu	20.000%	$67,864		$13,572.89
			Total	$13,573
J. Total Direct Costs				
				H And I
			Total	$108,587

Table 3. Proposed budget for Year 2 of Phase II

A. Senior Personnel		**Calendar Months**		
Name	**Title**	**Academic**	**Summer**	**Funds Requested**
Johnn Judd	PI	0	1	$9,228
Michael Barker	coPI	0	1	$12,163
			Total	$21,391
B. Other Personnel				
Number of Personnel	**Type**	**Academic M**	**Summer M**	**Funds Requested**
1	Graduate Students			$22,828
1	Undergraduate students			$8,000
1	EE consultant			$2,000
			Total	$32,828
C. Fringe Benefits				
				Funds Requested
				$11,645.83
D. Equipment				
Item				**Funds Requested**
1. SHM system equipment				$20,000
			Total	$20,000
E. Travel				
Descirption				**Funds Requested**
Travel Domestic				$2,000
Travel Foreign				$0
			Total	$2,000
F. Participant Support Costs				
Descirption				**Funds Requested**
				$0
G. Other Direct Costs				
Descirption				**Funds Requested**
1. Materials and Supplies				$1,000
2. Publication Costs				$0
3. Consultant Services				$0
4. Computer Services				$0
5. Subcontracts				$0
6. Other	UW student tution and fees, health insurance			$9,149
			Total	$10,149
H. Total Direct Costs				
				A Through G
			Total	$98,014
I. Indrect Costs				
Indirect Cost Item	**Rate %**	**Base**		**Funds Requested**
1. Total direct costs - tu	20.000%	$68,864		$13,772.89
			Total	$13,773
J. Total Direct Costs				
				H And I
			Total	$111,787

Data Management Plan

This proposed project will generate electronic data resulting from sensor recordings during bridge monitoring and field tests. In addition to the raw, uncorrected sensor data, converted and corrected data (in engineering units), as well as several forms of derived data, will be produced. Metadata that describes the monitoring and testing, materials, loads, experimental environment and parameters will be produced. The tests will also be recorded with still cameras and video cameras. Photos and videos will be part of the data collection.

In addition to the data describing the physical experiments, computational evaluations will be performed for comparison, validation, and extrapolation. It is estimated that approximately 2-5 TB of permanent data will be generated as part of this project.

Type of Data and Format

It is anticipated that computer code will be primarily written in Julia. Metadata will be stored in text files and in Microsoft Excel tables. Data will be plotted in Julia. The figures will also be saved in generic formats (such as .png and .tiff formats).

Data Storage, Retention, and Dissemination

Selected data will be retained in perpetuity. The investigators will utilize repositories at the University of Wyoming as the primary tool for long-term access and preservation of the research data during the duration of the projecct. The repository will contain metadata that can be harvested and indexed for wider re-use and dissemination by other standards-based protocols. In this way, secondary use of data from third parties will become a widely available option. Access will be free to any user with a supported web browser.

Condensed summaries of the data will be disseminated in peer-reviewed scholarly research journals. We do not anticipate significant intellectual property issues involved with the acquisition or sharing of the data. In the event that inventions are made in direct connection with this data, access to the data will be granted upon request once appropriate invention disclosures and/or provisional patent filings are made. All data will be freely available. There will be no conditions or disclaimers regarding the use of the raw data and images. It will be requested that anyone who is using the data should reference related publications by the investigators. Reuse of plots and figures in research journals are subject to publisher copyright rules and approval. The data acquired and preserved in the context of this proposal will be further governed by policies pertaining to intellectual property, record retention, and data management per the University of Wyoming and WYDOT.

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