A PROPOSAL FOR FIELD TESTING AND LONG-TERM MONITORING OF SELECTED HIGH-MAST LIGHTING TOWERS

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PROBLEM STATEMENT

In 2013, WYDOT Projects B139025 and B133026 installed a combined 21 high-mast light towers (HMLT) in District 1 and District 3. The HMLTs were fabricated by Valmont Industries according to WYDOT Standard Plan and were installed by Modern Electric of Casper, WY. In May 2016, after only three years of service, inspectors discovered fatigue cracks on two HMLTs located at the Wagonhound Rest Area of of I-80 near Exit 267. One of the HMLTs was missing a luminaire. Further inspection revealed that one more HMLT (also located at the Wagonhound Rest Area) had significant fatigue damage too. Weather data collected by a nearby weather station was reviewed by WYDOT officials showing high winds, rain and freezing temperatures. The cause of the fatigue cracking cannot be determined at this time.

LITERATURE REVIEW

A "full" literature review was not completed as the authors of this proposal have completed the most comprehensive study ever conducted on the in-service performance and behavior of HMLTs. This study was completed and is reported in NCHRP Report 718. During that study, the current fatigue loads used for the design of HMLTs were developed. Eight HMLTs were monitored around the USA for periods of up to two years, with two HMLTs being monitored in Wyoming near Creston Junction. During that study, the authors observed some level vibration that is proposed to be studied in this proposal, but only for very short durations. Further, anecdotal evidence at the time revealed high-amplitude vibration at other poles, in particular in South Dakota. However, this only came to light at the end of NCHRP 718 and it was conscientiously decided to postpone further study of this phenomena at that time. Thus, this study will fill the much needed gap related to this type of vibration. It is noted the authors are aware of other field monitoring studies, in particular those being conducted by Prof. Todd Helwig at UT Austin for Texas DOT. However, that study has revealed such high amplitude vibration. The authors of this proposal have an excellent working relationship with Dr. Helwig and will communicate with him regarding his current research as well as share data as permitted by Wyoming DOT.

OBJECTIVE

Monitor four high-mast light towers (HMLT) at locations designated by WYDOT officials in order to determine the cause of severe fatigue damage in the pole-to-base plate weld observed in the three HMLTs at the Wagonhound Rest Area. The outcome of this research is intended to determine what accelerated the fatigue failure of the HMLTs enabling WYDOT to take corrective action on existing and future HMLT installations in order to ensure the public safety.

BENEFITS

To the extent possible at this time, the following are qualitative and quantitative benefits foreseen for the proposed project.

- *Estimated cost savings or cost avoidance* – It is estimated that removal and replacement of a single HMLT is approximately $80,000. Discovering the cause of the premature fatigue failures will help avoid this replacement cost before reaching the service life of HMLTs.
- *Estimated reduction in crashes and fatalities* – Results from this study may provide information needed to prevent premature catastrophic failure of HMLTs, such as when they fall down across lanes of traffic.
- *How operational methods will be improved* – It is anticipated that improvements could be made to the inspection procedures for HMLTs.
- *How safety and mobility will be improved* – Safety and mobility of the WYDOT transportation systems requires a reliable lighting system. This project intends to

discover what is causing unreliable failures in the lighting system at certain locations. This will improve mobility, but also safety where unexpected HMLT failures can pose safety risks to the traveling public.

- *What percentage of increased public user support will be realized* – Unkown.
- *What specifications will be revised* – AASHTO/WYDOT specifications for design of HMLTs could be affected by identifying new load cases or requiring special wind studies.
- *What public relations should improve, and if so, how* – Unknown.
- *The expected reduction in energy consumed, and how practices will be improved or simplified* – Not applicable.
- *Whether WYDOT's policies will be impacted, and if so, how* – Results from the project may possible impact WYDOT inspection policies for HMLTs.

GOALS

The goal of the project is to determine the cause of fatigue damage in several HMLTs by using field-gathered data to determine the structural behavior of the HMLTs under their natural environmental loading. Specialized sensing capabilities will be employed, as discussed below, to determine behavior, response, and presence and impact of environmental factors, such as wind and ice.

This project corresponds with the WYDOT goals and mission statement by helping to provide a safe, high quality, and efficient transportation system with the following specific goals:

- **Improve the safety on the state transportation system** by identifying possible shortcomings in the current design for high mast light towers, possible shortcomings in the specifications for designing these structures, or both.
- Identifying at-risk assets and developing solutions to **take care of all physical aspects of the state transportation system** and **exercise good stewardship of WYDOT resources**.

OUTLINE OF TASKS

The following describes the outline of tasks to be completed throughout the performance of this research project. Methods to achieve said tasks are described in the Statement of Work.

- Task 1 – Design, purchase, and calibration of the instrumentation to be used during Tasks 2 and 3. This includes items such as the sensors, dataloggers, and communications.
- Task 2 – Pluck test. The pluck test is used to characterize the dynamic structural response of each HMLT prior to long-term monitoring.
- Task 3 – Long-term monitoring of each HMLT with remote data collection. Wind speed, wind direction, presence of ice, accelerations, and stresses will be monitored. Further details are provided in the Statement of Work.
- Task 4 – The final report will detail all tasks performed in addition to observations and conclusions that can be made from the data. Final deliverables will include the final report along with any additional photographs and data files desired by WYDOT.

STATEMENT OF WORK

The following section outlines how the research team plans to fulfill all deliverables for the research project.

Overall Project Approach

This proposal includes details related to field testing and long-term monitoring of four high-mast lighting towers (HMLTs) in the state of Wyoming. A few poles have exhibited unusual large-amplitude vibrations during certain wind events that likely resulted in fatigue cracking. During this research, four poles will be instrumented and monitored in an attempt to "capture" one of these unusual events in order to better define the loading and response associated with such an event. While similar events have been observed in other states, the cause has not been identified. Further, in absence of such data, it is not possible to develop and effective retrofit or mitigation strategy.

It is proposed to follow a similar field testing program conducted by the current Research Team used for NCHRP Report 718 (Project 10-74), *Fatigue Loading and Design Methodology for High-Mast Lighting Towers*, for the field testing and monitoring of the selected Wyoming DOT high-mast lighting towers (HMLT). The proposed field testing and monitoring will include a "pluck test" to determine dynamic properties as well as long-term monitoring to determine in-service environmental loading responses of four selected HMLTs. The proposed long-term field monitoring will be implemented over the course of 1-year, collecting temperature data, wind speed and direction data, bi-axial acceleration data, presence/absence of ice, stress time-history data, and stress-range histograms. It is noted that the monitoring can be extended as needed for a nominal cost per month if desired. However, this cost is not included in this proposal.

The following locations have been designated by WYDOT as the HMLTs for testing and the estimate is based on travel costs specific for these locations:

- Buffalo I-25/I-90 Int. (I-25 MP 300±) — 44°22'13.92"N, 106°41'18.58"W
- Dwyer Jct. Rest Area (I-25, MP 92±) — 42°14'2.73"N, 105° 1'2.51"W
- Wagonhound Int./Rest Area (I-80, MP 267±) — 41°37'54.12"N, 106°17'11.75"W
- Lyman Int./Rest Area (I-80, MP 42±) — 41°21'53.44"N, 110°17'52.53"W

Instrumentation (Task 1)

Each HMLT site will be configured with an independent data acquisition (DAQ) system that can be left in place with automatic remote data collection and remote access for software maintenance and program adjustments, as necessary. The monitoring system will be composed of communications equipment that includes a cellular modem and multiband antenna, a datalogger for sensor sampling and data transfer, an anemometer for wind speed and direction, an ice sensor for detecting the presence of ice, a bi-axial accelerometer for measuring accelerations in two primary axes, a thermocouple for measuring the temperature of the steel, and strain gages mounted on the HMLT near the base and at a nominal height of about 6 feet above the base plate for measuring nominal flexural stressess. A server housed at Purdue University will be programmed to communicate with each site on a regular basis to pull back data. This data will be safely stored on the server, which has automatic backup for added redundancy. In addition, the data can be published automatically to a website that can be made password protected for exclusive access by WYDOT officials only. The web-based interface would allow for the DOT officials to view data from each HMLT site, such as current and past weather conditions, stress plots, etc.

It is proposed that the anemometer be installed about 33' from the ground on a separate pole (steel or timber) that is provided by WYDOT about 10 feet from each HMLT. Access to the top of the pole will be provided by a WYDOT bucket truck. This configuration is better than mounting the anemometer directly to the HMLT because it moves the sensor away from the wind flow disruption of the HMLT. Figure 1 shows a typical setup that was used for the NCHRP 10-74 project, which would be replicated for this project. The accelerometer will also be mounted at a height of about 33 feet on the HMLT. Bucket truck access for this will also be required. Mounting for the anemometer to the pole and accelerometer to the HMLT will be provided by the Research Team (RT).

Power for the monitoring system will be provided by onsite 120V/240V available at each HMLT cabinet. Deep cycle marine batteries will be utilized to power the monitoring system and power from the cabinet will be used to recharge the battery bank each night. Power and communication lines will need to be buried in conduit between the anemometer pole, datalogger box, and power cabinet. It is proposed that the RT hand excavate shallow trenches for placement of PVC conduit for this purpose. This will help protect the lines from mowers or other motorized vehicles and rodents that may pass through the area.

Joboxes are typically used by the RT as environmental enclosures to house and protect the datalogger, battery bank, and communications. One box for each location will be purchased and modified by the RT and then shipped to a location designated by WYDOT. The RT will coordinate with WYDOT officials for delivery of the enclosures to each site at the time of instrumentation installation. Each enclosure will be setup with locks and chains to help ensure they are protected against potential theft or vandalism. If preferred, WYDOT may deliver the enclosures to each site prior to arrival of the RT, since the enclosure can be locked and chained in place.

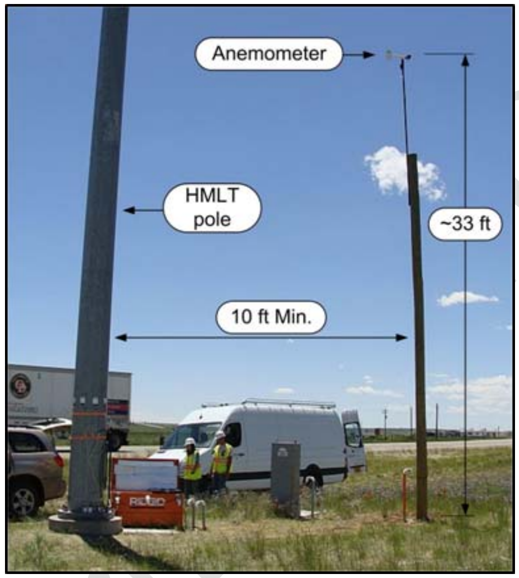

Figure 1. Typical setup proposed for instrumentation (From NCHRP 718 – Creston Junction, WY)

Pluck Test (Task 2)

Once an HMLT has been instrumented, a dynamic pluck test will be performed. A come-along winch will be attached to the HMLT about 30-feet from the base plate and to an anchor point (such as a truck hitch). A static load will be applied using the come-along while monitoring load with an inline tension load cell. The peak static load will be suddenly released allowing the elastic return of the HMLT to excite a dynamic response. Data collected during the pluck test will provide a baseline reference for data observed throughout long-term monitoring. The test will be repeated, for a total of two tests, to ensure valid and accurate data is collected.

Long-Term Monitoring (Task 3)

Long-term monitoring of the weather conditions and HMLT response will be performed over the course of a full year in order to observe all seasonal weather cycles. All sensors installed for the pluck test will be left in place, except for the load cell used to statically load the structure. In addition, an ice sensor will be installed on the HMLT during long-term monitoring. This sensor simply detects the presence of ice. If no ice is detected during sampling periods, then a "no-ice condition" is reported. If ice is detected, an "ice condition" output is recorded and the sensor temporarily heats itself up to melt the ice from its probe and then restarts monitoring for ice. The sensor will not be able to indicate how much ice is present, instead it will only be able to indicate that ice has built-up on the sensor, which when installed on the HMLT would indicate that ice has also accumulated on the HMLT. The benefit of the ice sensor will be to indicate if the presence of ice on the HMLT correlates with any change in the dynamic response during wind loading events. The ice sensor will most likely be mounted on the HMLT at a height of about 30 feet to keep it out of reach of potential theft or vandalism.

The Research Team will provide oversight and data collection throughout the long-term monitoring. Once the system is up and running and communicating regularly with the server, the data acquisition system becomes relatively autonomous requiring very little intervention. The RT will continue to monitor the system and incoming data, however, to ensure expected operation.

At the end of the long-term monitoring, the RT will travel to each location to remove the monitoring equipment. Bucket truck access to the anemometer, ice sensor, and accelerometer will be required for the RT at that time. This will be coordinated with WYDOT officials.

Final Report (Task 4)

Once all testing has concluded, the RT will evaluate the collected data and produce a thorough report. The report will include the research approach, details of the testing methods and instrumentation, photographs of testing and the data acquisition system, and conclusion reached. The draft report will be provided to WYDOT officials for review and comment prior to tender of the final report.

RESEARCH TEAM

Dr. Robert J. Connor will serve as the Principal Investigator throughout the duration of the project. Jason B. Lloyd will be the Co-Investigator.

WORK SCHEDULE

The estimated project schedule is provided below without start or end dates since this is not currently known. At this time, it is anticipated that the earliest start date for installation and testing is late spring to early summer of 2017. A 2-year project duration is proposed to avoid the need for extensions should additional testing or analysis be required. The proposed testing schedule is shown below.

Major project milestones include:

- Month 1 NTP, begin purchase of equipment
- Month 2 - 3 Calibrate equipment, Install DAQs, pluck test, begin monitoring
- Month 15 Conclude field testing, remove DAQs, begin data reduction
- Month 17 Submit draft final report
- Month 18 Submit final report

PROJECT BUDGET

The total estimated cost for the project, including equipment and labor costs is $177,119.00, as summarized in the table below. The respective WYDOT districts have agreed to provide equipment and manpower to assist with the installation of the anemometers using a bucket truck, as well as delivery of the environmental enclosures to each monitoring site. These costs are not included in the following summary table.

Labor & Benefits*		Percentage of Overall Budget
Professional Salary	$38,964	21.9
Hourly Student	$7,429	4.2
Subtotal Time (Labor)	**$46,393**	**26.1**
Direct Costs		
DAQ Systems (four systems)	$65,475	36.9
Misc. costs (i.e. cell data plan, shipping, misc. consumable materials)	$4,345	2.4
Travel costs (i.e. vehicle, lodging, meals)	$17,068	9.6
Subtotal Travel & Material	**$86,889**	**48.9**
University Overhead (Mat. & Labor)	**$44,497**	**25.0**
Total	**$177,779**	

*Includes all Purdue University employee benefits

IMPLEMENTATION

Results from this project could potentially impact WYDOT design specifications for HMLTs, as well inspection policies, as discussed above. Implementation logically falls upon agencies within WYDOT that oversee these documents and inspection practices. The project budget does not include actual proposed changes to existing specification content, but the results will provide the data and commentary in report format necessary for WYDOT to implement any required changes to these documents and policies, as deemed appropriate by WYDOT.

TECHNOLOGY TRANSFER

Technology transfer will be in the form of a final report, along with any raw data collected throughout the project. Improvements to technical practices, such as design, inspection or installation of HMLTs, will be discussed in detail in the final report. The research team will also present the results of the research at various conferences and meetings, such as to the AASHTO T-12 sign structure committee and at the annual TRB Conference in Washington DC if approved by Wyoming DOT. Further, the research team will provide a seminar at the Wyoming DOT that presents the final results and findings if requested by the sponsor.

DATA MANAGEMENT PLAN

The data management plan (DMP) is provided in Appendix A.

APPENDIX A – DATA MANAGEMENT PLAN (DMP)

Although most of the research will be archived through production of the final report, the raw data files collected during monitoring will not be. The research team recognizes the importance of organizing data in such a way that years later it is self-explanatory to search and find desired data. The data file type generated by the monitoring equipment during the proposed research is a generic file format that is compatible with most all data analysis and graphing software making it easy to share, as needed. The data files will be date stamped ASCII files that can be viewed and manipulated by most commercially available software, such as Microsoft Excel, SigmaPlot, OriginLab, etc.

Data from the sensors will be collected by the datalogger onsite for each of the monitored HMLTs and temporarily stored on secure digital data cards. Secured, automated linkup between a secure server and the dataloggers will be programmed to collect the data at a desired interval using the Campbell Scientific Inc., software called LoggerNet. The data will be deposited on a secure server machine that is housed, managed, and maintained within the Purdue University Engineering Computer Network (ECN) group. The server is kept in a controlled environment promoting optimal performance and durability. Data on the server is backed up daily to main servers, followed by weekly and monthly backups to digital tapes. This provides for a very robust and multi-level redundant data backup and storage system where files are secure and retrievable.

The data can be made available to WYDOT and/or other researchers as desired and determined by the WYDOT Champion and WYDOT Research Center. At this time it is not anticipated that the data would be shared with other researchers prior to completion of the research and acceptance of the final report. Final reports and other publications resulting from data collected during this research project will be assigned DOIs, as necessary.

Name of Contractor	Purdue University
Name of Project	Field Testing and Long-Term Monitoring Of Selected High-Mast Lighting Towers
Project Duration	24 months
DMP Version	
Date Amended, if any	
Name of all authors, and ORCID number for each author	Robert J. Connor, Jason B. Lloyd
WYDOT Project Number	
Name of all peer reviewed publications which have been generated using data from this project	
Any Digital Object Identifier (DOI), including any CROSSREF number, which has been assigned to any peer reviewed publication or data generated by this project	
URLs for all peer reviewed publications which have been generated using data from this project	
RiP RH Display ID Number	
Dataset URL, if available	

APPENDIX B – RESUMES OF KEY STAFF

Robert J. Connor

EDUCATION

Ph.D. in Civil Engineering, Lehigh University 2002
M.S. in Civil Engineering, Lehigh University, 1996
B.S. in Civil Engineering, Drexel University, 1990

EMPLOYMENT HISTORY

Title	Employer	Dates
Bridge Design Eng.	Greiner Engineering (URS Corp.)	June 1990 - December 1993
Graduate Research Assistant	Lehigh University ATLSS Center	January 1994 – May 2000
Visiting Research Engineer	Lehigh University ATLSS Center	June 2000 – September 2000
Research Engineer II	Lehigh University ATLSS Center	October 2000 – June 2002
Research Engineer III	Lehigh University ATLSS Center	July 2002 – April 2005
Senior Research Engineer	Lehigh University ATLSS Center	April 2005 – July 2005
Assistant Professor	School of Civil Eng., Purdue Univ.	August 2005 – June 2010
Associate Professor	School of Civil Eng., Purdue Univ.	July 2010 – June 2016
Professor	School of Civil Eng., Purdue Univ.	July 2016 - Present

PROFESSIONAL SUMMARY

Dr. Connor has over twenty years of experience in the research and testing of bridges and related structures. He is currently a Professor in the School of Civil Engineering at Purdue University and director of the Steel Bridge Research, Inspection, Training, and Education (S-BRITE) Center. Prior to joining the faculty at Purdue, he was a Senior Research Engineer and the manager of the Infrastructure Monitoring Program at the ATLSS Engineering Research Center at Lehigh University. Over his career, he has conducted field evaluations of bridges throughout the United States and in bridge evaluations internationally. He has researched fabrication flaws, fatigue cracking, and failures and developed repair strategies for structures for a variety of agencies including state DOT, rapid transit authorities, construction companies, and structural consultants. He has developed and is currently developing fatigue design specifications for highway bridge structures and bridge expansion joints for NCHRP and state agencies. In addition, he has developed short courses focused on fatigue and fracture design for steel bridge structures geared to toward practicing engineers and was the Chairman of the First International Conference on Fatigue and Fracture in the Infrastructure, held in August of 2006.

Prior to entering the academic profession, he worked as a design engineer responsible for the conceptual, preliminary, and final design of numerous bridge design and rehabilitation projects throughout the eastern United States.

Jason B. Lloyd

EDUCATION

M.S. in Civil Engineering, Purdue University, 2012

B.S. in Civil Engineering, Utah State University, 2005

PROFESSIONAL REGISTRATION

Professional Engineer in the state of Indiana

EMPLOYMENT HISTORY

Title	Employer	Dates
Research Engineer	School of Civil Eng., Purdue Univ.	May 2012 - Present
Graduate Research Assistant	School of Civil Eng., Purdue Univ.	January 2011 – May 2012
Assistant Public Works Officer	USN, Subase New London, CT	December 2008 – December 2010
Facilities Engineering Div. Officer	USN, Al Asad, Iraq	April 2008 – October 2008
Assistant Resident Officer In Charge of Construction	USN, Marine Corps Air Station Beaufort, SC	December 2005 – March 2008

PROFESSIONAL SUMMARY

Jason is a licensed Professional Engineer in the State of Indiana. He has over 11 years of professional experience in large scale research, infrastructure monitoring, and contract and construction management. He attained his M.S. Civil Engineering (Structures) from Purdue University where he currently works as a Structural Research Engineer and is pursuing his PhD with Dr. Robert Connor in Purdue's structures laboratory, Bowen Lab, and in the Steel Bridge Research, Inspection, Training, and Engineering (S-BRITE) Center. At Purdue Jason specializes in field testing and remote long-term and short-term monitoring of structures, data acquisition over remote communications, fatigue analysis of existing structures, fracture mechanics, large scale fatigue research, and steel bridge fatigue and fracture repair and retrofit. In addition, Jason's experiences in the US Navy Civil Engineer Corps have taken him across the United States and as far as Iraq where he managed hundreds of millions of dollars in construction contracts with multi-national contractors. He has been awarded the Navy Commendation Medal, Navy Achievement Medal, and the Iraqi Campaign Medal.