Field Deployment of Signal Head Vibration Absorbers to Reducing Fatigue in Wind-Excited Traffic Signal Structures

A Project Proposed for the
Transportation Pooled Fund Program

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Introduction and Background Summary

The proposed research project will conduct field testing of an innovative signal head vibration mitigation device called the signal head vibration absorber (SHVA) to reduce fatigue in traffic signal support structures that experience excessive wind-induced vibration. The SHVA uses the mass of the signal head as the mass of the vibration absorber and connects the signal head to the mast arm using a linear spring and damper to reduce unwanted vertical vibrations in traffic signal mast arms. This configuration is low cost, maintenance-free and rugged. The SHVA requires no external power or sensors for operation and is fully compatible to typical existing signal heads.

This novel SHVA concept has been tested in a full-scale laboratory experiment, in a project sponsored by the NCHRP-IDEA program (Project Number 141); where it has been shown to increase the damping in a 35-foot mast arm and pole from 0.15% of critical damping to over 10% of critical damping. This corresponds to a reduction in the steady state vibration of the mast arm by a factor of 80 and a reduction in the vibration of the signal head itself by a factor of 60 over the typical rigidly-connected system. The NCHRP-IDEA Project Number 141 final report was published and is available online at:

http://onlinepubs.trb.org/onlinepubs/idea/finalreports/highway/NCHRP141_Final_Report.pdf

Furthermore, at the request of the AASHTO's Standing Committee on Research (SCOR), the NCHRP-IDEA Program Committee Chair, Ms. Sandra Larson, made a presentation at its December 2010 meeting on the program's accomplishments; NCHRP-IDEA Project Number 141 was highlighted as an example of an NCHRP-IDEA success in Ms. Larson's presentation.

Also, NCHRP-IDEA Project Number 141 was identified as an IDEA product with a high near-term implementation/commercialization potential in the following document available online at:

http://onlinepubs.trb.org/Onlinepubs/IDEA/SuccessStories/IDEAProductsTables.pdf

The Connecticut Department of Transportation has posted a streaming video documenting the laboratory results of the NCHRP-IDEA project at:

mms://159.247.0.209/mediapoint/Uconn/NCHRP_Idea_141_v4.wmv

Significant progress was made under the concept exploration funding of NCHRP-IDEA.

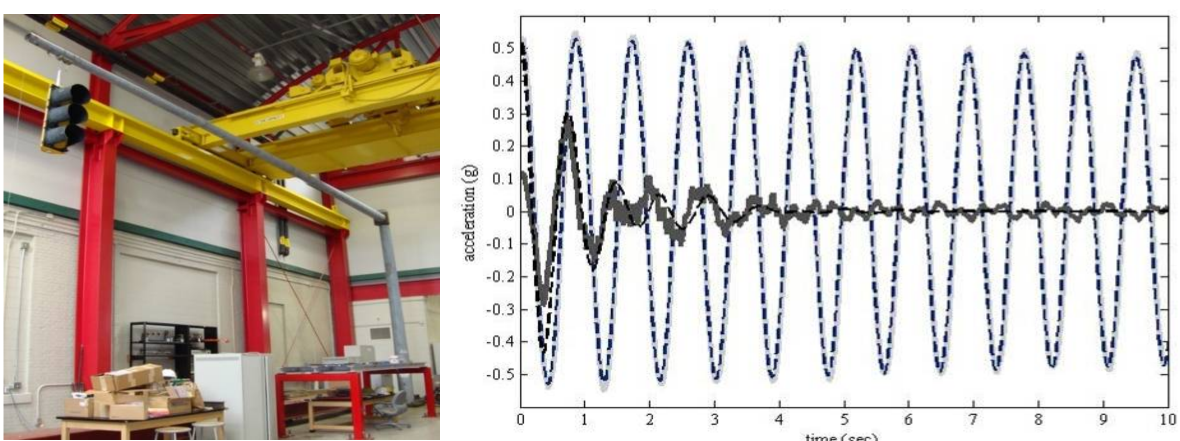


FIGURE 1 Experimental testing of the signal head vibration absorber.

Based on the success of the laboratory testing, a series of field tests will be conducted within this project to demonstrate the performance on traffic signal structures located in the field. All States involved in the project will have a representative on the project's Technical Advisory Committee (TAC). States will have the option to participate at the equipment level, where SHVAs are installed on a traffic signal support structure in the participating State. The proposed vibration mitigation device can reduce the wind-induced vibrations of traffic signal structures, reducing fatigue, increasing the safe life of the structure, and saving money. The SHVA can potentially change the way vibration in transportation structures are mitigated.

Problem Statement

Traffic signal support structures are slender, lightly-damped structures. These cantilevered signal supports are highly susceptible to wind-induced vibration. Excessive vibration can significantly reduce the fatigue life of the connections (e.g., post to arm connections) of these structures. Reducing the effective stress range, the difference between the maximum and minimum stress, of critical components can significantly increase the fatigue life of the structure. Excessive vibrations can also result in serviceability issues related to the motorists' awareness of the large mast arm displacements and motorist complaints and can diminish the accuracy of traffic detector cameras mounted on the mast arms.

While difficult to predict site characteristics (e.g., wind speed, direction, frequency) that result in excessive signal support vibration, this motion is routinely observed in built signal and sign structures across the nation. Eliminating the exciting force, the wind load, is not practical for many transportation structures, although alternative research has considered aerodynamic modifications, e.g., an airfoil, to reduce the effect of the wind on the structure with varying results. Changing the mass, stiffness, or aerodynamic properties of the structure has also been considered. Traditionally, signal support vibration is addressed by increasing the strength and stiffness of the structure. This results in larger poles and mast arms as well as overbuilt connection details. A third possibility is the application of structural control to introduce mechanical devices to redistribute and/or dissipate energy in the structure.

Two realizations of the SHVA, as shown in Figure 2, have been tested in the Structures Research Laboratory at UConn. The next step is to test the SHVA on traffic poles in the field. The second unit (on the right) will be the basis for the unit used in the field tests.

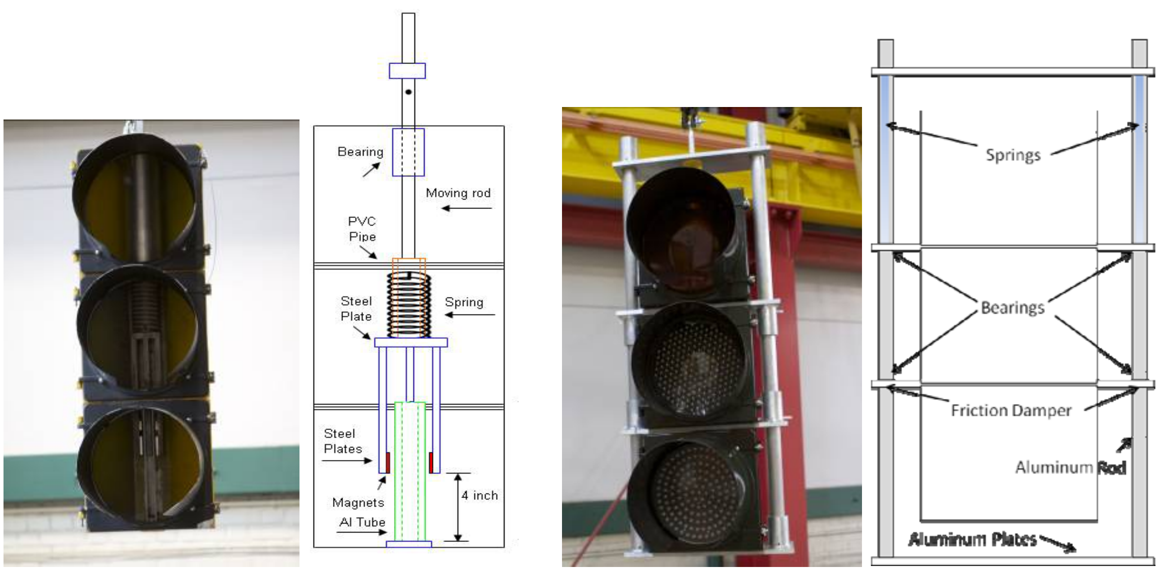


FIGURE 2 Signal head vibration mitigation devices tested at UConn.

This project will conduct field tests of a low-cost retrofit scheme for cantilevered traffic signal structures that incorporate a dynamic vibration absorber into the structure. The proposed signal head vibration absorber (SHVA), as shown attached to a 55 foot long mast arm, makes use of the mass of existing signal heads already present on the traffic support structure to provide the supplemental mass of the vibration absorber. The signal head vibration absorbers provide a relatively large supplemental mass to reduce vibration while adding no additional mass to the overall system. A linear spring and damper connect the signal head to the mast arm to provide the spring and damping forces. The optimal design of the spring and dampers can be simplified to a small number (i.e., two or three) designs that can provide sufficient protection over a wide range of traffic signal structures. The strain measurements at the mast arm to pole connection will be used to evaluate the performance of the signal head vibration absorber.

FIGURE 3 Signal head vibration mitigation devices tested at UConn.

Objectives

The objective of this project is to: 1.) conduct field tests to assess the performance of signal head vibration absorbers (SHVAs) on various signal support structure and signal head configurations; and, 2.) educate signal support structure owners to evaluate *effective* vibration mitigation devices for their infrastructure.

Each field deployment will include SHVAs applied to a mast arm to reduce wind induced vibration. The traffic signal structures will be evaluated with strain transducers and accelerometers to assess the performance. The SHVAs can be engaged and disengaged such that uncontrolled and controlled data can be taken: (i) when the system is first installed; and, (ii) at a time approximately 12 months after the installation. For each signal support structure tested, the reduction in stress range the SHVA can affect will be evaluated and reported to the Department of Transportation. Another objective is to provide signal support structure owners with the necessary tools to identify *effective* vibration mitigation devices for their specific traffic signal support structure inventory.

Evaluation Plan

The success of this research can be identified by:

1. Reduction in the stress-range (measured by the corresponding-strain range) of the mast-arm to pole connection in traffic signal structures resulting from vertical wind-induced motion of the structure when retrofitted with signal head vibration mitigation devices.
2. Improvements in the engineers' understanding of vibration mitigation techniques for traffic signal structures and ability to identify *effective* vibration mitigation devices for specific traffic signal structures.
3. Understanding of the field performance, limitations and robustness of the signal head vibration mitigation devices.

Benefits

- ✓ The proposed signal head vibration absorbers (SHVAs) can reduce wind induced vibrations of traffic signal structures, reducing fatigue and increasing the safe life of the structure. This will ultimately mean that less resources will need to be devoted to replacing and repairing fatigued traffic signal structures and result in a safer and more efficient transportation infrastructure.
- ✓ The proposed low-cost retrofit can be applied to the signal structures that exhibit excessive vibrations in the field and eliminate the serviceability issues related to the motorists' awareness of the large mast arm displacements and motorist complaints and to provide a stable base and improve performance for traffic detector cameras mounted on the mast arm.
- ✓ The proposed SHVAs can be used in lieu of designing to resist periodic galloping forces in the AASHTO fatigue design requirements, allowing for smaller poles to be used which will save significant material costs at the time of construction for new traffic poles built to Federal (AASHTO) standards.
- ✓ The proposed SHVAs can allow for existing poles already loaded to capacity to accommodate additional signs and signal heads (avoiding replacement of the traffic pole), allowing the existing infrastructure to remain in service.
- ✓ The proposed SHVAs can provide traffic pole owners the confidence to use longer traffic pole mast arms when the traffic signal design warrant without the concern of vibration, fatigue and failure.

Research Results

The products that will be delivered by this project include SHVAs installed and evaluated on traffic signal support structures. The finding of this project will be submitted for presentation and publication at the 2014 Transportation Research Board Annual Meeting. Additionally, project reports will include quarterly progress report, draft final report and final report, with executive summary included in the final report. Streaming media presentation of the first year presentation will be taped and made available on the Connecticut Department of Transportation website. Additionally, PowerPoint slides from the year two TAC meeting will also be posted on the Connecticut Department of Transportation website.

Implementation

This project will implement a signal head vibration mitigation device on a traffic signal support structure in each of the States participating at the equipment level. The standard implementation will include two signal head vibration mitigation devices attached on a single mast arm. If a State should want a more complex implementation, or implementation on multiple mast arms, this can be arranged on a case-by-case basis with a corresponding increase in the budget. In addition to the installation, strain sensors and accelerometers will be deployed on a temporary basis to measure and quantify the response of the retrofitted traffic signal structures with comparison to the structure with fixed signal heads. The performance and robustness will be directly assessed by dynamic strain measurements at the initial installation and after 12 months of operation. The signal head vibration mitigation device will be left on site after the duration of the project.

States and local traffic signal support structure owners will be responsible to applying the research results. The current standards in the AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaries and Traffic Signals -fifth edition, specify that in lieu of designing against fatigue from galloping and vortex shedding forces, an effective vibration mitigation device may be used to reduce vertical deflections. The intent of this project is to provide traffic pole owners with an understanding of what an effective vibration mitigation device is, and demonstrate this with an effective SHVA.

Work Plan

The field deployment and evaluation of the signal head vibration absorber will be conducted over an 18 month period. The work plan entails: identifying candidate traffic signal structures; designing, building and installing the signal head vibration mitigation devices on selected traffic signal structures; evaluating the performance of the signal head vibration absorbers at the time of installation and at a time 12 months later; and, regular reporting of these efforts and evaluation. The traffic signal structure owners will receive training to identify *effective* vibration mitigation devices for specific traffic signal structures. A detailed description of the resulting five research tasks and a schedule of these tasks is provided subsequently.

Task 1: Identification. Identify potential traffic signal structures susceptible to excessive wind-induced vibration in each of the partner states (partners at the equipment level). In this first task, the research team (PI and graduate student) will work with each of the partner states to identify an appropriate traffic signal support structure. Ideally, the traffic pole will be near a similar pole to allow for comparison of the traffic support structure with the signal head vibration mitigation devices to one without retrofits.

Task 2: Preparation. Prepare signal head vibration mitigation devices for the traffic signal structures in the study. This will include design of systems with multiple signal heads and different signal head support configurations. Prepare logistics for installation of the signal head.

Task 3: Deployment. Deploy signal head vibration mitigation devices on traffic signal structures in each state. The research team will travel to each of the partner states to assist the host DOT in installing the signal head vibration mitigation devices. The research team will install strain sensors and accelerometers with the assistance of the host DOT and collect data for the uncontrolled and controlled traffic signal structure using a portable data acquisition system.

Task 4: Evaluation. The data collected during the deployment phase will be analyzed by the research team to identify increased damping and quantify response reduction. An analytical model of the traffic pole will be developed to allow the research team to identify the effectiveness of the installed system and compare to the potential performance of the system.

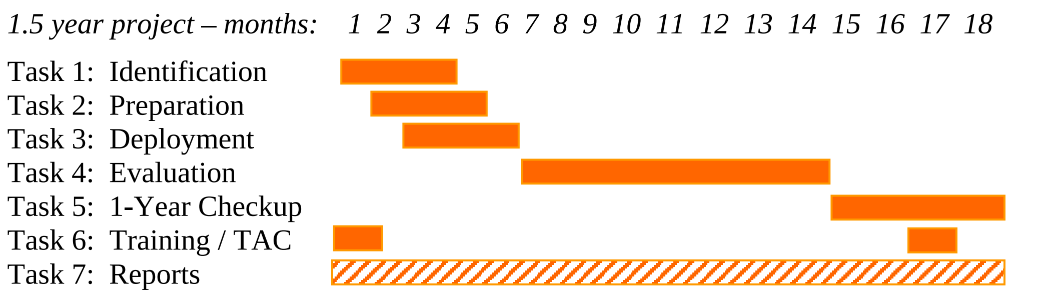
Task 5: One year checkup. The research team will travel again to each of the partner sites to collect uncontrolled and controlled data after a twelve month period to verify the SHVA's performance over a period of time.

Task 6: Training. The research team will provide training to the project members to identify *effective* vibration mitigation devices for specific traffic signal structures. At the beginning of the project, the TAC will attend a kick-off meeting in Connecticut. The theory and operation of the signal head vibration absorber will be presented and a signal head vibration absorber installation in Connecticut will be visited. The presentation will identify measures and methods that can be used to identify *effective* vibration mitigation devices. The presentation will be taped and available on the Connecticut Department of Transportation website. At the end of the project, a suitable installation State/site will be selected for a second meeting. This meeting will focus on reporting of the effectiveness of the signal head vibration mitigation devices in the various States and identification of lessons learned in the installation and maintenance of the signal head vibration mitigation devices.

Task 7: Reports. Progress reports will be prepared by UConn. Quarterly reports shall be written while the project is on-going to track the work that has been completed and to plan for future activities. Individual reports will be written for each State's traffic signal structures tested. A draft final report and final report, including executive summary, will be prepared by UConn at the end of the project.

<u>Anticipated Work Schedule</u>

This 18 month project will begin April 2013 and end in September 2014. The tentative schedule of the project is provided here.



Budget

The proposal assumes that six (6) States will participate in the project at the equipment level, and so, the cost of the project would be $66,001 in the first year and $74,999 in the second year, for a total cost of $141,000. The cost per State, with six (6) States participating in the project at the equipment level, would be $11,000 for the first year and $12,500 for the second year. This cost could increase if the State would like a more extensive deployment than two SHVAs attached on a single mast arm. The research team can discuss options and costs for different implementations. The project will supply the SHVA equipment (purchased from Vibration Mitigation Technologies) and technical support for the deployment in the field, but each State is responsible for supplying the signal head, lights, etc. and installation costs either using their own forces or contractors. The project team will install the needed instrumentation and SHVA when we are there for the installation. The research team will also assist in estimating travel costs for the State's TAC member to attend the project meetings. These TAC member travel costs can be added to the State's contribution, if desired.

2012 Fiscal Year:

Base cost of program	
1 Grad. Asst. for 3 summer months	$7,559
Administrative Support	$3,569
Fringe benefits	$2,153
Materials & supplies,	$5,720
Cost per State to install equipment	
Two (2) signal head vibration absorbers	$4,000
Travel – research team to State for deployment	$2,000
Indirect (20%)	$3,800 + $1,200/equip. state
2012 TOTAL:	**$22,801 + $7,200/Equip. State**

2013 Fiscal Year:

1 Grad. Asst. for academic year	$23,363
1 Grad. Asst. for 3 summer months	$7,672
Grad. Asst. Tuition	$6,892
Administrative Support	$3,747
Fringe benefits	$6,580
Materials & supplies,	$3,396
Cost per State to install equipment	
Travel – research team to state for deployment	$2,000
Indirect (20%)	$8,952 + $400/equip. state
2013 TOTAL:	**$60,602 + $2,400/Equip. State**