Chapter 17
Performance Evaluation of a Damped Vibration Absorber for Traffic Signal and Sign Structures

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Abstract Transportation ancillary structures (traffic structures), including traffic signal support structures and sign structures, are typically characterized by their high flexibility and low inherent damping. These dynamic characteristics make these structures particularly susceptible to wind-induced vibration. Wind loading, including galloping, vortex shedding, natural wind gusts, and truck-induced gusts, can result in vibration of these traffic structures. The low natural frequencies of these structures overlap with the excitation frequency of winds and can result in large amplitude and cyclical response and repeated live load stress variations which can induce fatigue and significantly reduce the safe life of these structures. Reducing the effective stress range, the difference between the maximum and minimum stress in a cycle, by minimizing the wind-induced vibration can significantly increase the operational life of the structure.

At the design stage, traffic structure vibration is commonly addressed by increasing the stiffness and strength of the structure. This results in larger poles and mast arms as well as overbuilt connection details. A more effective alternative is the application of vibration absorbers to increase the damping of the structure and reduce the response. An innovative damped vibration absorber has been developed utilizing both eddy current and pneumatic damping to provide a robust and durable vibration absorber for traffic structures. This presentation will document the effective damping of the proposed device over a range of structures. A series of laboratory and field tests on in-service structures will be presented to illustrate the efficacy of the damped vibration absorber over a wide-range of structures.

Keywords passive structural control · vibration mitigation

Introduction

Traffic signal structures are often supported by cantilevered flexible structural elements with low damping which makes them susceptible to wind-induced vibration and corresponding fatigue and failure. These structures are often located adjacent to or directly over roadways where maintenance, repair or replacement is costly in terms of time and money. Failure of the structure can compromise the safety of the traveling public. The current AASHTO LRFD Specifications for Structural Supports for Signs, Luminaries, and Traffic Signals (AASHTO LRFD SLTS Specifications) [1] addresses potential failure due to wind vibrations by requiring members and connections to have nominal strengths more than the expected loadings by a sufficient margin to reduce risk of failure to an acceptable amount [2]. This requirement can result in inefficient structural designs that use large members and overbuilt connections, which is a poor use of material and financial resources. The AASHTO LRFD SLTS Specifications indicate that in lieu of designing to resist periodic galloping forces, effective vibration-mitigation devices can be used for cantilever sign and traffic signal structures, based on historical or research verification of its vibration damping characteristics and as approved by the Owner. Recently approved revisions to the specifications, that will be published in the next AASHTO LRFD and LTS Specification Editions, will provide for a quantitative procedure to evaluate and implement effective mechanical vibration devices into the retrofit and design of traffic signal structures. In

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these revisions, an effective vibration-mitigation device can be accounted for in the design process by reducing the fatigue demand through use of a response modification factor (R, or R-factor). The use of an R-factor requires suitable testing and modeling of the vibration mitigation device is performed and documented.

Various devices have been considered to reduce excessive wind-induced vibrations in traffic signal structures. Vibration absorbers, such as tuned mass dampers, tuned liquid dampers, friction dampers, impact dampers, struts and elastomeric pads, work by dissipating the energy of the wind loading applied to the structure through mechanical means [3–11]. These devices have been observed to have various levels of success. Often, these mechanical damping devices must be tuned specifically for a given traffic signal structure or become ineffective. One particularly effective and robust mechanical damping device that does not require tuning is the Valmont TR1 damper. This presentation will present the laboratory and field testing of the TR1 vibration mitigation device for the use of dampers in the design and protection of traffic signal structures.

The device considered is the Valmont Industries TR1 damper (US Patent 9,470,288, 10,036,446, 11,181,165, 11,821,487, and various International Patents), which is intended to effectively reduce vertical mast arm and sign structure vibrations caused by wind vortex shedding, galloping, and truck gusts. The TR1 damper is a damped vibration absorber. The device consists of a 4.5” diameter by 43” long tube that is attached near the end of the mast arm, often hidden from view by signals or signs mounted on the mast arm, with a total weight of 35.75 lbs. The TR1 damper energy dissipation is through both eddy current damping and pneumatic damping. The eddy currents are circular electric currents induced within conductors by the movement of a magnet next to the conductive material. These circular currents are opposite the direction of movement creating a resistance and thus damping. The pneumatic damping occurs as the damper mass translates up and down within a sealed chamber. The exchange of air from the upper air chamber to the lower air chamber creates velocity dependent resistance.

Laboratory Testing

The TR1 damper is tested to determine its effect on the desired range of properties of target structures. Two traffic signal structures, both 50 foot (50’) long mast arms, with different cross sections and different added weights, are used to provide various combinations of frequency and dynamic weight for the laboratory testing in the Structures Research Laboratory at the University of Connecticut. The dynamic behavior characterized for the structure with the applied mechanical vibration mitigation device is the effective damping ratio, ζ, of the system. A strain sensor is installed on the mast arm near the connection to the pole. The damping ratio is determined through free vibration tests where the structure is manually excited vertically with a harmonic (sinusoidal) motion at the first natural frequency to an amplitude above 12” and the structure then released. The free vibration response is measured with the strain sensor and used to calculate the natural frequency and damping ratio.

The four traffic signal support structure configurations were realized by testing two different mast arms with and without added mass. Both mast arms were attached to the same shortened pole that was bolted to the strong floor. The steel pole had a height of 4.5 ft. with a 13.2” outside diameter (OD) at the base, a 12.5” OD at the tip, and a wall thickness of 0.2391”. Mast Arm 1 (Large 50’ Mast arm) was 50 ft. long with a 12.5” outside diameter (OD) at the base, a 5.5” OD at the tip, and a wall thickness of 0.2391”. Mast Arm 2 (Slender 50’ Mast arm) was 50 ft. long with a 10” outside diameter (OD) at the base, a 3” OD at the tip, and a wall thickness of 0.1793”. Damping in the first mode is determined from the free vibration tests to increase from 0.1% to between 2.3%-9.3%.

Field Testing

The damping performance verified with comprehensive field testing to ensure robust performance. Information on 17 field tests conducted in 11 different states and 1 foreign country will be provided in the presentation. The TR1 dampers have been applied to mast arms ranging from 45 ft to 75 ft and natural frequencies from 0.61 Hz to 1.2 Hz. The dampers have been observed to increase the first mode damping in the traffic signal structures from 30-60 times the inherent damping of the pole structure by itself. These field tests demonstrate definitively the performance achieved with the TR1 damper for various types of actual traffic signal structures.

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