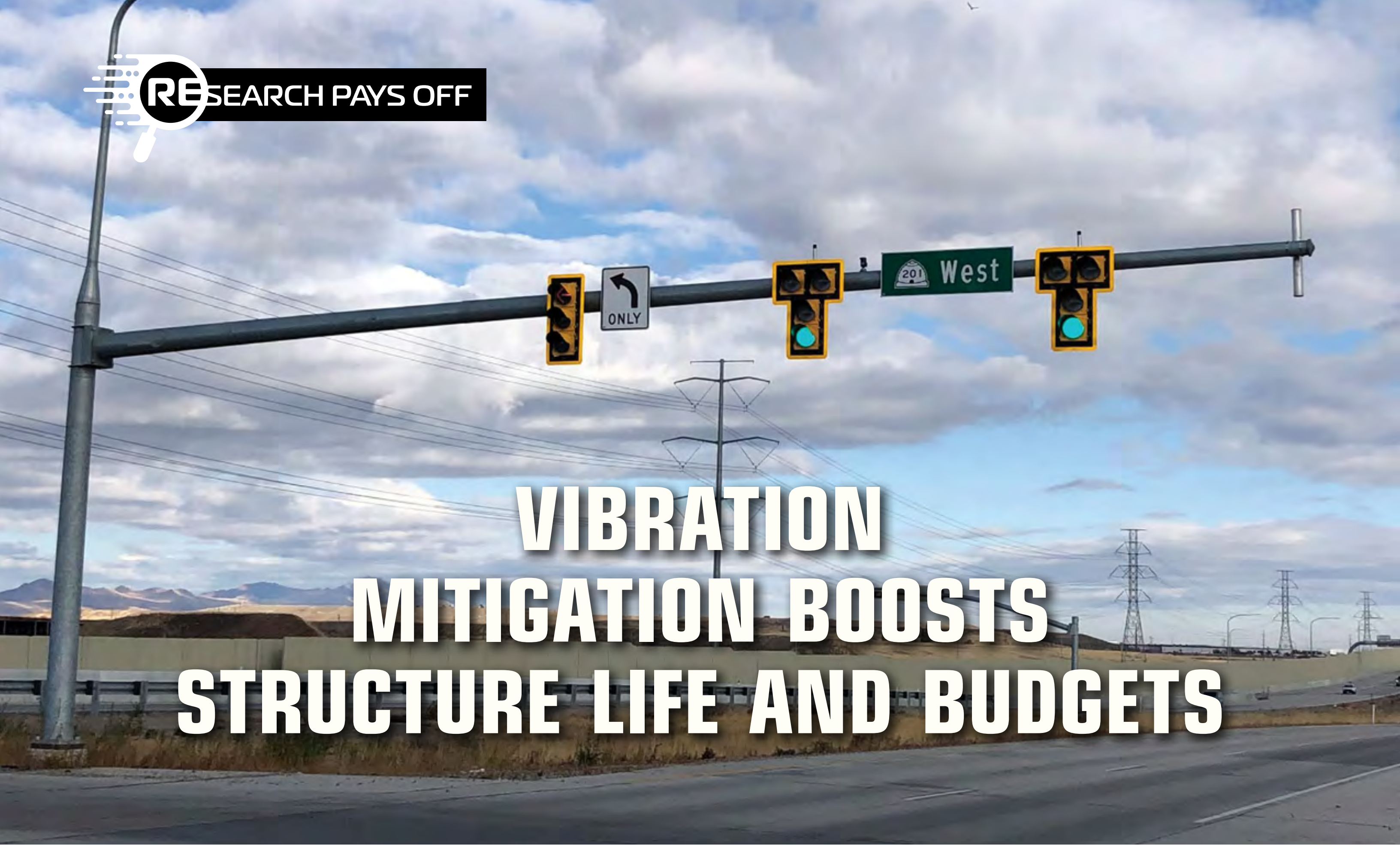
VIBRATION MITIGATION BOOSTS STRUCTURE LIFE AND BUDGETS



Mark Taylor

CARL J. MACCHIETTO AND MARK TAYLOR

Macchietto is vice president of product development and management at Valmont Industries, Inc. in Valley, Nebraska. Taylor is a traffic signal operations engineer at the Utah Department of Transportation in Salt Lake City.

When traffic signals or mast poles move repeatedly in the wind, traffic engineers call this *galloping*, during which the structure withstands vibrational stress that can cause premature fatiguing. In lieu of more costly solutions, adding a vibration damper stabilizes the structure, reduces fatigue, and improves structure lifespan.

The Valmont TR1 Mitigator vibration damper was designed using vibration theory and innovative damping technologies to reduce vibration stress from wind excitation and increase the fatigue life of a sign and traffic signal structure. The damper's technology built upon the knowledge and understanding presented in National Cooperative Highway Research Program (NCHRP) Innovations Deserving Exploratory Analysis (IDEA) research performed as part of NCHRP IDEA-141, "Signal Head Vibration Absorber for Traffic Signal Support Structures" (*1, 2*). Use of this device has resulted in more efficient traffic signal and sign support structures by

- Creating a more economical design;
- Improving safety for the traveling public;
- Extending the life of new and existing structures;
- Lowering maintenance, inspection, and repair costs; and
- Reducing mast arm movement, thus improving vehicle detection by cameras and radar systems.

The Problem with Vibrations

Traffic signal support structures have been increasingly observed to be susceptible to vibrations resulting from both normal and extreme wind conditions. Types of wind loading—including galloping, vortex shedding, natural wind gusts, and truck-induced gusts—can result in vibration of these structures. AASHTO defines galloping as large amplitude resonant oscillations in a plane normal to the direction of wind flow, usually limited to structures with nonsymmetrical cross-sections, such as sign and traffic signals mounted to an arm. AASHTO defines vortex shedding as the shedding of wind vortices on alternate sides of a member that results in resonant oscillations in a plane normal to the wind direction. Vibrations can lead to stress variations that can significantly reduce the fatigue life of these structures.

AASHTO's *LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* and subsequent interim revisions[1] address fatigue loading caused by wind-induced vibrations and truck gusts for traffic signal structures and strive to make our streets safer (*3, 4*). In many cases, to adhere to these revisions, the cost of traffic signal installations have doubled in the past decade. Key contributing factors are the added cost of bulkier steel poles and mast arms, larger foundations, and higher costs of labor.

A New Approach

The Valmont TR1 Mitigator vibration damper is a self-contained unit weighing approximately 35 pounds. It is easy to handle and mount. A reciprocating steel mass is suspended in the tube by a stainless steel extension spring. Magnets located on the reciprocation mass moving through the aluminum tube create eddy currents (electricity), which provide damping and are extremely effective in damping low- or high-amplitude motion. Specially designed bearings on the top and bottom of the steel mass provide proper pneumatic damping (air resistance), which is more effective at larger amplitudes (Figure 1).

Laboratory and field testing were completed to determine the TR1 Mitigator's efficacy as an alternative to larger poles, more steel, larger foundations, or other previous remedial measures aimed at minimizing the galloping of mast arms. Specifically, the research objective was to determine whether the vibration damper sufficiently reduces wind-induced vibration oscillations while keeping structure size and costs manageable and adhering to the minimum AASHTO fatigue design recommendations.

The laboratory tests were conducted at the University of Connecticut on cantilever mast arm configurations of different lengths, diameters, and added masses, to simulate a range of signal and sign structures. Free vibration (displacing the arm by a certain distance and letting it go) and force vibration (applying a steady continuous impulse force to the arm at the structure's natural frequency) tests were performed and measured with both strain gauges and accelerometers. These tests showed that the device effectively mitigates vibration movement on a wide variety of pole configurations and frequencies. The numerical model of the damper makes it possible to accurately—mathematically—predict the performance of the TR1 Mitigator while mounted on any traffic and sign structure. The free vibration tests conducted on 50-foot mast arms showed that the TR1 Mitigator reduced vibration amplitude by 97 percent to 99 percent (Table 1).

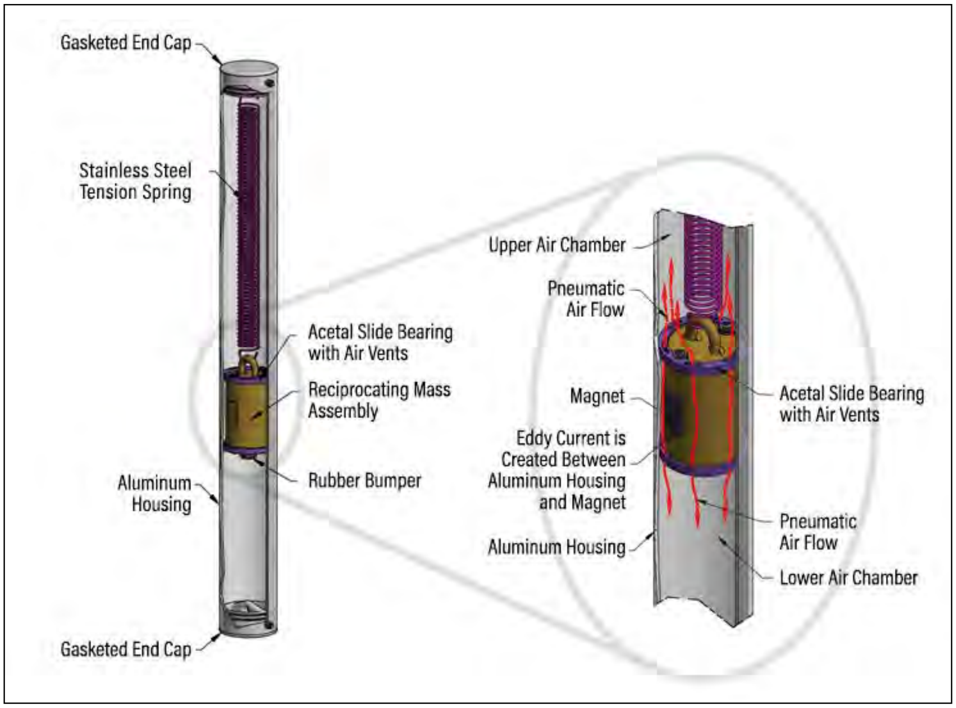


FIGURE 1 Internal view of the TR1 Mitigator vibration damper.

Table 1 Free Vibration Testing of 50-Foot Mast Arm at the University of Connecticut

Mast Arm Base OD & Wall Thickness (in.)	Natural Frequency (Hz)	Added Weight (lbs.)	Inherent Structural Damping (%)	Damping with TR1 Mitigator Damper (%)	Vibration Amplitude Response Reduction (%)
12.5 OD 0.2391 Wall	1.2	48.34	0.09	2.70	97
12.5 OD 0.2391 Wall	0.99	173.34	0.07	3.20	98
10.0 OD 0.1793 Wall	0.95	48.34	0.08	9.50	99
10.0 OD 0.1793 Wall	0.69	173.34	0.07	2.50	97

NOTE: OD = outside diameter on the large end of the tube. "Added Weight" refers to the extra weight (not including the Mitigator) used to change the structure's frequency and dynamic mass.

[1] LRFD stands for load and resistance factor design.

Table 2 TR1 Mitigator Field Tests

Date	Location	Mast Arm Length (Feet)
6/16/2016	City of Omaha, Nebraska	70
8/3/2016	State of Utah	40, 45, 50, 70, and 75[a]
11/10/2016	City of Seattle, Washington	65
5/24/2017	City of Harford, Connecticut	55
6/28/2017	State of Nevada	45
10/20/2017	Doha, Qatar	68[b]
12/20/2017	State of Colorado and City of Brighton, Colorado	65
6/14/2018	State of Arizona	40
11/20/2018	City of Fort Worth, Texas	50
2/12/2019	Clark County, Nevada	85
9/22/2021	Waterloo and Dubuque, Iowa	50
4/26/2022	State of Kansas	70

Note: [a]Three 75-foot mast arms. [b]Two 68-foot mast arms.

Some TR1 Mitigator installations in the United States and abroad have undergone field testing (Table 2). Measured performance from these field tests showed a reduction of vibration amplitude from 85 percent to 94 percent and further validated the laboratory developed mathematical performance model that gave calculated results within 1.5 percent of the measured results.

Putting This Research in the Field

Since 2016, the Utah Department of Transportation (DOT) has installed more than 1,200 of the devices and reported that it takes only a few minutes for installation. The TR1 Mitigator is standard for new traffic signal installations and Utah DOT is both pleased with the device's performance and impressed by its aesthetics because it blends in nicely with the other devices on the mast arm.

In March 2017, a Nevada standard flashing signal railroad crossing mast arm failed from metal fatigue near Reno, due to wind-induced vibration. The mast arm failed across the road, risking safety of the public, disrupting traffic flow, and causing a costly quick replacement. In June 2017, the State of Nevada replaced the signal arm and installed a TR1 Mitigator. The measured performance from a field-conducted test was 91 percent vibration response reduction. One other similar structure near this site also was retrofitted with a TR1 Mitigator to safeguard it from possible future failure. The State of Nevada now includes the TR1 Mitigator in their standard state plans for all related structures of this type.

Benefits

The TR1 Mitigator is expected to last as long as the structure on which it is placed. It provides a budget-friendly alternative for state DOTs and agencies looking to use resources more effectively through proactive preservation of the steel infrastructure. This allows state DOTs to better balance costs and the need to meet the most recent AASHTO wind-loading standards.

When an effective vibration mitigation device is used, the AASHTO specifications for 2013 or later allow the reduction from Fatigue Category I to Fatigue Category II and do not include the galloping fatigue loading case because it should no longer occur (*5*). This results in smaller and more economical traffic signal structures that are less likely to encroach on the compact right-of-way demands of the intersection. Because the TR1 Mitigator lessens signal movement, it

Mark Taylor

At more than 1,200 intersections like State Route 85 and State Route 171 in Utah's West Valley City, Utah DOT has pioneered the use of the TR1 Mitigator (the vertical device visible toward the end of the mast pole) on new and existing inventory.

Carl Macchietto

Carl Macchietto

Wind-induced vibration brought this flashing signal railroad crossing mast arm down across the road near Reno, Nevada (*left*). Shortly after the failure, it was moved to the side of the road. Metal fatigue (*above*) sheared the arm off its connector to the pole.

- Improves motorist visibility of traffic signals,
- Increases vehicle detection when cameras and radar are used,
- Heightens surveillance camera imagery by reducing motion,
- Lowers maintenance costs,
- Increases public safety, and
- Limits liability risk.

Acknowledgments

The authors thank Richard Christenson of the University of Connecticut for his research on vibration damping, performed as part of NCHRP IDEA-141.

To learn more, watch the video at https://www.valmontstructures.com/products-solutions/product-catalog/us/accessories/mitigator-tr1-traffic-damper.

REFERENCES

1. Christenson, R. *Reducing Fatigue in Wind-Excited Traffic Signal Support Structures Using Smart Damping Technologies: Final Report for NCHRP-IDEA Project 141.* NCHRP IDEA Program, Transportation Research Board, Washington, DC, Jan. 2011. https://onlinepubs.trb.org/onlinepubs/idea/finalreports/highway/NCHRP141_Final_Report.pdf.
2. NCHRP IDEA Program. "Products with an Impact or Potential Impact on Current Highway Practice: Notable Examples," pp. 81–83. Transportation Research Board, Washington, DC, April 2020. https://onlinepubs.trb.org/onlinepubs/IDEA/NCHRP_IDEA_Products_report2020.pdf.
3. AASHTO. *LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals,* 1st ed., 2015.
4. AASHTO. *2022 Interim Revisions to the LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals,* 1st ed., 2022.
5. AASHTO. *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, 6th ed., 2013.

VOLUNTEER VOICES

"Definitely the most memorable experience is my first presentation at the TRB Annual Meeting in 1989. It was my first-ever international presentation in English and at a conference where I had never visited before. Moreover, there were *too* many colleagues in the audience, giving more pressure to succeed. But everything went fine!

—VESA MÄNNISTÖ
Senior Advisor, Asset Management
Finnish Transport Infrastructure Agency, Helsinki