Dynamic Behavior of Bridge VMS Support Structure to Natural Wind and Truck-Induced Wind Gusts

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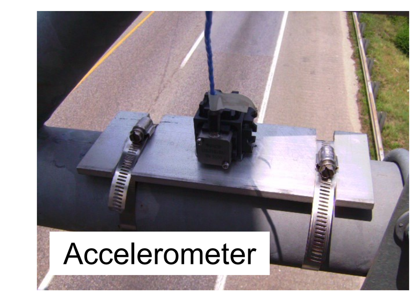
Abstract: The effect of fatigue due to wind-induced loads on highway overhead sign support structures is dependent on the structure's vibration characteristics. The design fatigue load equation for natural wind and truck-induced wind gusts in the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* were developed for sign structures with specific natural frequencies of vibration, modal shapes of vibration and damping values that are typically associated with cantilever type sign support structures. Prior research has shown that sign structures with different vibration behavior such as bridge type sign and variable message sign (VMS) support structures have a different response to fatigue loading, and therefore use of the Support Specifications' fatigue design equations may overestimate or underestimate the true fatigue effect. This research experimentally investigated the structural dynamics of an *in situ* bridge type VMS support structure to natural wind and truck-induced wind gusts. The determined vibration properties were compared to the vibration characteristics used to develop the AASHTO natural wind and truck-induced wind gust design fatigue load equations.

The Tested Highway Overhead Bridge VMS Support Structure

Structural Dynamic Experimental Instrumentation



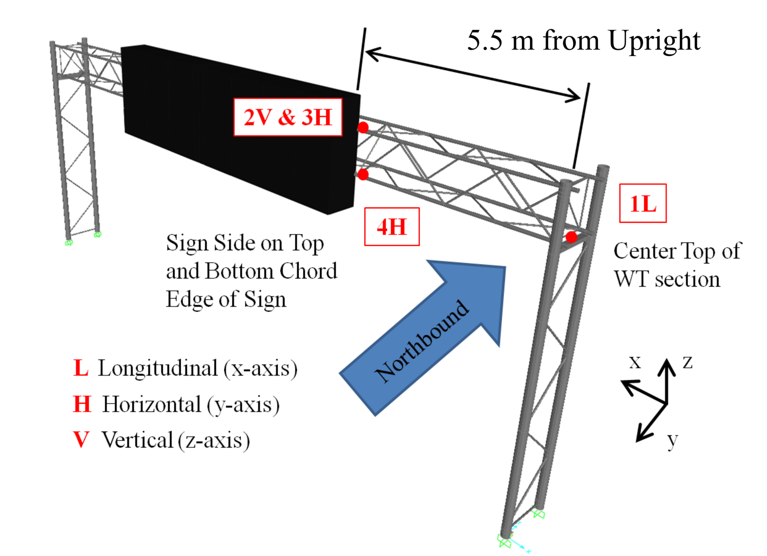


Fig. 1. Accelerometer locations, identifications, and vibratory directions.

Natural Wind Gusts Excitation

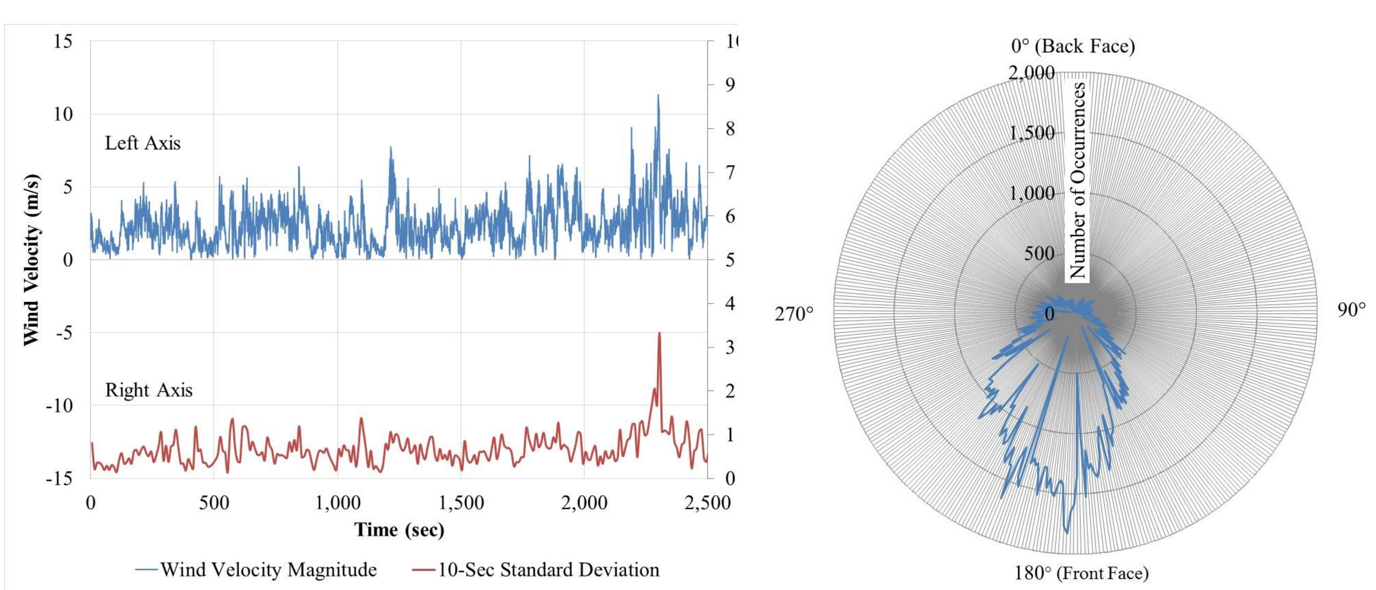


Fig. 2. Natural wind time history sample.

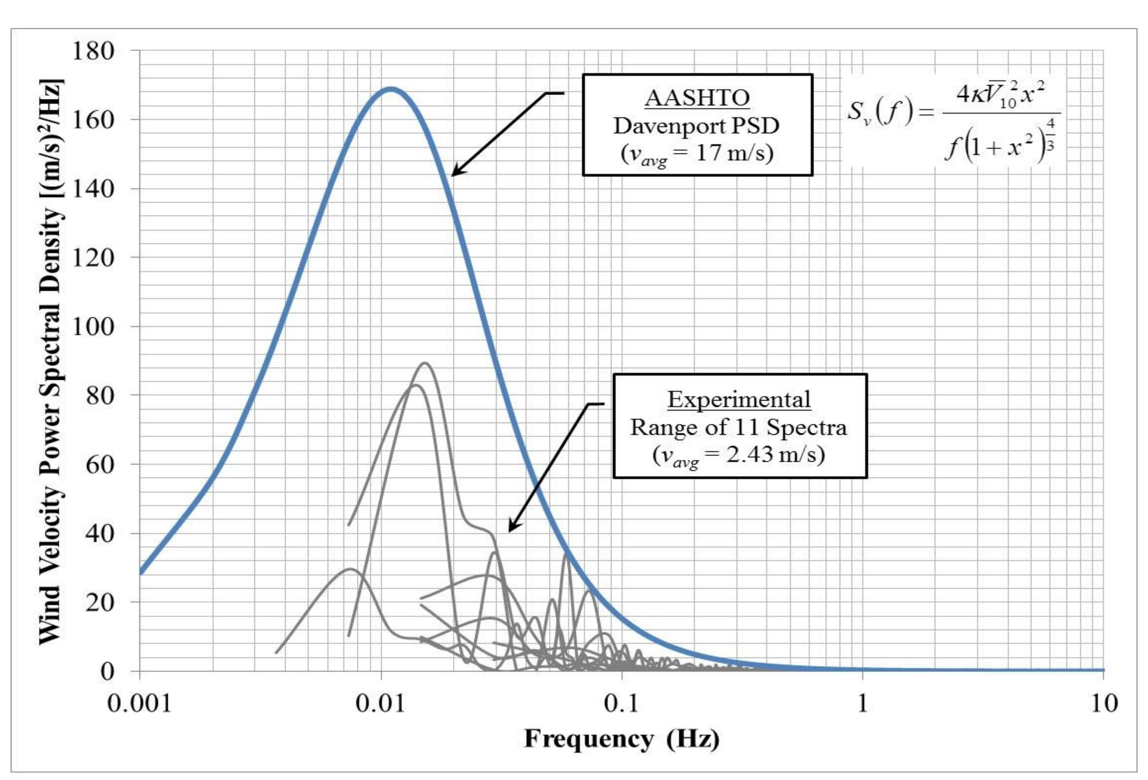


Fig. 3. Wind velocity power spectral density

Excitation following similar behavior modeled by the Davenport wind velocity power spectral density curve used by AASHTO natural wind fatigue provisions

- Broadband spectrum representing the gustiness & turbulence of natural wind
- On average, maximum peaks occurring around 0.01 Hz (100 sec periods)

Operational Modal Analysis of the Response

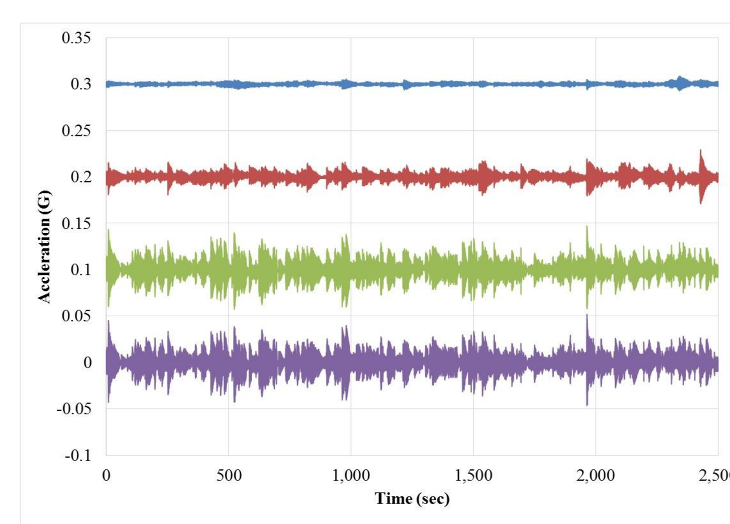


Fig. 4. Acceleration time history structural response to natural wind gusts.

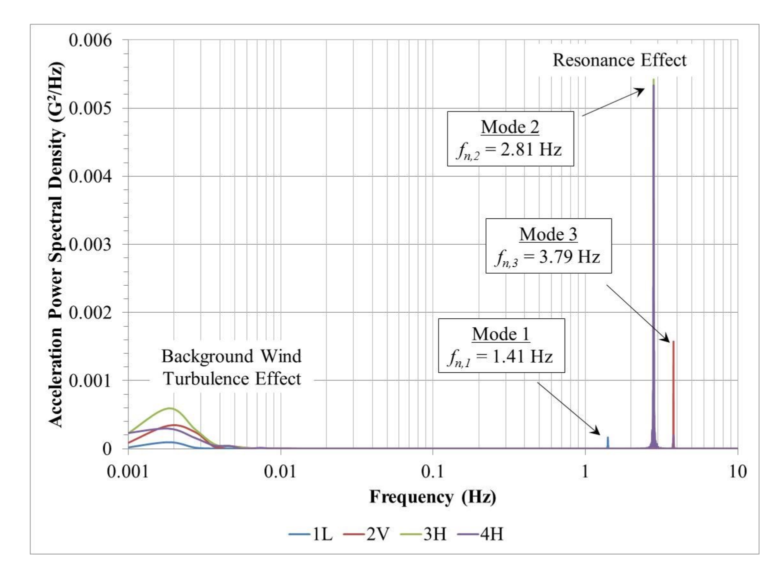


Fig. 5. Acceleration response power spectral density to natural wind gusts.

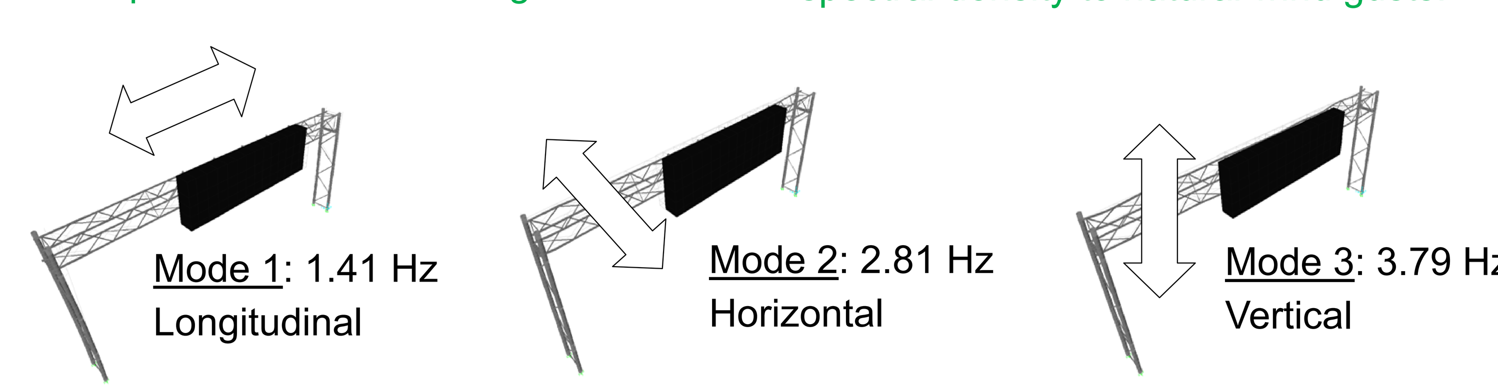


Fig. 6. Operational modal shapes in response to natural wind gusts.

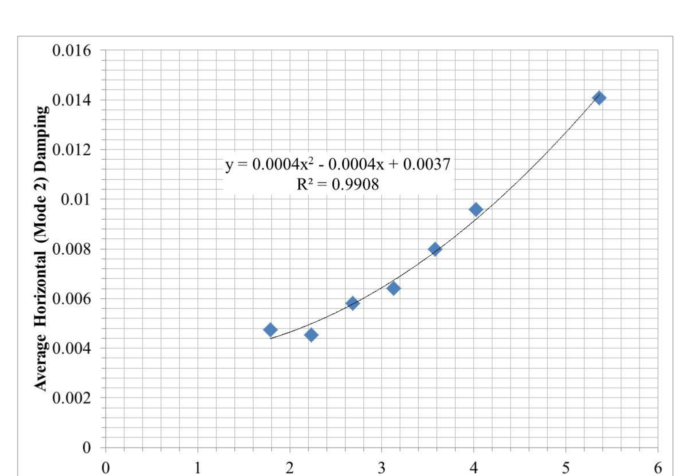


Fig. 7. Change in the critical damping with wind velocity of the horizontal mode of vibration (mode 2).

The acceleration response capturing the operational vibration behavior of the structure to natural wind gusts.

- Maximum vibration predominately controlled by the horizontal mode (mode 2).
- Critical damping in the horizontal direction increasing with increasing wind velocity.
- AASHTO natural wind provisions developed for structures with natural frequency and damping equal to 2 Hz and 2%.

Response due to Truck-Induced Wind Gusts

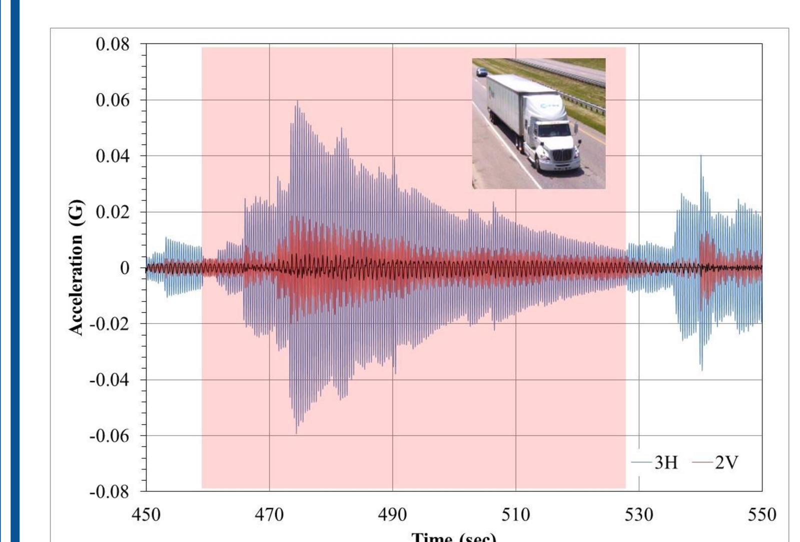


Fig. 8. Acceleration time history structural response to truck-induced wind gusts.

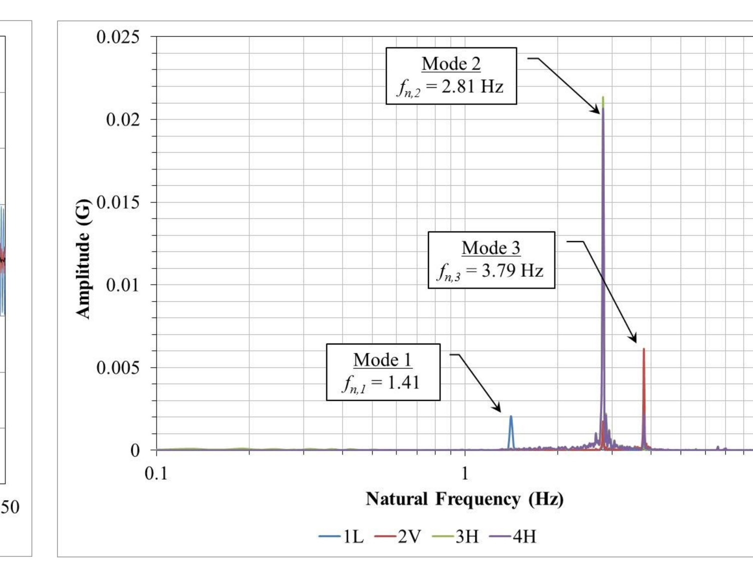


Fig. 9. Acceleration Fourier transform of the structural response to truck events.

The structural vibration behavior to truck-induced wind gust events showing a transient shock response to an impulsive excitation.

- Maximum vibration occurring in the horizontal direction (mode 2) with ranges equal to approximately 3.5 times greater than the vertical direction (mode 3).
- Critical damping in response to truck events equal to 0.36% for horizontal vibration (mode 2) and 0.12% for vertical vibration (mode 3).

Summary and Conclusions

Response of the VMS bridge were compared to the structural dynamic constants used to develop the AASHTO natural and truck-induced wind gusts provisions.

1. Natural wind excitation AASHTO model showing close agreement with experimentally collected data with respect to gust frequencies.
2. Dominate vibration frequency in the horizontal direction equal to 2.81 Hz versus 2 Hz used by AASHTO—the structure is less flexible (higher stiffness).
3. Aerodynamic damping showing a significant effect on the structural response.
4. Dominate vibration due to truck-induced wind gusts was in the horizontal direction as apposed to the vertical direction specified by AASHTO.