Abstract

Understanding Vehicle-Bridge Interaction through Field Measurements and Model-Based Simulations

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Driven by a desire for simplicity, bridge design and assessment approaches have historically employed a static model to estimate the forces and displacements resulting from trucks (the largest live loads that bridges experience). While these methods apply a constant factor in an attempt to account for the amplification that occurs due to the dynamic nature of truck loads, this approach fails to properly account for the dynamic interaction between trucks and bridges. As bridge designs continue to trade-off conservatism for cost savings, and loadings continue to increase (both in terms of magnitude, frequency, and nature (e.g. truck platooning)), historically-adequate simplifying assumptions (such as those associated with modeling truck loads in a static manner) must be critically examined to ensure their continued applicability.

Towards that end, the overarching aim of this research is to critically examine vehicle-bridge interaction (VBI) and develop a series of recommendations for how it should be addressed within the context of bridge design and assessment. More specifically, the following three objectives were identified to guide this research:

(1)   Establish the mechanisms that result in levels of VBI that render the common static live load model unconservative,

(2)   For the cases identified in (1) develop and validate a practical approach to estimating the effects of truck loads inclusive of VBI, and

(3)   Identify bridge vulnerabilities associated with truck platooning and make recommendations related to how VBI should be estimated and mitigated.

These objectives were realized by taking an inductive approach whereby a structure exhibiting large vibration levels was investigated to identify and characterize the underlying mechanisms through the Structural Identification (StId) framework. A series of field tests of this structure were performed to obtain operational responses that were subsequently used to calibrate and validate an FE model that was subsequently employed to simulate VBI using modal

superposition methods. The parameters examined in this study include roadway profile, vehicle suspension parameters, and bridge dynamic characteristics. The results from this study were employed to develop and validate a practical, simplified model for estimating dynamic load levels. This model was employed through a series of parametric studies to generate recommendations related to a wide range of issues including bridge assessment, construction, and policies related to truck platooning. Key findings include:

- A simple model that reduces both the bridge and vehicle to SDF systems was shown to reliably predict dynamic amplification and is recommended when FE simulation is impractical.
- Bridge responses are greatest when the profile induces oscillation in the vehicle close to the bridge's natural frequency and when the vehicle's natural frequency is 10-20% greater than that of the bridge.
- Rolling-straightedge length should be no less than 16 feet for a specified deviation of $1/8^{th}$ inch, and no less than 30 feet for a specified deviation of ¼ inch.
- Traffic and truck platoons can result in increased dynamic amplification because even a single previous truck can induce the bridge conditions (motion) that result in increased dynamic response (≈20%).
- As spacing between vehicles decreases and more vehicles are present on the bridge, the static load effect increases, but the dynamic amplification will likely be less than what would occur for a single vehicle.
- When designing for truck platoons, if static analysis accounts for multiple simultaneous vehicles, the dynamic amplification factor for a single vehicle can be used to conservatively account for the total dynamic response.