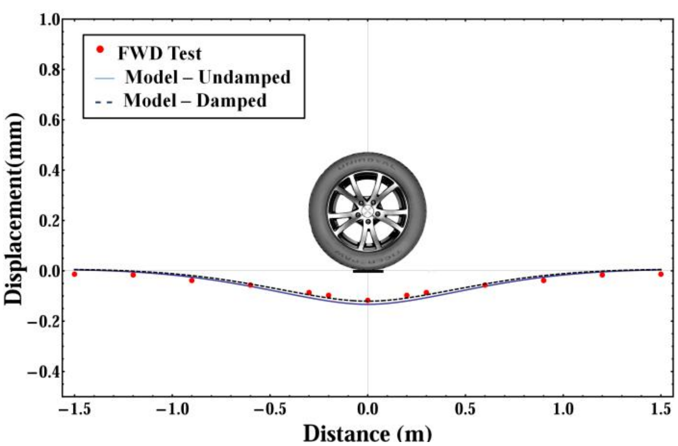
When the Rubber Hits the Road

Problem

Fuel consumption due to Pavement-Vehicle Interaction (PVI) is an essential part of life-cycle assessment (LCA) of pavement systems. Some estimates attribute up to 70% of greenhouse gas emissions (GHG) to PVI due to the unavoidable deflection of pavements when subject to vehicle load. Yet, the available field data on fuel consumption related to PVI for different pavement systems shows a high level of uncertainty varying by at least an order of magnitude, and is void of any structural and material properties of the particular pavement system tested. Furthermore, many models for the effects of pavement condition on fuel consumption were developed on the basis of data generated years ago in other countries for vehicles and pavement systems that vary substantially from those used currently in the United States. All this makes it difficult to reliably implement PVI into LCA of pavement systems. To this end, a quantitative mechanistic PVI model is needed to relate fuel consumption to structural design parameters (e.g. pavement thickness) and material properties (stiffness, viscosity, strength of top layer and subgrade, and so on).



Model prediction and experimental deflection data of Falling Weight Delectometer tests by FHWA (LTPP program). Displayed response is for an asphalt pavement of thickness h=0.2 m, top layer modulus E=6,879 MPa, and subgrade modulus k=66 MPa. Results with damping are for a damping ratio of 20%.

Approach

For first-order evaluations of PVI, we consider the simplest mechanistic pavement model: an Euler-Bernoulli beam on viscoelastic foundation subjected to a moving load. Wave propagation properties derived from Falling Weight Deflectometer time history data of FHWA's LongTerm Pavement Performance program (LTPP) are employed to calibrate top layer and substrate moduli for 12 asphalt and concrete systems. We validate the model against recorded deflection data. We use the mechanistic response to determine gradient force and rolling resistance to link deflection to vehicle fuel consumption. A comparison with independent field data provides an ultimate reality check of realistic order of magnitude estimates of fuel consumption due to PVI.

Findings

The use of a mechanistic model allows us to identify key design parameters to down-size fuel consumption due to PVI. For instance, the fuel consumption (IFC) is found to scale with the top layer and subgrade moduli as $E^{-1/2}$, while pavement thickness scales as $h^{-1.5}$. All other parameters equal, the model thus predicts that asphalt pavements need to be 25-60% thicker to display same fuel consumption performance as concrete.

Impact

This research suggests that a mechanistic approach can close the uncertainty gap of PVI in LCA of pavements. Implemented in an LCA environment, the derived functional relations between fuel consumption, structural and material pavement design parameters, provide pavement engineers and decision makers with a design tool to optimize our Nation's pavement inventory for high performance fuel and GHG efficiency.

More

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