MIT CSHub

Research Brief
Issue 7, 2015

Analyzing Pavement-Vehicle Interaction through Bench-Top Experiments

PROBLEM

Although the effect of deflection-induced Pavement-Vehicle Interaction (PVI) on wasted vehicle fuel consumption has been studied over the past few decades, the source of, and how to quantify, this phenomenon has been highly debated. We know that PVI can significantly contribute to the overall economic and environmental footprint of high traffic volume pavement systems. Deflection-induced PVI, which is the idea that a vehicle has to overcome a resisting force (i.e. dissipate energy due to deformation of the pavement structure), results in wasted fuel because the dissipated energy does not contribute to the vehicle's forward movement. Past studies examining PVI have taken an empirical approach, using actual trucks on actual pavements. This approach has ignored the pavement layer structure and material properties, and has led to high variability in the reported results. Further, empirical field studies are costly and time consuming at a large scale and issues may arise from inaccuracies in fuel consumption measurements, changing field conditions, and the difficulty of separating the three elements that impact PVI (texture, roughness, and deflection).

APPROACH

We eliminated the main limitations of an empirical study by developing a novel small-scale experiment that allowed us, for the first time, to look solely at the interaction of the wheel and the pavement structure. The experimental pavement system was represented as a viscoelastic[1] beam on an elastic subgrade through a two-layered silicone elastomer pavement. We gave the model pavement a range of top layer thicknesses, top layer elastic moduli, and top layer viscoelastic properties and observed the model pavements' response to a moving wheel of varying loads and speeds both visually and through the resulting horizontal force resisting its motion. Using a technique called photoelasticity,[2] we were able to look inside of the pavement structure and measure the PVI-induced dissipation (see Figure 1). We ran nearly 200 experimental configurations to investigate the scaling of the key PVI parameters with excess energy dissipation.

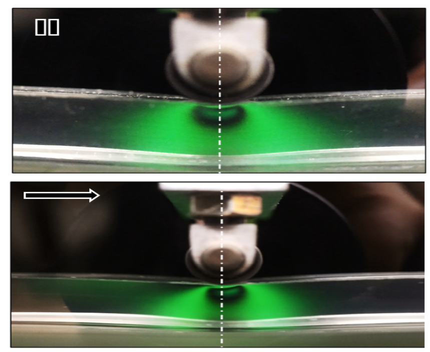

Figure 1: The green shows the stress field inside the polymer for a stationary wheel (top), and a moving wheel travelling to the right (bottom). The asymmetrical response shows resistance from the pavement against the direction the wheel is traveling. Effectively, the wheel is constantly rolling uphill.

FINDINGS

The advantage to using polymers and a small-scale experimental setup, as we did, is the ability to see inside the material and measure the direct forces from deflection-induced PVI that resist the wheel. Our experiment proves the existence of the deflection-induced PVI phenomenon. We were able to confirm visually that the stresses created in the material are not symmetrical (Figure 1), an indication that the wheel is moving on an uphill slope. We observed that dissipated energy is greatest at lower speeds and under high loads, and that an increase in load results in a rapid increase in dissipated energy, which increases fuel usage. We also found that an increase in pavement stiffness minimizes the impact of deflection-induced PVI. The results of our experimental scaling are consistent with those of our deflection-induced PVI model, as well as the findings of existing empirical studies where the maximum change in fuel consumption from PVI was observed on asphalt pavements at low speeds and under high loads.

IMPACT

Our experiment validates the contribution of pavement and vehicle related variables, such as vehicle load, speed, pavement thickness and pavement material properties, to excess fuel consumption. We also show that an increase in pavement stiffness minimizes the impact of deflection-induced PVI and we verified that deflection-induced PVI can have a significant impact on pavement lifecycle calculations.

[1] Viscoelasticity is the property of materials that exhibit both viscous (a substance that flows somewhat when deformed) and elastic (a

[2] Photoelasticity is an experimental technique for analysis of stresses and strains, based on the nature of light rays.

This research was carried out by CSHub@MIT with sponsorship provided by the Portland Cement Association and the Ready Mixed Concrete Research & Education Foundation. CSHub@MIT is solely responsible for content. Authors: Dr. M. Akbarian, in collaboration with Dr. A. Louhghalam, Dr. F. J. Ulm.