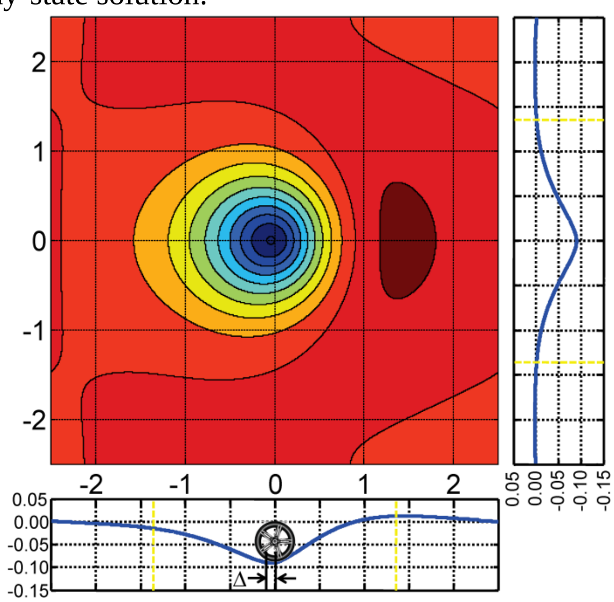
PVI Mechanistic Model Refined

Problem

Pavement-vehicle interaction (PVI) is widely accepted to be a factor in life cycle assessment (LCA) of pavement systems. PVI has a significant impact on vehicle fuel consumption and is strongly related to pavement structural and material properties. In our previous research, a mechanistic model based on Euler-Bernoulli beam on viscoelastic foundation under a moving load was developed to relate structural and material properties of the pavement to deflection-based PVI and the associated instantaneous fuel consumption (IFC). While this model contributes significantly in closing the uncertainty gap associated with PVI in pavement LCA, it has been argued that the model falls short in accounting for the two-dimensional load and deflection distribution that occurs below a rolling tire.

Approach

The focus of this research is to refine the mechanistic model to incorporate the two-dimensional deflection distribution and investigate the impact of this model change on IFC. The model refinement consists of an extension of the first order beam model to an infinite Kirchhoff-Love plate on a visco-elastic foundation subjected to a moving load. We solve the plate equation of motion in a moving coordinate system and find the steady-state solution.



The figure shows a sample output of the model: a contour plot of pavement deflection and deflection in two perpendicular directions.

We study the impact of different input parameters on instantaneous fuel consumption (IFC). The scaling relationship between the main input parameters and IFC is thus obtained and compared with those predicted by the beam model in the table below.

Parameter \ Model	Euler-Bernoulli beam model	Kirchhoff-Love plate model
Pavement modulus	$E^{-1/2}$	$E^{-3/4}$
Pavement thickness	$h^{-3/2}$	$h^{-9/4}$
Subgrade modulus	$k^{-1/2}$	$k^{-1/4}$
Vehicle mass	M^2	M^2

Findings

While the IFC scales differently for individual input parameters in beam and plate models, the scaling is strictly identical for two types of pavements on same subgrade. That is, for two different pavements to have equal fuel consumption, regardless of what model is used, the ratio between their thicknesses (h_1/h_2) is equal to the cubic root of the inverse of the stiffness ratio (E_2/E_1). For instance, if the stiffness of one pavement (E_1) is one tenth of the stiffness of an alternative ($E_1=E_2/10$), then it must be 2.15 times thicker than the alternative to achieve equivalent fuel efficiency ($h_1=2.15*h_2$).

Impact

The refined PVI model can be used to obtain the deflection in any direction (including the direction perpendicular to the motion) and allows us also to study effect of tire shape and multi wheels on an axel on IFC. The improved model can be used in LCAs to understand the contribution of deflection-based PVI to life cycle impact.

More

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