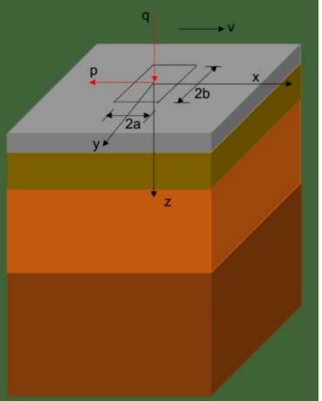
Transportation Consortium of South-Central States (Tran-SET)

Advanced Modeling and Design Methodology for Pavements using Plasticity-Based Shakedown



Highlight | Dec. 2020

Project No. 19PLSU09

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Shakedown Limit Analysis of Pavement System Considering the Vehicle-Road Coupling Effect

Shakedown is known as a phenomenon that an elastic-plastic structure, though deforms plastically in initial load cycles, responds purely elastically to subsequent load cycles if the applied load is above the yield limit but lower than a critical load. Plasticity-based shakedown analysis/ design aims at achieving a long pavement life without deep structural distresses and recently has been advocated as a rational criterion for the “perpetual design” of pavement systems. This project proposes an exploratory study on the application of the plasticity theory-based shakedown concept to the analysis of pavements under repeated loading, with more realistic incorporation of the roughness impact of the top pavement layer on the dynamic amplification of vehicle loading as well as on the elastic stress responses in the underlying subsoils.

Background

Pavement design is a process intended to find the most economical combination of layer thickness and material type for the pavement, taking into account the properties of the subgrade soil and the traffic to be carried during the service life of the road. The currently prevalent methods of pavement analysis and design are more or less empirical in U.S., which possess the shortcoming that the important type of pavement distress of rutting related to the accumulation of plastic or permanent deformations cannot be effectively considered. Moreover, the vehicle-road interaction effected by the road roughness, which is critically important for pavement on soft subgrade, is lacked in the current design approaches for flexible pavement system.

Project Summary

The main objectives of this research are:

(a) To develop a vehicle-road coupling model for estimating the additional vehicle dynamic load induced by pavement roughness considering the traveling speed;

(b) To derive a rigorous analytical solution for the elastodynamic stress fields in asphalt-base-subsoil systems due to the moving surface loads determined above, which is essentially desirable for the subsequent shakedown limit analysis; and

(c) To propose a linear programming approach to compute the critical shakedown load of the pavement system in association with an optimized, self-equilibrated residual stress field.

Status Update

Referring to Figure 1, a simplified two-layered system has been considered to explore the influences of various material properties of pavement and subsoil as well as the road roughness/vehicle speed on the critical shakedown limit of the pavement system. The vehicle is assumed to move at a speed of v along the positive direction of x-axis. The top and bottom layers (i.e., layers 1 and 2) represent the pavement and half-space subsoil, respectively.

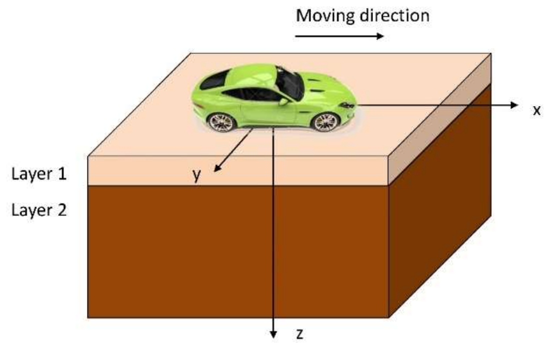
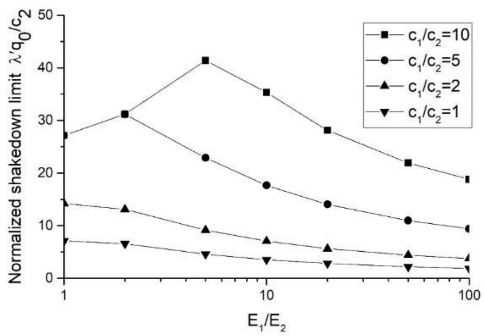
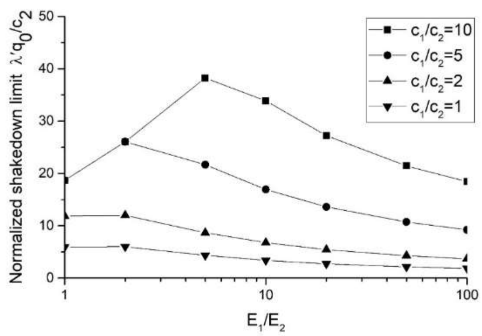


Figure 1. Computational model for a two-layered pavement system.

Numerical analysis indicates the necessity and importance of incorporating the factors of roughness/vehicle speed in the pavement response analysis. It also reveals that increases in the pavement cohesion strength and internal friction angle and in the pavement thickness have a positive influence on the calculated shakedown limit value. There generally exists an optimal Young’s modulus ratio between the pavement and subsoil, for which a maximum shakedown load of the pavement system will be reached, see Figure 2. The preliminary modelling resutls will be compared and correlated with previous studies and available data to further validate the applicabilty of the proposed shakedown methodology.



(a)



(b)

Figure 2. Influences of Young's modulus ratio on the shakedown limit at various cohesion ratios: (a) v = 20 m/s; (b) v = 45 m/s.

Impacts

The main benefit of this study is the proposition of an advanced shakedown analysis approach that enables the improvement of flexible pavement performance in its service life and therefore potentially reduces the huge costs on pavement maintenance in U.S.

The outcomes of this project are excepted to add contributions to the development of a more rational theoretical framework for the pavement design/analysis through the development of MATLAB codes. On the other hand, the shakedown design approach can prevent the flexible pavement from excessive rutting failure, and hence is of great practical value for prediction/design of the vehicle load, traveling speed, and layer thickness that is required to warrant shakedown state of the pavements (i.e., no excessive rutting) in the long run.

Tran-SET

Tran-SET is Region 6's University Transportation Center. It is a collaborative partnership between 11 institutions (see below) across 5 states (AR, LA, NM, OK, and TX). Tran-SET is led by Louisiana State University. It was established in late November 2016 "to address the accelerated deterioration of transportation infrastructure through the development, evaluation, and implementation of cutting-edge technologies, novel materials, and innovative construction management processes".

Learn More

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