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Original Research Paper

Study of the influence of pavement unevenness on the mechanical response of asphalt pavement by means of the finite element method

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HIGHLIGHTS

- Tire-pavement interaction FE models are developed.
- The model is verified by means of analytical and experimental methods.
- The results from uneven pavements are compared with flat pavements.

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ABSTRACT

Pavement unevenness affects the vehicle operating cost, speed, riding comfort, safety, pavement service life and etc. The current mechanistic-empirical (M-E) design procedure of asphalt pavements is based on the computational model of a flat pavement instead of uneven pavement as it is the case in reality. In this paper, a tire-pavement-interaction FE model is developed to investigate the influence of pavement unevenness on the mechanical responses of asphalt pavements. For both winter and summer conditions, the strain at the bottom of the asphalt layer due to the tire load is found to decrease as the wavelength of the unevenness increases. Moreover, the strain is larger at lower speeds and decreases as the speed increases. It is found that the stress levels are higher in summer conditions than under winter conditions for the same pavement irrespective of wavelength. The fatigue life increases with increase in speed of the tire for a pavement and also increases with increase in the wavelength of the pavement unevenness. The results indicate that pavement unevenness significantly influence the mechanical responses of asphalt pavements and thus influences the service life of asphalt pavements. As a result, the current M-E design algorithm of asphalt pavements should be modified to consider the pavement unevenness to allow better design processes for asphalt pavement.

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1. Introduction

Pavement unevenness affects the vehicle operating cost, speed, riding comfort, safety, fuel consumption, wear of tires, and pavement service life (Zhang et al., 2017). The occurrence of pavement unevenness as seen in Fig. 1 is influenced by the applied construction technology (including processes and equipment), the state of compaction, the construction quality control, the structure of the surface course and the materials (e.g., binder, aggregate and air voids), etc (Liu et al., 2017a, 2017b; Hu et al., 2016; Wang et al., 2017a, 2017b).

Pavement unevenness can lead to dynamic loads being induced on pavements; thus, the mechanical responses of uneven pavements will be significantly different with those of flat pavements (Ueckermann et al., 2015; Ueckermann and Steinauer, 2008). The current mechanistic-empirical (M-E) design procedure for asphalt pavements is based on the computational model of flat pavements (Gonzalez and Oeser, 2012). This idealization results in discrepancies from reality. Therefore, the influence of pavement unevenness on the mechanical responses of asphalt pavements needs to be studied. The finite element method (FEM) is an effective tool to study the mechanical response of asphalt pavements (Zienkiewicz and Taylor, 2000, 2005), and the tire-pavement interaction which has been used in past years (Liu et al., 2013, 2014; 2017c; Oeser and Möller, 2002).

Liu et al. (2017d) investigated the impact of heavy traffic loads on the asphalt pavement in terms of stress and strain distribution, surface deflection and fatigue life by using FEM code. In this FEM code, the tire can be implicitly simulated by an algorithm which simulates the movement process of the wheel realistically (Liu et al., 2015). The vertical pressure was distributed over a square contact area including several elements and the load process was divided into several increments. In such an increment when the mass center of wheel was exactly above the contact area, the elements covered by the contact area were assumed to be fully loaded. In subsequent increments the elements behind the wheel would be partly relieved and the elements in front of the wheel would be partly loaded. With this procedure, the load distribution of a rolling wheel approximated. Kaliske et al. (2015) and Wollny and Kaliske (2013, 2016a, 2016b) proposed a theoretical-numerical asphalt pavement model at material and structural level, whereby the focus is on a realistic and numerically efficient computation of pavements under a rolling tire load by using FEM based on an arbitrary Lagrangian Eulerian (ALE) formulation. In the ALE frame, the pavement was described in a moved reference configuration, so that the loading of the pavement with a rolling tire could be described as a time-independent process. Pavement structures under the load of a rolling truck tire were simulated. Stresses, strains and displacements of the pavement structures as well as the effect of different driving velocities of the tire were evaluated (Zopf et al., 2015). Wang et al. (2012) constructed a three-dimensional (3D) tire-pavement interaction model in the general-purpose FE program ABAQUS to predict the contact stress distributions for future use in the mechanistic analysis of pavement responses. A ribbed radial-ply tire was modeled as a composite structure (rubber and reinforcement); the tire material parameters were calibrated through load-deflection curves. The tire rolling process was also simulated using an ALE formulation. The model results were consistent with previous measurements and validated the existence of non-uniform vertical contact stresses and localized tangential contact stresses. The analysis results showed that the non-uniformity of vertical contact stresses decreased as the load increased, but increased as the inflation pressure increased. Vehicle maneuvering is affected significantly by the tire-pavement contact stress distributions.

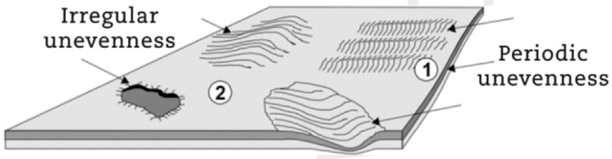

Fig. 1 – Periodic and irregular unevenness in the longitudinal direction (Krause and Maerschalk, 2010).

However, few previous investigations focused on the influence of the pavement unevenness on the mechanical response of asphalt pavements. In this study, the tire-pavement interaction FE models with different situations of pavement unevenness are developed. The modeling algorithm is described in detail. Verification of the developed FE model is carried out by means of analytical and experimental methods. Using this reliable FE model, the influence of the pavement unevenness on the mechanical response of asphalt pavements is studied.

Table 1 – Selected tire specifications.

Feature	Value
Overall diameter of the tire (mm)	970.0
Diameter of the rim (mm)	571.5
Section width of the tire (mm)	295.0
Thread depth (mm)	15.0
Max load capacity (kN)	26.7

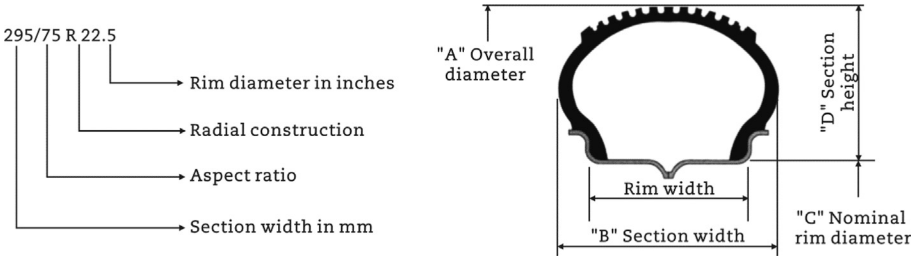

Fig. 2 – Tire specification (Panhead and Flathead Documentation, 2017).

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