



Development of a mid-depth profile monitoring system for accelerated pavement testing



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HIGHLIGHTS

- A system was developed to measure the flexible pavement layer deformation, and incorporated into APT facility.
- The developed MPMS is able to automatically measure the evolution of layer deformation with high accuracy.
- The MPMS was validated based on the agreement with previous studies.
- Only around 10% of rutting occurred in subgrade for full depth flexible pavement.
- Most of rutting occurred within the top two asphalt layers.

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ABSTRACT

This study presents the development of a new mid-depth profile monitoring system (MPMS) to investigate the rutting behavior of full-depth asphalt pavements. The scope incorporates an experimental study that uses a full-scale accelerated pavement testing (APT) facility. Two different thicknesses of full-depth asphalt pavements were constructed in the Indiana accelerated pavement-testing facility. A laser profile scanning system was designed to reconstruct the transverse profiles at each pavement layer interface throughout the process of accelerated pavement deterioration. The contribution of each pavement structural layer to the total rut depth and the evolution of layer deformation were determined. The developed system provides reasonable results with a high accuracy level based on the findings. First, the measured rutting curves at each layer interface agree well with the theoretical characteristics of rutting evolution and clearly exhibit the primary and secondary stages of rutting development. Furthermore, all the measured rutting curves have good coefficients of correlation. Second, the locations of critical rutting and the total rut depths were found to be independent of pavement thickness when the pavement is sufficiently thick, which is a finding that agrees with previous study results, the study reported the thickness threshold value to be 5.12 in. (13.00 cm) for their case. The results demonstrate MPMS developed in this study provides an excellent method to evaluate the rutting performance of asphalt pavements in the APT. In addition, MPMS has a potential application to in-service pavements.

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1. Introduction

Permanent deformation, which can be reflected at asphalt pavement surface as rutting, is one of the most serious forms of asphalt pavement distress. In terms of public and vehicle safety concerns, rutting is considered a hydroplaning safety hazard by many state departments of transportation. Rutting can be hazardous not only for vehicles and for passengers, but it also damages the pavement

itself. When water accumulates in the ruts, it often penetrates the pavement structure and further deteriorates the pavement [1].

Rutting usually is manifested by depressions along the wheel paths and sometimes causes uplifted material between and outside the wheel paths. The two major causes of rutting are permanent deformation in the subgrade and permanent deformation in one or more of the asphalt layers, typically the surface layer. Permanent deformation of the subgrade is usually due to the insufficient thickness of one or more of the pavement layers or excessive moisture in the subgrade. Permanent deformation of an asphalt layer usually is caused by a combination of consolidation (densification)

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and shear deformation. [2] Theoretically, the evolution of permanent deformation in pavement material can be characterized as three distinct stages. The primary stage consists predominantly of volumetric change with a decreasing rate of deformation; high initial densification occurs during this stage. The secondary stage is characterized by a combination of densification and shear deformation; a small but constant rate of deformation occurs during this stage. Finally, the tertiary stage always exhibits a high rate of rutting that is caused mostly by shear deformation. Pavement design and analysis methods typically do not consider the tertiary deformation stage, but rather only the primary and secondary deformation stages.

Quantifying rutting is critical to the understanding of the origins of asphalt permanent deformation failure, and thus is imperative for the improvement of the rutting models in design programs for both new and rehabilitated pavements. For example, the rutting global calibration models embedded within PavementME were developed using the total rut depths measured at the pavement surfaces in Long-Term Pavement Performance (LTPP) program test sections. However, trench data, or any other information that could be used to determine layer-wise rutting, are not available in the LTPP program [3]. Given this limitation, the PavementME rutting prediction models were calibrated globally based on the assumption that the contribution of each layer to the total rut depth measured at the surface would be similar to that predicted by the PavementME. This assumption might introduce errors into the models' prediction results. Several studies have indicated that the PavementME global calibration models predicted erroneously high rutting values [1,4–7]. Many researchers have suggested this over-prediction might be due to over-predicted subgrade rutting [5,6]. PavementME v. 2.2 offers an option to assign rutting model calibration factors to each individual asphalt layer; this feature is believed to improve the rutting model predictions. In order to incorporate this feature into pavement design properly, quantifying layer-wise deformation is even more critical for local calibration.

Test methods that measure mid-depth ruts include trench cutting and coring and instrumentation that uses sensors such as a multi-depth deflectometer (MDD) [2,8–12]. The trench-cut and coring methods have been commonly used as forensic analysis approaches whereby the cut or extracted sample allows direct observation of the deteriorated pavement structure and comprehensive information in order to investigate the pavement distresses. However, such methods require a considerable amount of work and cost because the traffic must be controlled and the pavement itself needs to be physically damaged. A common problem encountered with these methods is pavement settlement that occurs in and around the cuts or extraction locations. In addition, measurement accuracy may be compromised due to the lack of a distinct layer interface and the lack of initial layer thickness measurements. The MDD is another valuable tool that can be employed to study layer-wise deformation in asphalt pavement. The MDD has been used successfully in several research projects due to its ability to maintain high measurement accuracy and its effective automatic data acquisition process. However, the relatively high cost of the MDD sensor itself makes it uneconomical to be installed throughout a single project.

Due to the aforementioned limitations, a new method is needed that can provide accurate results, has the ability to reconstruct interface profiles, and has a relatively low cost. In this study, accelerated pavement testing (APT) technology was used in the method development. APT techniques also provide an opportunity to validate the developed monitoring system in cost- and time-efficient ways whereby the amount of damage that might take more than 10 or even 20 years to occur in the field can be achieved in a matter of months.

2. Research objective

The primary objective of this research was to develop a mid-depth profile monitoring system (MPMS) for full depth asphalt pavements using APT.

3. Measuring layer-wise deformation

3.1. Research approach overview

The developed MPMS consists of a series of mid-depth monitoring holes and an integrated laser profiler. An automatic laser scanning system was used to measure the layer interface deformations via the monitoring holes. The system was developed in an APT facility and has been tested using two full-depth asphalt pavement structures.

3.2. Accelerated pavement testing facility

This research was conducted at the APT facility located at the Division of Research and Development within the Indiana Department of Transportation (INDOT). As shown in Fig. 1, the APT loading is applied using a one-half standard axle with dual tire assembly. The tire size of 11R22.5, loading of 9000 lbs (4.5 tonnes), and tire pressure of 100 psi (0.69 MPa) were used in this study. The contact area was 58.59 in.² (378.00 cm²). Although 9000 lbs is a relatively low loading level considering the traffic volume and axle load have been increased dramatically over the past decades in the United States, it was chosen as the start point of this project because it represents the most commonly used equivalent single axle load (ESAL) in the U.S. (i.e. 18,000 lbs).

The loading machine can produce either unidirectional or bidirectional tire movement; unidirectional movement was used in this study. For this type of movement, the tire assembly is raised at the end of one loading cycle, moved back to the starting point, placed back onto the pavement, loaded to the desired load level, and then the load cycle is repeated. For each loading cycle, the loading frame needs 5 ft (1.52 m) to accelerate to maximum speed and 3 ft (0.91 m) to stop; the constant speed zone is 15 ft (4.57 m). One full load cycle takes about 11 s. The target load application was 50,000 passes, which produced about 0.4 in. (10.16 mm) of total rut depth at the pavement surface. This rut depth value was determined based on the rutting failure criterion used in INDOT practice. The test temperatures were determined based on the design high pavement temperature that was derived from the

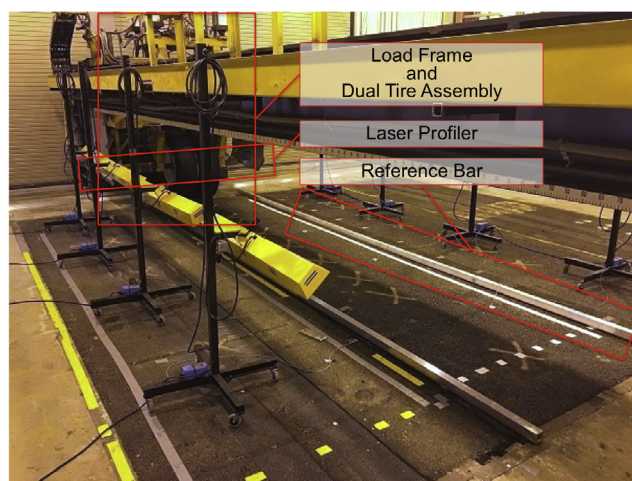


Fig. 1. APT setup.

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