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Permanent deformation and deflection relationship from pavement condition assessment

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Abstract

The development of permanent deformation in flexible pavements has been a research topic for several decades. Currently there are models included in the structural design of pavements that can predict this type of failure. However, the variables required for the prediction of this distress are complex or difficult to obtain in the field, making its application in pavement evaluation also difficult. Measurement of the deflection of pavement structures by means of non-destructive testing is a technique used to assess the condition of the pavement. This research study seeks to correlate data from deflections of the pavement surface with probable permanent deformation in time. In addition, prediction of the remaining life of the pavement structure using a specified criterion is also analyzed. In order to accomplish these objectives, data acquired from 4 different full scale accelerated pavement test tracks was used to develop a permanent deformation model as a function of deflection, load repetitions and pavement layer thickness. The developed model considered a time series model that incorporates an Auto-regressive parameter of order 1. The proposed model presents an advantage over currently available models because it reduces the required parameters to predict the permanent deformation and/or remaining life in the structure and because these variables can be easily found and updated in a pavement management system.

Keywords: HVS; Permanent deformation; Deflections; APT; Time series; Instrumentation

1. Introduction

Rutting is an undesired distress in a pavement for several reasons. For the road users, it gives an increase of fuel consumption due to increased friction, and also an increased risk of hydroplaning under wet weather conditions. Rutting is caused by several factors such as low density of the layer [1], stress conditions [2], and number of load applications, among others, and occurs in different layers of the pavement. A rule of thumb is that the wider the ruts are, the deeper in the pavement the permanent deformation has occurred.

It is well established that flexible pavement surface deflections measured in areas affected by rutting are higher than those measured in areas without failure [3]. This paper presents a predictive model of correlation between surface deflections and traffic loads with plastic deformations developed over time. The model was created using measurements from four accelerated pavement test tracks at the National Laboratory of Materials and Structural Models of the University of Costa Rica (LanammeUCR). The proposed model can be also used in the estimation of the remaining life of flexible pavements which is an important tool for decision making and planning.

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1.1. Background

There are many factors that can influence the development of plastic deformation in the structure of asphalt pavements. In empirical methods used to predict this failure, factors such as the material properties (resilient modulus), ambient temperature, tire inflation pressure, load duration, number of load cycles, and travel speed are considered [3]. However, the applicability of such factors may be limited to pavement design only and not so much during pavement condition assessment. Collection of all these factors, for an existing pavement structure, involves a considerable time and resource investment.

Repeated traffic loads develop vertical compressive strains (ε_c) on a pavement structure which will be subsequently permanently deformed. Previous studies have correlated vertical compressive strains with probable plastic deformations [4]. A general permanent deformation model is represented by Eq. (1). In this equation N_d is the number of load repetitions to failure, ε_c is the compressive strain at the top of the subgrade, and the coefficients f_1 and f_2 are regression coefficients obtained in the laboratory. Table 1 summarizes some of the models developed by several organizations based on this general formulation [4].

$$N_d = f_1(\varepsilon_c)^{-f_2} \tag{1}$$

The models that are based solely on the compression strain on the subgrade surface, which are developed under controlled laboratory conditions, tend to ignore the effect of permanent deformation in the upper layers. However, if the vertical compressive strain on the subgrade is high, the compressive strain of the other layers must have been high too. Since the equation lies within the empirical domain, the regression constants can be said to have accounted for the contribution of deformation from all the other layers. To try to mitigate this omission, the Federal Highway Administration (FHWA) has developed a pavement analysis system called VESYS, which has a simple model to estimate rutting. The model assumes that the permanent deformation is linearly related to resilient deformation, as shown in Eqs. (2) and (3) [5,6]. Eq. (3) is the SHRP revised version of the original VESYS model.

$$\varepsilon_p(N) = \mu\varepsilon N^{-\alpha} \tag{2}$$

$$\varepsilon_p(N) = aN^b \tag{3}$$

where $\varepsilon_p(N)$: Permanent deformation after N load repetitions, μ: linear coefficient calculated between the permanent deformation and elastic or resilient deformation, ε: Elastic or resilient deformation after 200 loads repetitions, N: Number of load repetitions, α: Permanent deformation parameter, and a, b: Regression coefficients.

Table 1
Permanent deformation models developed by several organizations.

Organization	Model
Asphalt Institute	$N_d = 1.365 \times 10^{-9}(\varepsilon_c)^{-4.477}$
Shell Petroleum	$N_d = 6.15 \times 10^{-7}(\varepsilon_c)^{-4}$
University of Nottingham	$N_d = 1.13 \times 10^{-6}(\varepsilon_c)^{-3.571}$
MnROAD	$N_d = 7.0 \times 10^{15}(\varepsilon_c)^{-3.909}$

The MEPDG mechanistic-empirical guide [7], defined permanent deformation as the sum of the deformations of each layer (Eq. (4)). For each layer there is a different equation depending on the material type and properties.

$$\mathrm{PD} = \sum_{i=1}^{n-layers} \varepsilon_p^i \cdot h_i \tag{4}$$

where PD: Total Permanent Deformation, ε_p^i: Total Deformation in Layer$_\mathrm{i}$, and h_i: Layer$_\mathrm{i}$ thickness.

On the other hand, one of the most recent guidelines for mechanistic-empirical pavement design called CalME, uses the concept of recursive incremental damage [8]. In this case, the material properties are updated over time to reflect the damage caused by loading and environmental conditions on the pavement. Every type of distress is a function of mechanistic responses, material properties, and the number of load repetitions as per Eq. (5). For example, the model for permanent deformation of the unbound layers utilizes the vertical compressive strain at the top of the layer:

$$\mathrm{Damage} = A \times \mathrm{MN}^{\alpha} \times \left(\frac{resp}{resp_{ref}}\right)^{\beta} \times \left(\frac{E}{E_{ref}}\right)^{\gamma} \tag{5}$$

where MN: Load repetitions in millions, $resp$: Pavement response related to the type of distress, $resp_{ref}$: Reference response, $E =$ Modulus of the material updated for each load repetition, $E_{ref} =$ Reference modulus, and A, α, β, and γ: Regression coefficients.

Finally, the National Material's Laboratory at the University of Costa Rica has developed models for permanent deformation following the structural forms shown in Eqs. (13) [9,10]. These models rely on material properties and environmental conditions of the pavement as shown in Eq. (6). In order to use the previous models in pavement evaluation, input variables that are not easily obtained during non-destructive testing are required. For example, pavement responses such as stresses and strains require an estimation based on backcalulated layer moduli or the use of sensors installed within the pavement structure. To reduce the number of variables and reduce the number of computations, this study focused on the development of simple models that relates a measurable response such as surface deflection by means non-destructive testing with the level of permanent deformation. Additionally, it is intended that this type of modeling could be implemented in pavement management systems.

$$\mathrm{PD} = k_1 X^{k_2} N^{k_3} \tag{6}$$

where PD: Permanent Deformation, X: Group dependent material properties (temperature, deviator stress, confining stress, moisture content), N: Load repetitions, and k_1, k_2, k_3: Regression coefficients.