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Database Construction based upon Numerical Modelling of Pavement Deflection Behaviour under the Traffic Speed Deflectometer

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Résumé :

Le déflectomètre circulant à la vitesse du trafic (Traffic Speed Deflectometer - TSD) a été développé pour faire face aux limites des appareils de mesure de la déflexion existants. Le TSD permet d'effectuer des mesures de la déflexion sans interruption du trafic routier tout en augmentant la sécurité des opérateurs du chantier, à l'inverse des outils de mesures conventionnels. Cet article présente un modèle numérique pour simuler de façon optimale la mesure de la déflexion à partir d'un TSD en tenant compte de l'ensemble des charges du véhicule (poids lourd) porteur du système de mesure. La structure de la chaussée est modélisée sous forme d'un milieu synthétique stratifié semi-infini. Une base de données (BD) de plus de 7 millions de structures a été constituée, sur la base du modèle de chaussée de Burnister, pour simuler les différentes configurations de mesure du TSD. La BD tient compte de différents paramètres dont le type de structures (épaisseurs et nature des matériaux), le niveau de l'endommagement (des matériaux et/ou des interfaces) et les conditions environnementales telles que les gradients de température.

Abstract :

Traffic Speed Deflectometer (TSD) was developed as an alternative solution to cope with the limitations of the traditional deflection devices, as it operates at traffic speed without lane closure and workplace hazards. Hence, this paper presents the development of a numerical model for analyzing the pavement behaviour under the TSD in accurate manner by taking into account all vehicle loads (wheels), instead of only the rear axial load. In consequence, a numerical database of 7 million structures was built as per Burmister's pavement model (elastic linear, isotropic, homogeneous, with infinite layer in-plane). The database takes into account various parameters including the type of structures (thickness and nature of materials), the level of damage (materials and interfaces), and environmental conditions such as temperature gradients.

Mots clefs : Pavement Deflection, Numerical Modelling, Traffic Speed Deflectometer, Database

1 Introduction

Nowadays, structural assessment is one of the main means to evaluate pavements profile conditions. Recently, extensive researches demonstrated that the current pavement deflection measurement devices such as Falling Weight Deflectometer FWD (Stationary), Benkelman Beam (Static), or Curviameter and Deflectograph (Slow-moving 18 and 08 km/h respectively) have operational limitations such as lane closure, traffic congestion, and potential workplace risks [1-3]. Consequently, some European countries decided to suspend the utilization of the deflection measurement at the network level of the pavement management system (PMS) [2]. Today, there is substantial progress in integrating the structural assessment data at the network level. This progression happened principally thanks to the introduction of the Traffic Speed Deflectometer Devices (TSDDs) spanning TSD and the Rapid Pavement Tester (Raptor). The major feature of TSDDs is related to its capacity in measuring the deflection velocity at normal traffic speed without road management [1, 3].

Therefore, the main objective of this paper is to present a novel numerical model for simulating efficiently the pavement deflection behaviour under the whole TSD. The pavement model is based on Burmester's approach (elastic linear isotropic with infinite layer in-plane). Furthermore, a database of more than 7 million structures has been numerically developed and relatively analyzed. The database have taken into consideration a variety of pavement profiles of varying thicknesses, temperature, material properties along with incremental pavement failures levels.

2 TSD Operation Analysis

TSD consists of an articulated truck, which applies a rear axle of almost 100 kN loading on the pavement. It runs at a driving velocity of 70 - 80 km/h. TSD has more than 10 Doppler lasers sensors for measuring the deflection around its rear axle load [3]. TSD has no measurement at the loading point due to the difficulty of placing the laser on the position of the rear axle loading (wheel).

The laser sensors record the vertical deflection velocity which is assumed to be equal to the slope of the deflection basin after correcting the driving velocity as shown in Figure 1 [2]. To this end, pavement deflection can be calculated by integrating the deflection slope from the center (deflection under load) to any point in the radial position [4].

In a similar manner to the falling weight deflectometer (FWD), various insightful parameters and indices can be extracted from TSD deflection basin, These parameters can be exploited for estimating the structural state and lifetime of the asphalt such as the Basic Damage Index (BDI), Surface Curvature Index (SCI) [5].

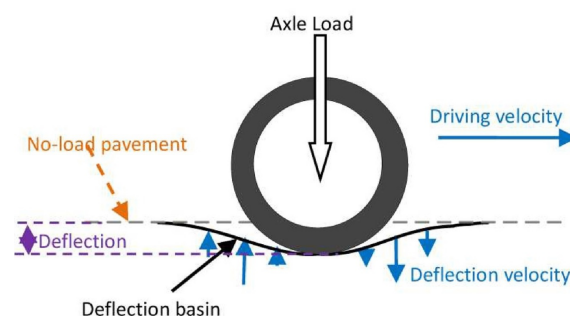


FIGURE 1 – The deflection velocity and deflection basin under the rolling load, (Source [6])

3 Bias in TSD Measurement

For the sake of conducting an accurate deflection measurements via TSD, there are major systematic errors (bias) have to be corrected as part of the calibration procedures, namely :

1. Servo-hydraulic beam (vibration bias) corrected through alignment installation of an inclinometer, gyroscope, and the accelerometer (compensating the beam movement). Moreover, the beam maintains a fixed temperature through a climate controller to correct the thermal bending [2].
2. Reference sensor bias that is corrected by assuming the velocity slope and the deflection are null at its measuring point [4].
3. Variation in Dynamic Load that is effectively corrected by conducting a rolling average over certain distance [1].
4. Orientation of the Laser Doppler Sensors that can be corrected via the calibration process [7].

4 Numerical Modelling of TSD

4.1 Structural Modelling via Alize 2

Alize 2 is the reference software for roads and motorways pavement design in France since more than thirty years. It integrates the Burmister's model. It is based on the computation of the pavement resilient stresses-strains and deflection in roadways by the classical multi-layer elastic linear model [8].

The design is carried out through Alize by comparing these calculated values in all the layers, to the admissible values which could be also evaluated according to the fatigue characteristics of the materials (bounded materials) or their rutting behaviour by considering the cumulative traffic specified for the pavement. The material properties inside the layers from the integrated database based on the French standard (NF P98-086/2019) (Guide 1994 or Catalogue 1998) [9].

4.2 TSD Mechanical Principle of Operation

when the preliminary vertical surface deflection velocity collected, the deflection slope is obtained then it is converted to actual pavement deflection by curve fitting or numerical integration. Figure 1 [2-3].

As the measured deflection velocity depends on the speed of the TSD ; this dependency can be eliminated by dividing the vertical deflection velocity by the instantaneous horizontal TSD speed, which allows obtaining the deflection slope at each location of measurement. Moreover, the variation in dynamic Load that is effectively corrected by conducting a rolling average over certain distance [4].

4.3 Deflection Basin Simulation under TSD

The first step for simulating the deflection behaviour under TSD begins by calculating the deflection under a reference single TSD wheel as a function of the distance to the loading points. Alizé2® software handles this step after pre-defining the corresponding material properties and TSD configuration [8]. Then, in the second step, the deflection under each of TSD 10 wheels will be interpolated independently.

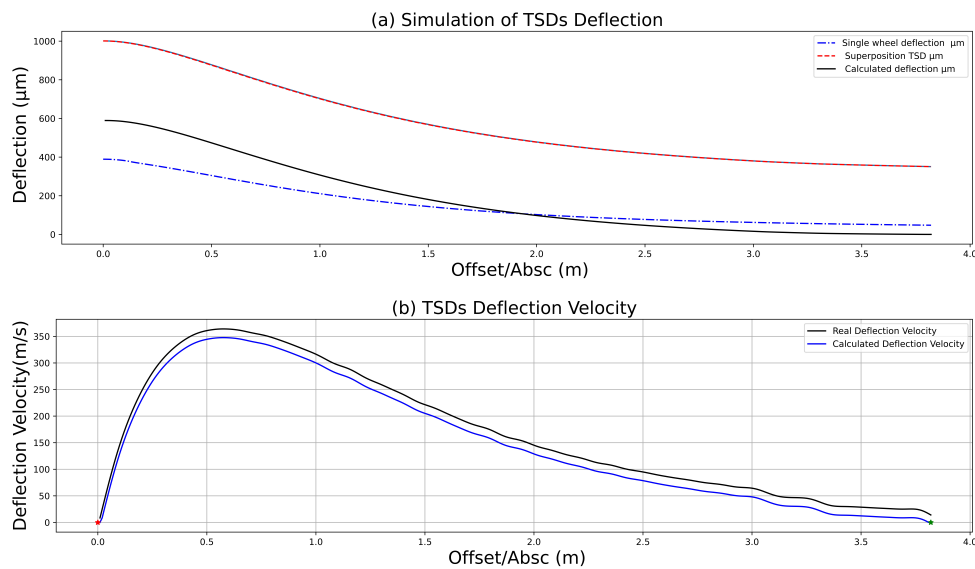


FIGURE 2 – (a) Simulation of TSD Deflection (b) Real to calculated deflection velocity

Given that, the pavement behaviour is considered (elastic linear), therefore, in the third step, the load superposition principle will be applied to determine the deflection under the sum of the wheels, see the red curve of Figure 2a [10]. Subsequently, the deflection velocity slope in Figure 2b is derived by applying the first order partial derivative to the red curve (superposition) in Figure 2a. Eventually, the final step is to calculate the deflection under TSD (which is the black curve in Figure 2a), this obtained by analytically integrating the velocity curve in Figure 2b.

Figure 2b illustrates as well the difference between the real deflection velocity and the measured one. This variation exists due to the hypothesis of no deflection velocity recorded at the rear axle wheel (loading point), and also at the position of the reference Doppler laser sensor.

5 Database Structure

A numerical database that contains more than 7 millions pavement structures has been developed. The database takes into account several pavement structure cases with various thicknesses and different material properties, which are totally or partially damaged. Additionally, environmental conditions are embedded in the pavement layers using different vertical temperature profiles. The input parameters that were used to build the database are shown in Table - 1 and explained as follows :

- The French catalogue of structure [11] : this catalogue includes 25 structure profiles for national roads. Each profile defines several design structures according to the traffic class and the platform bearing capacity. Each structure is defined by the number of layers, their thicknesses and their material type (bituminous, concrete or unbound granular, ...). A total of 226 structures have been defined with a number of bituminous layers varying between 0 to 3.
- Bituminous material has viscoelastic properties sensitive to temperature. Its equivalent Young modulus decreases when the temperature increases [12]. To account for this sensitivity, 102 in depth-temperature profiles have been defined from a temperature database recorded at University Gustave Eiffel's Carrousel. Surface (resp. 30cm depth) temperature varies between -5°C to 40°C . The young modulus of each bituminous layer was modulated accordingly.

- Inter-layer bond (Interface). In our study, two different interface conditions are considered : fully bond (full friction) and fully slip (frictionless) interface bond. The objective of including interface bond in the database is to quantify the interface influence on the deflection basin.
- Material Fatigue : the database has been broadened by 4 levels of damage for each layer. The standard Young modulus after temperature correction was reduced to 3/4, 2/4 or 1/4 (full damage) to obtained 4 different level of damages, which are independent from one layer to another.

Table-1 presents the overall structure of the database as well as the major parameters that have been taken into account in the development processes.

TABLE 1 – Essential parameters in building the numerical database

N° Layer	N° Bituminous Layers	National Road French Catalogue	Temperature Cases	Interfece Cases De/bounded	Material Fatigue Level	N° Simulated structure
04	3/4	36/226	50	8 Cases	256 Cases	3.686.400
	2/4	44/226	23			2.072.576
	1/4 Surface	80/226	09			1.474.560
03	1/3 Surface	30/226	09	4 Cases	64 Cases	69.120
	1/3 Second	08/226	08			16.384
	0/3 Non	28/226	01			07.168
Total N° of Structure						7.326.208

6 Results and Discussion

Figure 3 illustrates the analysis of +400 flexible and rigid structures simulated under the same context. The both simulated structures analyze the deflection behaviour over type 3 and 4 platforms bearing capacity (PF3 and PF4 according to French norm). Figure 3 highlights also the variance between the real deflection and the measured one with reference to the green intermittent line that represents the ideal correlation of equality between them.

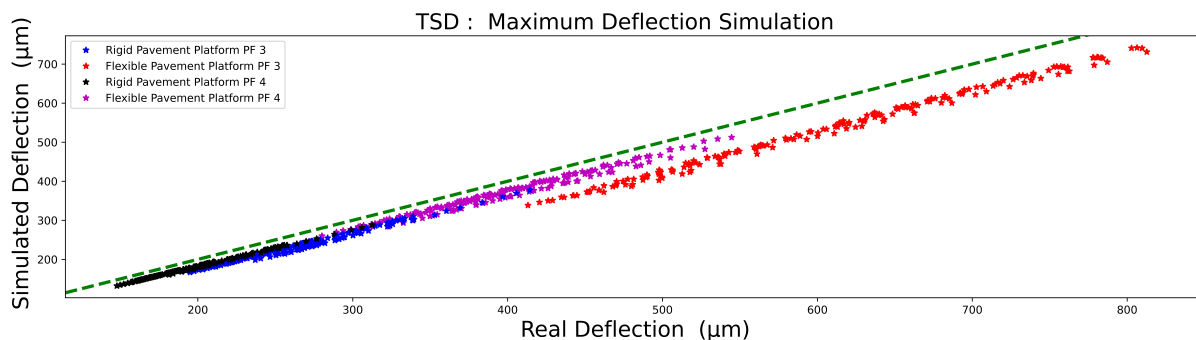


FIGURE 3 – Systematic bias between the real and simulated deflection in flexible and rigid pavement

By analysing the + 400 structures extracted from the database in Table-1, we can summarize our observations as follows :

- There is a proportional relationship between the deflection and the pavement type.
- The platform has a direct influence on the deflection measurement.
- The simulated deflection behavior are under-estimated compared to the real one, this variance being more prominent with a type 3 platform of the flexible pavement (red dots).
- Based on the above point regarding the variance, quantitative analysis about the platform and the traffic class are paramount to correct the bias between the real and t

7 Conclusion and Perspectives

TSD provides continuous bearing capacity results at project and network level while following the flow of traffic. This makes it a cost-effective and risk-free device. Nonetheless, it requires several configurations and rigorous calibration procedures prior to operation.

This paper presents a novel method for numerically simulating the deflection under the whole TSD, while shedding the light on the variation between the real deflection and the calculated one, this difference originates from the systematic bias in the reference sensor measurement.

In parallel with the TSD numerical modelling, this paper presents as well a methodological framework for developing a volumetric numerical database that consists of more than 7 million structures. The database has been built and analysed based on a parametric study of varying material properties with totally or partially damages structure.

The acquired results showed a non-linear systematic between the simulated and real deflection measurements. Moreover, the observation concludes that there is a proportional relation between the type of pavement material, the traffic class and the platform with deflection behaviour under the TSD.

As a perspective, The first data analysis and learning application will be conducted on synthetic data with and without noise, then the database will be broadened with measurements from in-situ pavement auscultations and investigations that will be performed at several sites.

To this end, The mentioned database will be used to set up simple learning methods as regression and classification in order to backcalculate the elastic modulus. The learning methods coming from the artificial intelligence domain and allowing the identification of structural defects and the assessment of the residual mechanical characteristics of pavements.

Finally, ranking methods will allow to classify signals in different structural states using deflection measurements, so a fast solution to the administrator could be offered.

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