Assessment of the Behavior of a Flexible Pavement Under Load Based on Strains Measurements with Fiber Optic Sensors in In-Situ Conditions

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https://doi.org/10.29227/IM-2025-02-02-027

Submission date: *2025-07-31* | Review date: *2025-08-27*

Abstract

Road pavements are made of layers of various materials. In the case of a flexible pavement, it is a system of layers consisting of: a mineral-asphalt mixture (the upper part of the pavement), a sub-base made of an unbound mixture (the layer below the mineral-asphalt mixture) and lower layers of the pavement and the improved/unimproved subgrade. The load on the pavement causes stresses and strains in its layers. The values of strains and stresses determine its fatigue life. When designing a road pavement, the values of strains are calculated theoretically, e.g. using software based on constitutive models. The development of measurement technologies allows for an increasingly better assessment of the pavement behavior in real conditions. In particular, recent years have brought great progress in the use of fiber optic sensors to measure strains during the operation of the surface layers. The paper presents the results of tests of a flexible pavement using DOFS (Distributed Optical Fiber Sensors). The tests were carried out on a test section specially prepared for the needs of the research project.

Keywords: *Flexible pavement, Optical fibers, Distributed Optical Fiber Sensors (DOFS), field test*

1. Introduction

The durability of road surfaces is determined by many factors. Among them, three groups can be distinguished. The first group concerns the design phase of the pavement structure, including knowledge of how the surface behaves under load. The second group concerns the quality of construction work. The third group concerns the impact of roadway maintenance on the condition of the surface [1-2]. Each of these groups has a significant impact on pavement durability. This article focuses on issues related to the first group, i.e., assessing pavement behavior under actual loading based on the distribution of horizontal deformations. Deformations are the fundamental quantity used in road pavement dimensioning [1]. The pavement design process involves theoretically calculating the strain distribution and then using the calculated values in the subsequent structural design process. Dynamically developing measurement technologies now enable physical measurement of quantities, such as strain, in-situ. This is particularly true for measurement technologies using fiber optics [3], allows for highly precise measurements of the observed structure's behawior [4–6]. The use of DOFS (Distributed Optical Fiber Sensors) enables the measurement of deformations along the sensor axis with a continuous distribution. The data collected in this way quantitatively and qualitatively demonstrate the relationship between load (cause) and pavement deformation (effect). These data can also be used to verify previously used computational methods in pavement dimensioning.

This article presents the results from an ongoing research program. The tests were conducted on a dedicated test track (field training ground) with a circular motion. The field training ground had previously been used in another research program [6]. The aim of this article is to present a qualitative analysis of strain distribution in asphalt pavement layers. The presented results represent the initial stage of analysis of field test data only. Subsequent work will utilize software (e.g., FEM Finite Element Method) to verify the calculation results against actual measurement data.

2. Field research

The subject of the study was a mineral-asphalt mixture with various mineral compositions, including the use of anthropogenic aggregate. The study was conducted on a circular test track, also used in a previous research program (assessing the impact of increased reclaimed asphalt content in the mineral-asphalt mixture).

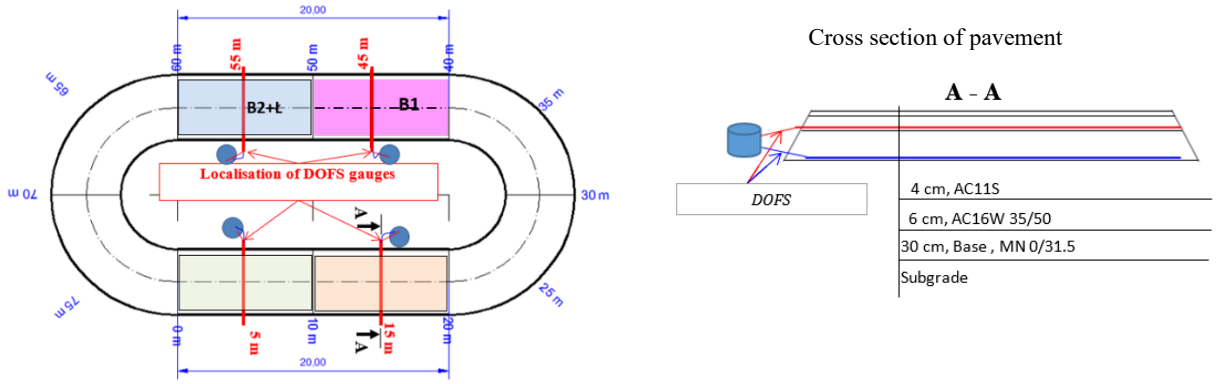

Fig. 1. Characteristics experimental sections B1, B2+Ł and localization DOFS gauges (based on [3])

The presented results come from measurement section B1 (Fig. 1). The tested section had a layer arrangement as shown in Fig. 1. The surface was loaded by a truck with characteristics as shown in Fig. 2. The rear axle wheel loads were transmitted through contact surfaces as shown in Fig. 3. The rear axle of the vehicle had a single axle and twin wheels.

View of the vehicle View of the rear axle

Fig. 2. Vehicle used during surface testing

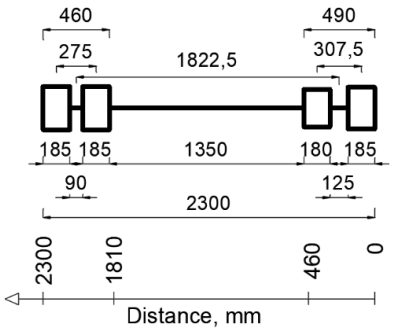

Fig. 3. Characteristics of the contact surface of the rear axle wheels with the road surface (top view)

3. Test results

The DOFS sensor was used to record the deformation state of the asphalt package at various positions of the vehicle's rear axle relative to the sensor. Deformations were recorded before, during, and after the rear axle passed over the DOFS sensor (Fig. 4). Due to the large number of recorded deformations, only two measurement series were selected for further analysis (Fig. 5). These series (Fig. 5) correspond to the position of the vehicle's rear axle for extreme deformation values in the right and left wheel tracks.

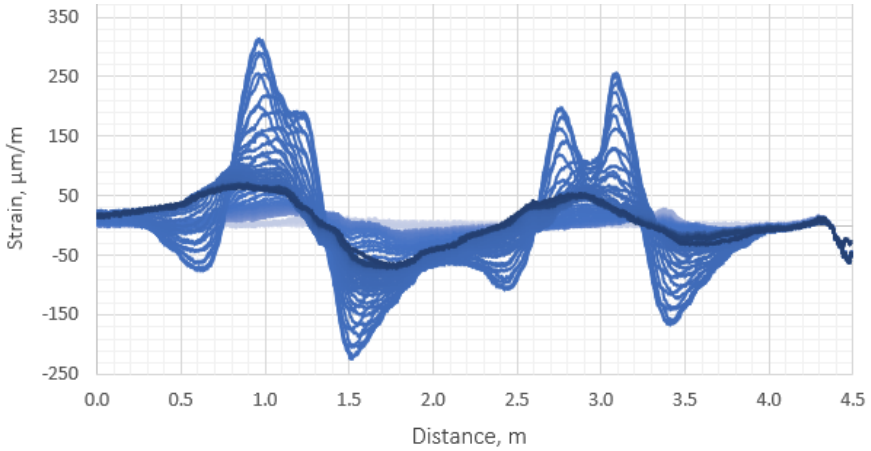

Fig. 4. Measurement of deformations at the bottom of the mineral-asphalt package at different positions of the vehicle's rear axle relative to the measuring cross-section

It should be noted that the DOFS sensor was not perfectly at a 90º angle to the truck's travel axis, as shown in Fig. 5. For this reason, the extreme deformations under the left and right wheel tracks do not occur at the same rear axle position.

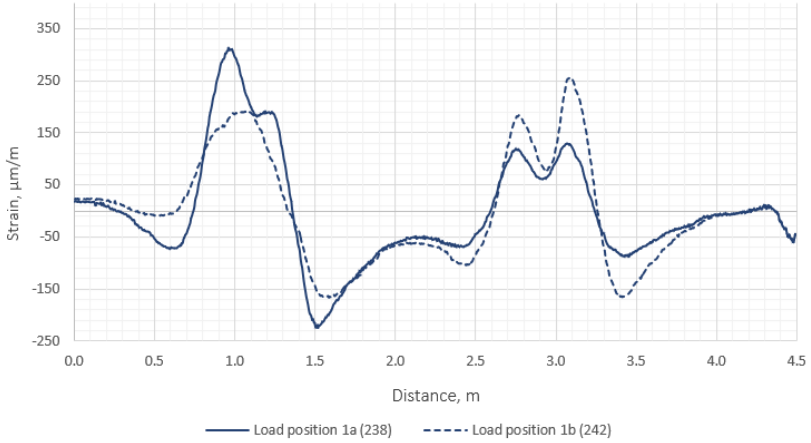

Fig. 5. Extreme strain distribution in the left and right wheel tracks

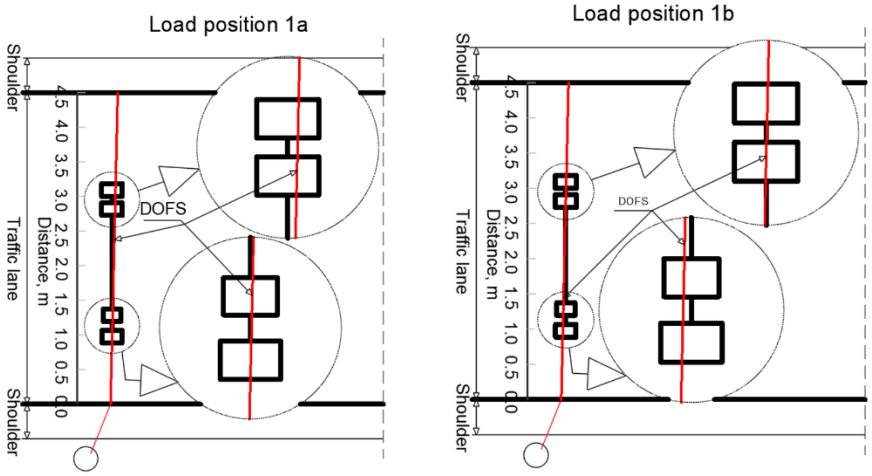

Fig. 6. Location of the rear axle wheels relative to the cross-section with the DOFS fiber optic installed

4. Analysis

The test results allowed us to observe the state of axial deformation in relation to the position of the rear wheels. Comparing the dimensions of the contact surfaces with the recorded deformation distribution allowed for a comparison of characteristic dimensions: the cause (loading surface) and the effects (deformation recorded at the bottom of the asphalt package).

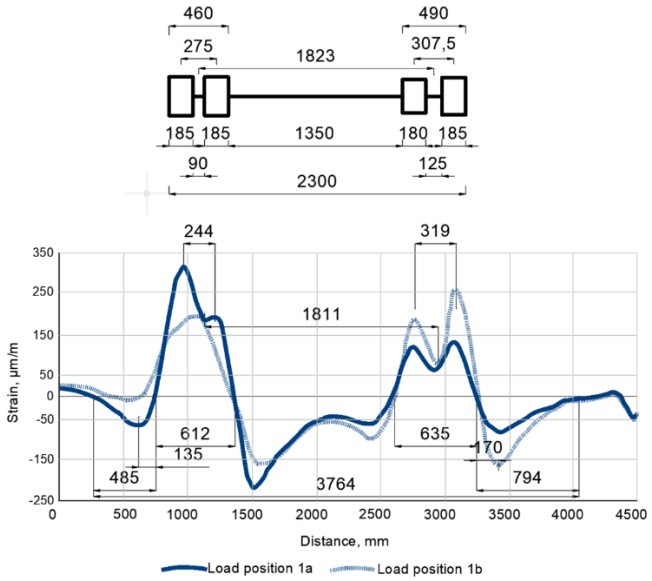

Fig. 7. Distribution of extreme deformations at the bottom of the asphalt layers corresponding to the location of the rear axles 1a and 1b (according to Fig. 6)

The distribution of strains recorded in the horizontal plane indicates that the road surface response is not uniform. Extreme tensile strain values occur in the left wheel track, reaching 300 µm/m. In the right wheel track, they are lower, reaching 250 µm/m. Zones of compressive strain are clearly visible – in the central zone, i.e., between the wheels, and in the zones at the outer edge of the track. Under the right wheel track, the strain distribution shows the influence of both tires and the gap between them. Such a characteristic distribution is absent in the left wheel track. These differences may result, among other things, from the smaller space between the wheels. On the left side, the inner edges of the wheels are separated by a space 9 cm wide, while on the right side, it is 12.5 cm wide. To identify characteristic deformation zones corresponding to compression or tension, a diagram of the occurrence of positive (tension) and negative (compression) strains was prepared (Fig. 9). The field height corresponds to the extreme deformation recorded in a given zone. When assessing the widths of the compression and tension zones, two pieces of information are noteworthy. The first piece of information concerns the lack of symmetry in the width distribution of individual zones, which is determined both by the uniform stiffness of the pavement layers and the distribution of ballast on the truck. The second piece of information indicates that the total width of the deformation distribution is approximately 3.75 m, i.e., the width from the recorded change in (compressive) deformation to the return of deformation to a value of ~0 µm/m. The recorded width of 3.75 m is significant, as in Polish conditions it is used only for the highest class roads – such as motorways. On lower class roads, where the lane width is less than 3.5 m, such a deformation distribution can cause accelerated degradation of the pavement edges. This observation may also explain the faster degradation (permanent deformations, cracks) of the pavement in the right wheel track, which is located close to the final edge of the pavement structural layers.

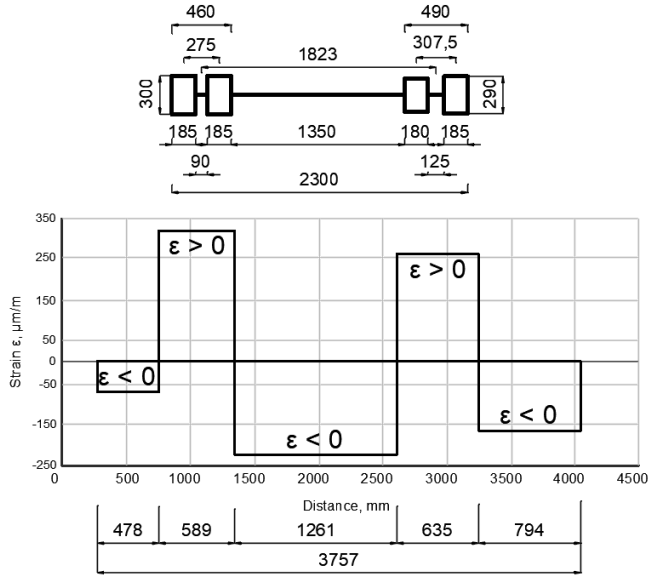

Fig. 9. Zones of horizontal deformations (positive and negative) occurring at the bottom of the mineral-asphalt package, i.e. at a depth of 10 cm

5. Conclusion

Field tests of the road surface using DOFS sensors, under the load of a truck, allowed the formulation of two basic conclusions:

- The use of DOFS sensors enables a very detailed analysis of the cause-effect relationship between the surface load (cause) and the deformation distribution (effect),
- The distribution of deformations in the transverse direction in the range of extreme values and the width of compression and

tension zones is not symmetrical, which is a consequence of the non-uniform stiffness of the pavement layers and/or the uneven load transferred by the vehicle (e.g. uneven vehicle loading, pressure in the vehicle wheels, etc.).

Further in-depth analysis of the results will be performed using the results of strain distribution calculations using FEM (Finite Element Method).

Acknowledgments

The presented research results were obtained during the implementation of the project entitled "Development of technology for the production of mineral-asphalt mixtures with the use of mining waste from the coal industry" carried out by ZRD and TZ "ROMUS" JERZY MUSIAŁ, MACIEJ ROTYŃSKI SPÓŁKA JAWNA and co-financed by the European Union under the Regional Operational Program of the Silesian Voivodeship for 2014-2020, for the priority axis: I. Modern economy, for the measure: 1.2. Research, development and innovation in enterprises.

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