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EXPERIMENTAL ANALYSIS OF PAVEMENT STRUCTURE BEHAVIOUR IN A LABORATORY FULL-SCALE MODEL

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Abstract

The paper deals with the analysis of pavement layers behaviour under simulated traffic loading. The road structure of a category one road designed according to the technical recommendations for pavement design in the Czech Republic (TP 170 supplement No 1.) is subjected to long term dynamic impulse loading applied through the contact surfaces of dual wheel assembly mounted on heavy goods vehicle axle [1]. The model is equipped with several sensors for measuring stress, horizontal strain, temperature, and moisture. The results of the measurements provide information on the changes in the condition of the pavement layers in terms of long-term monitoring of stresses and strains, the development of permanent deformations and the interaction between various structural layers. Combined with the different structures tested, this research will lead to a detailed description of the behaviour of the strength and deformation characteristics of the pavement layers and refined specification of pavement design.

Keywords: full-scale road model, laboratory modelling of pavement layers, stress and strain measuring, road structural layers testing

1 Introduction

The development and utilization of new, sustainable materials in road construction is closely associated with the emergence of new or modifications to older standards, regulations, and test procedures. These documents regulate the conditions for the handling, use, and processing of these materials, and establish methods for testing their quality and applicability to road construction layers. These include, for example, Ordinance No. 283/2023 Coll., CSN 73 6147, TP 210 [2-4]. Standard empirical and functional tests are usually used to obtain the parameters of these materials and the pavement structural layers made of them. Even if the test results of the materials and structural layers meet the requirements of the relevant regulations, their suitability for use in any pavement layer is not guaranteed. To verify the interaction and behaviour of the pavement layer, a test section can be set up, but it is time-consuming, costly, and difficult to organize. A computational pavement model can be constructed to save money, but it is usually adapted to conventional pavement materials and not to new types of materials. But such a computational model or program cannot work without input data that cannot be obtained otherwise than by measuring the real structure.
This paper focuses on the above mentioned measuring various parameters of a real pavement using a Full-Scale pavement model. In the following sections, the pavement model itself is briefly described, as well as the method of loading, the types of measuring equipment installed in the model and the results of the load test performed so far.

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Now, the initial reference pavement model is being tested and will be compared to the outcomes recorded on following pavement structures constructed with recycled construction materials. The model itself is still in a state of production and will be gradually modified and upgraded during further research to make the simulated measurements as close as possible to the actual in situ conditions.

2 Description of the Full-Scale model

The Full-Scale model consists of a solid metal frame with an Inova AH-63 hydraulic load press with linear actuator [5]. This press transfers the load through a spreader beam to two identical circular load plates placed on the wearing course of the tested pavement (Fig. 1.). The dimensions of the plates and the applied contact stress are derived from the contact area of the tyres of the dual-mounted heavy goods vehicle (HGV) design axle as specified in the technical recommendations TP 170 [1]. The HGV is defined as a hypothetical vehicle that averages different types of trucks (small trucks, buses, trailers, semi-trailer combinations, etc.).

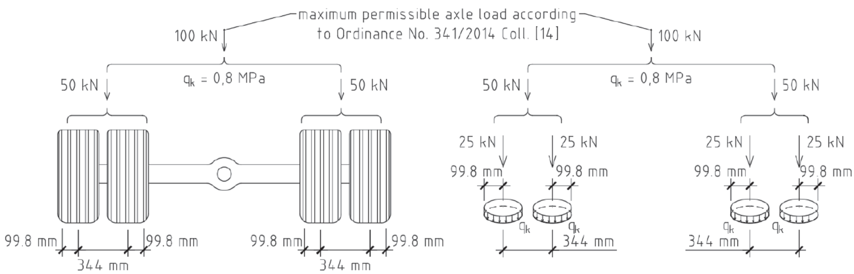

Figure 1 Diagram of dual-mounted HGV design axle

The pavement being tested is placed in a 1,5 m³ cubic steel box, which was designed and built as part of previous research [6]. The reference road model was based on the standard class one road composition. This composition was chosen as an appropriate benchmark for subsequent comparison with other pavement layers because it is one of the most used and heavily loaded types of asphalt concrete pavements. The reference road model consists of following layers:

• stone mastix asphalt	SMA 11 S	40 mm
• asphalt concrete for binder course	ACBINDER 22 S	80 mm
• asphalt concrete for base course	ACBASE 22 S	110 mm
• mechanically strengthened aggregate	MSA 0/32	200 mm
• mixture for granular subbase course	GSC 0/32	250 mm
• clay with intermediate plasticity	F6 CI	800 mm

Standard empirical and functional tests were performed on the substrate and all materials of the structural layers, or the layers themselves, before incorporation into the model. These included the Proctor compaction test, static load test, impact load test performed on the subgrade and base layers, and the determination of stiffness moduli, resistance to fatigue, determination of the water sensitivity, wheel tracking test, and determination of low temperature cracking and properties by uniaxial tension test performed on the asphalt layers. These results of the abovementioned tests, combined with the pavement loading results obtained from the Full-Scale model (Fig. 2), form a complex description of the reference pavement composition.

3 Pavement model instrumentation

Various measuring sensors are embedded in the structural layers of the model, which continuously record the current state in each layer. The following subsections provide a more detailed description of each sensor. The types of sensors were chosen according to the experience from foreign sientific articles [7, 8].

Figure 2 Full-Scale model - load plates, spreader beam, hydraulic press

3.1 Temperature probes

To measure the temperature inside the asphalt layer of the model, a PT1000TG8/E temperature probe is installed on the neutral axis of each asphalt layer. Additionally, a PT1000TG7/E probe is installed on the pavement surface to measure the temperature of the surface. These sensors only monitor slight temperature changes during the alternating day and night cycles under current conditions. Further research is planned to utilize the sensors extensively, with the possibility of installing a conditioning chamber to mimic temperature changes in the pavement.

3.2 Pressure gauge boxes

Pressure gauge boxes that measure stress are situated in the subbase courses. The first pressure gauge sensor GEOKON 3500 with a range of 0-250 kPa is located at the interface between the lower subbase layer of gravel and upper subbase layer of mechanically strengthened aggregate (MSA). The second sensor, a TML KDC 500 strain gauge sensor with a range of 0-500 kPa, is located at the interface between MSA and the asphalt base course. The pressure gauge boxes utilized are depicted in the images below (Fig. 3).

Figure 3 Pressure gauge boxes TML KDC-500 (left) and GEOKON 3500 (right)

3.3 Horizontal strain sensors

The KM-100HAS horizontal strain sensors installed in the test rig are embedded in asphalt mixtures and have a temperature resistance of up to 180 °C and a measuring range of up to 5000 microstrain. A horizontal strain sensor is positioned on the bottom face of the asphalt layer below the center of one load plate. An additional, fourth sensor is placed in the middle of the base course, again on the bottom face of the base course (the area most subject to tensile stress in asphalt pavements). The strain sensors in the asphalt base course are shown in the figure 4.

Figure 4 Horizontal strain sensors KM-100HAS designed for asphalt layers

4 Pavement loading

The road surface is loaded impulsively, modelling the passing of the design axle of a heavy goods vehicle. The load function takes the form of a discontinuous haversine curve (Fig. 5) with a total length of one load cycle of 250 ms, the pulse itself being 150 ms long. The length of the load pulses was chosen both according to previous research by scientists from foreign scientific institutions who measured these values on in situ test sections and according to the testing time of one pavement structure. The total number of pavements loading cycles, which is equal to the number of HGV´s design axle passes, was set to 22 million according to the technical recommendations TP 170 [1]. Therefore, testing of a single pavement structure took approximately 2 months [8-10].

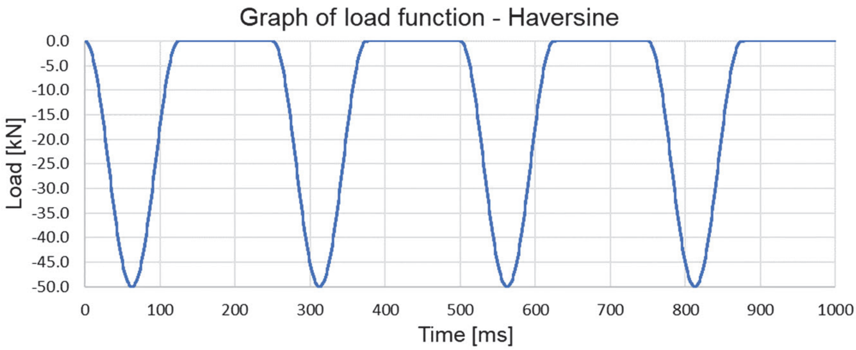

Figure 5 Load function in the form of a discontinuous haversine function

5 Loading results of the reference pavement

The following parameters of structural layers were continuously monitored during long-term loading:

- horizontal strain in asphalt layers,
- temperature in asphalt layers,
- stress at the interface between the asphalt base course and the subbase layer, as well as between the subbase layers themselves,
- subgrade moisture.

The scanning frequency was set to once every 15 minutes, with a measuring time of 2 seconds. The results obtained at this frequency describe with sufficient precision the changes in the measured parameters of the individual layers. The evaluation software developed for data collection and filtering is not yet fully functional and therefore the following plots of horizontal strain (Fig. 6) and compressive stress (Fig. 7) were evaluated manually and contain only a fraction of the measured data. Even so, these graphs provide a sufficient depiction of the evolution of these parameters over time.

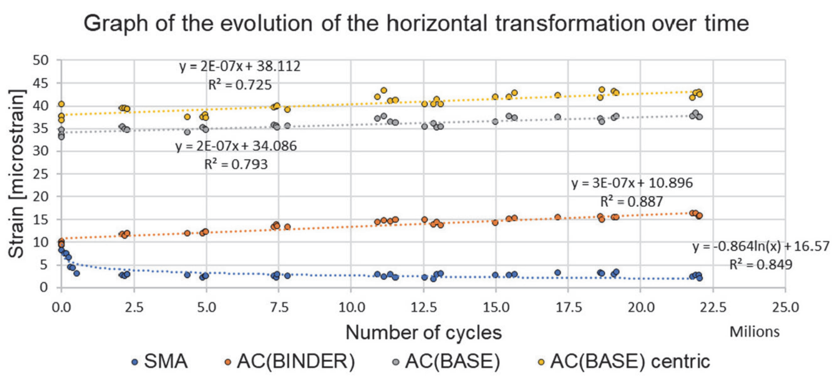

Figure 6 Graph of the evolution of the horizontal transformation over time

According to the horizontal strain graph (Fig. 6), none of the asphalt layers analysed exceeded the critical horizontal strain value of 50 microstrain, above which fatigue of the asphalt layers occurs. At the same time, there were no visual defects on the pavement that would suggest damage or deformation.

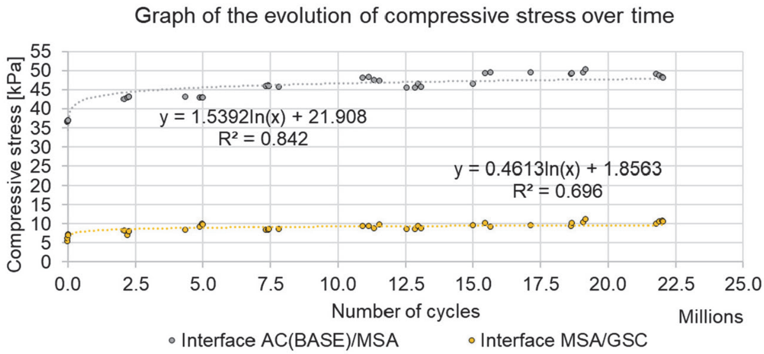

Figure 7 Graph of the evolution of compressive stress over time

The compressive stress values shown in the figure 7 show a slight stress increasement (from 37 to 43 kPa) at the interface of the asphalt base course and upper subbase layer and a very low value of the compressive stress (up to 10 kPa) at the interface between the upper and lower subbase layer (at the depth of 430 mm below surface).

Performing the standards-required tests (CSN EN 73 6121 [11], CSN EN 73 61261 [12], CSN EN 73 6133 [13]) on all layers resulted in satisfactory results. It can therefore be concluded that the monitored category one road structure is overdimensioned in terms of the expected traffic load over its lifetime, respectively in terms of the expected number of HGV´s design axle passes. Since the road model was not exposed to the same climatic conditions as a conventional pavement, it is uncertain if it would not fail under the same load on a standard insitu test section. The strain and stress parameters were measured on the reference pavement mainly for their further comparison with the same parameters from other pavement compositions, designed mostly of recycled materials.

Since, according to the measured values, no damage has occurred to the pavement, it is continued to load the same reference structure, but with a newly moistened subgrade. This option is further described in the following chapter “Discussion on the follow-up research”.

6 Discussion on the follow-up research

Based on the results achieved so far, there have been no signs of fatigue, increased deformation, or damage to the reference pavement layer. As a result, it was decided to saturate the subgrade and re-expose the road pavement to load cycles. The level of soil saturation in the subgrade and the water saturation elevation is regularly monitored using moisture sensors. The flooding of the model will simulate the condition of the road in areas with high groundwater levels or clogged drainage facilities.

Subsequent research is investigating the possibility of installing an air-conditioning chamber that could make the simulated conditions in the laboratory more similar to the actual effects affecting the road in real conditions.

Once the tests on the reference pavement will be finished, the pavement layers will be demolished and replaced with new, sustainable pavement structures which aren’t used that often yet. The plan is to construct new subbase layers of recycled construction materials as well as new types of asphalt layers designed mainly of reclaimed asphalt pavement (RAP). The road compositions mentioned above will focus on both the less loaded higherclass pavements and the lower-class pavements. At the same time, the test time will be reduced due to the lower number of load cycles (N_{cd}) for these road categories.

7 Conclusion

Pavement models of this type could simplify and improve the principle of pavement design. Unfortunately, at a time of rapid growth and the development of new technologies and materials for pavement construction, there is no time for longterm testing and verification of their properties, as was previously the case. The Full-Scale Pavement Model allows for the application of new innovative ideas and materials and their testing in any pavement design within a short period of time. Additionally, the Full-Scale model allows to specify, update, or extend the calculation software used for pavement design (e.g. LayEps, Laymed, ELaS, etc.) with new data, which were previously only obtained from foreign scientific articles and standards. The measured stress and strain values obtained from the pavement model as well as the simulated values obtained from the pavement design computational programs are supposed to be compared with the results from an equivalent in-situ test section to evaluate the validity of the model.

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