# Discussion of "Validation of a Novel Sensing Approach for Continuous Pavement Monitoring Using Full-Scale APT Testing" by Mario Manosalvas-Paredes, Kenji Aono, Shantanu Chakrabartty, Juliette Blanc, Davide Lo Presti, Karim Chatti and Nizar Lajnef. (DOI:10.1061/JPEODX.0000397)

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The authors conducted a comprehensive full-scale accelerated pavement test (APT) on conventional flexible pavement for the detection of bottom-up fatigue cracking. During the APT loading process, the changes in pavement materials and structural conditions, such as structural capacity (layer moduli) and functional performance (international roughness index-IRI), were monitored using piezo-powered smart sensors to track the harvested variations in strain energy rather than the traditional stain measurements. The comparison study between the newly developed sensors and the conventional condition-based approach indicated that the piezoelectric sensor was successfully validated with the conventional strain gauge in a full-scale testing pavement system. In addition, the cumulative loading time of piezo-voltage could serve as an indicator of the pavement damage progress, and the timing of the activation of sensor thresholds with different voltage levels could reveal the pavement structural damage severity, contributing to the pavement structural health monitoring (SHM) and maintenance. The discussers highly appreciate the work of the authors and would like to provide some comments regarding the experimental process, analysis, and results.

Design of the pavement structure (layers and thickness) plays a significant role in controlling the structural responses of pavement under the repeated loading process, especially during the full-scale APT testing (Cortes Avellaneda 2010; Jiang et al. 2022b; Li et al. 1999; Terrell et al. 2003). The discussers recommend the authors explain why the thicknesses of the asphalt concrete layer (AC), unbound aggregate base layer (UAB), and subgrade are set as 102 mm, 760 mm, and 1,600 mm, respectively. The relative layer thickness of the pavement among all layers determines its performance (Jiang et al. 2021). Therefore, an explanation for the pavement design could provide a good reference for future applications.

Accelerated pavement test (APT) is considered a highly-efficient and versatile testing approach to simulate the actual wheel loading on the full-scale pavement structure, and evaluate pavement structural responses and performance in a shorter duration (Jiang et al. 2022c; Ling et al. 2020). Compared with conventional on-site investigations, the full-scale APT test on the pavement has the advantages of controlled loading and environmental conditions. In this study, single-axle dual-wheels of 65 kN and an approximate velocity of 76 km/h of moving wheels were chosen. It is worthwhile that the authors could explain how to set the parameters of the APT facility. In addition, the authors could provide operation experiences of APT equipment, contributing to the development of the APT facility.

Falling weight deflectometer (FWD) is a type of nondestructive road testing device for pavement structural analysis (Horak 2008; Jiang et al. 2022a; c; Talvik and Aavik 2009). In this study, the authors concluded that most deflection change was limited to the upper layers, and most damage was taking place in the asphalt layer. Usually, the deformation of the subgrade accounts for the largest proportion among all pavement layers (Gong et al. 2018; Maina and Matsui 2004; Vyas et al. 2020; Wang et al. 2022). Thus, the authors are recommended to clarify this phenomenon. In addition, the qualitative analysis of the FWD deflection could not reveal the actual layers' condition. In this study, the layer moduli back-calculation using Dynatest ELMOD version 6 software was conducted to back-calculate the different layer moduli of the pavement. However, the back-calculation program because the solution's reliability depended on the seed moduli, making the back-calculation an ill-posed process. Due to inaccurate results, the multi-layer linear elastic theory and back-calculation procedures have come under scrutiny (Horak 2008). In addition, the accuracy of any back-calculation method primarily depends on the exact estimate of individual layer thickness. Nevertheless, the actual layers' thicknesses were not validated in this study. In previous studies, coring and ground penetration radar (GPR) are popular methods to assess pavement layer thickness. Coring operations are significantly time-consuming and resource-intensive. Traffic management is required when coring is conducted, bringing burdens to daily traffic operations. GPR has not been put into regular use by most transportation agencies, which hinders the evaluation progress. Thus, a more convenient, safe, and cost-efficient method is needed to investigate the pavement layers' performance (modulus) after repeated loadings. For the conventional flexible pavement, a deflection basin parameters (DBPs)-based pavement evaluation was proposed by Horak et al (Horak, E., Emery, S., and Maina 2015). The evaluation parameters such as Surface Curvature Index (SCI), Base Damage Index (BDI), and Base Curvature Index (BCI) were used to characterize the condition of the surface layer, base layer, and subgrade layer, respectively. SCI represents the difference of deflections measured with load geo- phones located at the center of the loading plate ($D_0$) and 300 mm (12 in.) from the center. BDI represents the difference of deflections measured with load geophones located at a distance of 300 mm (12 in.) and 600 mm (24 in.). BCI represents the difference of deflections measured with load geophones located at 600 mm (24 in.) and 900 mm (36 in.). The threshold values were also presented based on a load of 40 kN or a contact pressure of 560 kPa by the FWD testing method. Therefore, the authors are recommended to apply the DBPs-based evaluation system after loading calibration in future field investigation.

Environmental factors such as temperature and moisture are of great importance to the performance of the pavement structure. In this study, the back-calculated asphalt modulus was corrected to a reference temperature of 20°C following Highways England CS 229. The authors are recommended to show how to control the testing temperatures during the APT test. In addition, the IFSTTAR circular test track (CTT) is an outdoor APT facility. Moisture in the base layers and subgrade soil could degrade the performance of the pavement structures. Could you provide the experience for controlling the moisture or considering the moisture effects of the base layers and subgrade of the testing pavements? The discussers believe the authors could provide a reasonable explanation for these questions.

Visual observation based on the experience could provide a fast and direct evaluation of the surface layer condition. In this study, the extent of cracking in the longitudinal and transverse directions was investigated and calculated. However, the criteria (widths) for the cracking detection were missing. According to the Federal Highway Administration (FHWA) standard (*The Long-Term Pavement Performance Program* 2017), three severity levels according to the crack width: low (⩽6 mm), medium (6 to19 mm), and high (⩾19 mm). The authors are recommended to provide the evaluation criteria for visual cracking detection. In this study, the cracks were considered classical bottom-up fatigue. However, bottom-up fatigue usually occurs in rigid pavement due to the reflective cracks from the cement-treated base layer. Could you provide your analysis for classifying these cracks?

The major contribution of this study is to develop a novel piezo-powered sensing system combined with a new response-only-based approach for data reduction and interpretation for the continuous monitoring of pavement conditions. In this study, the piezoelectric sensors were placed at the bottom of the asphalt layer. The unbound aggregates were below the AC layer and the potential slippery between the aggregates and the AC bottom would occur, influencing the accuracy of the sensors. Thus, the authors are recommended to provide an explanation for the data accuracy acquired by piezo-powered sensors. In addition, the construction experience for the AC layer containing sensors is recommended to be provided.

The structural responses of the UAB layer have attracted attention from academia and industry for many years. The stress dependency of the granular materials plays an important role in pavement performance. In this study, the selected piezo-transducers for this work were designed to respond only to tension and not to compression. Nevertheless, the unbound aggregates could not experience tension during the loading process. If this type of sensor is applied to the UAB layer in the future, what improvements or modifications will you do?

The long-term monitoring of the pavement's structural health is critical to the pavement industry and stakeholders. The authors' research is of great value to the technical advances and promotion of pavement maintenance and rehabilitation. The discussers believe the authors would complete more comprehensive and valuable studies after reviewing and answering the above discussions and questions.

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