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Subsurface characterization of Removable Urban Pavements (RUP) using Ground Penetrating Radar (GPR)

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Abstract. In the pursuit of improving transport infrastructure as part of the overall sustainable development policy, new coatings and emerging structures are coming to the forefront. This is the case with Removable Urban Pavements (RUP). This new type of structure, thanks to lightweight equipment, is removable in parts and allows quick access to underground networks. To assess the design and potential degradation of RUP, the use of multi-technique tools for Non-Destructive Techniques (NDT) is implemented as part of the European HERON project. These methods are increasingly sought after by transport infrastructure managers, both for corrective and preventive/predictive maintenance. Among them, Ground Penetrating Radar (GPR) is gaining popularity among pavement professionals for multi-object detection/characterization in the subsurface, as well as for assessing the geometry of structures. In this context, a RUP structure, installed on the fatigue carousel at Gustave Eiffel University (Nantes, France) and subjected to various mechanical and hydraulic solicitations, has been studied using GPR.

1. Introduction

In a policy aiming for zero risk, it is essential to control hazards and enhance our knowledge of transportation infrastructures. The objective is to implement corrective, preventive, and/or predictive maintenance that minimizes risks below a certain threshold of acceptability. Therefore, the instrumentation of pavements, particularly in the context of preventive monitoring, is a crucial tool in the risk analysis approach. It is important in this case to better understand the behavior of structures and provide reliable data for a robust risk analysis. For this purpose, the European project HERON [1] aims to combine the principles of repair and/or replacement action with automatic detection of areas that may exhibit defects. In this context, the Forever Open Road (FOR) [2] principle with its national variations (such as R5G in France) has been developed by the Forum of European National Highway Research Laboratories (FEHRL). Thus, HERON addresses three FOR principles: resilience, automation, and adaptability. In terms of technological objectives, the HERON project aims to develop an integrated automated system for the maintenance and renovation of the road network, including crack sealing, pothole patching, rejuvenation of asphalt pavement, detection/removal of traffic cones and other potential obstacles, detection of marking defects, autonomous replacement of elements of Removable Urban Pavements (RUP) [3], etc. We focus here on this latter innovative technology. To accomplish



these tasks, the HERON system consists of an instrumented autonomous terrestrial robotic vehicle and drones for coordinating maintenance and intervention phases, a detection interface allowing enhanced monitoring of structural conditions, augmented reality visualization tools, data processing of collected information, and workflow coordination through deep learning methods (YOLO method). Finally, HERON enables a modular design of the operational system, maximizing capabilities and adaptability for transportation infrastructures, while reducing human risks, maintenance costs, traffic disruptions, and thereby contributing to the improvement of network efficiency.

Among the innovative structures, RUP have been selected for evaluation within the project. Gustave Eiffel University is involved in the design and deployment of RUP on various test sites in France [4]. This enables full-scale trials, where the HERON project can now fit into a multi-technique Non-Destructive Techniques (NDT) framework, whether on the surface (LiDAR, photogrammetry, imaging, etc.) and subsurface (GPR). In the frame of this research work, we first introduce the principle of RUP and highlight the relevance of using GPR for subsurface characterization. Next, we present the fatigue carousel at the university on which a test structure has been implemented. Finally, we conclude with the initial results obtained using GPR, followed by a conclusion and research outlook.

2. Presentation of RUP

In 2008, Gustave Eiffel University proposed an original concept of Removable Urban Pavement (RUP) whose purpose is to ensure an easy and fast access to the sub-base and to the networks underneath, for maintenance or extension needs. The concept is based on interlocked precast hexagonal concrete slabs. The slabs were designed with keys to avoid slab rocking risk under heavy traffic. A first prototype confirmed the proof of concept [3]. Within a collaborative project Gustave Eiffel University has been developing since 2017 a new type of permeable RUP as this property is becoming more and more pregnant in a context of climate change and violent climatic events [4]. The presence of vertical holes together with a wearing course made of porous concrete allows the water drainage. The slabs are laid on an original excavatable and draining cement treated base (figure 1 and figure 2).

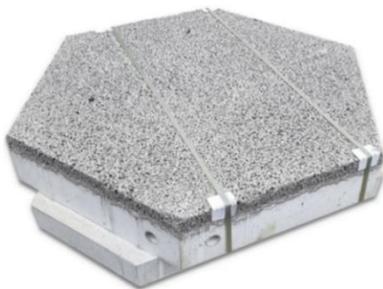


Figure 1. RUP (hexagonal slab).

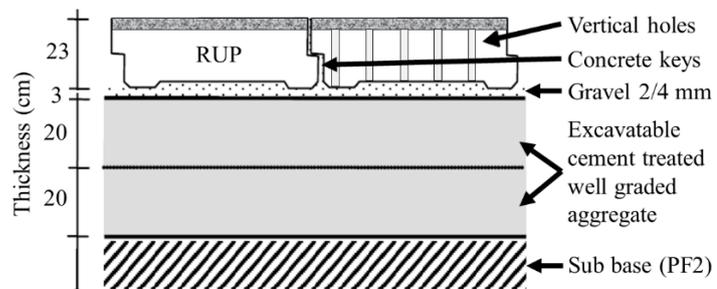


Figure 2. Implementation of RUP on a structure.

3. Experiment and result

The Gustave Eiffel University (Nantes, France), has been equipped for over 45 years with an accelerated pavement testing system under the loads of a heavy vehicle at speeds up to 100 km/h [5] (figure 3). This allows the validation of new structures through fatigue testing before scaling up to demonstrator testing on the road network. Thus, for the execution of a mechanical and hydraulic design campaign on RUP conducted in 2020/2021 for 2 months, the University constructed a section measuring 8.35 meters in length by 2.31 meters in width. The section consists of slabs with a 46 cm edge and 23 cm thickness (including 4 cm of porous concrete on the surface for the 22 double-layer hexagonal slabs, 4 cm of hydraulic concrete for the 15 half-edge slabs, and 2 single-layer quarter-slabs) (figure 4). This section was subjected to 200,000 cycles of loading by a half-axle with dual wheels (which corresponds on average to traffic between 45 and 91 buses/day/direction for 20 years) (figure 5).



Figure 3. Fatigue carousel (Gustave Eiffel University – Nantes, France).



Figure 4. Studied RUP Structure.

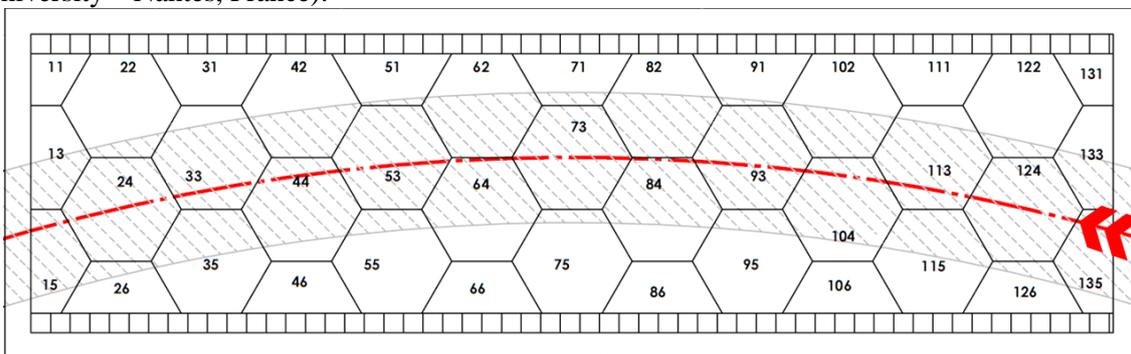


Figure 5. Layout of the RUP structure on the fatigue carousel (the hatched surface represents the half-axle wandering).

As slabs interlocking is mandatory for the concept, it is important to verify its integrity. As this information is not reachable from a visual inspection, Ground Penetrating Radar (GPR) appears as a potential alternative. Using multi-channel GPR ground-coupled antenna, we have inspected the RUP structure after 200,000 loading cycles on a large frequency bandwidth [1 – 4.5] GHz. The goal here is to observe the subsurface structure and collect a large dataset on continuous acquisition to identify some anomalies. A global approach (raw signals without pre-processing) is initially employed, followed by a local approach (pre-processing with the extraction of key features) to enable data processing through artificial intelligence methods. We perform automatic anomaly detection using a YOLO-type deep learning algorithm combined with an SVM-type machine learning algorithm for effective classification. Building upon the key features observed in figure 6, the first results show excellent automatic anomaly detection in B-scans (figures 6a and 6d), cross-scans (figures 6b and 6e), and A-scans (figures 6c and 6f). The objective now is to enhance the classification of these anomalies and integrate them into a multi-technique approach (surface and subsurface), helping decision-making, as advocated in the HERON project.

4. Conclusion et perspectives

In conclusion, it seems to be possible to characterize RUP subsurface, thereby extracting data/images that can serve as features for building a database complementary to the surface database obtained through imaging, LiDAR, and/or photogrammetry techniques. These features are used as inputs to deep learning algorithms for pattern recognition (as YOLO v4), able to identify potential structural anomalies and SVM for the classification [6]. In addition, thanks to Full Waveform Inversion (FWI) methods, it is possible to obtain observable physical quantities such as the dielectric permittivity of the examined medium. A hybrid data processing approach will then enhance algorithm performance while reducing computation times [7]. With the creation of a comprehensive multi-technique database, the possibility of decision-making and intervention in maintenance operations becomes feasible.

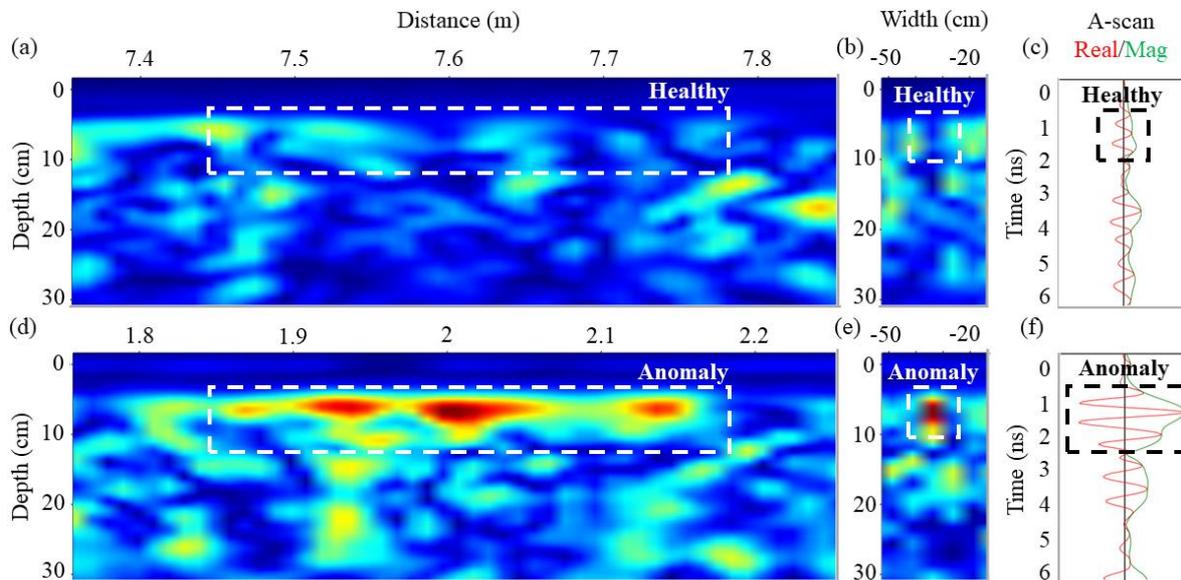


Figure 6. RUP Data (in magnitude) from the fatigue carousel after 200 keycles of loading (a) Slab n°42 B-scan (b) Slab n°42 Cross-scan (c) Slab n°42 A-scan (d) Slab n°122 B-scan (e) Slab n°122 Cross-scan (f) Slab n°122 A-scan

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