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The acoustic assessment of concrete pavement structural health

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ABSTRACT

Determining the in-situ asset condition of a pavement is necessary to programme pavement renewal and life extension work. Concrete pavements can develop different forms of structural faults including variable types of cracking, spalling, slab rocking, corrosion of reinforcement and softening of subgrade. This paper reports on work designed to detect deterioration before it manifests at the surface, in the form of defects that would only then have been picked up through visual inspection.

The approach involves non-destructive, real-time monitoring with a Close Proximity (CPX) trailer, utilising both microphones and a tri-axial accelerometer. Dependent on its condition, the concrete pavement and subgrade will respond differently to traffic induced acoustic noise and vibration from the tyres.

The variability in response is analysed using specialist spectral and acoustic signal processing techniques, to detect any internal and external cracks in the pavement, as well as to assess the condition of the subgrade. By characterising the pavement into uncracked, lightly cracked and heavily cracked areas, the collected data is used to map crack locations and their severity. Repeated surveys will allow temporal changes to be monitored and its rate of decay to be predicted, enabling the scheduling of renewal and life extension maintenance work to be optimised.

1. INTRODUCTION

Maintaining a road surface in good condition is vital to both the safety and satisfaction of road users as well those living next to the road. Reliably detecting defects in concrete pavements is a critical part of the maintenance regime for such road surfaces. As TRAffic-speed Condition Surveys (TRACS) [1] are not always capable of collecting defects specific to concrete surfaced pavements, Visual Condition Surveys (VCS) [2] are often relied upon to report on deterioration

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and inform decision making. With its reliance on lane closures and human inspection, VCS can only detect defects visible to the human eye, involves an element of risk for those involved and can be time-consuming and expensive due to the requirement for lane closures.

Therefore, alternate methods for determining the condition of concrete pavements, through the use of non-destructive real time monitoring, present a valuable opportunity to reduce the need for human intervention in asset management routine maintenance practice, remove exposure to harm for road workers and enable more data-led decision making.

Following on from some initial success in looking at the structural health of the pavement with a static sound camera using a beamforming array, this paper describes an approach currently being trialled to exploit the analysis of noise and vibration data associated with a vehicle driving over the concrete pavement. A Close Proximity (CPX) trailer, designed to measure the acoustic performance of road surfaces, is instrumented with four omni-directional ¼" microphones and one tri-axial accelerometer. A fifth microphone is mounted to the towing vehicle to measure sound from the rear tyre in the left wheel track to capture data following the general principles of the On-Board Sound Intensity Method (OBSI) method [3]. Dependent on its condition, the concrete pavement and subgrade will respond differently to traffic induced seismic and acoustic vibration from the tyre.

The variability in response can be analysed using specialist spectral and acoustic signal processing techniques, to detect any internal and external cracks in the pavement, as well as to assess the condition of the subgrade. It is noted that unlike external cracks, internal cracks in concrete pavements are often not visible to the naked eye and can be hard to detect, localise and quantify using standard approaches. Internal cracks particularly in the early stages of a concrete pavement life tend to propagate from a weak subgrade upward through the layers of a pavement, to eventually reach the surface. The passive acoustic technique is able to characterise the pavement into uncracked, lightly cracked and heavily cracked areas. With the trailer linked to road position via GPS, the collected data can be used to map crack locations, their severity and temporal activity for the full width of the carriageway. Areas of differential concrete slab movement and other anomalies may also be found. Finally, over time the real time data can be analysed to quantify the progressive change of pavement condition.

This paper describes Phase I of the project, covering the planning, equipment, procedures and sites for testing. Phase II of the project, covering the testing of concrete pavements and associated defects is planned for the summer of 2024 with results available in the Autumn of 2024.

2. DEFECTS IN CONCRETE ROADS

A list of defects found in concrete pavements, relevant to this work, is presented in Table 1. The definitions provided are intended to give an idea as to what types of features may be classified from the analysis of the acoustic data. It is not exhaustive or intended to substitute the definition of defects provided in Concrete Pavements Maintenance Manual [4], which remains the formal guidance document for designers and practitioners.

Table 1. Selected feature types and definition

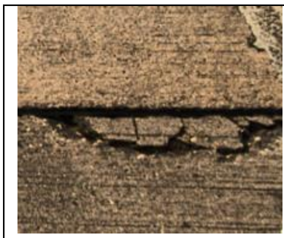
Name	**Definition**
Transverse crack	Transverse cracks divide the concrete slab perpendicularly across the width, to create (similarly to transverse joints) multiple bays.
Longitudinal crack	Longitudinal cracks divide the slab roughly parallel to the pavement centreline, to create (similarly to longitudinal joints) two narrower slabs.
Diagonal crack	Diagonal cracks traverses two perpendicular joints in a bay and is greater than 2 m in length. If shorter, this is then considered be a corner crack.

Name	**Definition**
Corner crack	Corner cracks are between 0.3 m and 2 m in length across the corner of the bay. If longer, they are then considered diagonal cracks.
Area cracking	Area cracking refers to the intersection of multiple crack types, to form a sort of grid, and cover a certain area of the whole slab.
Major spalling	Spalls are a breakdown of the surface material at the slab edges or joints but can also occur at cracks. Isolated islands of concrete near a joint are over 100 mm in width.
Minor spalling	Definition of a spall is as above. However, a spall is defined as minor if loss of material near a joint is under 100 mm in width.
Scaling	Scaling is the delamination or disintegration of the slab surface, occurring over a portion of a slab.
Pop-out	Pop-outs are isolated losses of surface material that typically range from 25 mm to 100 mm in diameter and 10 mm to 50 mm in depth.
Concrete repair	Concrete repairs consist of using concrete material to replace part of a slab.
Asphalt repair	Asphalt repairs consist of using asphalt material to cover or replace part of a slab.

Examples of some of these defect types are provided in Table 2.

Table 2. Pictorial examples of some defect types

	**Crack (linear)**: All cracks in a linear direction.		**Pop-out**: an isolated area of material loss from the surface.
	**Cracks (area):** An area of intersecting cracks, usually found within an asphalt or concrete repair.		**Concrete repair:** Where the original surface has been replaced to rectify a defect, an old core / road stud (a reinstatement repair).
	**Corner crack:** Cracks that extend across the corner of a slab, providing they are between 0.3 – 2 m in length.		**Asphalt repair:** Where the original surface has been replaced to rectify a defect, an old core / road stud (a reinstatement repair).

	**Major spalling:** The breaking up of surface material at or within 0.6 m of concrete joints. Loss of material or isolated islands of concrete created by a crack near a joint perceived to be over 100 mm in width.		**Minor spalling:** The breaking up of surface material at or within 0.6 m of concrete joints. Loss of material or isolated islands of concrete created by a crack near a joint perceived to be under 100 mm in width.

3. THE CPX METHOD

The CPX method is described in ISO 11819-2:2017 [5] and involves measuring the tyre / road noise at microphone positions close to the contact patch of the tyre. The test tyre(s) roll freely over the road surface (i.e. does not have a drive axle) and they are usually enclosed within a semi-anechoic chamber to ensure that other noise sources do not influence the levels recorded at the microphones by more than 1 dB. The method provides a direct measure of the influence of the road surface on the generation of tyre noise. Aside from free-flowing traffic conditions and a dry road surface, there are few practical constraints on performing CPX measurements. There are standard reference tyres for cars and trucks, and these are defined in ISO/TS 11819-3:2021 [6].

For this research project, a CoMeT CPX-XXL trailer [7] has been constructed. The trailer is fitted with the standard reference tyres for cars and a sound-absorbing casing, shielding microphones from interference noise such as wind, background traffic and the towing vehicle. The two-wheeled trailer ensures each wheel has its own separate acoustic chamber, allowing both wheel tracks to be measured simultaneously. The acoustic enclosure in the XXL version of trailer is large enough to accommodate all the mandatory and optional microphone positions described in ISO 11819-2:2017.

Standard CPX measurements are taken at two specified microphone positions 20 cm from the tyre wall, 20 cm in front and behind the contact patch, and 10 cm above the road surface. Results are averaged over 20 m road sections and across the two microphone positions at a reference speed of 50, 80 or 110km/h. However, for this research project relies on the notion that, dependent on its condition, the concrete pavement and subgrade will respond differently to traffic induced seismic and acoustic vibration from the tyre. Therefore, the position of the four microphones and the speed of the trailer will be adjusted to find the conditions which provide the most distinct and repeatable signature for each defect. The tri-axial accelerometer will be placed on the trailer axle to pick up vibrations associated with the pavement surface. Acoustic data will also be collected with respect to a tyre on the towing vehicle with a fifth microphone located close to the outside wall of the tyre, following the general principles of the OBSI method.

The associated data acquisition system sample rate can be adjusted and allows for greater than the minimum range of frequencies specified in ISO 11819-2:2017 to be covered. The required GPS and temperature data are also recorded, and the trial runs filmed so that a cross reference of the system with visual inspection can be made.

Pictures of the CoMeT CPX-XXL trailer to be used are given in Figure 1.

Figure 1: The CoMeT CPX-XXL trailer.

4. FUTURE WORK – PHASE II

The CPX trailer will be used to survey 10 sites across the strategic road network in England over the summer of 2024. The sites will be chosen to reflect a variety of concrete pavements, including some with visible defects, some considered in good condition and others without any visible defects but potential issues in the subgrade. A variety of signal processing techniques will be used to classify each defect in terms of its acoustic signature. Continued monthly monitoring will be completed at a chosen location to understand how the acoustic signature changes over time as the surface ages.

It is hoped that this passive acoustic technique could allow for early identification and treatment of internal cracks, often not picked up in a visual survey, before they reach the surface, allowing National Highways to improve forward planning of concrete maintenance. This would come with both safety benefits as pavements are repaired before excessive deterioration and cost benefits as efficient maintenance regimes can be arranged in advance.

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