Investigating the effect of layer thickness on the variability of porous asphalt tyre/road noise

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ABSTRACT

Longitudinal variability in tyre/road noise is often associated with low-noise porous asphalt surfaces, with CPX testing results for individual 20-metre road segments commonly varying by up to 6 dB along new projects in New Zealand. In November 2018, following on from previous trials investigating the effects of air voids and stone size, three EPA7 trial sections were constructed to investigate the effects of layer thickness on tyre/road noise. The thickness effect was found to be approximately –2 dB $L_{CPX:P1,80}$ per 10 mm increase in target layer thickness across the three trial sections. Core samples taken from a new road showed EPA7 layer thicknesses that differed from the target layer thickness by up to 15 mm. These findings suggest that variations in layer thickness may be a key contributor to longitudinal variations in tyre/road noise on roading projects using porous asphalt. A further investigation involving a detailed thickness survey is currently underway to better understand layer thickness variability and its effect on tyre/road noise.

INTRODUCTION

In New Zealand, longitudinal variability in tyre/road noise is commonly seen across porous asphalt surfaces, with CPX testing results for individual 20-metre road segments often varying by up to 6 dB along new projects. If this longitudinal variability is not considered when specifying porous asphalt surfaces (for their noise benefit) some noise sensitive receivers will experience noise levels several decibels above the average expected for the surface. Potential causes of the variability in tyre/road noise have not been rigorously investigated until recently, hampering efforts to reduce it.

NZ road surface noise research

Since 2017 Waka Kotahi NZ Transport Agency has commissioned a series of research projects to optimise its road surfaces for low tyre/road noise. “Low-noise” porous asphalt surfaces have been the initial focus of this work given noise can be a primary reason these surfaces are specified, and the high cost of porous asphalt surfaces compared to the more commonly used chipseal surfaces (surface dressings).

There have been two main focuses of the porous asphalt research:

1. To understand how bulk changes to the physical properties of a surface affects tyre/road noise, in the interest of finding an improved “low-noise” surface.
2. To investigate causes of longitudinal variability in tyre/road noise and identify methods to reduce this variability.

The first item has been approached though the use of several short (~300-metre-long) surface trial sections around Christchurch city. The specific surface designs were chosen based on previous local and international research, while also working within the limits of existing material supplies and construction methods. This work has led to a 40 mm thick EPA7 (nominally 20–25% voids and 7 mm stones) becoming the preferred “low-noise” road surface on NZ State highways, with a slightly thicker 50 mm version for particularly noise sensitive locations.

The second (longitudinal variability) focus has been approached by monitoring the construction process and taking post-construction measurements along several-kilometre long sections of new motorways around Christchurch city. This has been supported by the findings of shorter surface trial sections.

Epoxy-modified porous asphalt

OECD research on extending the life of road surfaces noted that epoxy asphalt was the only material with a track record of long life performance [1]. Over the past decade the inclusion of epoxy in porous asphalt surfaces has become common practice in New Zealand and it is now a requirement on major NZ State highway projects.

Bituminous binders oxidise as they age causing the binder to become brittle over time. This eventually causes the surface to begin to lose stones or “ravel”. The inclusion of epoxy in the binder slows down the bitumen oxidation process, thereby extending the life of the porous asphalt surface beyond its typical 8-year lifespan. The higher upfront cost of epoxy-modified porous asphalt (30% more expensive) is offset by lower overall life-cycle costs. Laboratory testing suggests a 5 times increase in life, and field performance of similar products on major bridges have achieved 40-year lives [2][3]. Investigations into porous asphalt surface greenhouse gas emissions have also shown a reduction in greenhouse gases when epoxy-modified binders are used over conventional binders [4].

The epoxy currently being used in NZ porous asphalt binders is based on a high-strength blend originally designed for use on bridge decks. The epoxy is diluted with local bitumen. Given that the additional strength provided by the epoxy is not the primary reason for its use, there may be future opportunities to modify the epoxy blend to achieve a more flexible binder more in line with the novel PoroElastic Road Surfaces (“PERS”).

All of the NZ surface noise trial sections constructed since 2017 have made use of epoxy-modified binders. These surfaces are denoted by the “EPA” code for “Epoxy-modified Porous Asphalt”.

CPX trailer system

Waka Kotahi has operated its own close proximity (“CPX”) trailer system since early 2017 (Figure 1). The system was designed and built in accordance with the draft version of ISO 11819-2 [5], which was released as an official standard in mid-2017 [6].

The CPX trailer system has been used extensively within the NZ road surface noise research programme. The outputs from this programme are available of the Waka Kotahi website [7].

Figure 1. Waka Kotahi / NZ Transport Agency CPX trailer system.

VARIABLES AFFECTING TYRE/ROAD NOISE

Tyre/road noise is known to be primarily affected by surface macrotexture (tread impact mechanism) and the ability of the surface to allow air trapped by a rolling tyre to escape (air pumping mechanism) [8].

Surface properties

The ability of a porous surface to allow trapped air to escape is controlled by its air voids content, thickness and macrotexture (larger macrotexture provides more paths at the tyre/road interface). This relationship is further complicated by the fact that surfaces with a higher percentage of air voids generally have higher macrotexture, caused by the lower fraction of fine particles used in the surface mix.

In summary, the surface properties affecting porous asphalt tyre/road noise are primarily:

- macrotexture;
- air voids content; and
- surface layer thickness.

Any difference in these properties (either between bulk surface specifications, between different locations using the same surface specification, or along the length of a road using one surface specification) can reasonably be expected to give slightly different tyre/road noise characteristics.

Construction properties

For a single surface specification (aggregate grading, binder type and fraction, and target thickness) the final macrotexture, air voids content and surface layer thickness will be affected by the:

- paving process (paving thickness, temperature, speed and stoppages); and
- rolling process (rolling temperature and number of passes).

WESTERN BELFAST BYPASS (2018)

The Western Belfast bypass is a 3 km stretch of new two-lane dual carriageway motorway on the northern side of Christchurch city. A nominally 40 mm thick EPA7 surface was chosen by the project team following a favourable noise result from the small chip noise trials [9].

Study areas

Thickness trial sections

Around 900 metres of the new Western Belfast Bypass project was set aside to investigate the effect of changes to the surface design thickness. This followed previous trials looking at the effects of void percentage and stone size on tyre/road noise [9]. Variations in thickness across a roading project were also expected to play a role in longitudinal variability of tyre/road noise, and there was a desire to quantify this effect through a controlled trial.

Three 300-metre-long trial sections were constructed using the same surface specification as the rest of the project (EPA7) but with differing target thicknesses of 30 mm, 40 mm and 50 mm.

Table 1. Data collected as part of the Western Belfast Bypass project.

Property	Measured by	Notes
Tyre/road noise	$L_{CPX,P1,80}$	CPX trailer system
Macrotexture	Mean profile depth ("MPD")	WDM high-speed data collection truck
Void content	Dielectric constant	Ground penetrating radar ("GPR")
	Direct	Laboratory testing of core samples
Thickness	Direct	3D scan (before and after paving)
	Direct	Ground penetrating radar (time-of-flight)
	Direct	Trace sheet (volume over area)
	Direct	Thickness of core samples
Roughness	IRI / NAASRA count	WDM high-speed data collection truck
Paving temperature	Direct	Infrared temperature sensors (3x)
Paving speed and stoppages	Direct	GPS logger
Rolling temperature	Direct	Infrared temperature sensor (1 per roller)
Rolling passes	Direct	GPS logger
Permeability	Direct	Constant head water column

Longitudinal variability study area

The remainder of the Western Belfast Bypass project (nominally 40 mm thick EPA7) was used to study the longitudinal variability.

Data collected

The data described in Table 1 was collected as part of the Western Belfast Bypass project to support the thickness trials and longitudinal variability study. Full details can be found in the project report [10].

Results

Thickness trial sections

Several attempts were made to measure the as-built porous asphalt layer thickness so the average thicknesses of the three trial sections (nominally 30 mm, 40 mm and 50 mm) could be precisely determined.

The high-resolution methods (3D scan, GPR and paving trace sheets) all failed to yield reliable results, so it was not possible to determine the as-built thicknesses over a wide area. However, the paving crew did actively monitor the approximate thickness during construction using a wire gauge, and post-construction core samples suggest approximate thicknesses of 30 mm, 40 mm and 50 mm were achieved within the three trial sections.

The target thicknesses of 30 mm, 40 mm and 50 mm were taken to represent the as-built thicknesses, giving a target layer thickness (*t*, in mm) to $L_{CPX:P1,80}$ relationship of:

$$L_{CPX:P1,80} = -0.24t + 102.4$$

The results are shown in Figure 2 below.

The frequency spectra from the three thickness trial sections show clear differences in noise character (see Figure 3).

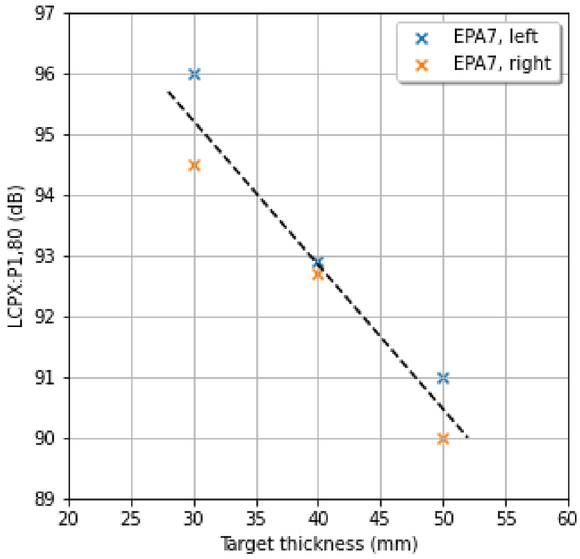

Figure 2. Target layer thickness to $L_{CPX:P1,80}$ relationship from the Western Belfast Bypass thickness trial.

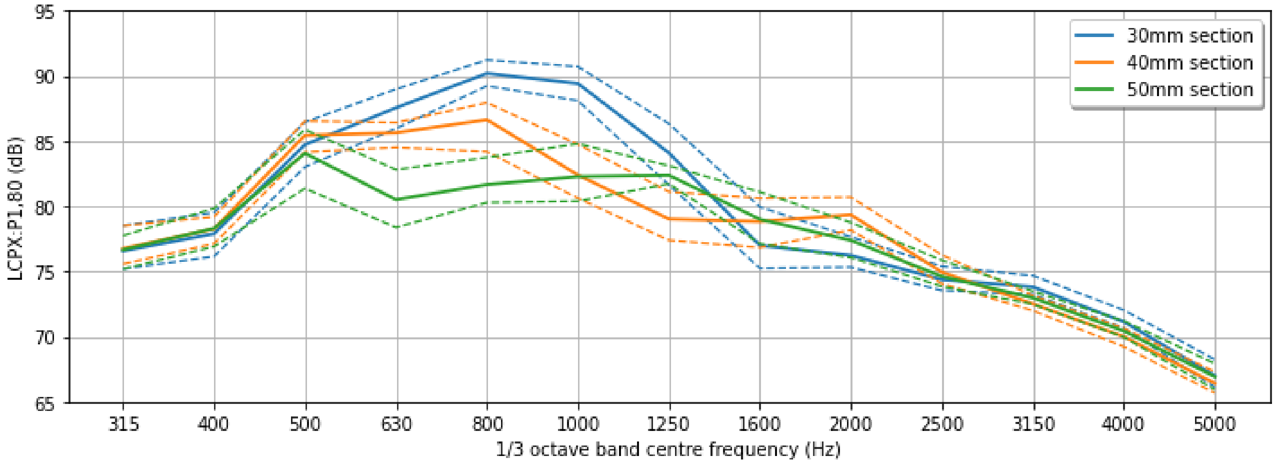

Figure 3. $L_{CPX:P1,80}$ frequency spectra for the three thickness trial sections. 20-metre road segment average (solid lines) and 95th percentile (dashed lines).

Longitudinal variability study

The lack of a comprehensive as-built thickness dataset limited the ability to investigate other sources of variability. The effect of local surface and construction properties on tyre/road noise was investigated by simply plotting the 20-metre road segment data for each property against the tyre/road noise. Apart from a weak correlation between the surface dielectric constant and tyre/road noise, no clear relationships were observed.

The as-built surface layer thickness was able to be determined at several discrete locations using core samples (3 per location) and compared to the $L_{CPX:P1,80}$ for the corresponding 20-metre road segment (Figure 4). The specific coring locations were chosen based on the measured tyre/road noise to ensure the full range of $L_{CPX:P1,80}$ was captured.

The thickness (t, in mm) to $L_{CPX:P1,80}$ relationship based on the as-built layer thickness at discrete locations is:

$$L_{CPX:P1,80} = -0.22t + 103.0$$

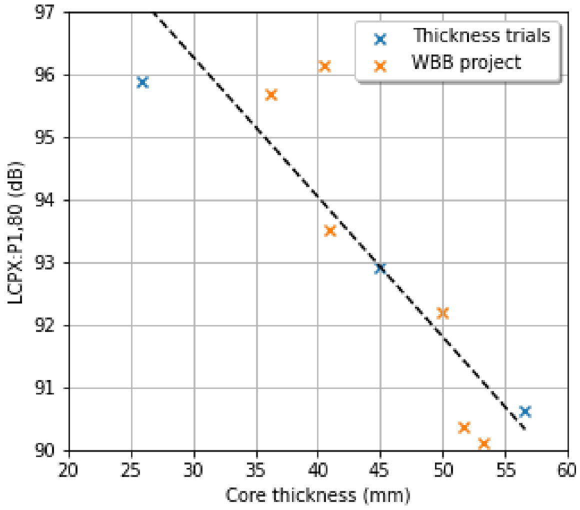

Figure 4. As-built layer thickness (from core samples) to $L_{CPX:P1,80}$ (corresponding 20-metre road segment) relationship.

The maximum and minimum as-built layer thicknesses from individual core samples taken across the nominally 40 mm thick sections of the study area were 55 mm and 35 mm, respectively; noting that these locations were chosen for their low and high $L_{CPX:P1,80}$ values respectively.

CHRISTCHURCH SOUTHERN MOTORWAY – STAGE 2 (2021)

After being unable to determine the as-built porous asphalt layer thickness at Western Belfast Bypass a second attempt was made on the Christchurch Southern Motorway, where a more rigorous survey was performed.

A nominally 40 mm thick EPA7 surface was chosen by the project team following the favourable noise result from the small chip noise trials [9] and at the Western Belfast Bypass project.

Study area and data collected

Two sections from the north and southbound carriageways were selected for a detailed thickness survey using a Leica LS15 digital level [11]. The thickness readings were taken in the left wheel path of the left lane (outer-most wheel path) at a spacing of 3 metres. The total length of lane surveyed was 2.8 km.

A short section of the study area was also surveyed using tomography with a MIT-SCAN-T3 unit [12]. This required fixing 70 mm diameter aluminium disks to the underlying pavement surface before construction of the porous asphalt layer.

Tyre/road noise measurements were taken using the CPX trailer system, and the onboard GPS was used to generate road segments that aligned with the thickness survey points.

Results

The distribution of as-built porous asphalt thicknesses across the study area is shown in Figure 5. These generally align with the maximum and minimum core thicknesses observed at the Western Belfast Bypass.

The average thickness across the study area is 43.1 mm.

Variability in $L_{CPX:P1,80}$ across the study area was considerably lower than seen across previous projects with acoustic variability s_{P1} (3-metre segments) of 0.4 dB (see Figure 6). The average $L_{CPX:P1,80}$ across the study area is 92.2 dB.

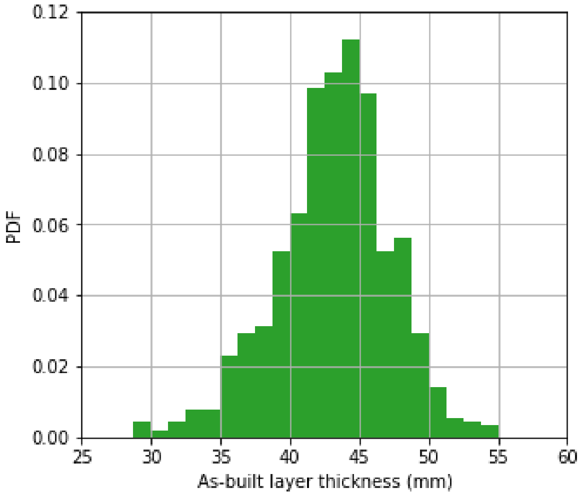

Figure 5. As-built layer thickness distribution across the study area.

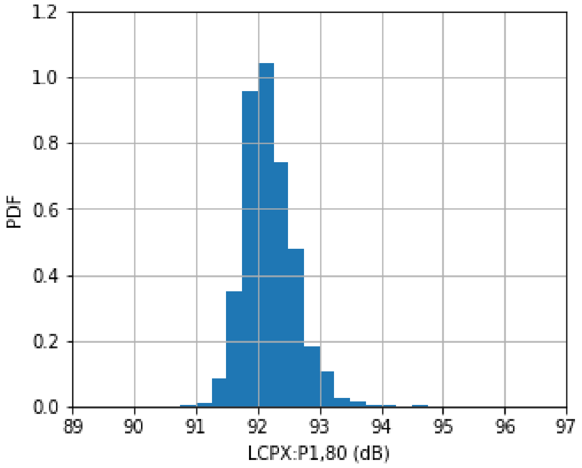

Figure 6. $L_{CPX:P1,80}$ distribution (3-metre segments) across the study area.

A linear regression of as-built layer thickness on broadband $L_{CPX:P1,80}$ did not indicate a strong relationship (see Figure 7). Moderate strength correlations were observed in some 1/3 octave bands, specifically the 500 Hz, 630 Hz, 1,000 Hz (+ve slope) and 1,600 Hz (see example in Figure 8), but these do not hold for the overall tyre/road noise level.

Grouping the 3-metre road segment results into 10 mm wide bins and comparing the frequency spectra shows a different noise character to that seen at the Western Belfast Bypass (see Figure 9), suggesting there may be differences in the surface mix compared to the previous project.

Investigations of the air voids content are underway to determine whether the Christchurch Southern Motorway surface mix differs from the Western Belfast Bypass surface mix, which could explain the difference in tyre/road noise behaviour.

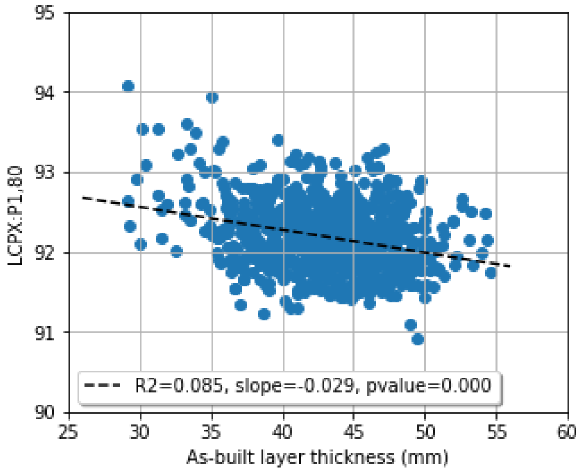

Figure 7. As-built layer thickness vs $L_{CPX:P1,80}$ (3-metre segments).

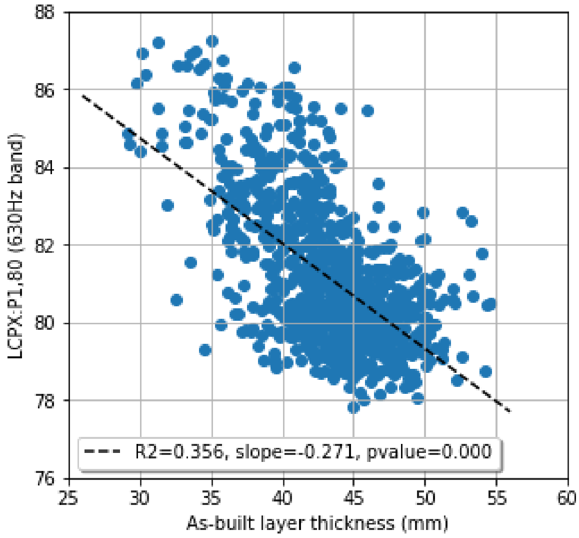

Figure 8. As-built thickness vs $L_{CPX:P1,80}$ in the 630 Hz 1/3 octave band (3-metre segments).

MIT-SCAN

The MIT-SCAN-T3 unit potentially provides a more time-efficient means of determining the as-built layer thickness compared to the precise level surveying method.

The relationship between the two methods is listed below (also see Figure 10). The relationship was based on 18 survey locations. Note that the MIT-SCAN-T3 unit reports thicknesses to the nearest 1 mm.

Based on these results the MIT-SCAN-T3 unit will likely be the primary tool used in any future surface layer thickness studies.

$$t_{MITSCAN} = 0.98t_{precise\ level} + 0.928$$

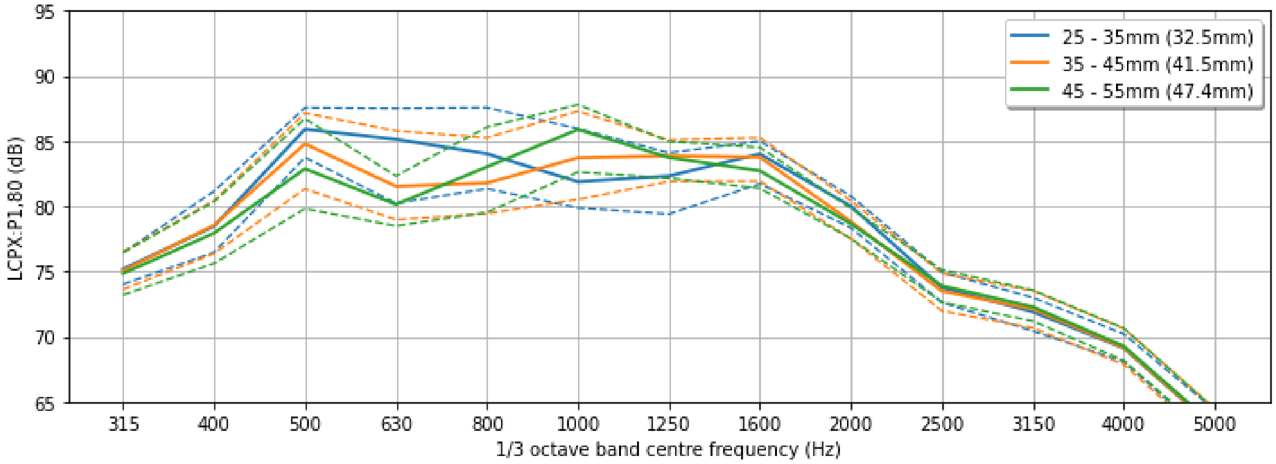

Figure 9. $L_{CPX:P1,80}$ frequency spectra grouped by as-built layer thickness (average thickness in legend). 3-metre road segment average (solid lines) and 95th percentile (dashed lines).

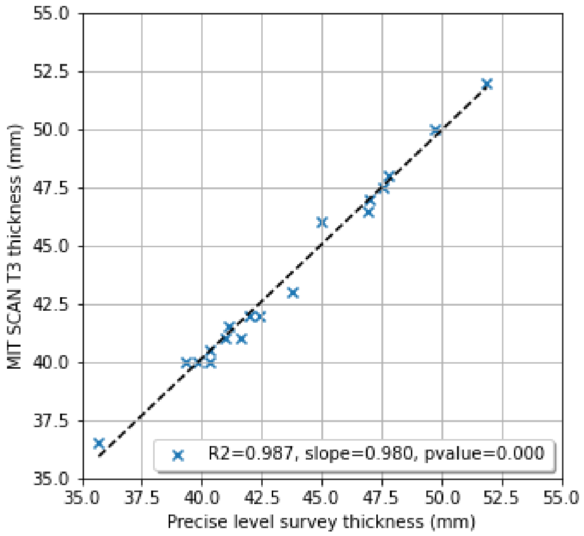

Figure 10. As-built surface layer thickness determined using the MIT-SCAN-T3 unit and precise level survey method.

UPCOMING TRIALS

A third roading project in Christchurch (Northern Corridor) is scheduled to receive a porous asphalt surface in early 2022. Several 300-metre-long noise trial sections will be included within the project. In addition, both 30 mm and 50 mm thick sections of EPA7 will form part of the wider project and provide another opportunity to investigate the thickness to tyre/road noise relationship.

SUMMARY

- The effect of thickness on tyre/road noise was investigated across three 300-metre-long trial sections and found to be approximately –2 dB $L_{CPX:P1,80}$ per 10 mm increase in target layer thickness.
- The results from the thickness trial (and previous small chip trials) have led to a 40 mm thick (E)PA7 surface becoming the preferred “low-noise” surface for use on New Zealand State highways, with a slightly thicker 50 mm version being preferred in particularly noise-sensitive areas.
- The effect of local surface and construction properties on tyre/road noise was investigated in a study of longitudinal variability. Comparison between the available datasets and $L_{CPX:P1,80}$ showed only a weak correlation with the dielectric constant; however, the absence of a reliable as-built thickness dataset meant that it is likely the main source of variability was not accounted for.
- Core samples were taken at discrete locations across the wider Western Belfast Bypass project to provide a limited as-built porous asphalt layer thickness dataset. These thicknesses were compared to the $L_{CPX:P1,80}$ values from the corresponding 20-metre segments and showed a similar – 2 dB per 10 mm increase in thickness. Differences of up to +15 mm and –5 mm between the as-built thickness and target thickness were observed.
- A further thickness survey along Christchurch Southern Motorway proved successful in gaining a detailed as-built thickness dataset but has so far been unsuccessful in verifying that longitudinal variability in porous asphalt tyre/road noise is primarily caused by variations in the surface layer thickness. The frequency spectra suggest different behaviour to that seen at the Western Belfast Bypass and differences between the two surface mixes are currently being investigated.
- The MIT-SCAN-T3 unit proved to be a reliable means of measuring the as-built porous asphalt layer thickness and will likely be the primary tool used in any future surface layer thickness studies.

ACKNOWLEDGMENTS

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