ALTISSIMO CONSULTING

Road Surface Noise

Texture Measurement Validation and
Its Effect on Tyre/Road Noise

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Project	Road Surface Noise
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Prepared by

George Bell
Consultant

Reviewed by

Robin Wareing
Principal Acoustic Engineer

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A	01-05-2024	Release draft report for client review
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Abstract

A laser line profile sensor has been installed on the Waka Kotahi CPX trailer to concurrently measure macrotexture (hereafter texture) alongside tyre/road noise. The laser and CPX tyre are aligned transversely, ensuring that the tyre/road noise measurement encompasses the observed texture.

This report has two main components, (1) validation of the measurement system, and (2) exploration of the influence of texture, specifically mean profile depth (MPD), on tyre/road noise for a range of chipseals and porous asphaltic mixes.

The measurement of MPD was not significantly affected between CPX trailer speeds of 40 and 80 km/h. The measurement of MPD was demonstrated to be independent of the current sampling rate of 800 to 900 Hz, however there is no opportunity to significantly decrease the sample rate. The laser line profile sensor measured a lower MPD when using segments of the transverse profile that were further from the centre position of the laser. In addition, the rate of dropouts was observed to increase significantly away from the centre position.

A comparative measurement of a static profile machined into a steel plate was made between the CPX laser and stationary line profilometer (SLP); the CPX laser measured a profile height of 9.90 mm compared to 10.00 mm for the SLP. The MPDs of chipseals and asphaltic mixes measured by the CPX laser were compared to the most recent CAPTIF SLP and 2024 high speed data (HSD) surveys, where the mean deltas were 0.10 and 0.02 mm less for the CPX laser, respectively. The CPX laser typically measured a lower MPD for porous asphaltic mixes, which is possibly due to the angle of incidence (minimum of 21°) limiting the ability to measure deeper surface voids. The validation suggests that the CPX laser measurements are suitable for exploring the influence of texture on tyre/road noise.

For chipseals, the MPD was observed to be a poor predictor of the overall close-proximity sound pressure level for the analysed data. However, MPD was a stronger predictor of the one-third octave bands. The 315 to 800 Hz bands were observed to be positively correlated with MPD, which is possibly due to texture-induced vibration of the tyre. The 1,250 to 5,000 Hz bands were observed to be negatively correlated with MPD, which is possibly due to a reduction in turbulent air flow noise.

When considering 7, 10, and 14 mm nominal maximum aggregate size (NMAS) porous asphaltic mixes together, a positive linear relationship between MPD and the overall close-proximity sound pressure level was observed; however, given the limited sample sizes of the 10 and 14 mm NMAS groups, the relationship must be considered as indicative. Within the subset of 30 ±3 mm thick 7 mm NMAS surfaces on CNC, MPD was found to be positively correlated with the overall close-proximity sound pressure level. For the one-third octave bands, MPD was found to be positively correlated in the 400 to 1,000 Hz bands and negatively correlated with the 2,000 and 5,000 Hz bands. While correlations were observed, MPD was a weak predictor of the one-third octave band levels for porous asphaltic mixes. Generally, achieving reduced close-proximity sound pressure levels with porous asphalt mixes required a low MPD.

Contents

Glossary

CAPTIF	Canterbury Accelerated Pavement Testing Indoor Facility
CNC	Christchurch Northern Corridor
CPX	Close proximity
CPX laser	Laser line profile sensor installed on the CPX trailer
CSM1	Christchurch Southern Motorway – Stage 1
CSM2	Christchurch Southern Motorway – Stage 2
EPA	Epoxy-modified porous asphalt
HSD	High speed data – an annual condition survey of the New Zealand state highway network
Lane 1	Closest lane to the centre of the road (see Figure 25)
Lane 2	Second-closest lane to the centre of the road (see Figure 25)
L_{CPX}	Close proximity sound pressure level. Shortened form of $L_{CPX:P1,80}$.
LWP	Left wheel path
Macrotexture	The component of surface texture with wavelengths between 0.5 and 50 mm
MPD	Mean profile depth
NB	Northbound
NMAS	Nominal maximum aggregate size
PA	Porous asphalt
PA7 HS	Porous asphalt high strength (7 mm NMAS)
RAMM	Road assessment and maintenance management
S2G	SH1 Johns Road from The Groynes to Sawyers Arms Road
SB	Southbound
SEM	Standard error of the mean
SLP	Stationary laser profilometer
SMA	Stone mastic asphalt
P1	Standard reference test tyre (passenger tyre)
WBB	Western Belfast Bypass

1 Introduction

This study is a continuation of research into tyre/road noise led by Waka Kotahi (Noise and Vibration Research | Waka Kotahi NZ Transport Agency). The aim of this work was to (1) validate the macrotexture measurements made using the newly installed laser line profile sensor on the CPX trailer, and (2) explore the influence of macrotexture (hereafter referred to as texture) on tyre/road noise for chipseals and porous asphaltic mixes.

The capability to measure texture was added to the CPX trailer in late 2023 to enable the collection of concurrent and transversely aligned data. Previous attempts to add the capability to measure texture to the CPX trailer in 2020 (Wareing, 2020) and early 2023 were unsuccessful due to the failure of hardware. The direct measurement of texture enables exploration of the full high-resolution surface profiles; these profiles are not readily accessible from the annual HSD surveys. An LMI Gocator line profile sensor was installed ahead of and in transverse alignment with the left wheel, this sensor collects 150 mm wide transverse profiles at a sample rate up to 900 Hz. For example, when travelling at 80 km/h, a 150 mm wide transverse profile is collected every 25 mm.

The primary metric for characterising texture for road surfaces is the mean profile depth (MPD), which is described in ISO 13473-1:2019. A 2023 study investigated the use of an envelopment model to develop relationships with tyre/road noise for a limited sample of asphaltic mixes on the Christchurch Northern Corridor (CNC) in New Zealand (Bell, 2023). It was determined that the texture metrics from the envelopment model proposed by Goubert and Sandberg (2018) exhibited similar predictive ability as MPD for tyre/road noise. Tyre/road noise was observed to be positively correlated with MPD in the 315 to 1,000 Hz bands, and uncorrelated from 1,250 to 5,000 Hz.

A 2019 study explored the relationship between MPD and the overall tyre/road noise level for a range of asphaltic mixes and chipseals in New Zealand (Jackett, 2019). When considering the mean MPD and close--proximity sound pressure level grouped by surface type (e.g., PA10, SMA10, etc.), a linear relationship was observed with a slope of 3.42 dB/mm. When considering the 20 m segments within each surface type, the variation in MPD only accounted for a maximum of 30% of the observed change in the close-proximity sound pressure level.

This investigation aimed to expand the understanding of the influence of texture on tyre/road noise through the use of the MPD measured by the CPX laser for a range of chipseals and asphaltic mix surfaces in Canterbury.

This report contains the following:

- A brief description of the CPX laser.
- A summary of the data used in the analyses.
- Validation of the CPX laser measurement system through:
    - Exploration of key parameters including CPX trailer speed, sample rate, transverse effects, and dropouts.
    - Comparisons of the measured results to other sources.
- Exploration of the relationships between texture and tyre/road noise.

2 CPX Laser

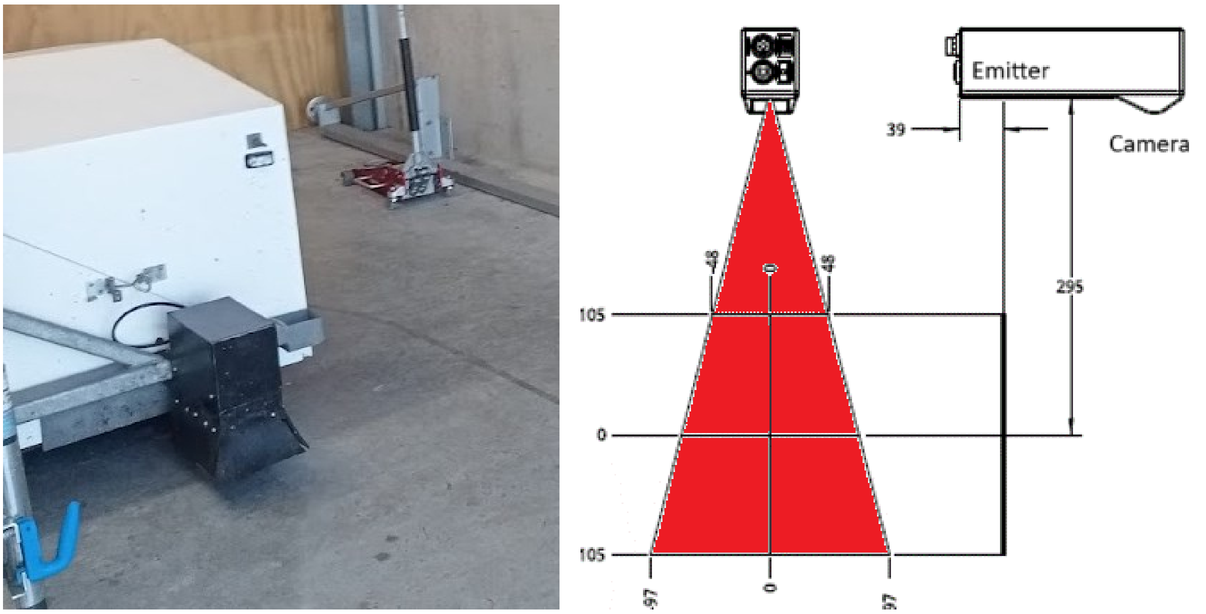
An LMI Gocator line profile sensor was installed on the CPX trailer – see Table 1 for device details and (LMI, 2024) for the specification sheet. Hereafter, the term "CPX laser" is used to refer to the laser line profile sensor installed on the Waka Kotahi CPX Trailer.

Table 1: Details of the CPX laser.

CPX Laser	
Brand	LMI
Description	Gocator Line Profile Sensor
Model	Gocator 2140
Transverse resolution*	0.19 to 0.34 mm (640 points)
Height resolution	0.013 to 0.037 mm

*Increasing the height of the laser decreases the transverse resolution as the quantity of points is fixed at 640.

Figure 1 shows (a) a photo of the CPX laser installed on the Waka Kotahi CPX trailer and (b) a diagram of the sensor. The CPX laser is fitted 1 m ahead (i.e., in the direction of travel) of and transversely aligned with the left wheel. The emitter and camera are 300 mm above the surface of the road under static loading (i.e., no movement of the suspension). The CPX laser measures an approximately 150 mm wide transverse profile at a sample rate up to 900 Hz. When travelling at 80 km/h, a 150 mm wide transverse profile is captured every 25 mm along the road. The emitter and camera are 115 mm apart (in the longitudinal direction), with the laser being vertical. When the emitter is 300 mm from the surface of the road, there is a 21° angle between the emitter and camera. The CPX laser is shrouded to minimise external light, increasing the maximum sampling rate. The CPX laser measurements are captured using the CPX data acquisition system, which allows for precise geo-positioning and timing alignment.



(a) (b)

Figure 1: (a) Photo of the CPX laser enclosure fitted on the Waka Kotahi CPX trailer, and (b) diagram of the sensor and field of view.

3 Data and Measurements

Table 2 contains details of the data used in the analyses. The sample length by surface type and location can be found in Table 7 in the appendix. A table of surfaces is maintained by CAPTIF that records the extents of trial sites and routinely measured locations; accurate positional data was collected for the start and end positions. Only surface types and extents recorded in the CAPTIF surfaces table were used in this investigation (surface properties from RAMM were not used). All CPX measurements followed ISO 11819 and are for the left wheel path (LWP) and were made with the P1 tyre at 80 km/h. Within the text of this report L_{CPX} is equivalent to $L_{CPX:P1,80}$.

Table 2: Details of data used in the analyses.

Source	Data	Longitudinal Resolution	Location	Measurement Date
Waka Kotahi CPX Trailer	Tyre/road noise (L_{CPX}) & Texture (MPD)	4 m	CNC	09-01-2024
			CSM1&2	12-01-2024
			Groynes Ramps	12-01-2024
			S2G	09-01-2024
			SH73***	12-01-2024
			Aylesbury Corner	12-01-2024
			Paparua Prison	12-01-2024
			Kirwee	12-01-2024
			WBB	12-01-2024
CAPTIF SLP*	Texture (MPD)	1.8 m / 10 m**	CNC	08-03-2023
			Aylesbury Corner	10-10-2023
			Paparua Prison	10-10-2023
			Kirwee	11-04-2023
2024 HSD Annual Survey	Texture (MPD)	10 m	CSM1 & 2	02-03-2024
			CNC	01-03-2024
			SH73**	01-03-2024
			S2G	29-02-2024
			WBB	29-02-2024

*Stationary laser profilometer

** SLP profiles are 1.8 m long and are typically taken every 10 m along the road.

***The Kirwee, Aylesbury Corner, and Paparua Prison sites are all located on SH73. When "SH73" is used, this includes all three sites and the connecting sections. Where only the site names are used, it is limited to the trial location(s).

4 Texture Measurement and Validation

The validation of the CPX laser has been divided into two parts: (1) measurement parameters, and (2) measurement comparisons. The measurement parameters considered the effect of the CPX trailer speed during measurement, the sample rate, the influence of transverse position on MPD, and the dropout rate. The measurement comparisons included measuring a static profile with the CPX laser and the SLP, and comparison of the MPD measurements by the CPX laser and most recent CAPTIF SLP and 2024 HSD annual survey of various chipseals and asphaltic mix surfaces.

4.1 Measurement Parameters

4.1.1 CPX Trailer Speed

It is intended that the CPX laser will be operated in parallel with routine tyre/road noise surveys, which are typically performed at 80 km/h. To confirm that the measured MPD is independent of the CPX trailer speed the SMA10 (40 mm) on the Groynes northbound off-ramp was surveyed at 40 and 80 km/h. One run was undertaken at each speed. A 130 m section was separated into 1 m long segments. A histogram of the deltas between the MPD of each segment measured at 80 and 40 km/h is shown in Figure 2. There was a mean difference of 0.01 mm, which is practically and statistically insignificant. The standard deviation of the deltas was 0.06 mm, which suggests small measurement-to-measurement variability within segments. This variability may arise from the GPS accuracy of the start and end points of each segment, differences in the transverse position in the lane of the laser between runs, or another factor. Limitations of this analysis are the relatively short (130 m) length and only completing a single run at each speed. There is no indication that the measurement of MPD has any dependence on CPX trailer speed between 40 and 80 km/h.

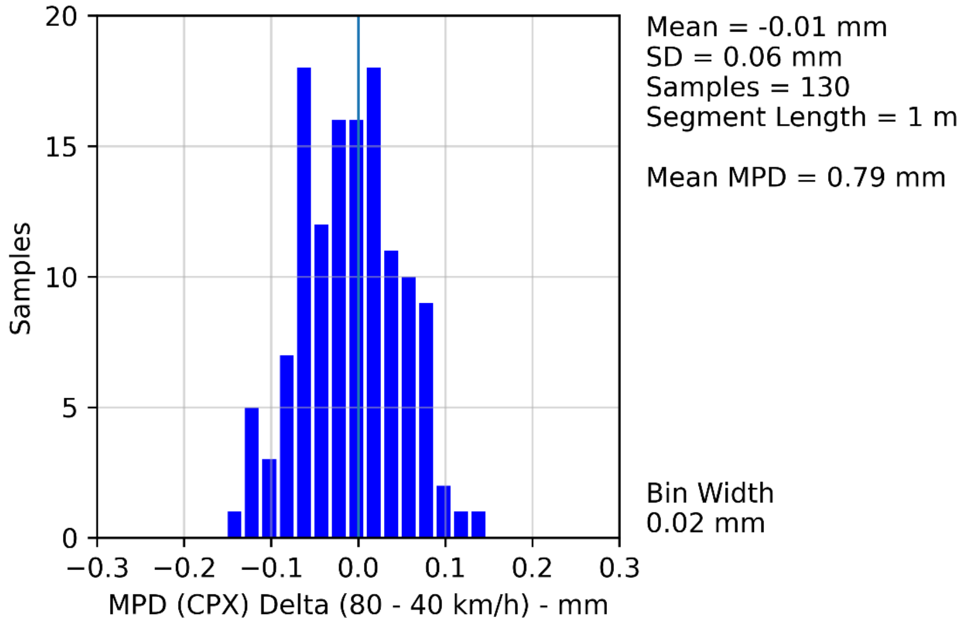


Figure 2: Distribution of deltas between 80 and 40 km/h measurements for the SMA10 (40 mm) on the Groynes northbound off ramp.

4.1.2 Sample Rate

This analysis aimed to assess how the sample rate affects the measured MPD. For instance, with a sample rate of 876 Hz and a CPX trailer speed of 80 km/h, the CPX laser records a transverse road profile every 25 mm. The sample rate is set at the beginning of each measurement run. The onboard controller automatically determines the maximum sample rate based on the conditions at the time (e.g., ambient lighting, field of view, surface reflectivity, etc.). During the Canterbury survey, the sample rate fluctuated between 800 and 900 Hz. The sample rate can also be manually set. This analysis sought to determine whether manually reducing the sample rate impacts the resulting MPD measurements.

A lower sample rate may be beneficial in reducing the file sizes and data handling requirements. For example, at the highest sample rate, a measurement session for CNC with two runs in each lane on both carriageways accumulates 4 GB of raw texture data. The file size is directly proportional to the sample rate, therefore quartering the sample rate from 800 to 200 Hz would also quarter the file size.

The following steps were undertaken to determine the influence of the sample rate on MPD. The steps are described for a single 10 m long segment of road with a sample rate of 876 Hz. There is then a description of how this was applied to a larger sample. For this analysis, all data collected at the highest sample rate was treated as if it were the full population.

1. The population mean for the segment was calculated. For a 10 m segment, there were 394 MPD measurements.
2. Decreased sample rates were simulated by uniformly down-sampling the population in the segment (e.g., a sample rate of 438 Hz was achieved by using every second measurement from the full population, therefore using 197 samples).
3. The difference in the down-sampled group from the population mean was calculated, expressed as the absolute percentage of the population mean. E.g., for a population mean of 1.0 mm and a down-sampled group mean of 0.9 mm, there is a difference of 0.1 mm, which is 10% of the population mean.
4. The process was repeated for subsequent sampling increments. The minimum sampling rate assessed was 10 Hz (4 samples in a 10 m segment).

When exploring the relationships between tyre/road noise and MPD, discrete longitudinal segments are typically considered. The length of these segments can vary depending on the analysis, but lengths up to 20 m are commonly used. Six kilometres of lane 2 on the southbound carriageway of CNC were separated into longitudinal segments of 1, 10, and 20 m and the above steps were completed for every segment. The mean absolute delta was calculated for each segment length and simulated sample rate.

Figure 3 presents the mean absolute deviation from the population mean, expressed as a percentage, as a function of sample rate for segment lengths of 1, 10, and 20 m. An example of how to interpret the figure is as follows: if the sample rate was reduced to 29 Hz (sample spacing of 750 mm) and a segment length of 10 m was used, the measured mean MPD would be within ±4% of the population mean. Maintaining the sample rate at the highest achievable level is advisable to facilitate the possible utilisation of shorter segment lengths while mitigating sensitivity to variations in sampling.

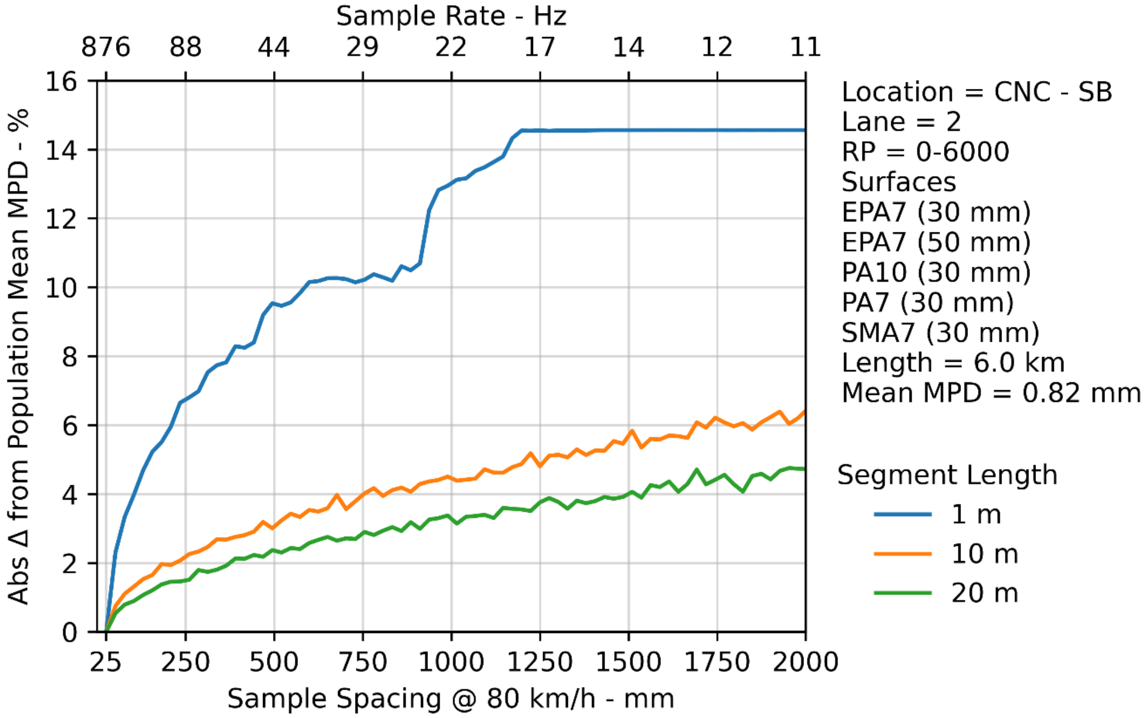


Figure 3: Change in mean MPD as a function of longitudinal sample spacing and sample rate for porous asphaltic mixes on CNC.

4.1.3 Transverse Effects

The CPX laser is a line profile sensor, where a line is emitted from a source and reflections are captured by an adjacent camera (see Figure 1 (b)). This type of laser differs from the type used by the CAPTIF SLP and HSD annual survey, which use single-point lasers that are traversed longitudinally along the road. The CPX laser captures a line that is approximately 150 mm wide (centred transversely about the source), which corresponds to a lateral angle of ±14° about the centreline. In addition to the transverse incidence angle, the 115 mm spacing between the emitter and camera introduces a 21° longitudinal incidence. Given the minimum of a 21° incidence, the CPX laser is unable to capture the full depth of some troughs in surfaces with texture angles that approach vertical (e.g., some surface voids on porous asphalt). This analysis explored the influence of the transverse position on the measured MPD.

Figure 4 contains a simplified diagram of a line profile sensor measuring a textured surface; note that the diagram does not have the same proportions as the CPX laser. The diagram highlights that the laser can more directly view (and therefore measure) troughs beneath the emitter/camera, but this ability is reduced at greater angles of transverse incidence.

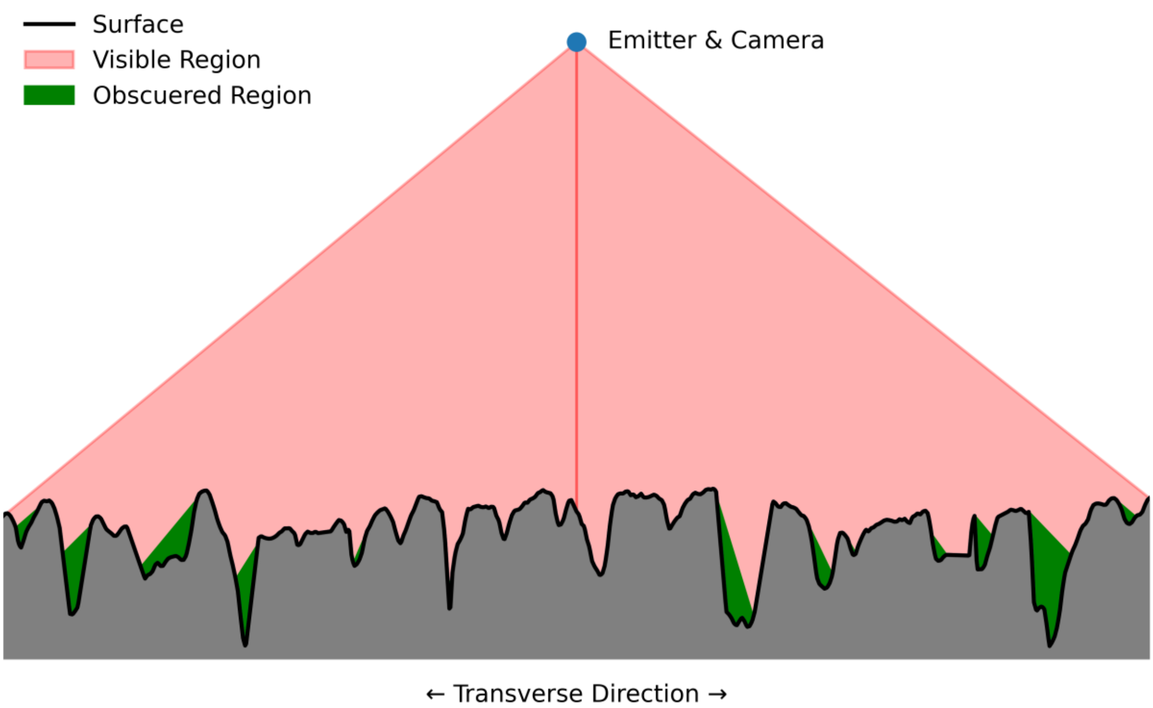


Figure 4: Diagram of the transverse field of view of a line profile sensor for a textured surface.

Part of the calculation of MPD requires the delta between mean and peak height for a segment of the texture profile (hereafter "profile segment"). For this analysis, a profile segment length of 50 mm was used. The centre position of the profile segment (e.g., -50 mm for the -75 to -25 mm segment) was incremented in 0.5 mm steps from --50 to +50 mm. For each step, the MPD was calculated. This was undertaken for a sample of porous asphaltic mixes on CNC. Due to processing limitations, a subsample was used that consisted of 16,384 (2^{14}) randomly selected profiles. It was assumed that this subsample was representative of porous asphaltic mixes for the purpose of exploring transverse effects. However, it must be noted that the independence of this assumption from the sample size was not explicitly verified.

The resulting MPD as a function of transverse location is shown in Figure 5. As suggested above, the MPD was greatest for segments in transverse alignment with the emitter and camera. If the segment is centred ±25 mm from the central location, the measured MPD decreased by 2%. It is recommended that the central 50 mm of each transverse profile is used in the calculation of MPD to minimise the influence of the transverse angle of incidence.

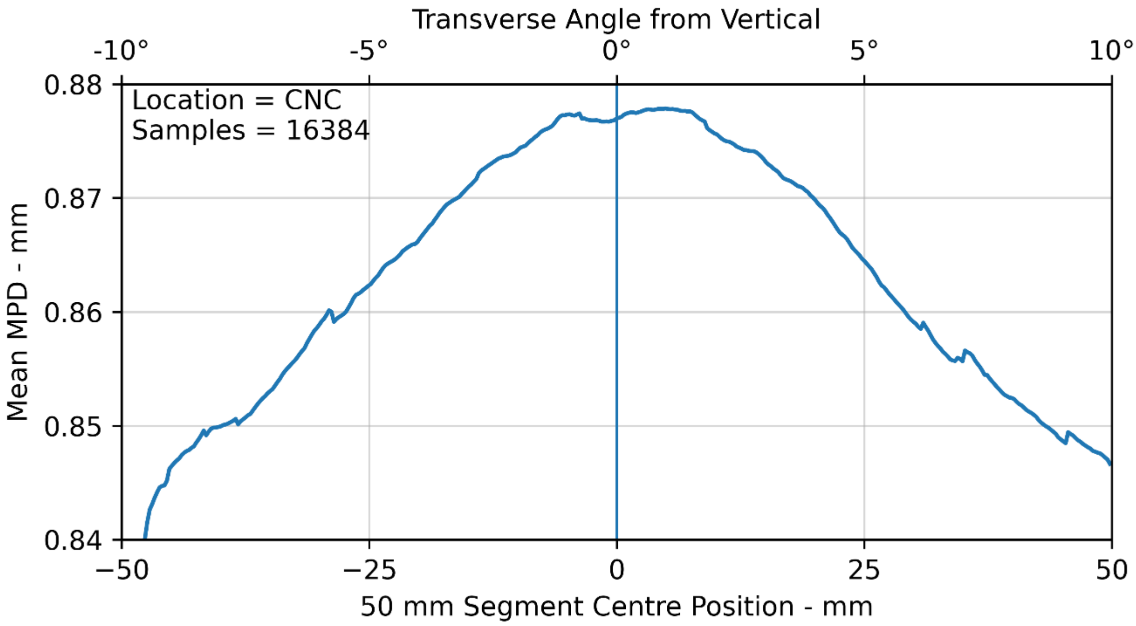


Figure 5: Mean MPD as a function of transverse position for porous asphaltic mixes on CNC.

4.1.4 Dropouts

During measurements, the CPX laser may return a "dropout" value for a position. Dropouts can occur due to the following:

- Surface irregularities causing obstructions between the emitter and camera (e.g., voids, cracks, deep texture, etc.).
- Abnormal light reflection properties (e.g., absorption, reflection, scatter, etc.) of the surface, which could be caused by oil-based films, moisture, etc.
- Interference by external light.

ISO 13473-1:2019 allows for a maximum of 20% dropouts in a single profile before it must be discarded. For profiles with less than 20% dropouts, the intervening values may be filled by linear interpolation.

The rate of dropouts experienced by the CPX laser was explored. Both the overall and transverse effects were considered. The analysis was separated into the porous asphaltic mixes on CNC and the chipseals on SH73; this grouping was done due to the distinct surface characteristics of porous asphaltic mixes and chipseals, such as positive and negative texture, and the presence of voids. Subsets of the full populations were used, which consisted of 16,384 (2^{14}) randomly selected profiles. It was assumed that these subsamples were representative of porous asphaltic mixes and chipseals for the purpose of observing dropouts. However, it must be noted that the independence of this assumption from the sample size has not been explicitly verified.

The distributions of the overall percentage of dropouts for the asphaltic mixes and chipseals are shown in Figure 6 and Figure 7, respectively. The dropout rate is for the full transverse profile (i.e., approximately 150 mm). For asphaltic mixes, 71.5% of the transverse profiles met the 20% threshold, while 99.3% of the chipseal profiles achieved the same requirement. The mean overall percentage of dropouts for asphaltic mixes was 16.4%, which was markedly higher than the mean of 6.3% for chipseals. The higher rate of dropouts for asphaltic mixes may possibly be attributable to the presence of voids at the surface (i.e., negative texture).

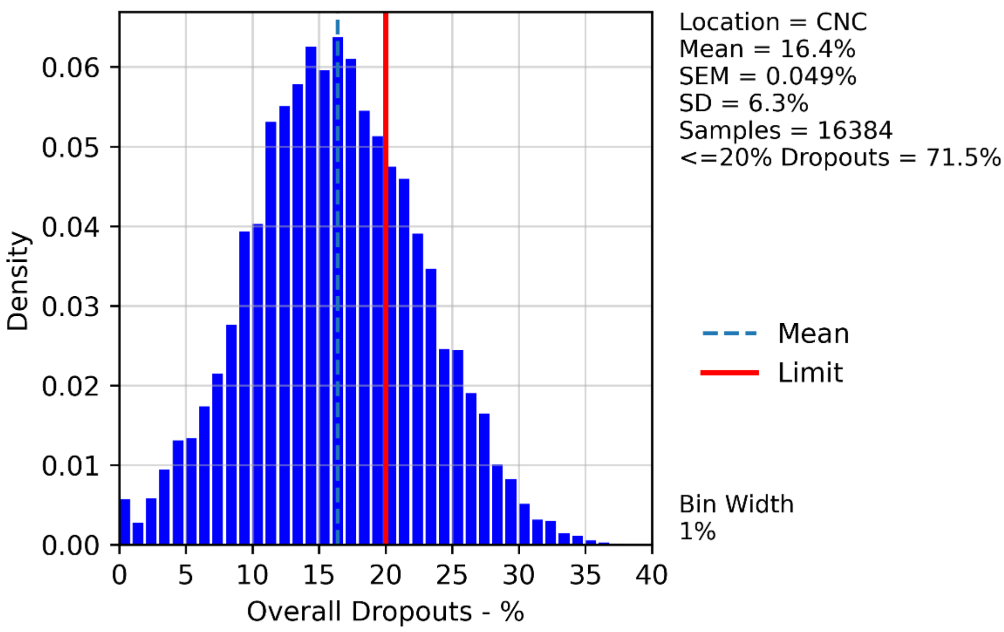


Figure 6: Distribution of overall dropouts for porous asphaltic mixes on CNC.

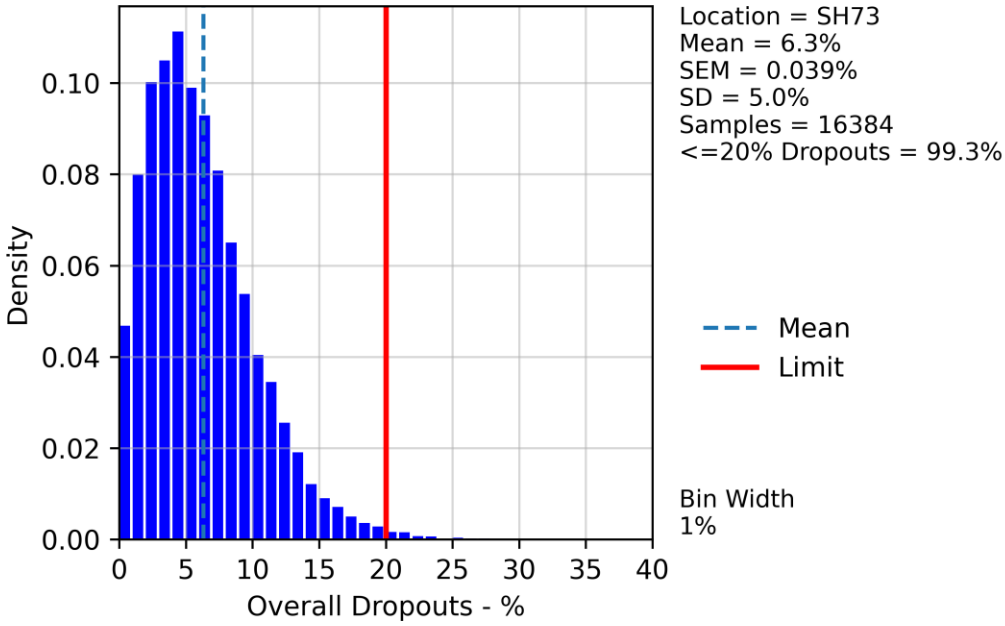


Figure 7: Distribution of overall dropouts for chipseals on SH73.

The rate of dropouts by transverse position was explored to determine if measuring away from the centreline of the emitter/camera influenced the measurement. The same subsets were used as above. The mean rate of dropouts by transverse position (as the distance from the centreline of the laser) for asphaltic mixes and chipseals are given in Figure 8 and Figure 9, respectively. The corresponding transverse angle from vertical for a laser height of 300 mm is included in the figures. For both surface types, the lowest rate of dropouts occurred near the centreline of the laser and increased up to an angle of approximately 10°. Using the central 50 mm instead of 100 mm of each profile for the calculation of MPD results in the mean dropout rate decreasing from 15.3 to 12.3% for the subset of asphaltic mixes and 5.7 to 4.3% for the subset of chipseals. The reduction in the dropout rate increases the quantity of valid profiles and decreases the use of interpolation. Interpolating missing values may mask physical texture. The lowest dropout rate appears to have occurred at approximately 1°, which may suggest a small misalignment; this has not been explored further in this investigation.

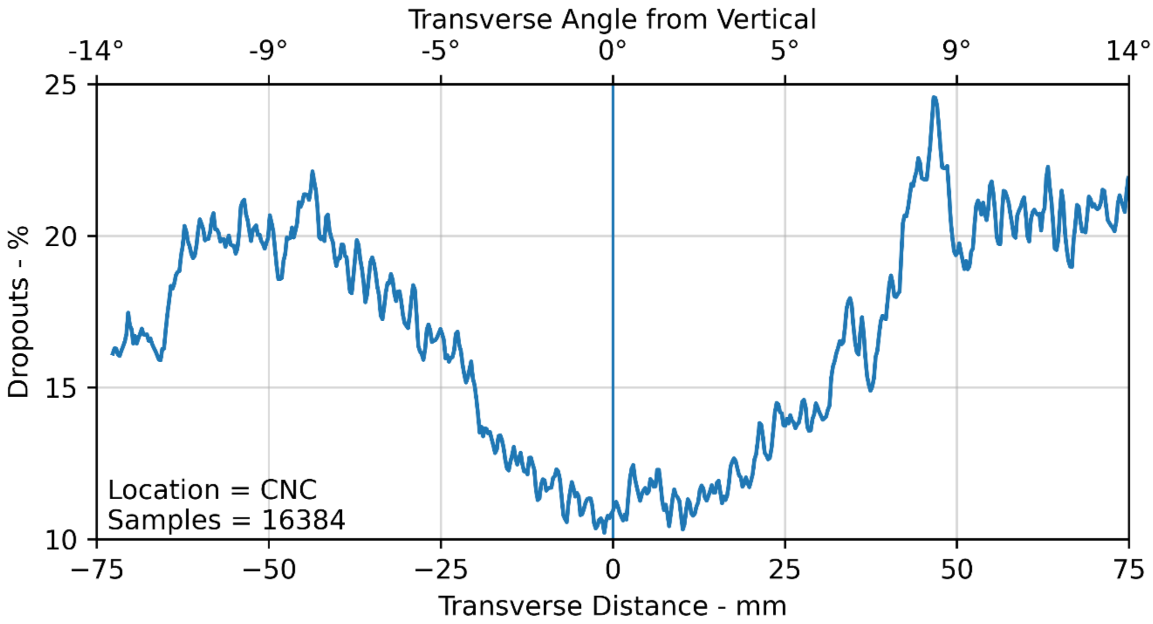


Figure 8: Mean dropouts as a function of transverse position for asphaltic mixes on CNC.

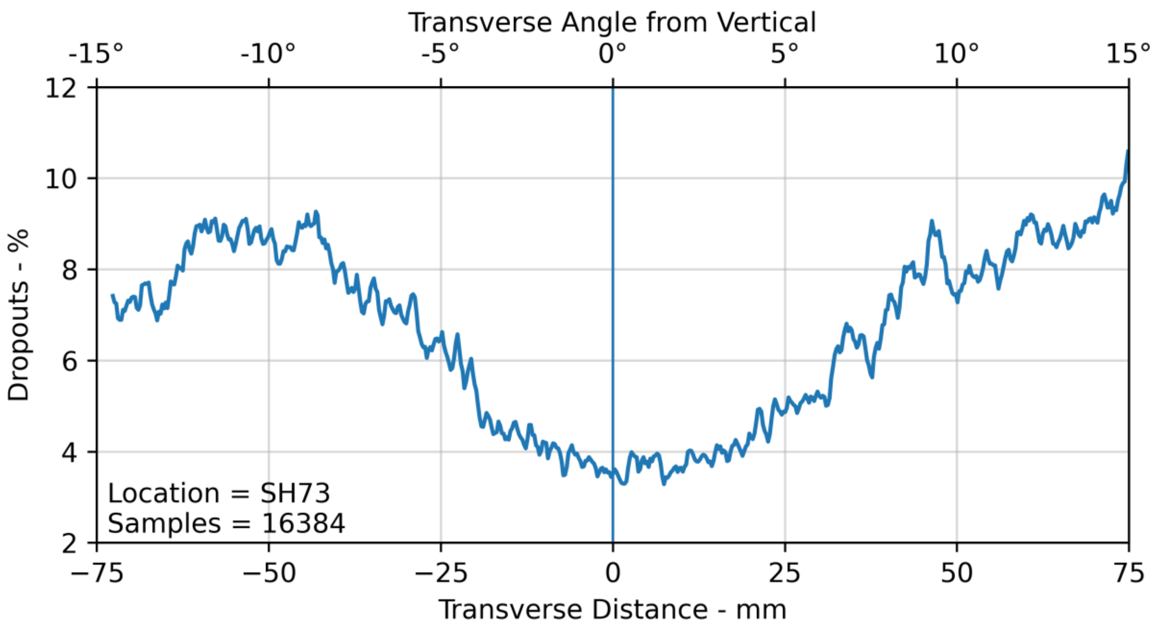


Figure 9: Mean dropouts as a function of transverse position for chipseal surfaces on SH73.

4.2 Comparative Measurements

4.2.1 Comparative Measurement of a Static Profile

The same static profile was measured using the CPX laser and SLP to explore whether there were any differences in the outputs from the two methods. The static profile is a saw-tooth waveform that is machined into a steel plate. The saw-tooth has a nominal peak-to-peak horizontal pitch of 20 mm and a nominal peak to trough height of 10 mm. Measuring a sawtooth profile using a system that produces discrete transverse points presents a significant limitation, as the exact peaks and troughs of the profile can be easily missed.

The profile measured by the CPX laser is shown in Figure 10. The CPX laser and SLP measured mean peak-to-trough heights of 9.90 ±0.03 and 10.00 ±0.08 mm, respectively. The 0.10 mm difference in mean peak-to-trough height between the two methods is 1% of the nominal height. This difference is expected to have minimal practical implications when comparing texture measurements made by the CPX laser and SLP.

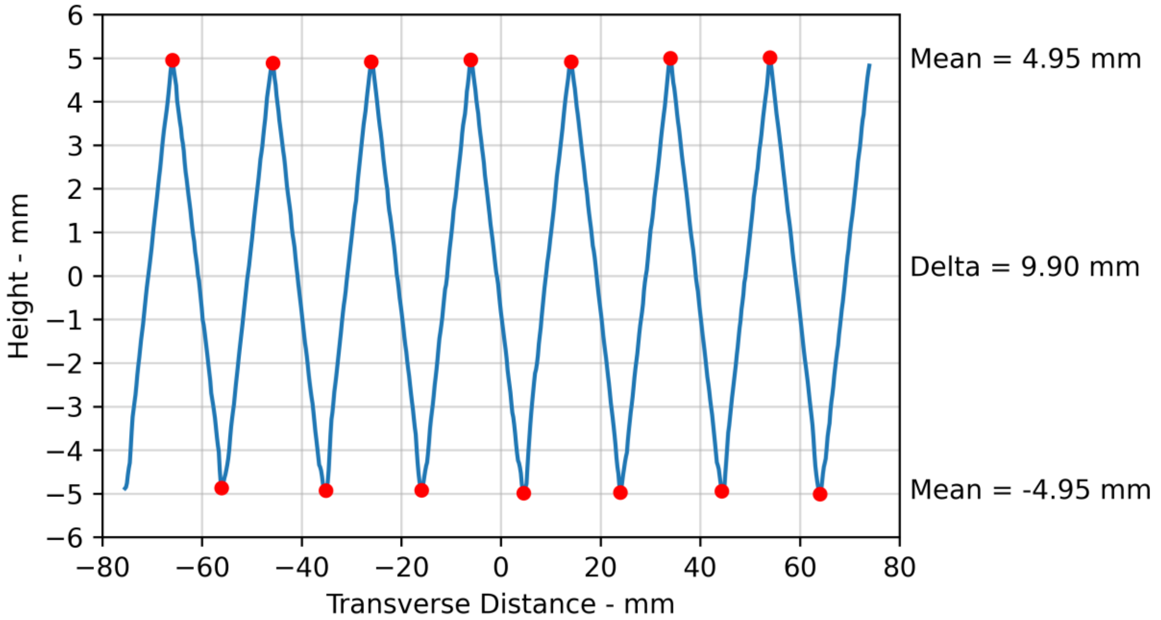


Figure 10: Measured profile of the static plate using the CPX laser.

4.2.2 Stationary Laser Profilometer

The MPD measured by the CPX laser was compared to that captured during the CAPTIF SLP survey of four sites. The most recent CAPTIF SLP survey results were used. The quantities of samples and time intervals between the two measurements are given in Table 3. For all sites, the CAPTIF SLP survey preceded the CPX laser measurements. The SLP has an angle of 21° between the emitter and camera, which matches the minimum angle at the central transverse position for the CPX laser. The mean MPDs of all transverse profiles measured by the CPX laser (at approximately every 25 mm along the road) within the 1.8 m SLP longitudinal profile were calculated for each measurement location. All measurements made using the CPX laser were at a CPX trailer speed of 80 km/h. Both the SLP and CPX laser measurements were in the left wheel path.

Table 3: Sample quantities, and time deltas between CPX laser and CAPTIF SLP measurements.

Location	Samples	Time Delta (CPX - SLP) - Months
CNC	97	9
Aylesbury Corner	29	3
Paparua Prison	14	3
Kirwee	52	9

The comparison between MPD measured by the CPX laser and SLP is shown in Figure 11. Strong agreement was observed between the two measurements, evidenced by a linear fit with a slope of 0.99 mm/mm and an R^2 value of 0.96.

Potential causes of deviations between the two measurements include:

- A mismatch in the start and end positions of the 1.8 m long segments from the GPS.
- The use of transverse (CPX laser) compared to longitudinal (SLP) profiles.
- Unintentionally capturing a slightly different transverse position within the lane.
- Physical changes to the surfaces between the two measurements.

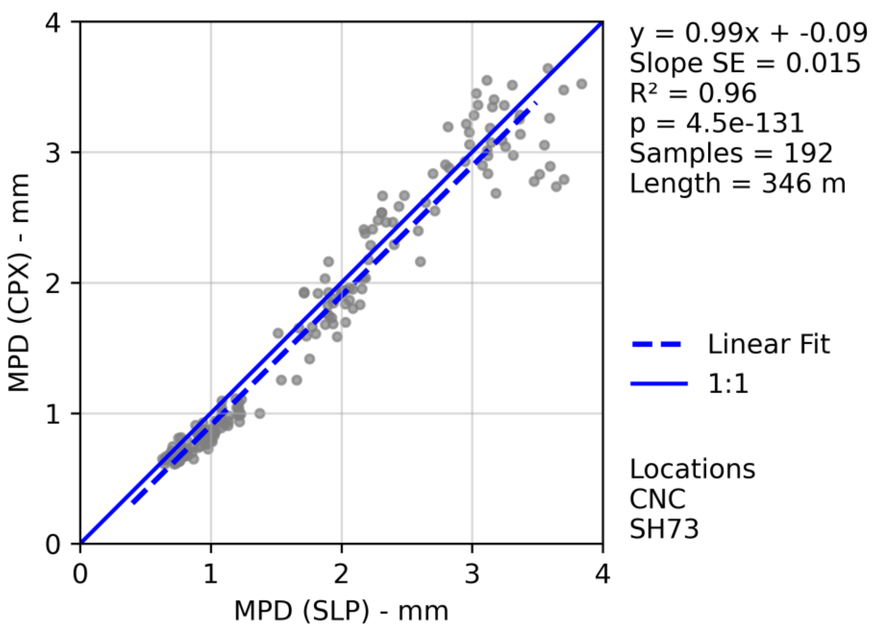


Figure 11: MPD measured using the CAPTIF SLP versus the CPX laser.

A histogram of the deltas between each point is shown in Figure 12. In addition, the deltas as a function of absolute MPD (from the SLP) are shown. The CPX laser measured a mean MPD of 0.10 mm less than the SLP. There is an indication that the mean MPDs for asphaltic mixes on CNC (MPDs less than approximately 1.5 mm) measured by the CPX laser were less than that measured by the SLP, while no or minimal difference was observed for the mean MPD of chipseals. These differences are explored further within the HSD comparison.

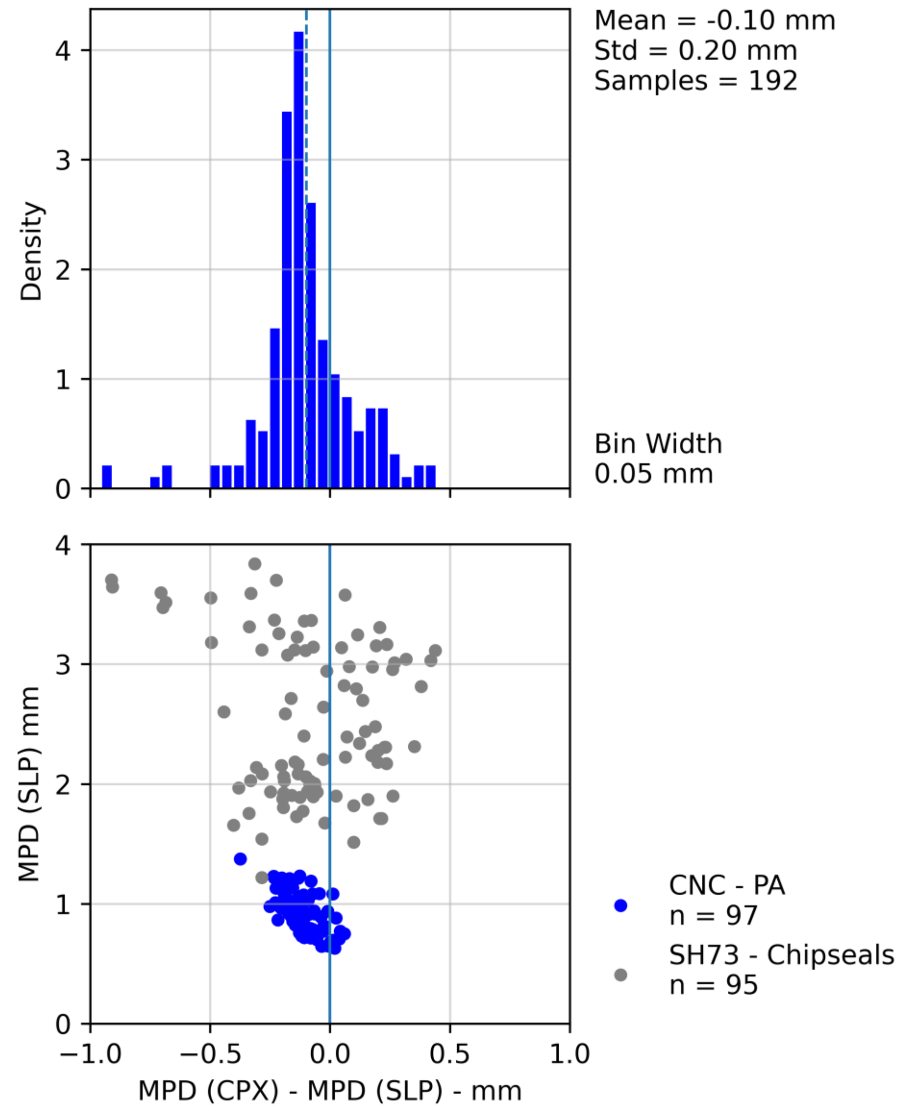


Figure 12: Distribution of the deltas in MPD measured by the SLP and CPX laser.

4.2.3 Annual HSD Survey

The results from the CPX laser were compared to those captured during the 2024 HSD survey (WDM, 2019). The 2024 HSD survey at the relevant locations was completed within a period of two months after the CPX laser measurements (see specific dates in Table 2). The HSD survey reports MPD at a longitudinal resolution of 10 m; the mean MPD measured by the CPX laser was calculated for each 10 m long segment.

The comparison between MPD measured by the CPX laser and HSD survey is shown in Figure 13. Strong agreement was observed between the two measurements, evidenced by a linear fit with a slope of 1.13 mm/mm and an R^2 value of 0.91. The slope being greater than one suggests that the CPX laser generally recorded lower values at low MPDs and higher values at high MPDs compared to the HSD survey. A histogram of the deltas between each measurement is shown in Figure 14. The CPX laser measured a mean MPD of 0.02 mm less than the HSD survey results, with a standard deviation of 0.19 mm.

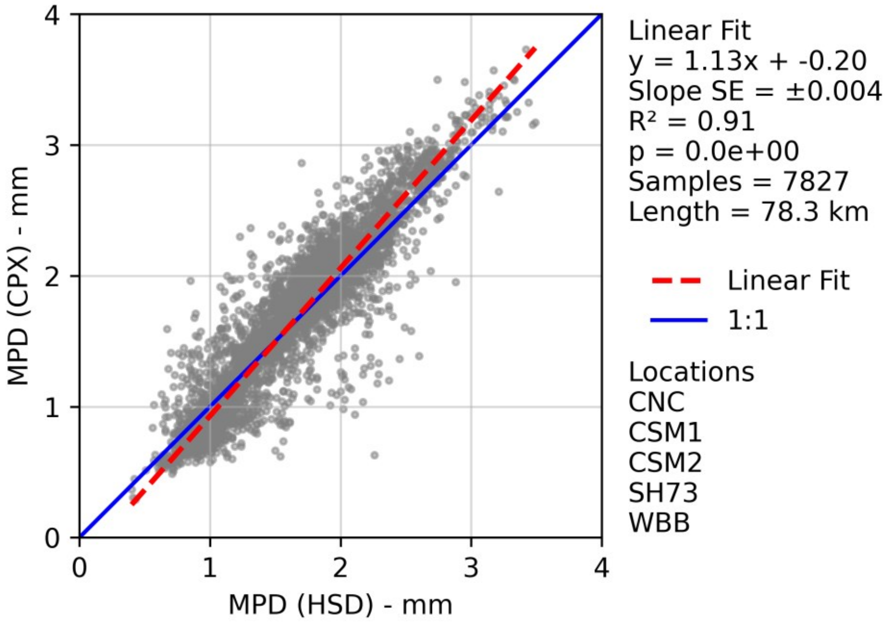


Figure 13: MPD measured during the 2024 HSD survey versus the CPX laser.

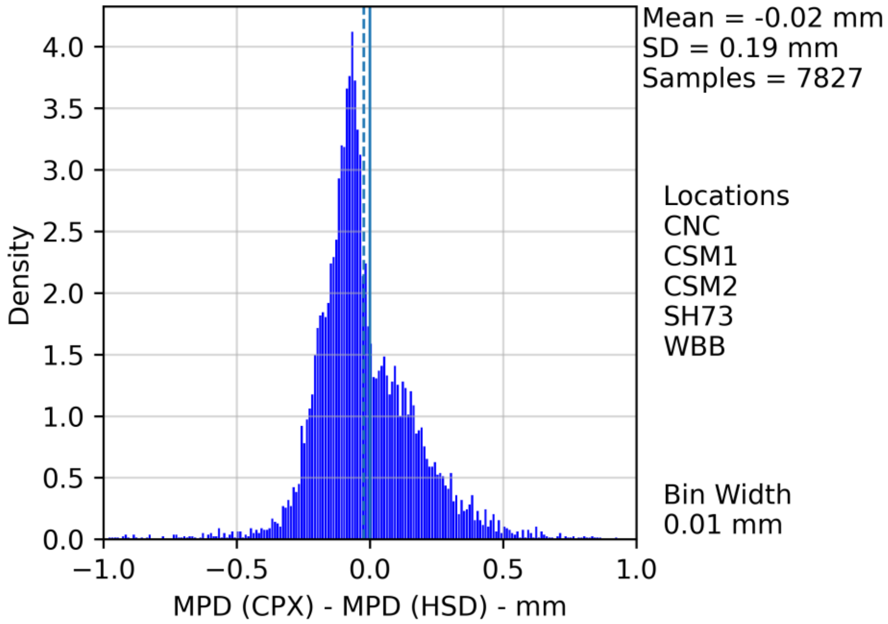


Figure 14: Distribution of the deltas in MPD measured during the 2024 HSD survey and by the CPX laser.

The deltas between the CPX laser and HSD survey were grouped into porous asphaltic mixes and chipseals. The key statistics for each group are given in Table 4. The mean deltas (CPX minus HSD) were -0.12 mm and 0.14 mm for porous asphaltic mixes and chipseals, respectively. The percentage difference of the mean is significantly larger for porous asphaltic mixes than chipseals (-14% versus 6%). It is hypothesised that the lower MPD for the CPX laser on porous asphaltic mixes arises from the 21° angle between the emitter and camera constraining the ability to measure into surface voids. The cause of the positive difference for chipseals is unknown.

Table 4: Summary of deltas between the CPX laser and HSD survey grouped by surface material.

Material	Sample Length	Mean MPD (CPX)	Mean MPD (HSD)	Delta (CPX - HSD)	SD of Deltas
Porous Asphaltic Mixes	38.5 km	0.86 mm	0.98 mm	-0.12 mm	0.17 mm
Chipseals	4.9 km	2.20 mm	2.06 mm	0.14 mm	0.39 mm

4.3 Summary of Measurement Validation

It was confirmed that MPD was not significantly affected between CPX trailer speeds of 40 and 80 km/h, indicating that measurements taken in parallel with tyre/road noise surveys at 80 km/h are suitable for use. The current sample rate of 800 to 900 Hz is sufficiently high to ensure independence of the measured MPD from the sampling rate; however, there is limited opportunity to lower the sample rate to reduce the file size.

The line profile sensor measured a lower MPD when using segments of the transverse profile that were away from the centre position. In addition, the rate of dropouts was observed to increase significantly away from the centre position. Therefore, it is recommended to utilise the central 50 mm of each profile when calculating MPD.

Comparisons with other measurement systems were undertaken, key conclusions were:

- **Comparative Measurement of a Static Profile**
  The CPX laser and SLP measured heights within 1% of each other for a static profile with a nominal height of 10 mm.
- **CAPTIF SLP Survey**
  The MPDs measured by the CPX laser were on average 0.10 mm less than those measured during the CAPTIF SLP survey.
- **2024 HSD Survey**
  The MPDs measured by the CPX laser were on average 0.02 mm less than those measured during the 2024 HSD survey. The CPX laser typically measured lower MPDs for porous asphaltic mixes and higher values for chipseals.

The findings suggest that the CPX laser yields measurements suitable for exploring the influence of texture on tyre/road noise.

5 Effects of Texture on Tyre/Road Noise

The effects of texture, specifically MPD, on tyre/road noise were explored using the data collected in January 2024 in Canterbury. L_{CPX} versus MPD is shown in Figure 15 with the data grouped into surface material (chipseals, PA, and SMA). The boundaries of each region represent the lower 2.5th and 97.5th percentiles. Only surface materials from the CAPTIF surfaces table are included in this figure due to the high confidence in the data.

The general trend was that surfaces with texture greater than approximately 1.5 mm had corresponding L_{CPX} values over 100 dB. Only surfaces with an MPD less than 1.0 mm were able to achieve significantly reduced levels of L_{CPX}. However, the range of L_{CPX} for surfaces with an MPD of less than 1.0 mm extended from approximately 90 to 100 dB, indicating that lower texture alone does not result in a low L_{CPX}. Only surfaces with porosity and high top asphalt layer thickness (i.e., 50 mm) achieved the lowest observed L_{CPX} values. Porous asphalt was the only surface material to achieve an L_{CPX} less than 97 dB, however the observed range extended to 103 dB. The SMA ranged from 97 to 100.5 dB, but critically lacked any surfaces with an NMAS larger than 10 mm. All chipseals were above 99 dB, and do not include any single-coat grade 4 or 5 surfaces.

The analyses below have been separated into chipseals and porous asphalt. There is no further consideration of SMA in this report due to the limited spans of MPD and L_{CPX} in the available data.

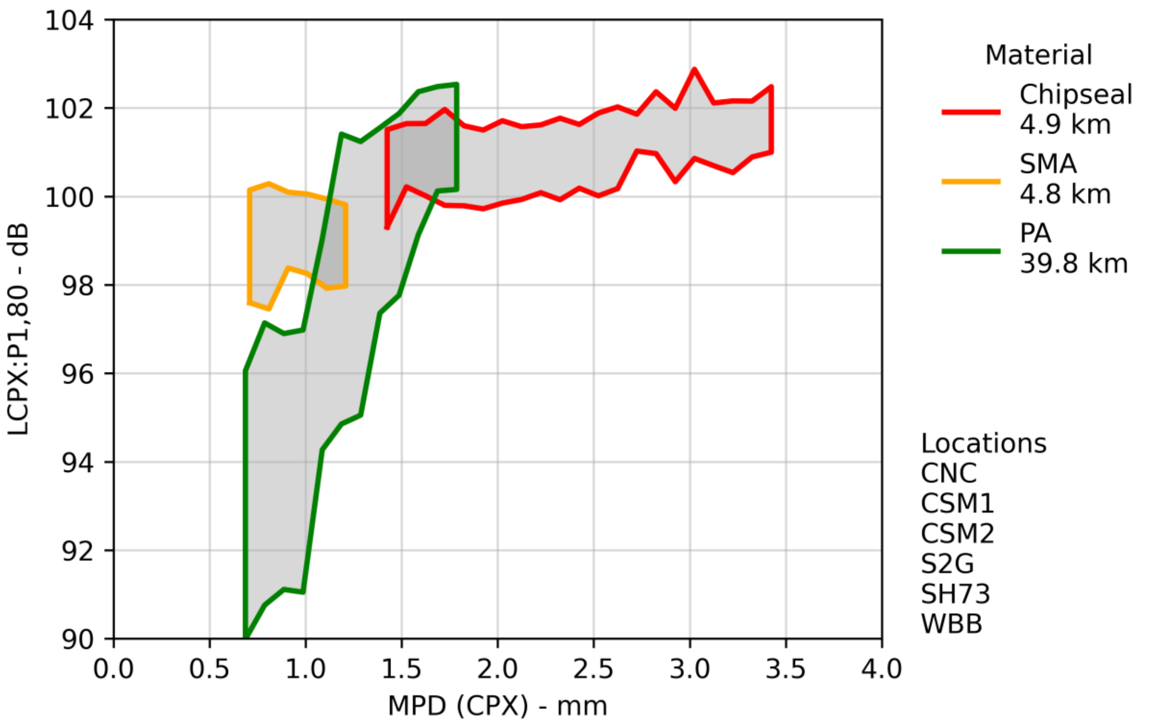


Figure 15: 2.5th to 97.5th percentile boundaries of L_{CPX} as a function of MPD grouped by surface material.

5.1 Chipseals

This analysis considered the influence of MPD on the overall L_{CPX} and one-third octave bands for a range of chipseals on SH73. The included locations are given in Table 5. The samples contain chipseals with largest aggregate grades of 2 and 3, and single to multiple bitumen coats. The age of the surfaces ranged from new to 20 years with a mean of 6.5 years.

Table 5: Boundaries and lengths of samples on SH73 used for the chipseal analysis.

Road ID	Start	End	Length*
1713	6,000	18,240	23.4 km
1841	4,904	8,704	7.6 km

*Length includes both directions and has some internal sections removed (e.g., passing through townships, invalid CPX segments, etc.).

5.1.1 Overall L_{CPX}

The overall L_{CPX} versus MPD is shown in Figure 16. A linear fit between L_{CPX} and MPD had a positive slope of 0.47 dB/mm. The linear fit had an R^2 of 0.10 with the measured data, suggesting that MPD is a very weak predictor of the overall L_{CPX} for this sample of chipseals.

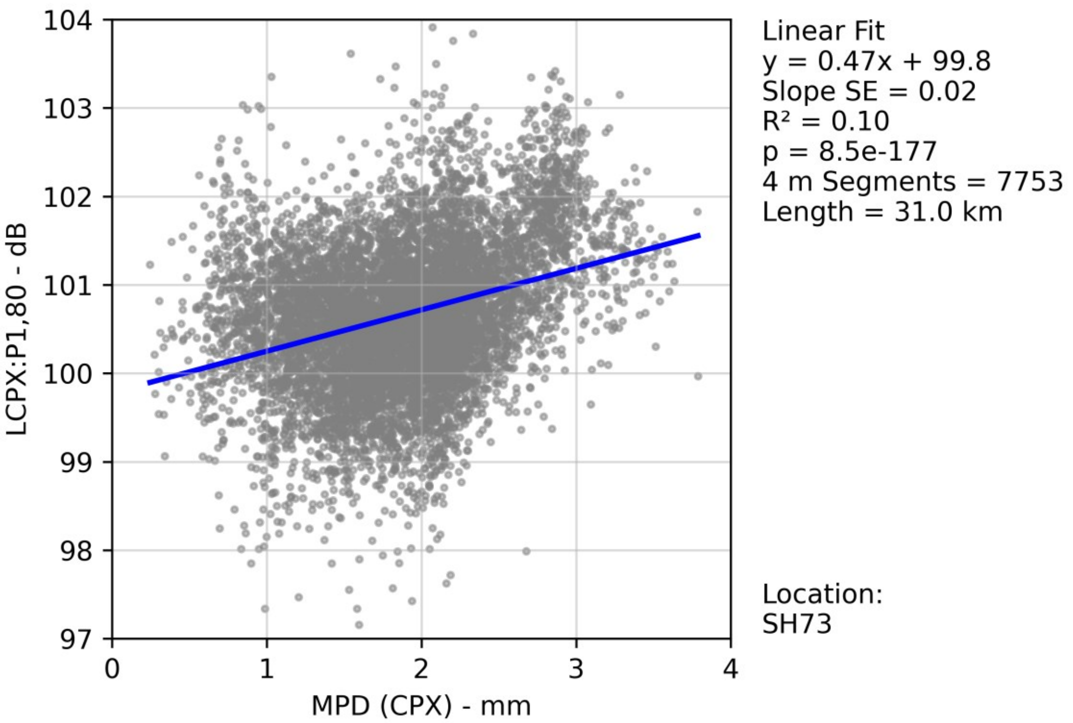


Figure 16: L_{CPX} versus MPD for chipseals on SH73.

5.1.2 L_{CPX} Spectra

The influence of MPD on the one-third octave band L_{CPX} spectra was explored. Linear models were applied between each one-third octave band and MPD. The resulting slopes of the linear models and R^2 values are shown in Figure 17. Only relationships significant at $p \leq 0.01$ are included.

L_{CPX} was positively correlated with MPD in the 315 to 800 Hz bands, uncorrelated in the 1,000 Hz band, and negatively correlated in the 1,250 to 5,000 Hz bands. The following mechanisms are hypothesised:

- The positive correlations may be due to the surface texture exciting the tyre.
- The negative correlations are possibly due to a reduction in turbulent air flow noise from air pumping; this is because the greater texture allows for a portion of the air displaced by the tyre to be more easily dispersed in the unenveloped deeper texture.
- The L_{CPX} in the 1,000 Hz band being uncorrelated with MPD is possibly due to overlapping influences of the texture-induced vibration and turbulent air flow noise.

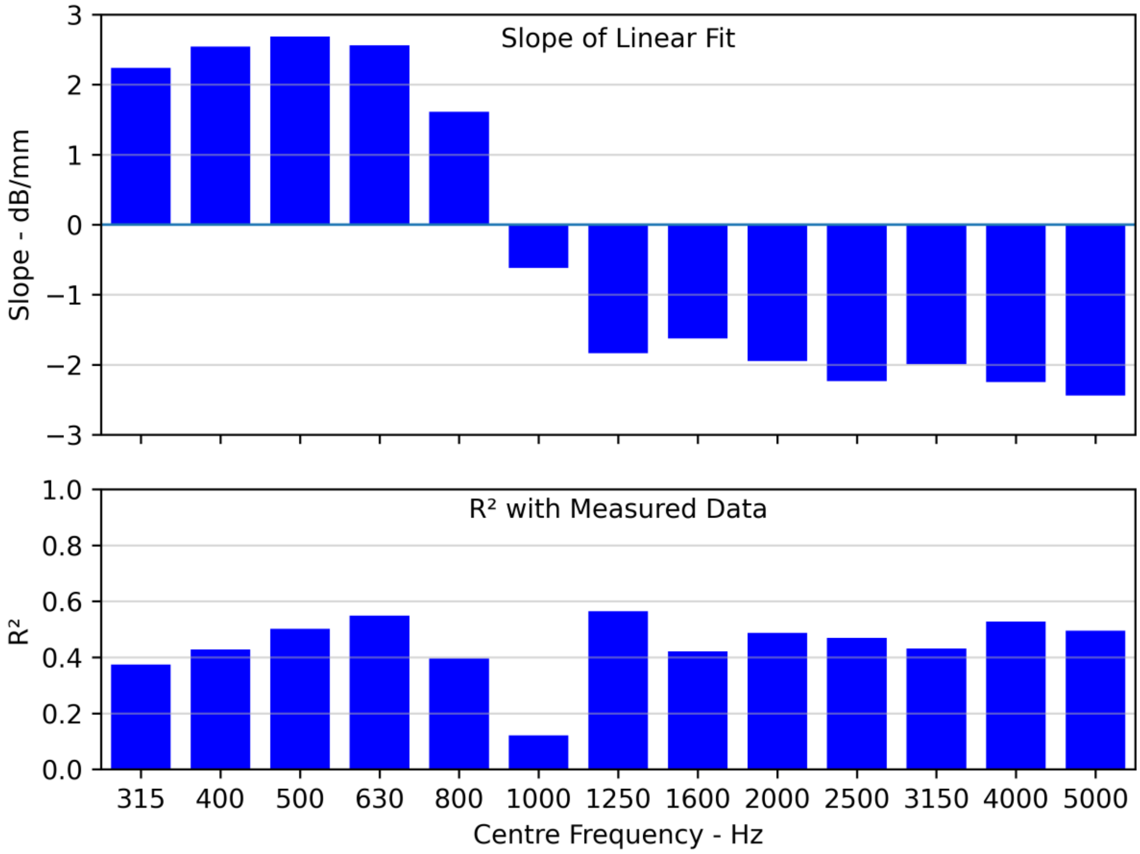


Figure 17: Slopes and R^2 of linear fits between L_{CPX} and MPD for chipseals on SH73.

One-third octave spectra for MPDs of 1, 2, and 3 mm are shown in Figure 18. As indicated by the linear models, the 315 to 800 Hz bands increase with MPD, while the 1,250 to 5,000 Hz bands decrease with MPD. While the overall level is minimally affected by MPD, the different spectra might be perceivably different to a roadside observer.

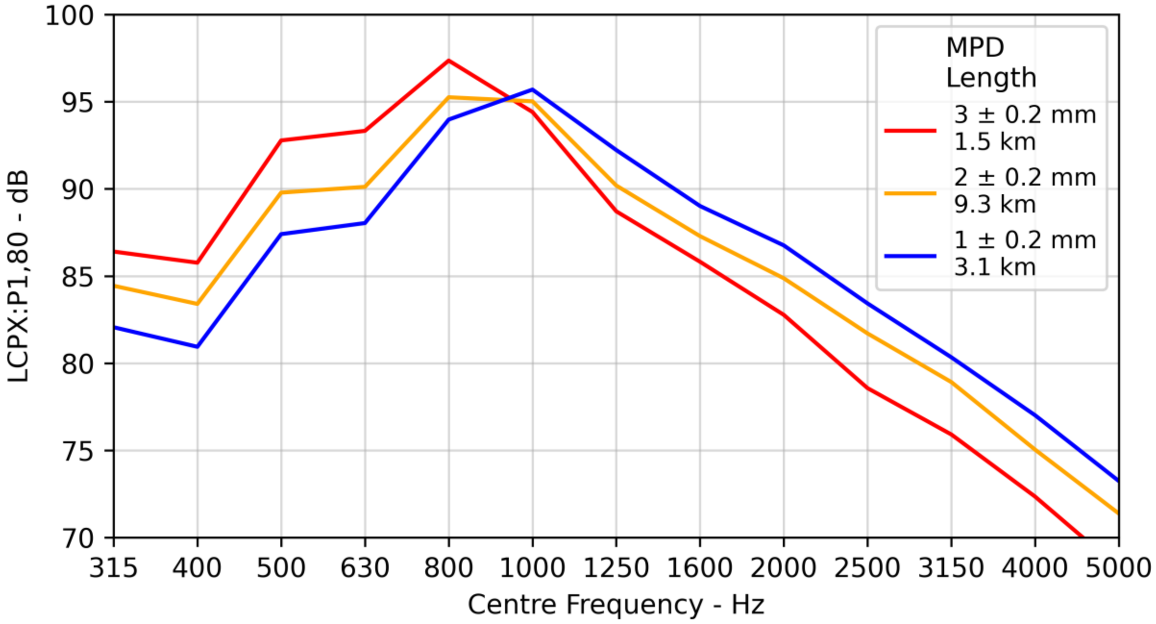


Figure 18: One-third octave band L_{CPX} spectra grouped by MPD for chipseals on SH73.

Scatter plots of the 630 and 4,000 Hz bands versus MPD are shown in Figure 19. These two frequency bands were selected to illustrate the positive and negative correlations. For the 630 Hz band, the variance of the L_{CPX} from the linear fit is approximately constant over the range of MPDs. For the 4,000 Hz band, the measured L_{CPX} diverges from the linear fit above an MPD of approximately 2.0 mm. The mechanism that is causing this phenomenon is unknown.

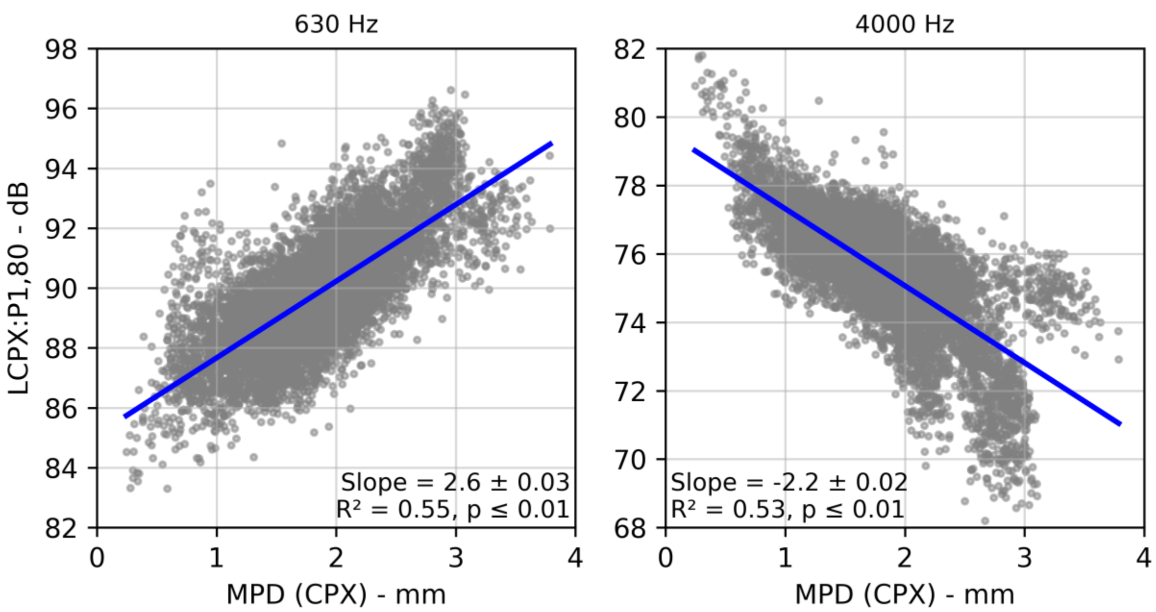


Figure 19: 630 and 4,000 Hz L_{CPX} bands versus MPD for chipseals on SH73.

5.2 Porous Asphaltic Mixes

This analysis considered the influence of MPD on the overall L_{CPX} and one-third octave bands for a range of porous asphaltic mixes in Canterbury. Table 6 contains the locations and surface types.

Table 6: Surface types by location

Location	Surfaces
CNC	EPA7 (30 mm) EPA7 (50 mm) PA7 (30 mm) PA7 HS (30 mm) PA7 LV (30 mm) PA10 (30 mm)
CSM2	EPA7 (40 mm)
S2G	EPA10 (30 mm) EPA10 HV (30 mm) EPA14 (30 mm)
WBB	EPA7 (30 mm) EPA7 (40 mm) EPA7 (50 mm)

This analysis has the following components:

- Overall L_{CPX} versus MPD for all nominal maximum aggregate size (NMAS) groups.
- Comparison of MPD by nominal maximum aggregate size (NMAS) group.
- Overall L_{CPX} versus MPD for 7 mm NMAS for filtered thicknesses on CNC.
- One-third octave band L_{CPX} versus MPD for 7 mm NMAS for filtered thicknesses on CNC.

The analysis was limited to CNC for the last two steps as the high-spatial resolution thickness data allowed for filtering to the specified level (e.g., thicknesses of 30 ±3 mm). Filtering to a narrow thickness band allowed for the minimisation of this dominant source of variation in L_{CPX}.

5.2.1 Overall L_{CPX}

Figure 20 shows the boundaries of the overall L_{CPX} versus MPD grouped by NMAS for a range of porous asphaltic mix surfaces (see Table 6). The upper and lower boundaries of each NMAS envelope correspond to the 2.5th and 97.5th percentiles. The linear fit is between the mean MPD and mean L_{CPX} for each NMAS group (i.e., three points). The linear fit has a slope of 10.3 dB/mm; this should be considered as indicative given the very low sample lengths of 0.9 and 0.3 km for the 10 and 14 mm NMAS groups, respectively. Figure 20 highlights the presence of a strong positive relationship between L_{CPX} and MPD. It appears that NMAS is a strong driver of MPD, with minimal overlap between the groups - albeit with the limitation in sample size. Within the 7 mm NMAS group, there was a range of 0.6 to 1.0 mm in MPD and 90 to 97 dB in L_{CPX}. It is expected that the range of L_{CPX} for the 7 mm group is primarily due to the layer thickness as this sample includes surfaces with specified thicknesses of 30 to 50 mm.

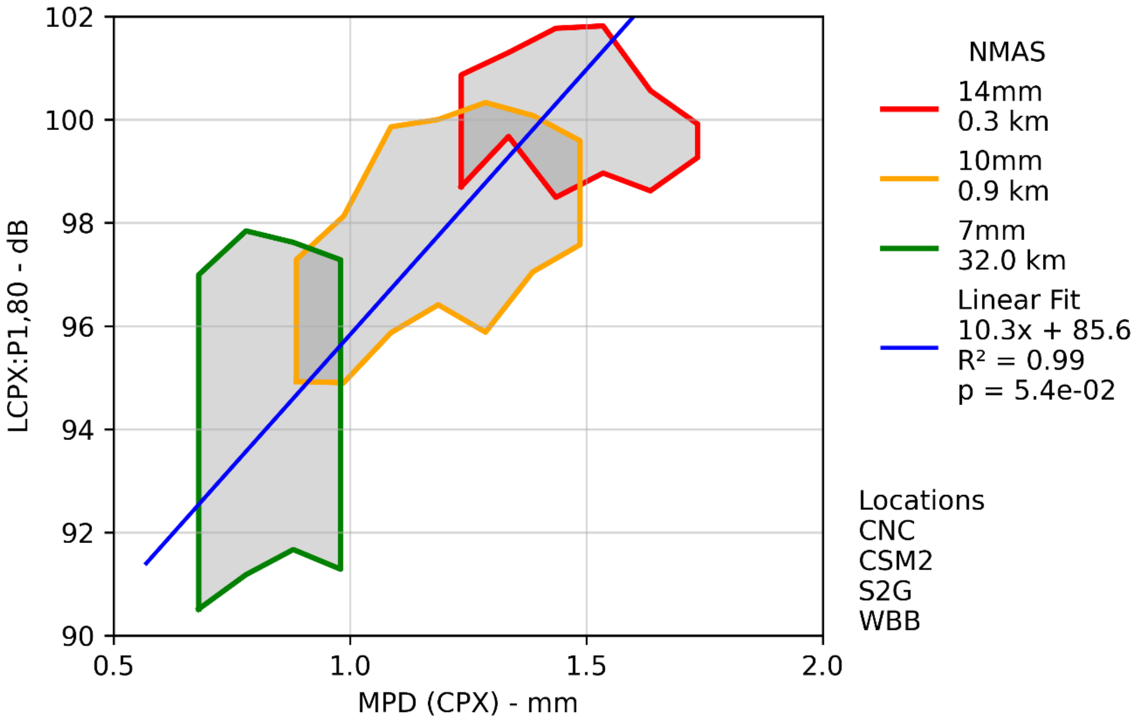


Figure 20: 2.5th to 97.5th percentile boundaries of L_{CPX} versus MPD for porous asphaltic mix surfaces grouped by NMAS.

5.2.2 MPD versus NMAS

From Figure 20 it appeared that MPD was primarily influenced by NMAS. Boxplots of MPD grouped by NMAS are shown in Figure 21. Note that there is no thickness filtering and all surfaces in Table 6 are included. The mean MPDs were ranked in order of the NMAS, with significant differences (T-Test $p \leq 0.01$) in the means between all groups. The variation of MPD within each NMAS group may be due to a variety of factors including void fraction, mix design, aggregate variability, trafficking, and construction processes; however, these appear to be less influential than NMAS for the analysed data. A linear model between MPD and NMAS had a positive slope of 0.093 ±0.001 mm/mm with $p \leq 0.01$ and $n = 8,300$. The linear model had an R^2 of 0.46 with the measured data, indicating that NMAS is likely the dominant source of variation in MPD for this sample.

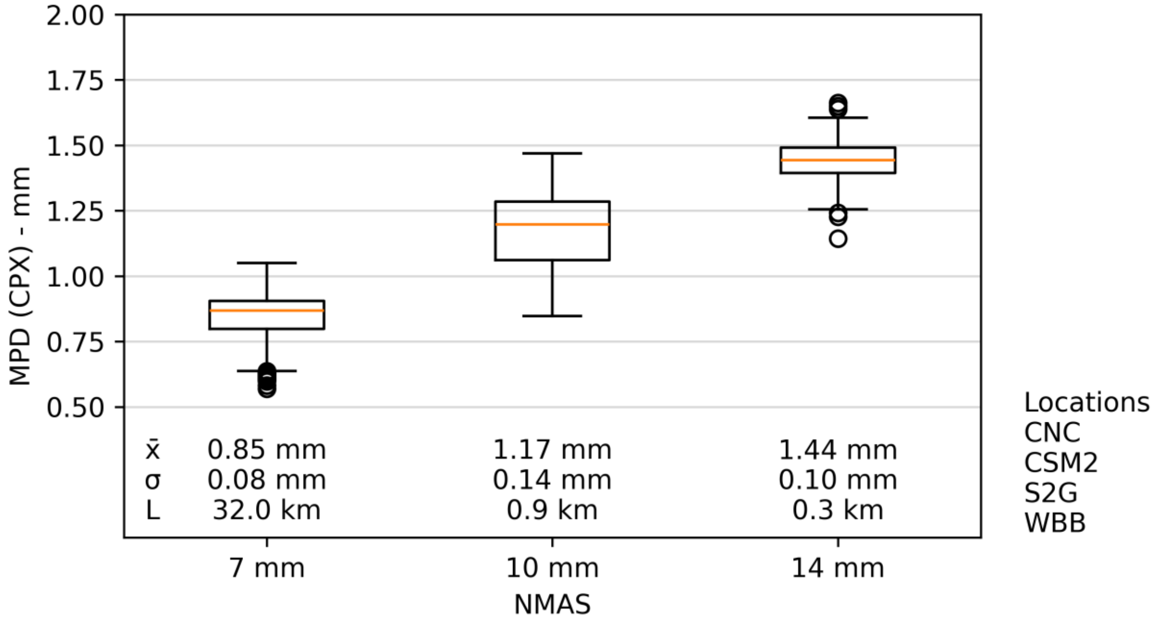


Figure 21: Boxplots of MPD grouped by NMAS.

5.2.3 Overall L_{CPX} for 7 mm NMAS

A subset of 7 mm NMAS surfaces on CNC was considered further. The sample was filtered to 4 m long segments with a mean thickness within 3 mm of the nominal value (i.e., 30 ±3 mm). The subset contained four surface mixes, including EPA7 (30 mm), PA7 (30 mm), PA7 HS (30 mm), and PA7 LV (30 mm).

Figure 22 contains a scatter plot of L_{CPX} versus MPD for the subset. L_{CPX} and MPD were positively correlated, with a linear fit having a slope of 6.81 dB/mm. The linear fit had an R^2 of 0.27 with the measured data, suggesting that MPD was a weak predictor of the overall L_{CPX} for this sample. The sample had an MPD span of 0.6 to 1.0 mm, which may be a limiting factor in fitting models that are predictors of L_{CPX}. The same data is presented in Figure 23 with only the bounding 2.5th and 97.5th percentiles grouped by surface type. The PA7 HS (30 mm) had both the lowest overall MPD and L_{CPX} with minimal overlap with the other surface types.

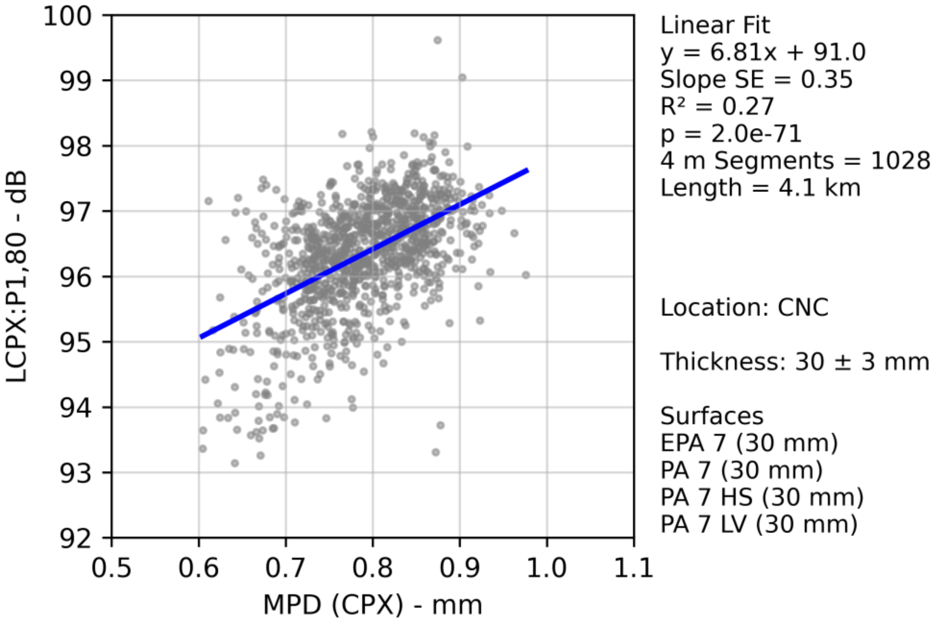


Figure 22: L_{CPX} versus MPD for porous asphaltic mixes on CNC with thicknesses of 30 ± 3 mm.

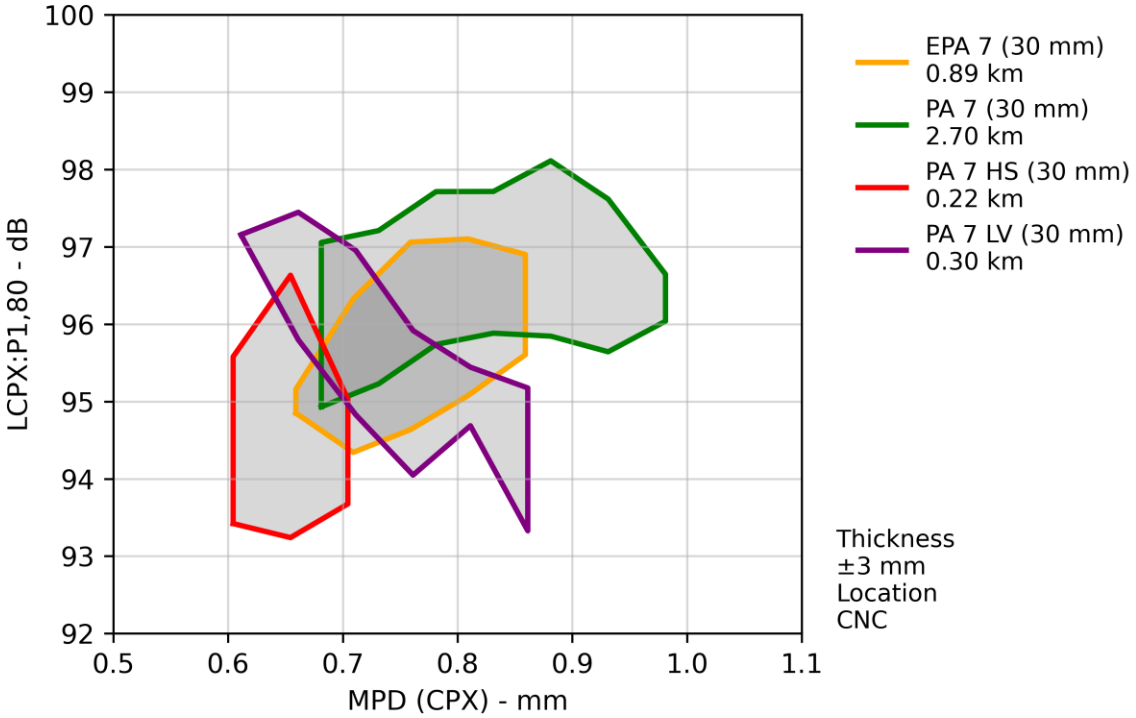


Figure 23: 2.5th to 97.5th percentile boundaries of L_{CPX} versus MPD for porous asphaltic mixes on CNC with thicknesses of 30 ± 3 mm.

5.2.4 L_{CPX} Spectra for 7 mm NMAS

The influence of MPD on the one-third octave band L_{CPX} spectra was explored for the 30 mm thick 7 mm NMAS subset of porous asphalt surfaces on CNC. Linear models were applied between each one-third octave band and MPD. The resulting slopes of the linear models and R^2 values are shown in Figure 24. Only relationships significant at $p \leq 0.01$ are included.

L_{CPX} was positively correlated with MPD in the 400 to 1,000 Hz bands, and negatively correlated in the 2,000 and 5,000 Hz bands. The linear models were typically weak predictors of L_{CPX} (indicated by low R^2 values). The following mechanisms are hypothesised:

- Positive correlations are due to texture-induced vibration of the tyre.
- Negative correlations are due to either decreasing turbulent air flow noise or increasing acoustic absorption.

Several factors may explain the weakness of the observed relationships (or their absence), these include:

- The narrow span of MPDs (0.6 to 1.0 mm) does not provide sufficient range for analysis.
- Another factor, such as void fraction, is exerting a more significant influence on L_{CPX}.
- MPD is not a strong predictor of L_{CPX} for porous asphalt and another metric for texture may be more appropriate.

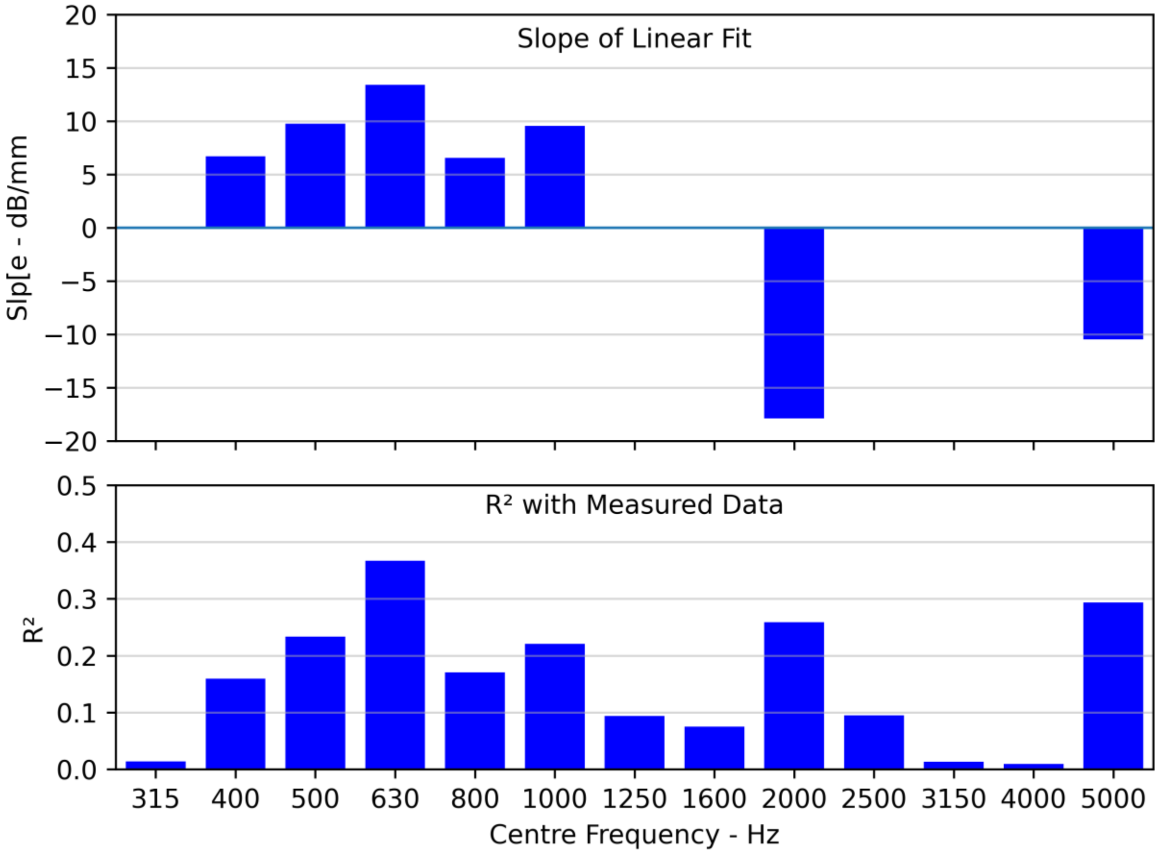


Figure 24: Slopes and R^2 of linear fits between L_{CPX} and MPD for porous asphaltic mixes on CNC with thicknesses of 30 ± 3 mm.

6 Future Work

Based on the findings in this report, the following areas are recommended for further investigation.

- **Expanded Data Set**

  Expand the analysis of the influence of texture on tyre/road noise to include data from the full national CPX survey – including both asphaltic mixes and chipseals.

- **Nominal Maximum Aggregate Size**

  Expand the analysis of the influence of NMAS on texture and tyre/road noise.

- **Cross-Sectional Texture Study**

  Use the 2024 CPX survey results to conduct a cross-sectional study of the relationship between texture and surface age. Ensure that trafficking is considered in this analysis.

- **CPX Laser Validation**

  Continue investigating observed discrepancies between the CPX laser, and SLP and annual HSD survey measurements.

- **Operational Settings**

  Explore how the operating settings of the laser can be tuned to maximise measurement robustness. May include periodic exposure setting, sample rate adjustment, and narrowing of the field of view.

- **Multivariate Regression**

  Explore the influence of texture using multivariate regression with other surface properties (e.g., thickness, void fraction, absorption, etc.).

- **Chipseals**

  Explore the influence of texture on tyre/road noise for a wider range of chipseals, including grade, coats, etc.

- **Texture Metrics**

  Explore the use of other texture metrics and their relationships with tyre/road noise. This may include the use of an envelopment model and texture wavelengths.

- **Low-Frequencies**

  Explore whether the relationships between tyre/road noise and texture extend below the 315 Hz band.

It is recommended to prioritise the operational settings, CPX laser validation, and the multivariate regression. The second-level priorities are the expanded data set (i.e., 2023-2024 annual CPX survey), and the NMAS analysis.

7 Conclusions

A laser line profile sensor was installed on the Waka Kotahi CPX trailer to measure the surface texture concurrently with tyre/road noise. There were two main components to this investigation, (1) validation of the measurement system, and (2) an analysis of the influence of texture on tyre/road noise for a range of chipseals and porous asphaltic mixes in Canterbury.

The validation demonstrated that accurate measurements were possible independent of differences in CPX trailer speed and sample rate. In addition, good overall agreement was observed between the MPD measured by the CPX laser and the most recent CAPTIF SLP and 2024 HSD surveys. However, the CPX laser typically measured a lower MPD for porous asphaltic mixes than the other systems. The comparisons suggest that the CPX laser yields measurements suitable for exploring the influence of texture on tyre/road noise. However, further analyses are required in order to use these results for assessing road surface compliance (e.g., NZTA T10).

For 4 m long segments of chipseals, the MPD was observed to be a poor predictor of the overall L_{CPX}, for the analysed data. However, mixed correlations between the one-third octave bands and MPD were observed, with a pattern of positive correlations in the 315 to 800 Hz bands and negative correlations in the 1,250 to 5,000 Hz bands. The positive and negative correlations are hypothesised to be due to increasing texture-induced vibration of the tyre and reducing turbulent air flow noise from air pumping, respectively.

When considering the 7, 10, and 14 mm NMAS porous asphaltic mixes together, an indicative positive linear relationship between MPD and L_{CPX} was observed. Within the subset of 30 mm thick 7 mm NMAS surfaces on CNC, MPD was found to be positively correlated with the overall L_{CPX}; however, a linear fit was a weak predictor of L_{CPX} for the analysed data. For the one-third octave bands, MPD was found to be positively correlated in the 400 to 1,000 Hz bands and negatively correlated with the 2,000 and 5,000 Hz bands. While correlations were observed, MPD was a weak predictor of the one-third octave band levels. Generally, achieving reduced noise levels with porous asphalt mixes requires a low MPD.

NMAS and MPD were observed to be positively correlated for porous asphaltic mixes. NMAS was found to be the likely dominant source of variation in MPD for the analysed data.

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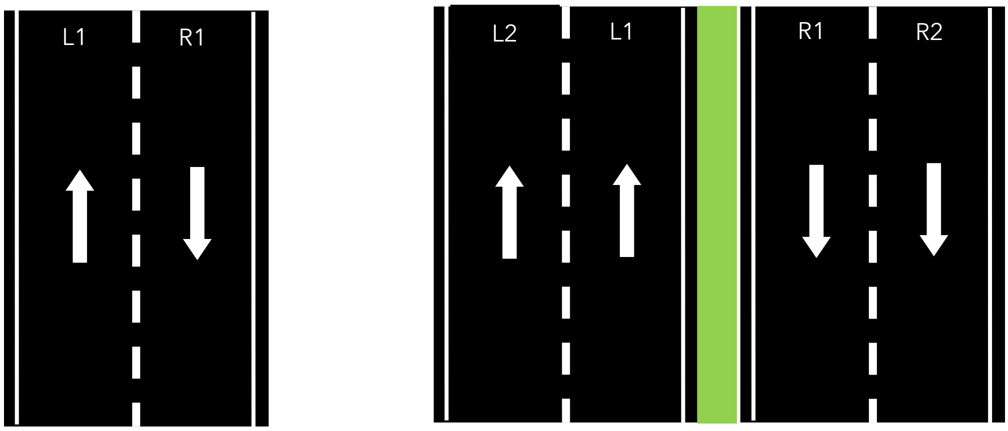
Appendix A – Supplementary Data

Table 7: Sample lengths by location and surface.

Location	Road ID	Surface Type	Length - km
CNC	3843	EPA7 (30 mm)	1.55
	3843	EPA7 (50 mm)	2.30
	3843	PA10 (30 mm)	0.38
	3843	PA7 (30 mm)	1.67
	3844	EPA7 (50 mm)	2.31
	3844	PA7 (30 mm)	3.39
	3844	PA7 HS (30 mm)	0.35
	3844	PA7 LV (30 mm)	0.39
CSM1	655	EPA10 (40 mm)	0.63
	655	PA10 (40 mm)	0.40
	656	EPA10 (40 mm)	0.30
	656	PA10 (40 mm)	0.49
	656	PA 11 (40 mm)	0.32
CSM2	3318	EPA7 (40 mm)	7.17
	3318	SMA10 (45 mm)	0.90
	3319	EPA7 (40 mm)	5.27
	3319	SMA10 (45 mm)	2.42
	3902	EPA7 (40 mm)	2.78
	3902	SMA10 (45 mm)	0.22
	3903	EPA7 (40 mm)	1.84
	3903	SMA10 (45 mm)	1.05
Groynes Ramps	3654	SMA10 (40 mm)	0.28
S2G	3664	EPA10 (30 mm)	0.24
	3664	EPA10 HV (30 mm)	0.30
	3664	EPA14 (30 mm)	0.26
SH73	1713	Epoxy Grade 3/5 Dry-Lock	0.59
	1713	Grade 2 Single-Coat	0.54
	1713	Grade 2/4 Racked-In	0.54
	1713	Grade 2/4 Two-Coat	0.54
	1713	Grade 2/4/6 Multi-Coat	0.54
	1713	Grade 3 Single-Coat	1.12
	1713	Grade 3/5 Two-Coat	0.74
	1841	Epoxy Grade 3/5 Dry-Lock	0.28
WBB	1715	EPA7 (30 mm)	0.26
	1715	EPA7 (40 mm)	2.50
	1715	EPA7 (50 mm)	0.27
	1715	SMA10 (40 mm)	0.11

Appendix B – Lane Labelling



(a) Single carriageway

(b) Dual carriageway

Figure 25. Lane numbering convention (assuming increasing direction toward the top of the page).