ALTISSIMO CONSULTING

ROAD SURFACE NOISE

Analysis of Chipseal Surfaces

Client: Waka Kotahi / NZ Transport Agency

Date: 9/8/2023

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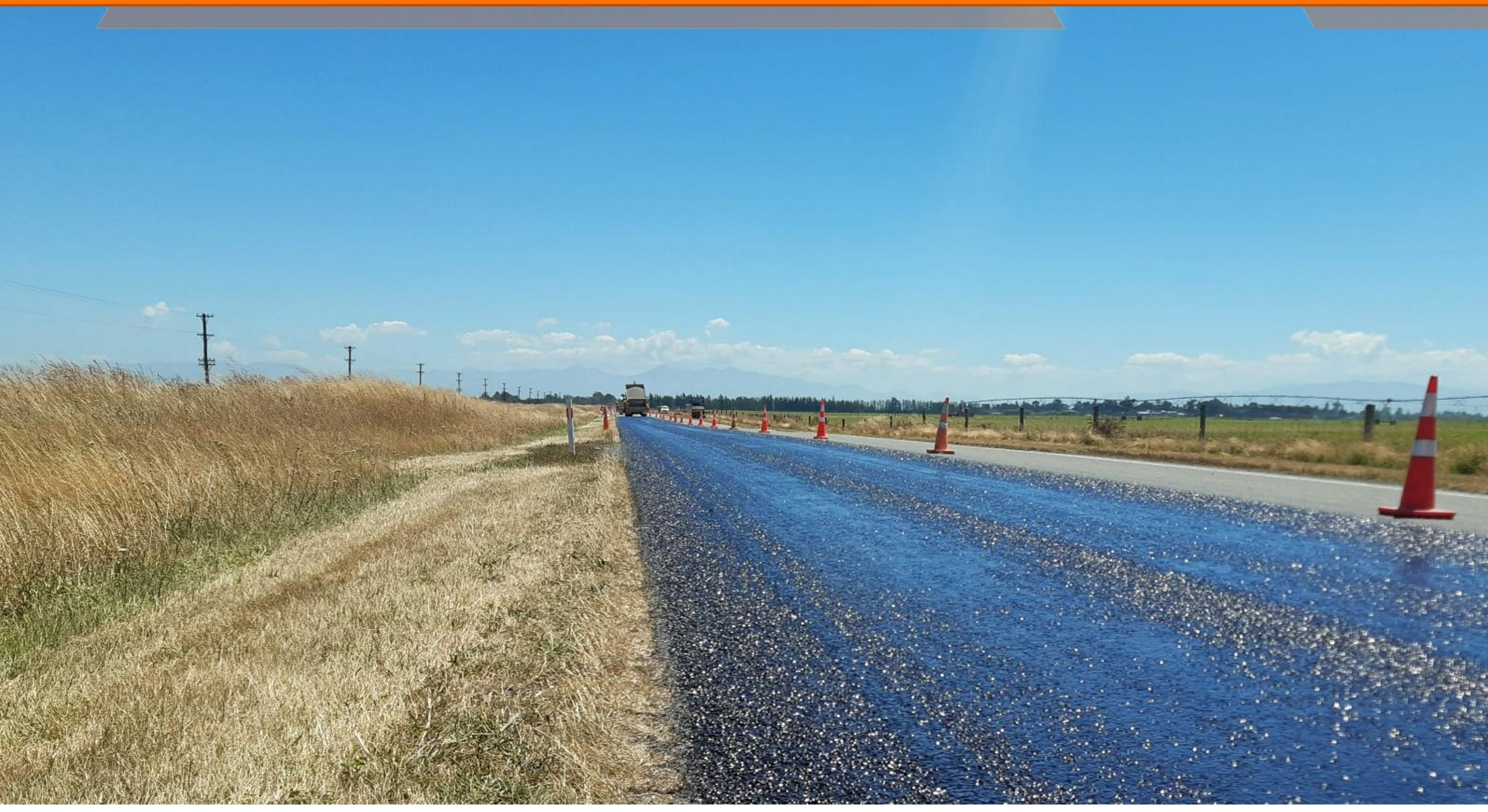

Prepared for (the Client)

Waka Kotahi / NZ Transport Agency

Prepared by (the Consultant)

Altissimo Consulting Ltd

Project	Road Surface Noise
Report	Analysis of Chipseal Surfaces
Reference	22-105-R02-C

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Version	Date	Comment
A	24/02/2023	First draft.
B	17/03/2023	Updated following review.
C	9/08/2023	Corrected terminology and formatting.

Abstract

Chipseal surfaces make up over 90% of New Zealand's 11,000 km state highway network. The effect of the surface specification on noise was explored through the analysis of six controlled chipseals on SH73. The surfaces included (1) single-coat grade 3, (2) two-coat grade 3/5, (3) single-coat grade 2, (4) racked-in grade 2/4, (5) two-coat grade 2/4, and (6) multi-coat grade 2/4/6. The close-proximity sound level, pass-by sound level, sound quality, and texture were considered.

While none of the evaluated surfaces would be considered subjectively quiet, the grade 3 were marginally quieter than the grade 2 surfaces. No objective noise benefit was measured for the multi-coat grade 2/4/6 surface. The correlations between L_{CPX} and MPD were explored. There were weak positive correlations between the overall L_{CPX} and MPD for the two-coat grade 2/4 and multi-coat grade 2/4/6. Within the one-third octave bands, there were positive correlations in some of the lower (<800 Hz) bands, and negative correlations in the higher frequency bands. A comparison between L_{CPX} and SPB measurements showed a weak positive correlation.

The sound quality analysis revealed only small differences between the surface types when based on the sound recorded 200 mm from the tyre. The two-coat grade 3/5 exhibited a marginal increase in sharpness, and the grade 2-based surfaces showed a marginal increase in loudness.

Contents

Glossary

CPX	Close proximity
CSM2	Christchurch Southern Motorway stage 2
EB	Eastbound
EPA	Epoxy-modified porous asphalt
L_{CPX}	Close proximity sound pressure level. All measurements were conducted using the P1 tyre at a nominal speed of 80 km/h ($L_{CPX} = L_{CPX,P1,80}$)
MPD	Mean profile depth
NB	Northbound
SB	Southbound
SLP	Stationary laser profilometer
SPB	Statistical pass by
WB	Westbound

1 Introduction

Over 90% of New Zealand's 11,000 km state highway network utilise chipseal surfaces. While chipseal surfaces are generally economical to construct, they have typically exhibited high noise levels within vehicle cabins and at the roadside.

Previous large-scale analysis of noise data revealed the close-proximity noise level (L_{CPX}) of a chipseal surface is strongly influenced by the size of the stones (Jackett, 2019). Other characteristics of the stones (e.g., shape, aspect ratio, etc.) have been hypothesised to influence noise, but these were unable to be quantified with the available data. A non-negligible difference in noise due to the stone source was hypothesised (Bagshaw & Jackett, 2020).

A series of trial sections of State Highway 73 were constructed to evaluate the influence of design and construction parameters on tyre/road noise (Bull, SH73 Chipseal Noise Trial - Planning, 2022). To isolate the trial from extraneous factors, the stones were supplied from a single source (Isaac's Quarry), and all work was conducted by a single contractor (Downer). Waka Kotahi and Altissimo staff were onsite for the duration of surfacing to record observations (Bull, SH73 Chipseal Noise Trial - Construction Monitoring, 2022). The trial is long-term with scheduled reviews of noise, macrotexture, and age-related degradation.

This investigation aimed to quantify the differences in the overall sound level due to the surface specification. In addition, the one-third octave bands, narrow band, mean profile depth, statistical pass-by levels, and sound quality were explored.

This report contains a description of the surface types, data sources, analysis methodology, results and discussion, and a list of potential areas for future investigations. All supporting figures are included in Appendix A – Additional Figures. A summary of sound quality metrics is included in Appendix B - Sound Quality Metrics. All data processing and analysis scripts have been provided to Waka Kotahi.

2 Methodology

2.1 Projects and Trial Sections

The present study focused on the six trial sections on SH73 near Kirwee. See Figure 28 for a map of the trial sections. The six surface types are shown in Table 1. For further details on the trial sections refer to the trial planning report (Bull, SH73 Chipseal Noise Trial - Planning, 2022).

TABLE 1. SH73 CHIPSEAL TRIAL SECTIONS.

Section	Name	Short Name	Length* - m
1	Single-coat grade 3	SC-3	543
2	Two-coat grade 3/5	TC-3/5	250
3	Single-coat grade 2	SC-2	250
4	Racked-in grade 2/4	RI-2/4	250
5	Two-coat grade 2/4	TC-2/4	250
6	Multi-coat grade 2/4/6	MC-2/4/6	250

*Length is after trimming to exclude 10 m either side of joints.

*Length is for a single lane. Both EB and WB lanes were analysed therefore the effective length is doubled.

2.2 Data

Table 2 shows the data sources used for the analysis. Table 3 contains the resealing and measurement dates. Construction monitoring notes can be found in (Bull, SH73 Chipseal Noise Trial - Construction Monitoring, 2022). Details of the tyre/road noise measurements can be found in (Wareing, 2022).

TABLE 2. SUMMARY OF DATA SETS.

Parameter	Data
Tyre/road noise	Overall, one third octave, and narrow band $L_{CPX:P1,80}$
Macrotexture	Stationary laser profilometer (SLP)
Construction observations	On-site observations record
Statistical pass by*	Single session for all sites

*SPB followed ISO 11819-1, with 7 m setback from the roadside.

TABLE 3. RESEALING AND MEASUREMENT DATES.

	Date	Age - Months
Resealing	Jan 2022	
CPX	Feb 2022	< 1
	Jun 2022	5
	Feb 2023	12
Texture	Feb 2022	< 1
	Jun 2022	5
	Oct 2022	9
Statistical pass by	Jan 2023	12

2.3 Processing and Analysis

2.3.1 L_{CPX} and MPD

The MPD measurements were merged into the CPX data by taking the numerical average of all points fully contained within the CPX segment. Only CPX measurements from the left enclosure and MPD measurements from the left wheel path were used. Data within 10 m of a surface joint was excluded.

The overall L_{CPX} and one-third octave bands were considered for each surface type. The narrow band spectrum and 1/24th octave bands were calculated. The relationships between MPD and L_{CPX} were explored for the overall level and one third octave bands. The correlations between MPD and L_{CPX} were calculated.

2.3.2 Sound Quality

Sound quality was analysed by extracting five-second samples of each surface type from the left-front microphone from the second CPX measurement in June for the WB lane (five months after resealing). The sample windows were chosen by subjectively determining the clearest section (e.g., free from suspension movement, stone noise, etc.). Table 4 contains the start and end chainages, and length of the sound quality samples. A five second sample of EPA7-40 mm from the NB carriageway on CSM2 was also included as a basic comparison to a known low-noise surface.

TABLE 4. LOCATIONS OF SAMPLES USED FOR SOUND QUALITY ANALYSIS.

Section	Name	Chainage		Length
		Start	End	m
1	Single-coat grade 3	15570	15690	120
2	Two-coat grade 3/5	16090	16200	110
3	Single-coat grade 2	16370	16490	120
4	Racked-in grade 2/4	16650	16770	120
5	Two-coat grade 2/4	16910	17030	120
6	Multi-coat grade 2/4/6	17200	17320	120

The concatenated signal was passed to a series of MOSQITO functions (Green Forge Coop, 2023) to calculate loudness, sharpness, and roughness. A separate function for modulation was used (National Transport Commission, 2007). Sound quality metrics are intended for use at the location of an observer, the present study acknowledges and accepts the results may be different at the roadside due to changes in frequency components and levels.

3 Results and Discussion

The results are presented and discussed in this section. All additional supporting figures can be found in Appendix A – Additional Figures.

3.1 Overall Results

The mean L_{CPX}, MPD, and SPB level for each surface type are shown in Table 5. Boxplots of the L_{CPX} and MPD five months after resealing for each surface type are shown in Figure 1.

TABLE 5. OVERALL L_{CPX}, MPD, AND SPB LEVEL FOR EACH SURFACE TYPE FIVE MONTHS AFTER RESEALING.

Surface	SC-3	TC-3/5	SC-2	RI-2/4	TC-2/4	MC-2/4/6
L_{CPX} dB	101.7	101.7	101.9	102.0	101.8	102.2
MPD mm	2.50	2.13	2.81	2.52	2.52	2.04
SPB dB	82.4	83.2	84.8	83.4	83.9	84.1

There was a relatively small difference in the overall L_{CPX} for all surface types. At five months after resealing, there was a 0.5 dB range in the mean L_{CPX} for each surface type. There was an overall range of 1.7 dB for all CPX segments across all surface types. The SC-3 and TC-3/5 had marginally better overall mean L_{CPX} than the grade 2-based surfaces. The MC-2/4/6 had the highest L_{CPX}.

Figure 14 and Figure 15 contain boxplots of the MPD of each surface type across the three SLP measurement sessions (one, five, and nine months). The MC-2/4/6 and TC-3/5 had the lowest mean MPDs. The SC-2 had the greatest mean MPD. All surfaces showed a decrease in MPD with time.

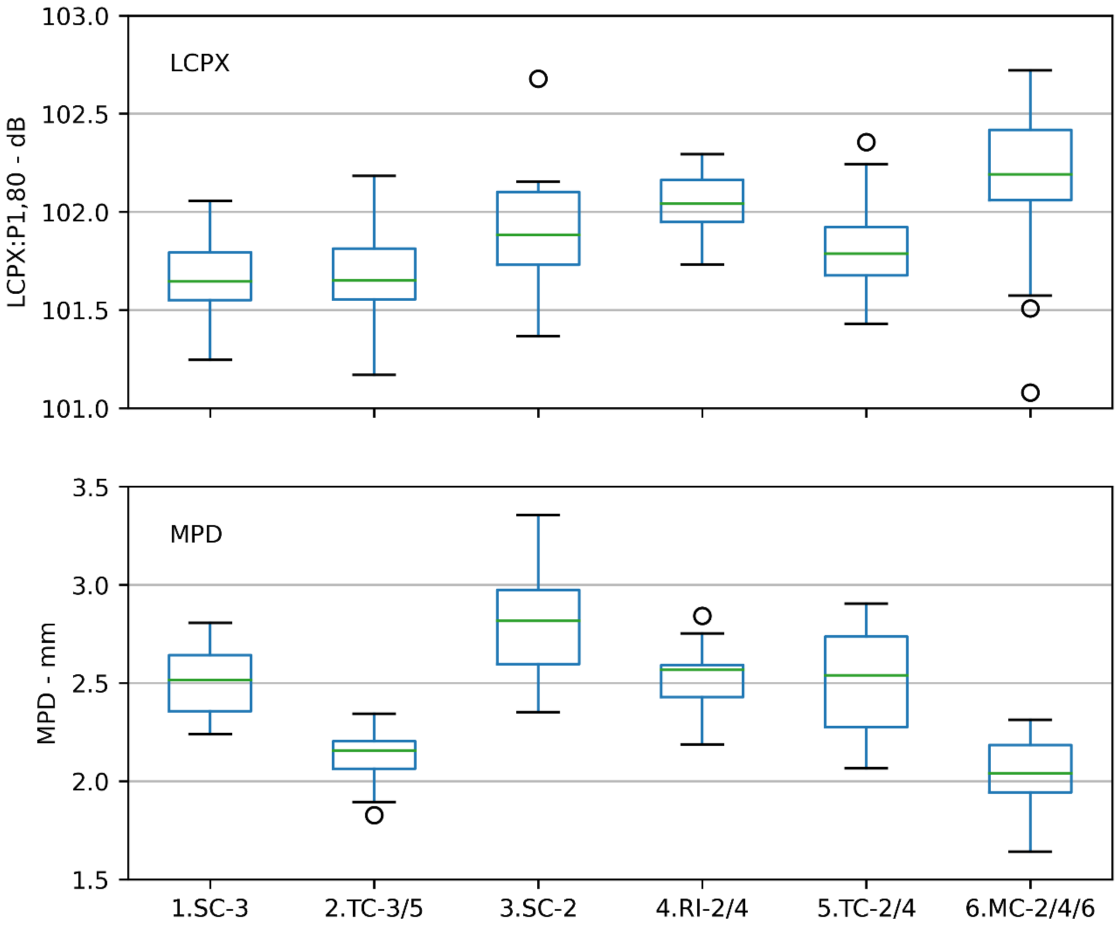

FIGURE 1. BOXPLOTS OF L_{CPX} AND MPD FOR EACH SURFACE TYPE FIVE MONTHS AFTER RESEALING.

3.2 Spectral Analysis

The one third octave band distributions for each surface type are shown in Figure 2. The intra-band levels for each surface are shown in Figure 10. The range between surface types of one-third octave band levels is low (<4 dB). 800 and 1,000 Hz are the dominant bands, with an inter-surface range of <1 dB. The small range in the dominant 800 and 1,000 Hz bands aligns with the minor differences in the overall levels.

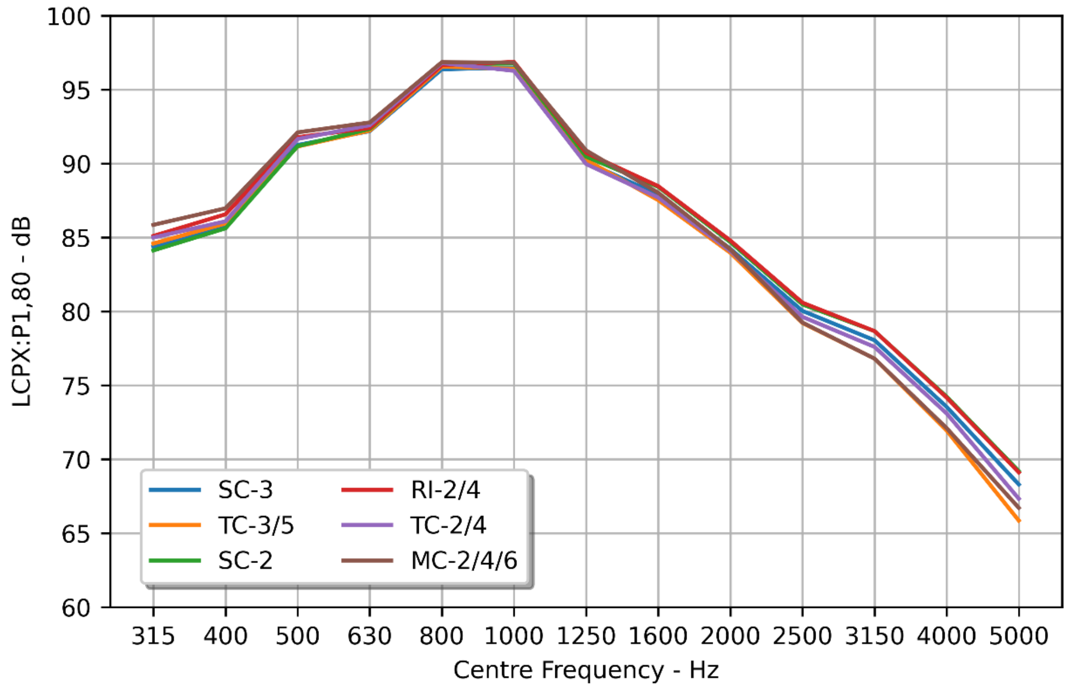

FIGURE 2. ONE-THIRD OCTAVE BAND DISTRIBUTION FOR EACH SURFACE TYPE FIVE MONTHS AFTER RESEALING.

The 1/24th octave band and narrow band spectrums are shown in Figure 12 and Figure 13, respectively. Both charts only pertain to the front left microphone for a single CPX measurement run. The narrow band spectrums were limited to the range of the dominant 800 and 1,000 Hz one-third octave bands.

There were no clearly discernible differences in the narrow band spectra in the dominant frequency bands. The spectrums had no obvious tones.

The 1/24th octave band distributions appeared to show more unique characteristics of the spectrums between the chipseal and PA surfaces. For example, the form of the distributions were similar below 600 and above 1,200 Hz, and only significantly differed in amplitude. The elevated levels of several groupings of bands may also offer a means of quantifying differences in the underlying noise generation mechanisms. It is recommended that a future study utilises the 1/24th octave bands to further analyse the noise generating mechanisms and effects of critical surface parameters.

3.3 MPD versus L_{CPX}

The overall L_{CPX} versus MPD is shown in Figure 3 for all surface types (see Figure 16 for separated figures). Only the TC-2/4 and MC-2/4/6 had weak positive correlations between L_{CPX} and MPD with R^2 of 0.29 (p = 0.010)) and 0.38 (p = 0.002), respectively.

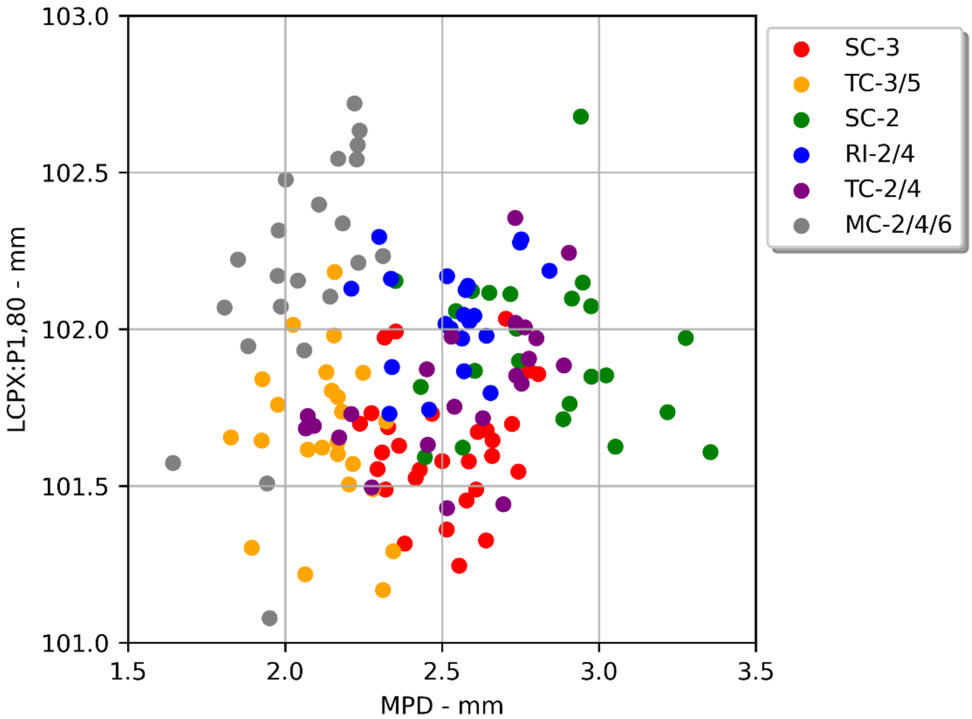

FIGURE 3. COMBINED L_{CPX} VERSUS MPD FOR ALL SURFACE TYPES FIVE MONTHS AFTER RESEALING.

The one-third octave band L_{CPX} versus MPD is shown in Figure 17 to Figure 22 for each surface. A summary of the correlations is shown in Figure 4 with the associated R^2 values shown in Figure 23.

In general, there were positive correlations between L_{CPX} and MPD below 1,000 Hz and negative correlations above 1,000 Hz. The positive correlations may be due to increasing tread impact and tyre vibration. The negative correlations may be due to reducing resistance to air dispersion at the leading tyre/road interface.

The correlations between L_{CPX} and MPD were weaker than initially hypothesised. The 1.5 mm range in MPD was contained within 1.7 dB for the overall level. The relatively smooth MC-2/4/6 unexpectedly had the highest overall L_{CPX} level. The correlations may have been limited by the restricted MPD data for each segment (1.8 m within the 20 m). It is recommended that a future study investigate L_{CPX} versus MPD with full texture data for each surface. It is also recommended that other methods and metrics to characterise texture are explored.

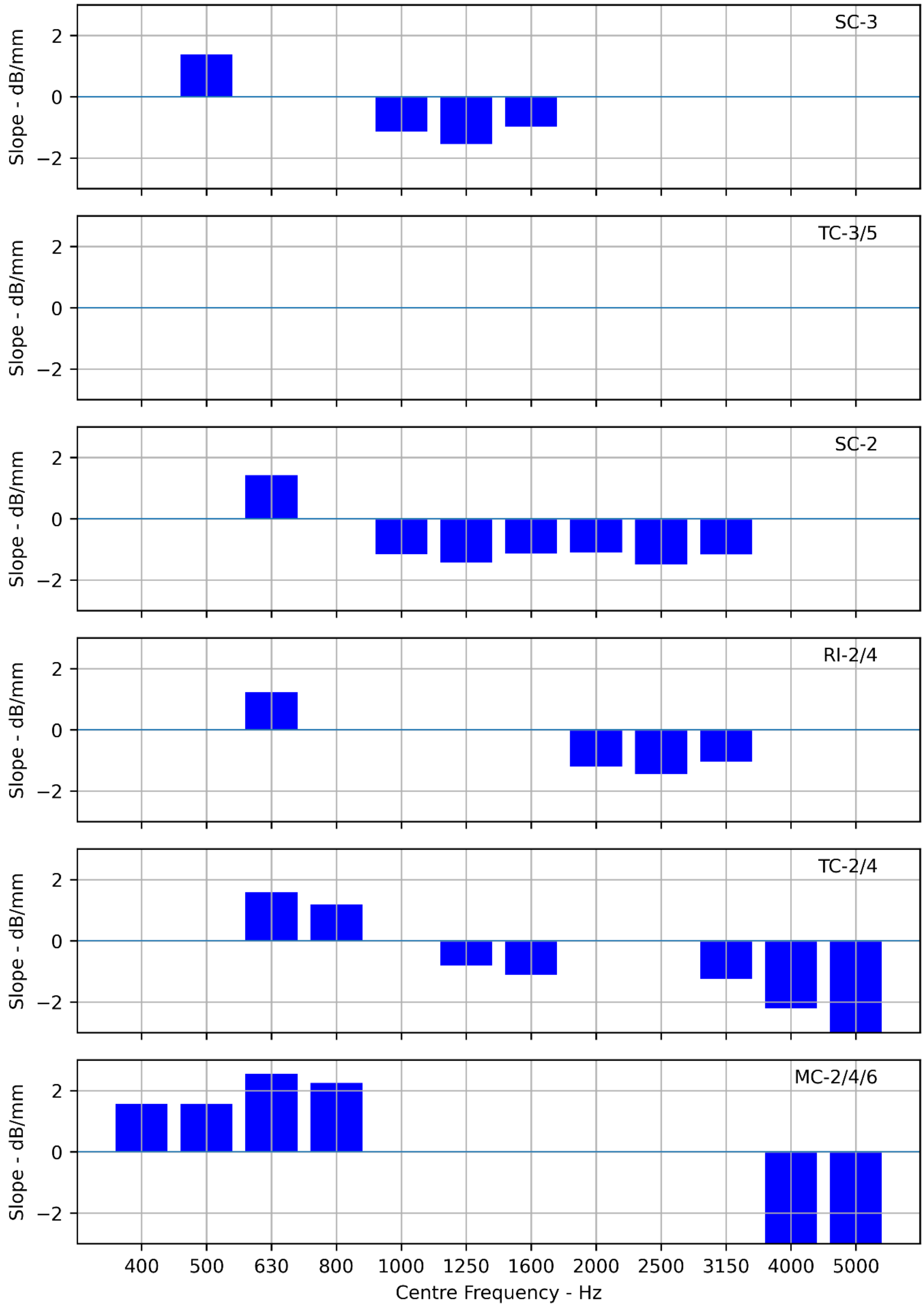

FIGURE 4. CORRELATIONS BETWEEN ONE-THIRD OCTAVE L_{CPX} AND MPD FOR EACH SURFACE TYPE FIVE MONTHS AFTER RESEALING. CORRELATIONS ARE ONLY SHOWN WHERE R^2 IS GREATER THAN 0.25.

3.4 L_{CPX} versus SPB

The overall L_{CPX} at five months is compared to the SPB level at 12 months in Figure 5. The limited range (0.5 dB) of the mean L_{CPX} for each surface type is unlikely to be resolvable by SPB measurements, which had a standard deviation of 1.6 to 2.7 dB. The correlation displayed in Figure 5 only pertains to the mean values and does not account for the actual distribution of measurements; it should only be considered as indicative. No further statistical analysis was conducted on the L_{CPX} and SPB relationship due to the limited range of values.

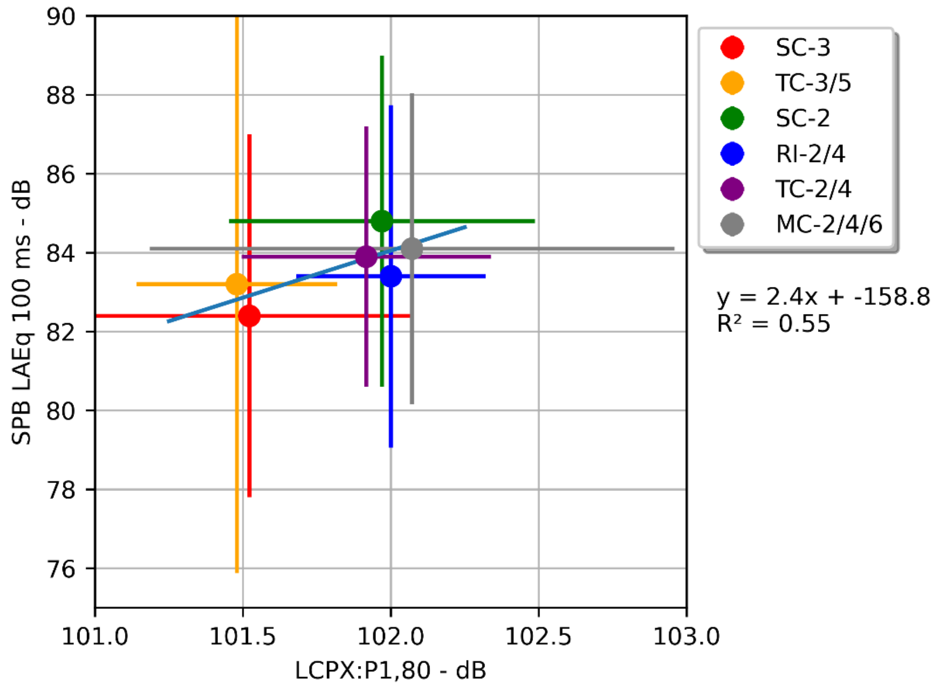

FIGURE 5. SPB VS. L_{CPX} FOR EACH SURFACE TYPE. MEASUREMENTS WERE TAKEN FIVE AND 12 MONTHS AFTER RESEALING FOR L_{CPX} AND SPB, RESPECTIVELY

3.5 Sound Quality

Zwicker loudness, sharpness, roughness, and modulation were calculated for each surface type. A typical sample of a low-noise EPA7-40 mm surface was included for reference. Loudness, sharpness, roughness, and modulation are shown in Figure 24, Figure 25, Figure 26, and Figure 27, respectively.

Use of the close proximity recording (200 mm from the tyre) provided a sample that was free from extraneous sounds but did not necessarily represent what would be perceived at the roadside. Pass-by recordings could offer a solution, but the confounding of other factors would need to be accounted for in the design of the experiment.

There was no significant difference between the loudness of chipseal surface types. The ~30% reduction in Sones for the EPA7-40 mm surface represents the perceived equivalent change (i.e. a listener would describe the sound as being 30% quieter). As described above, changes in close proximity perceived loudness have not been confirmed at the roadside.

There was a small increase in sharpness from the grade 3 to grade 2 surfaces; this could be subjectively perceived by listening to the raw audio file. The grade 2 surfaces also typically exhibited greater levels in the high frequency one-third octave bands. The EPA7-40 mm surface had a significantly greater sharpness compared to the chipseal surface; this was due to it having a greater proportion of higher frequency noise, despite having lower absolute levels in all bands. The perceived sharpness of the road/tyre noise may be driven by the dispersion of air, further analysis is required to understand these mechanisms.

No differences were observed in roughness or modulation between all surfaces. Short sections of the untrimmed audio file had higher modulation; this was attributed to oscillations in the suspension as the trailer passed over the inter-surface joints. While no differences in roughness were observed in the present study, the underlying reasons for the range of values is unknown. An in-depth study of texture versus acoustic roughness is recommended.

While there were no significant differences in sound quality between the chipseal surfaces, the methodology should be considered for use in future analyses of asphalt surfaces, which typically have a greater range of noise levels.

3.6 Other Factors

The standard deviation of 0.30 dB for all CPX segments across the entire trial site represented low variability. Presently available data does not account for the small variation. The construction observations were reviewed against changes in L_{CPX} and MPD; no conclusive relationships were found.

Several of the noteworthy observations are listed below. No direct impacts on L_{CPX} or MPD were found.

- No pre-spray for the multi-coat 2/4/6 in either direction.
- Multi-coat not rolled in EB lane between chips, only after 6.
- During sealing of section 2 and the intersection, section 3 (EB) had stationary traffic due to the location of the stop/go threshold. This stationary traffic was on the section between 1320h and 1750h. Some minor damage was observed on the surface.

There are several characteristics of the aggregate that may have an influence on texture and noise, a detailed desktop review can be found in (Bagshaw & Jackett, 2020). It is recommended that a future study explores how aggregate parameters vary within and between sections.

Picture frames (photos at the same position on the road) were captured periodically along the trial section. A future study may consider quantifiable metrics that can be extracted from the picture frames and their relationships with texture and noise.

4 Future Investigations

Several areas are recommended for further investigation, these include:

- Explore alternative methods and metrics for characterising texture using high-resolution profiles captured using the CPX laser or SLP.
- Explore relationships between L_{CPX} and MPD for chipseals over larger samples using the CPX laser.
- Use 1/24th octave bands to compare larger samples of common chipseal surfaces.
- Explore the effect of other aggregate parameters (e.g., aspect ratio, etc.) and their effect on noise.
- Develop objective metrics from picture frames and explore their relationships with texture and noise.
- Explore relationships between L_{CPX}, MPD, and age.
- Conduct road-side sound quality analysis.

5 Conclusions

The tyre/road noise for the six chipseal surface types on SH73 was explored. While none of the surfaces would be considered quiet, the grade 3 surfaces were marginally quieter than the grade 2 surfaces. No noise benefit was measured for the multi-coat grade 2/4/6 surface.

The correlations between L_{CPX} and MPD were explored. There were weak positive correlations between the overall L_{CPX} and MPD for the two-coat grade 2/4 and multi-coat grade 2/4/6. Within the one-third octave bands, there were positive correlations in several of the lower (<800 Hz) bands, and negative correlations in the higher frequency bands.

A comparison between L_{CPX} and SPB measurements showed a weak positive correlation. The small range in the mean L_{CPX} (0.5 dB) and large standard deviation in the SPB measurements (1.6 to 3.7 dB) limited the ability to draw any significant conclusions.

The sound quality analysis revealed only small differences between the surface types when assessed beside the tyre. The two-coat grade 3/5 exhibited a marginal increase in sharpness, and the grade 2-based surfaces showed marginal increase in loudness.

6 References

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7 Appendix A – Additional Figures

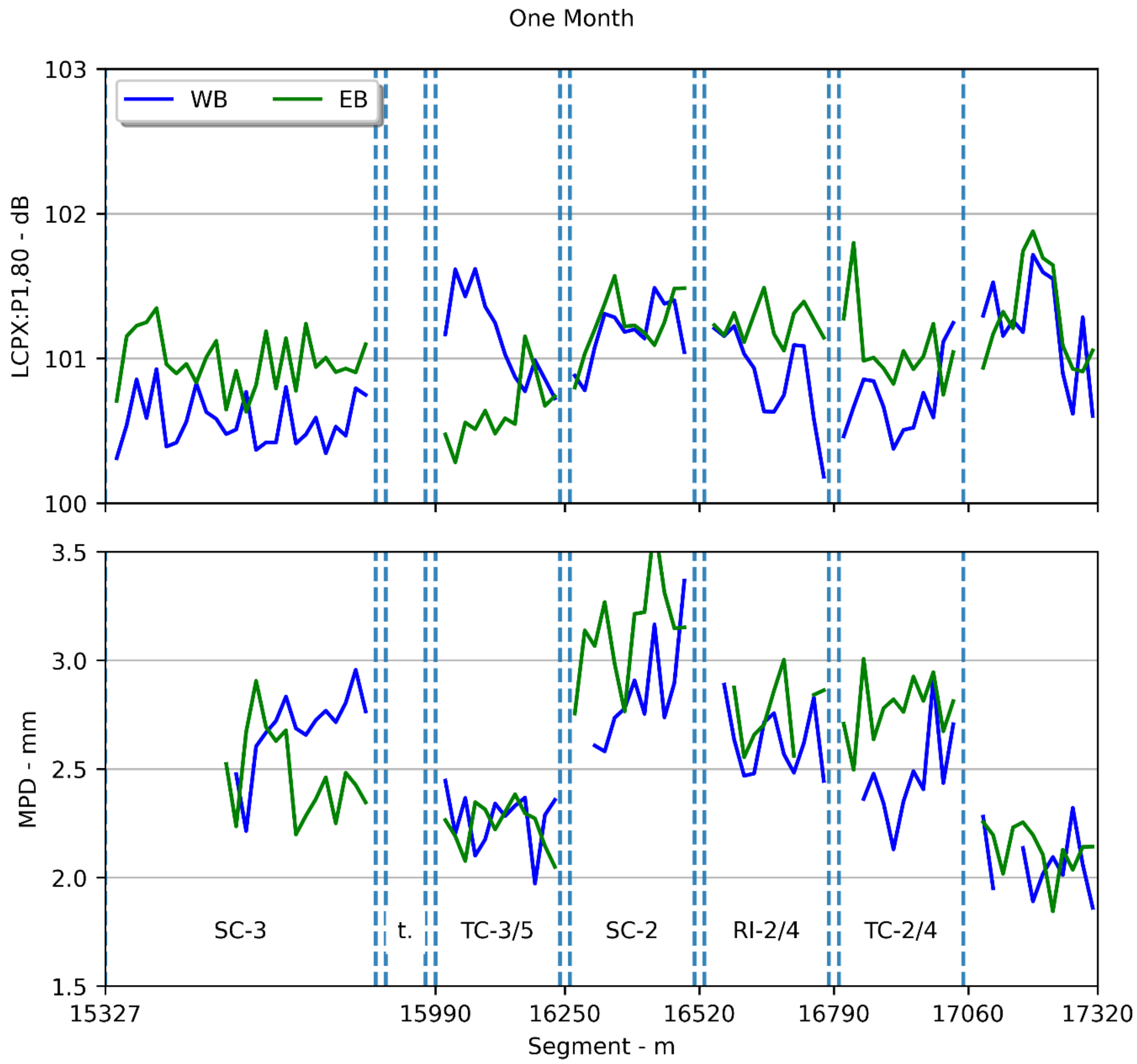

FIGURE 6. LONGITUDINAL PLOTS OF L_{CPX} AND MPD ONE MONTH AFTER RESEALING.

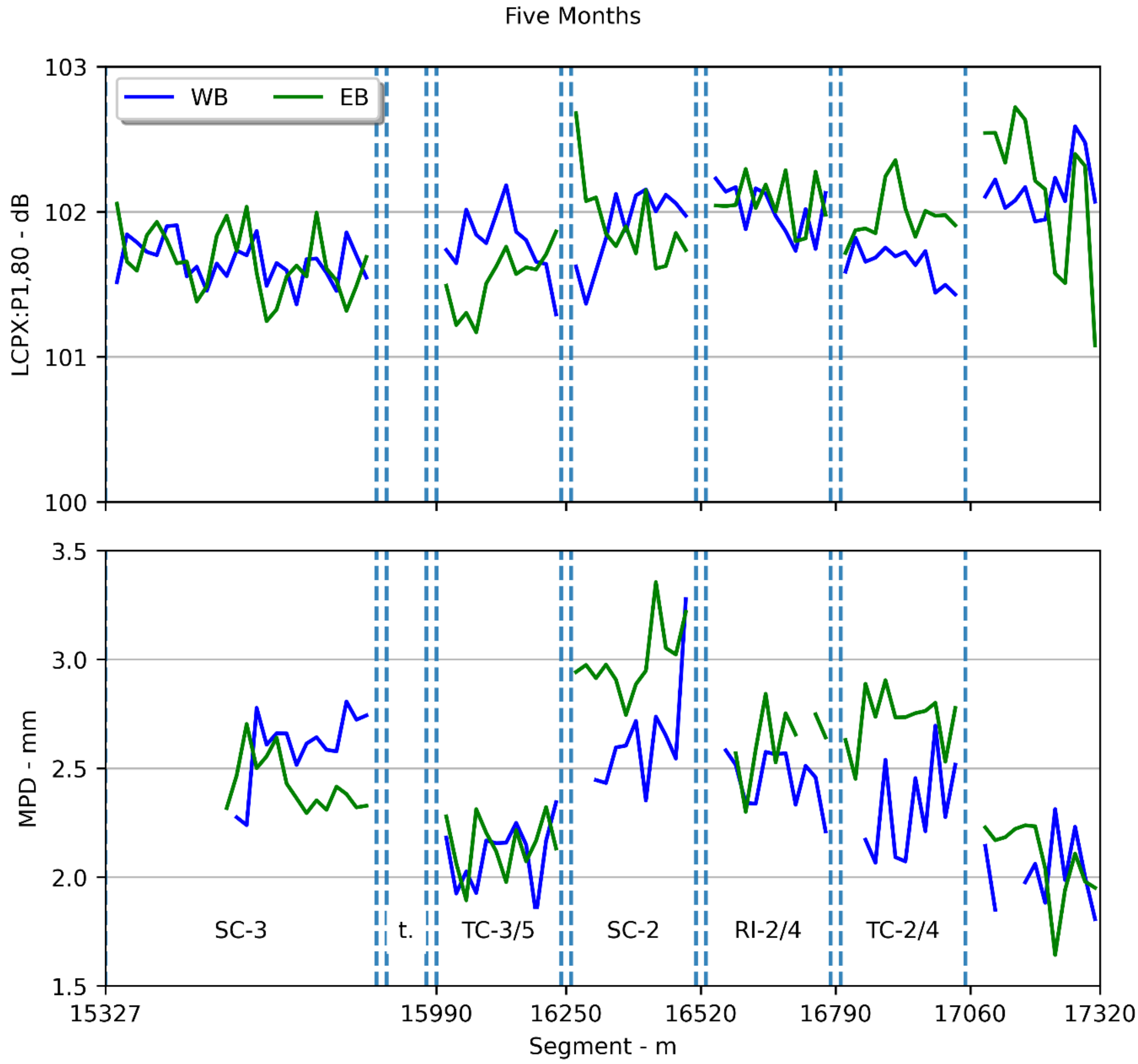

FIGURE 7. LONGITUDINAL PLOTS OF L_{CPX} AND MPD FIVE MONTHS AFTER RESEALING.

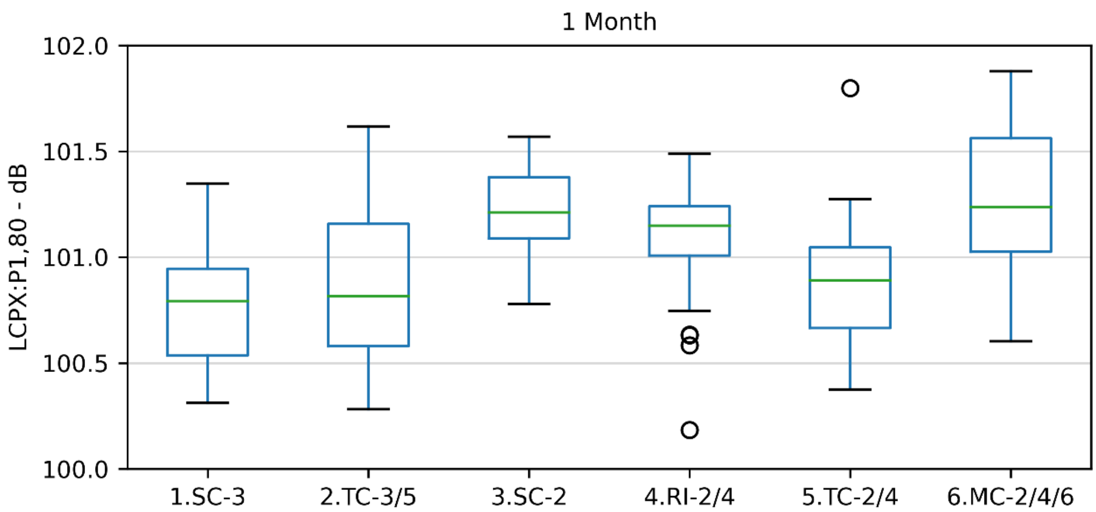

FIGURE 8. BOXPLOTS OF L_{CPX} FOR EACH SURFACE TYPE ONE MONTH AFTER RESEALING.

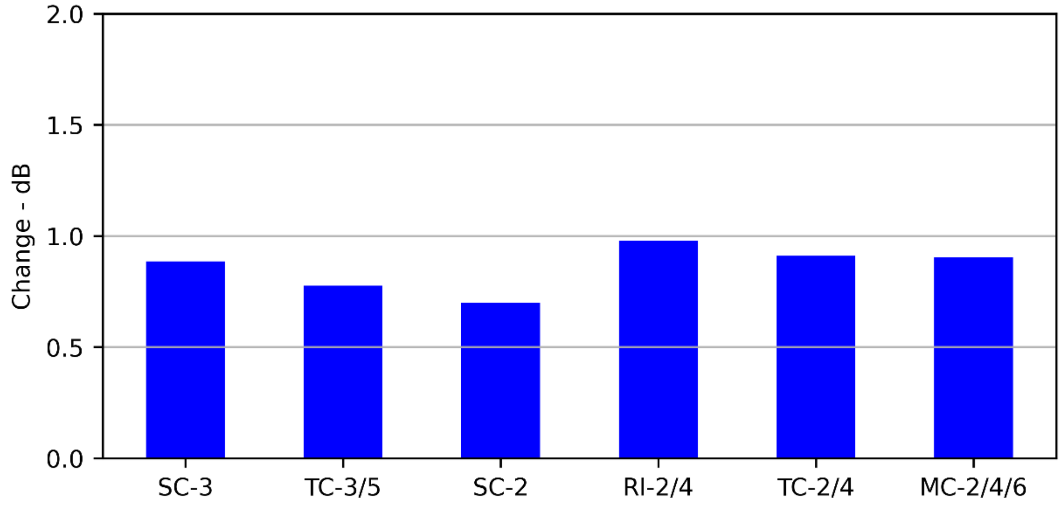

FIGURE 9. CHANGE IN OVERALL L_{CPX} BETWEEN ONE AND FIVE MONTHS FOR EACH SURFACE TYPE.

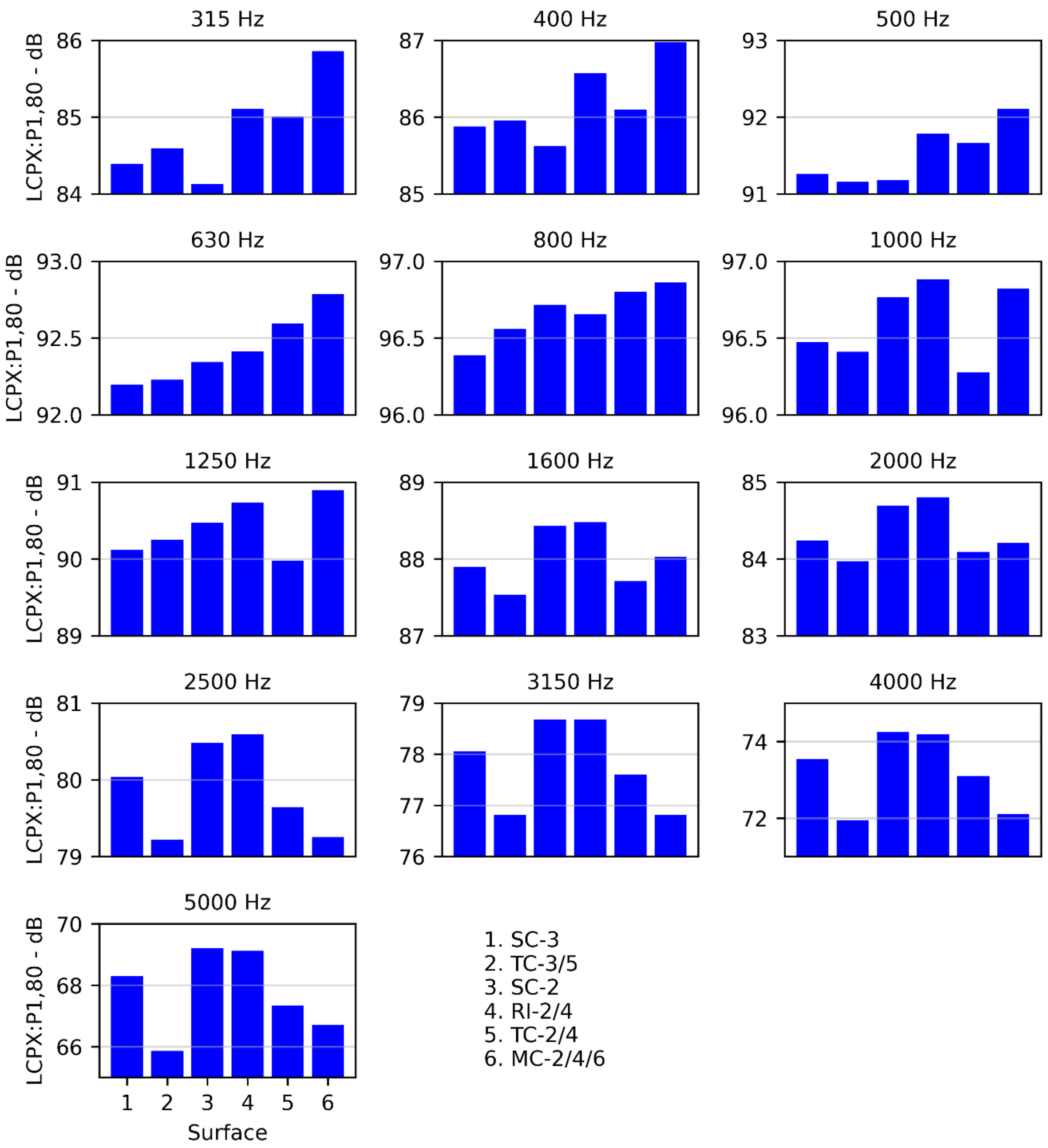

FIGURE 10. INTER-SURFACE ONE-THIRD OCTAVE BAND LEVELS FIVE MONTHS AFTER RESEALING.

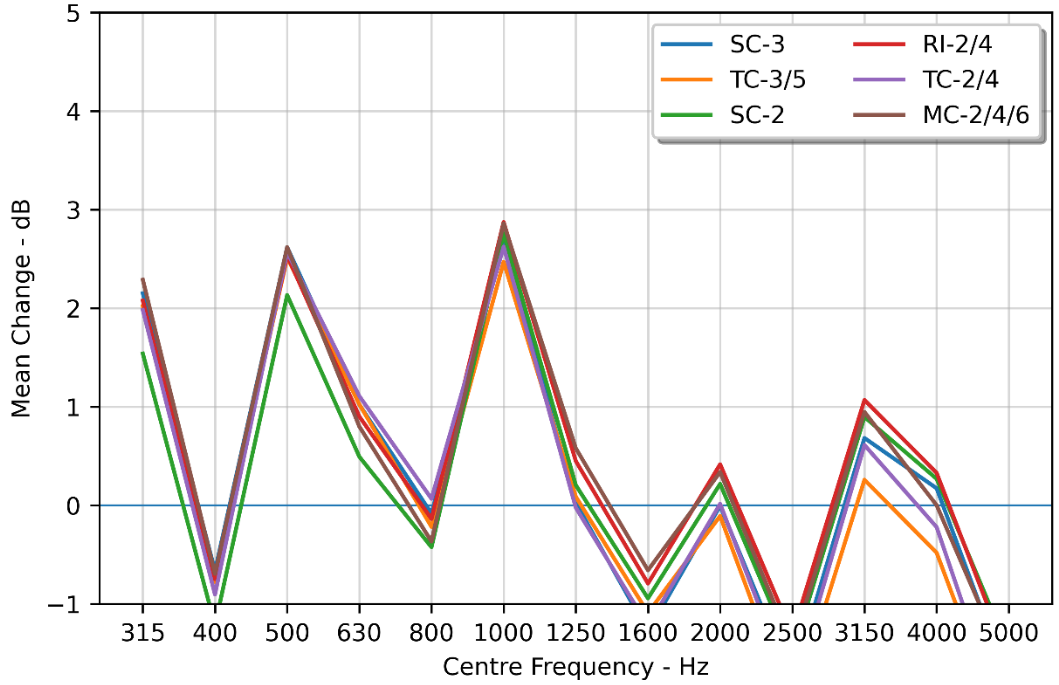

FIGURE 11. CHANGE IN ONE-THIRD OCTAVE BAND LEVELS BETWEEN ONE AND FIVE MONTHS.

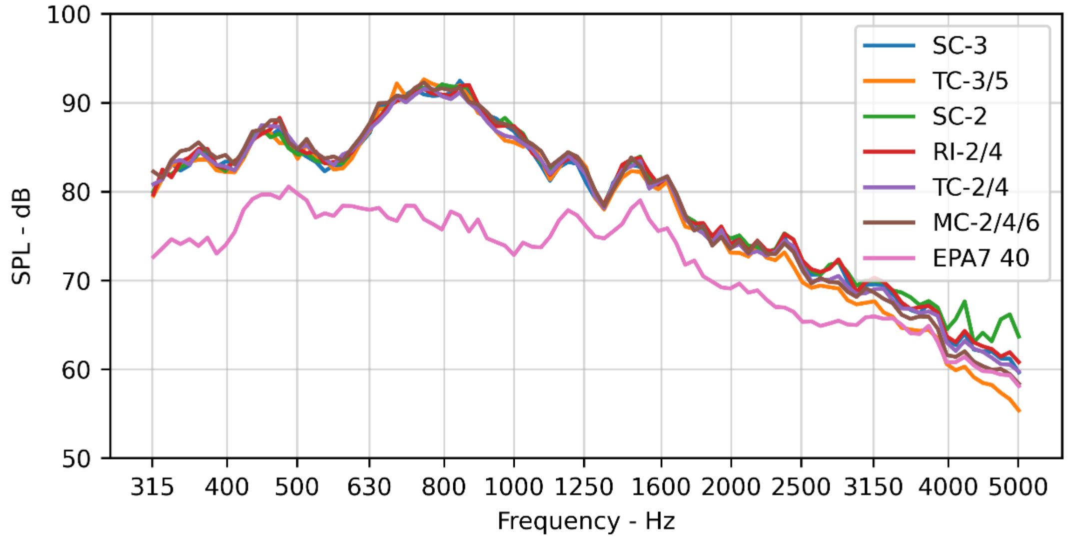

FIGURE 12. 1/24TH OCTAVE BAND DISTRIBUTION FOR ALL CHIPSEAL SURFACES AND EPA 7 – 40 MM ON CSM2.

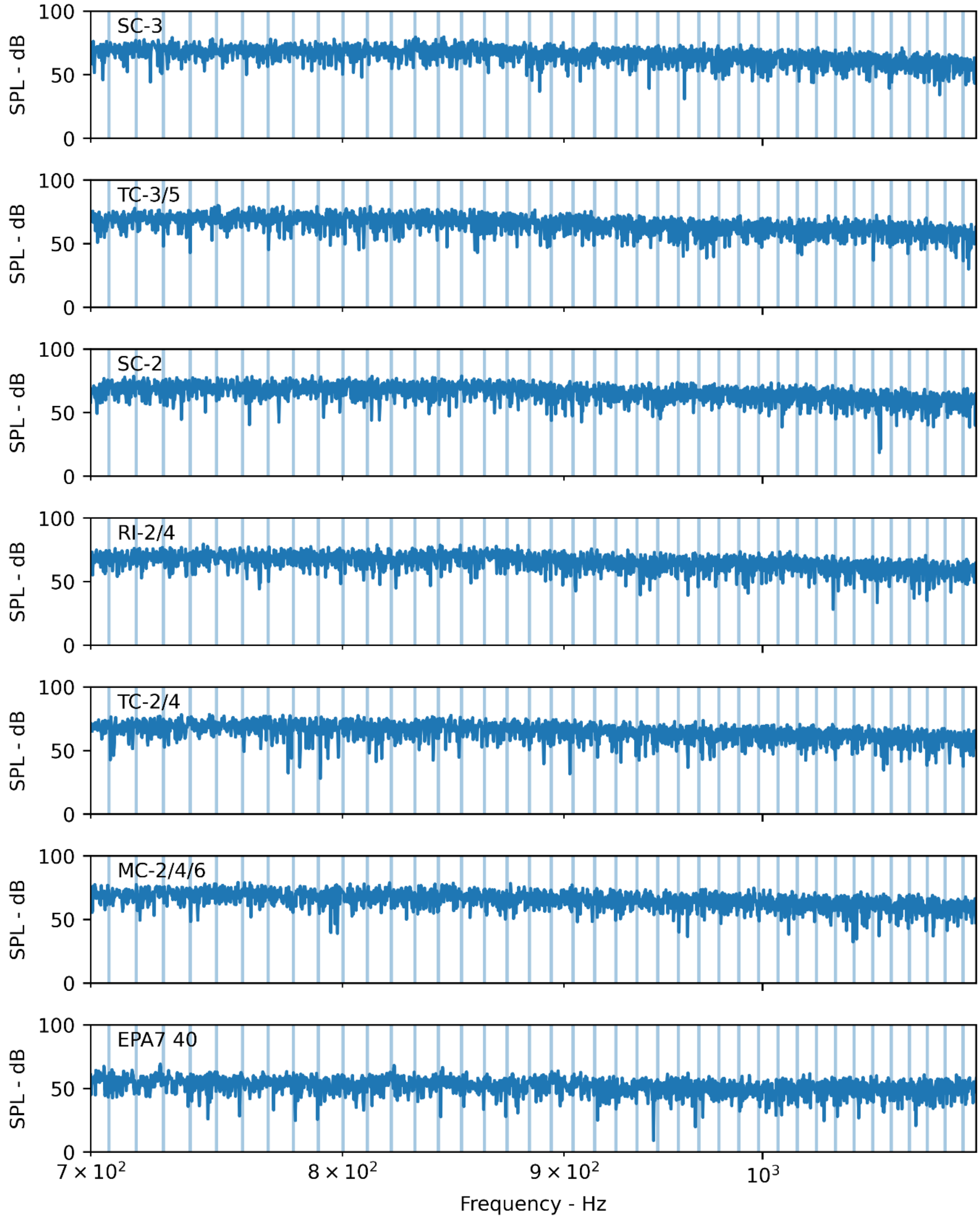

FIGURE 13. NARROW BAND SPECTRUMS FOR ALL CHIPSEAL SURFACES AND A SAMPLE OF EPA7-40 MM ON CSM2.

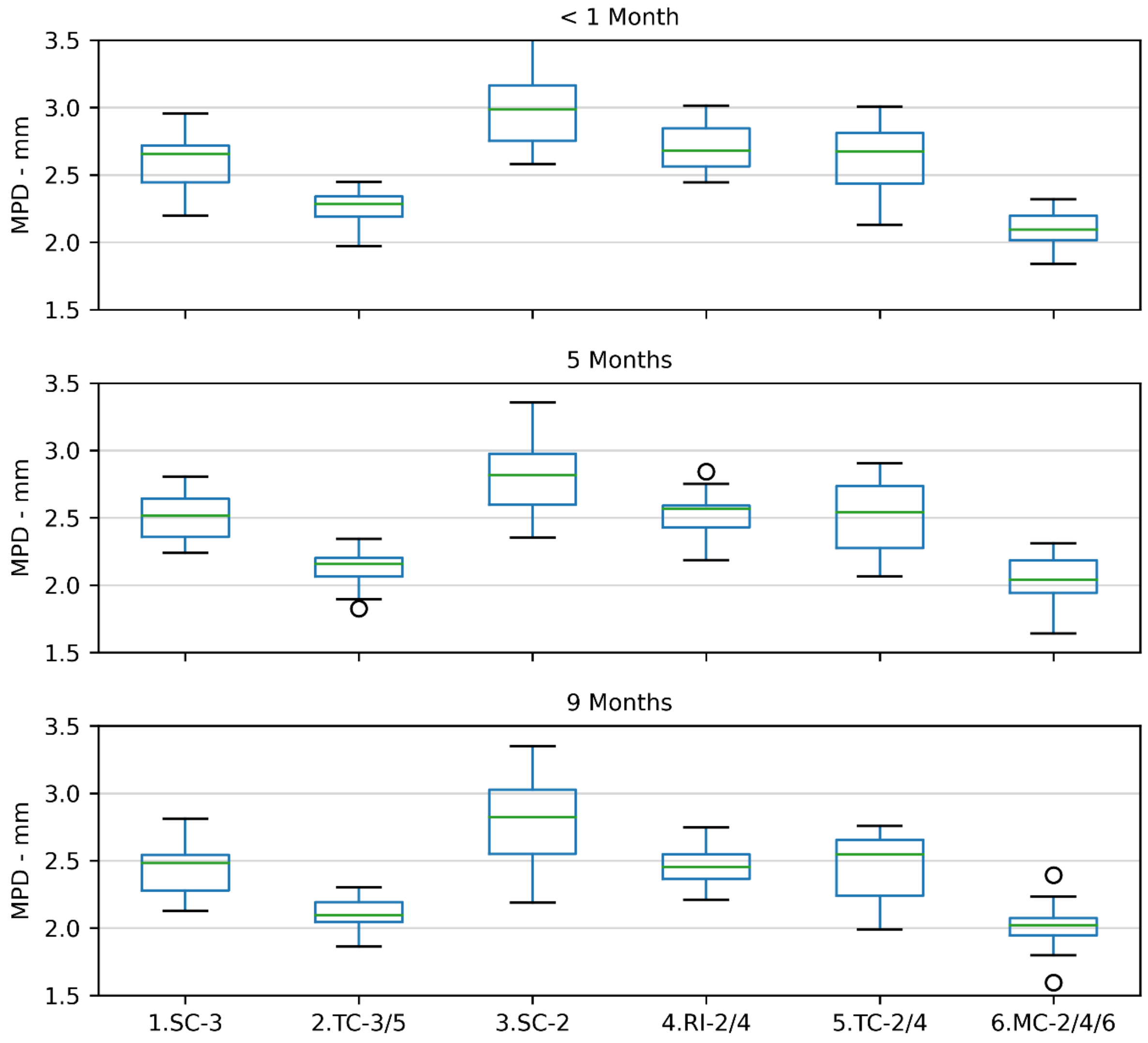

Figure 14. Boxplots of MPD by surface type at one, five, and nine months after resealing.

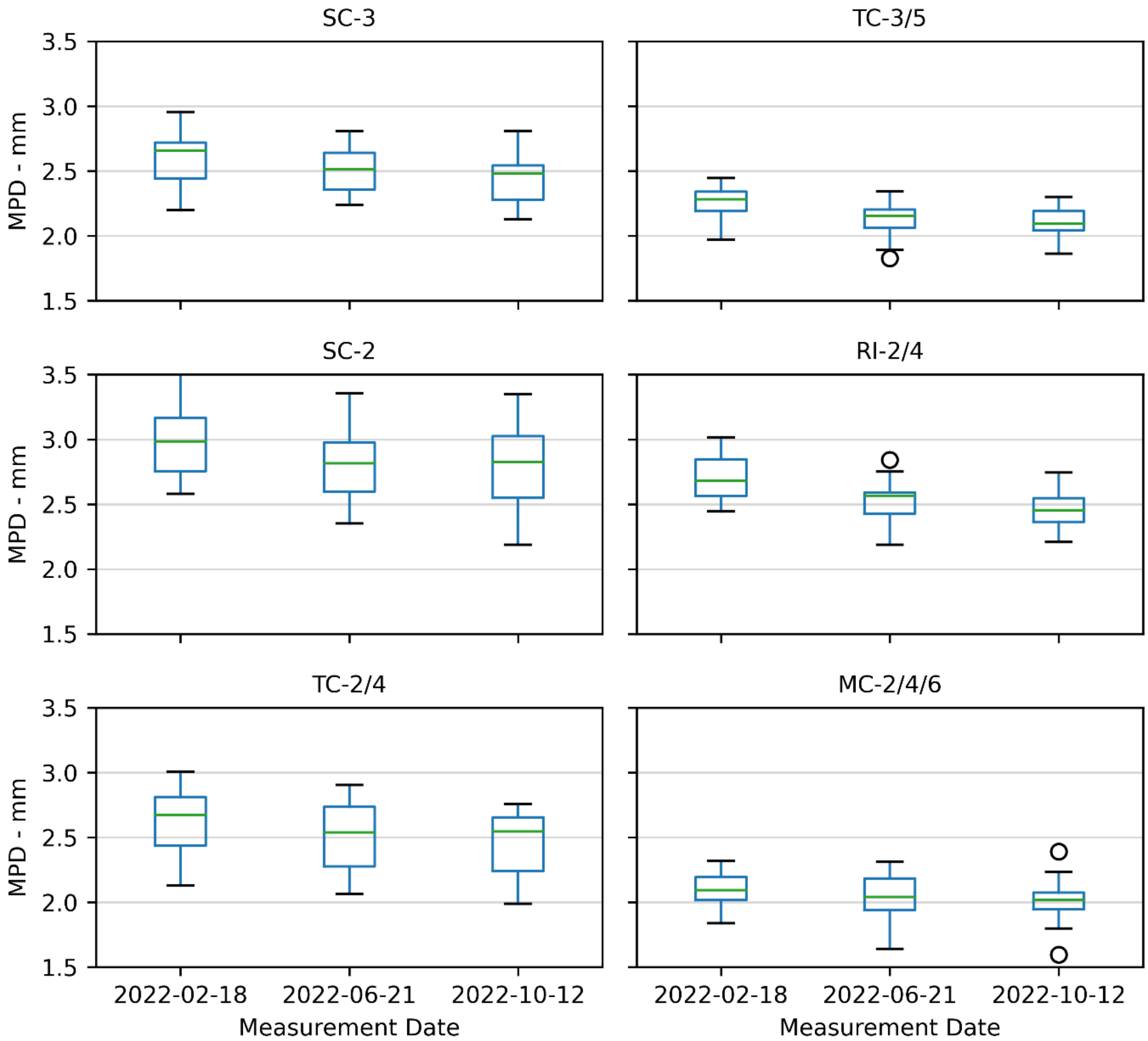

FIGURE 15. BOXPLOTS OF MPD BY SURFACE TYPE AT ONE, FIVE, AND NINE MONTHS AFTER RESEALING.

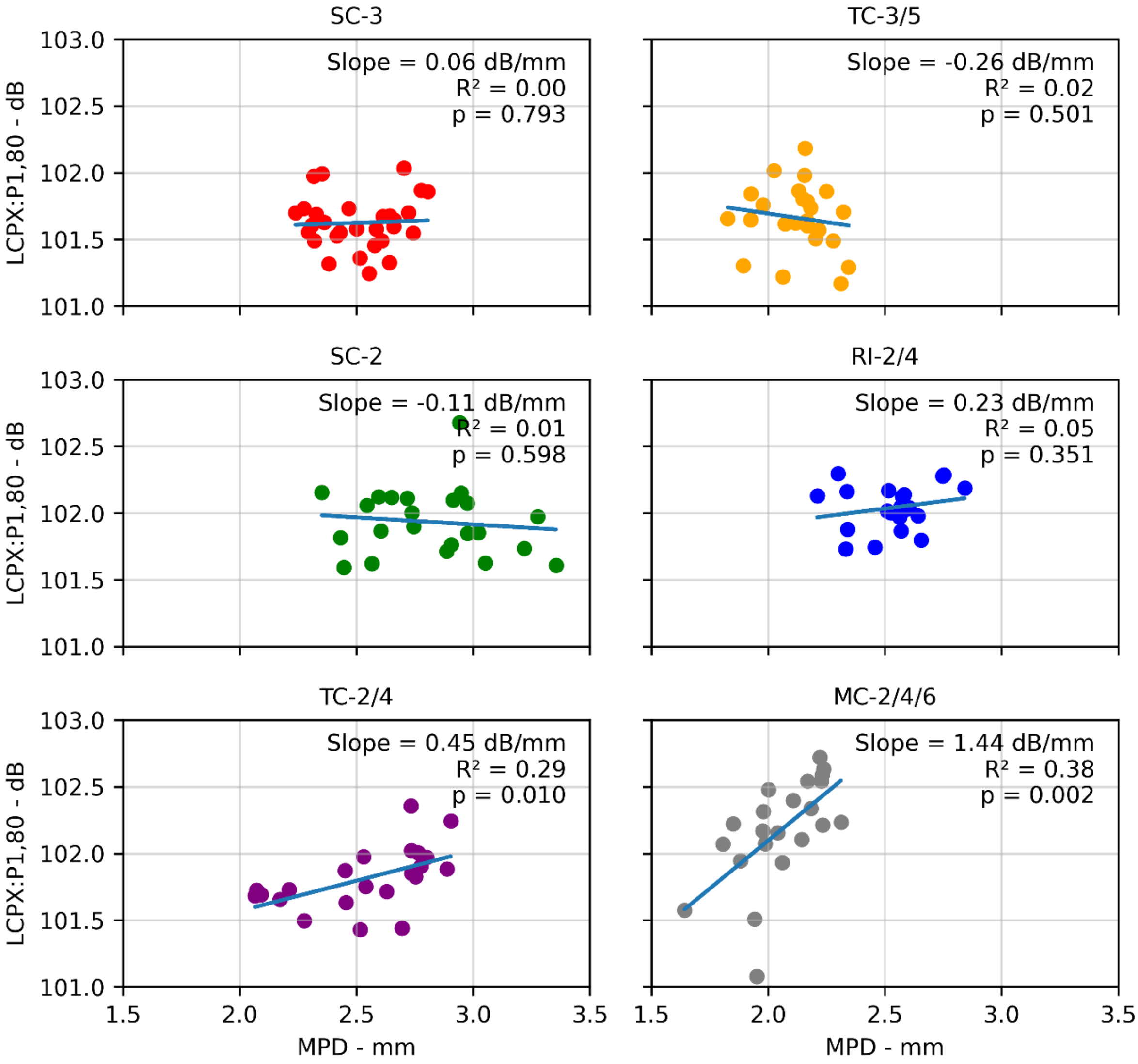

FIGURE 16. L_{CPX} VERSUS MPD FOR EACH SURFACE TYPE FIVE MONTHS AFTER RESEALING.

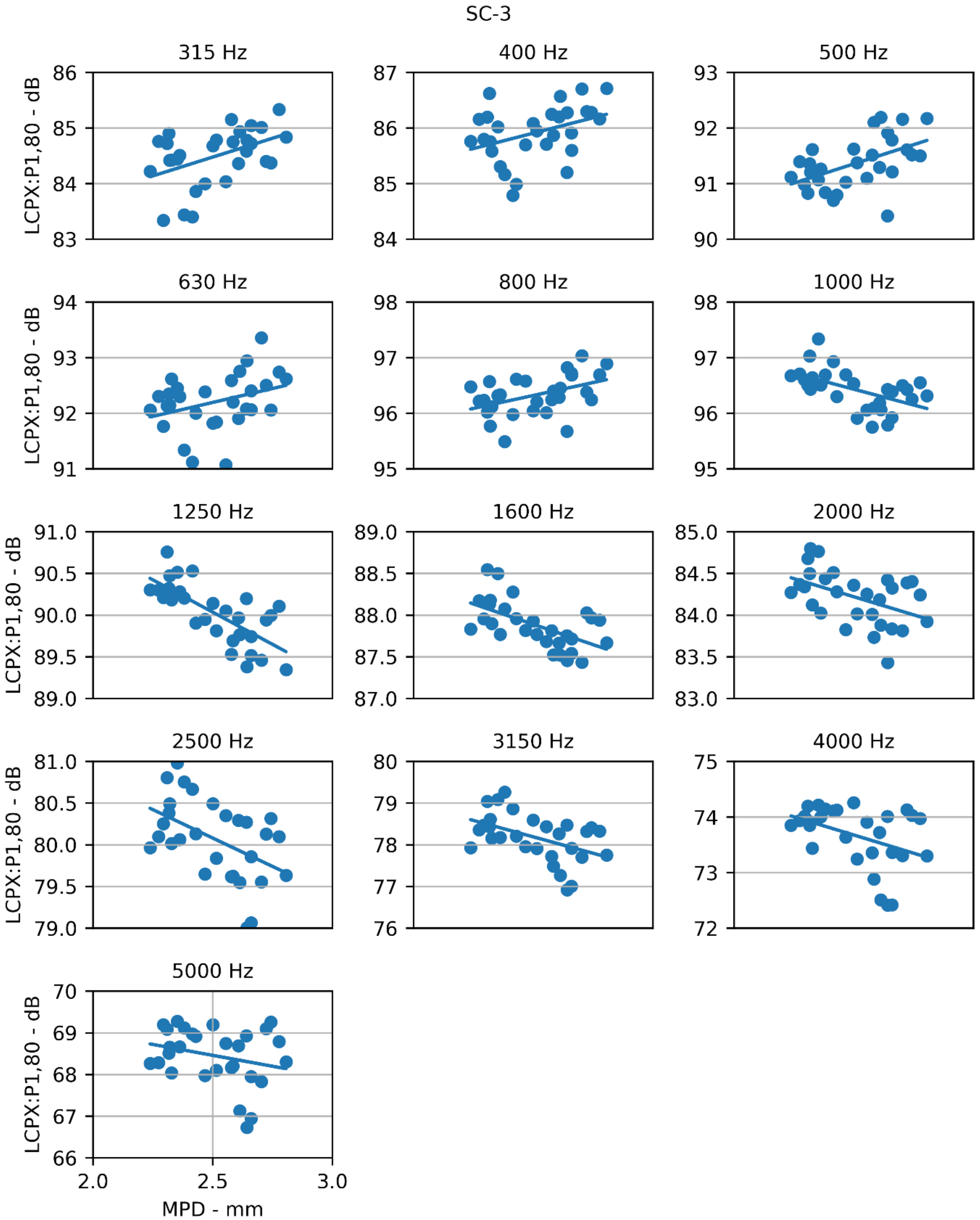

FIGURE 17. ONE-THIRD OCTAVE BAND L_{CPX} VERSUS MPD FOR SINGLE-COAT GRADE 3 FIVE MONTHS AFTER RESEALING.

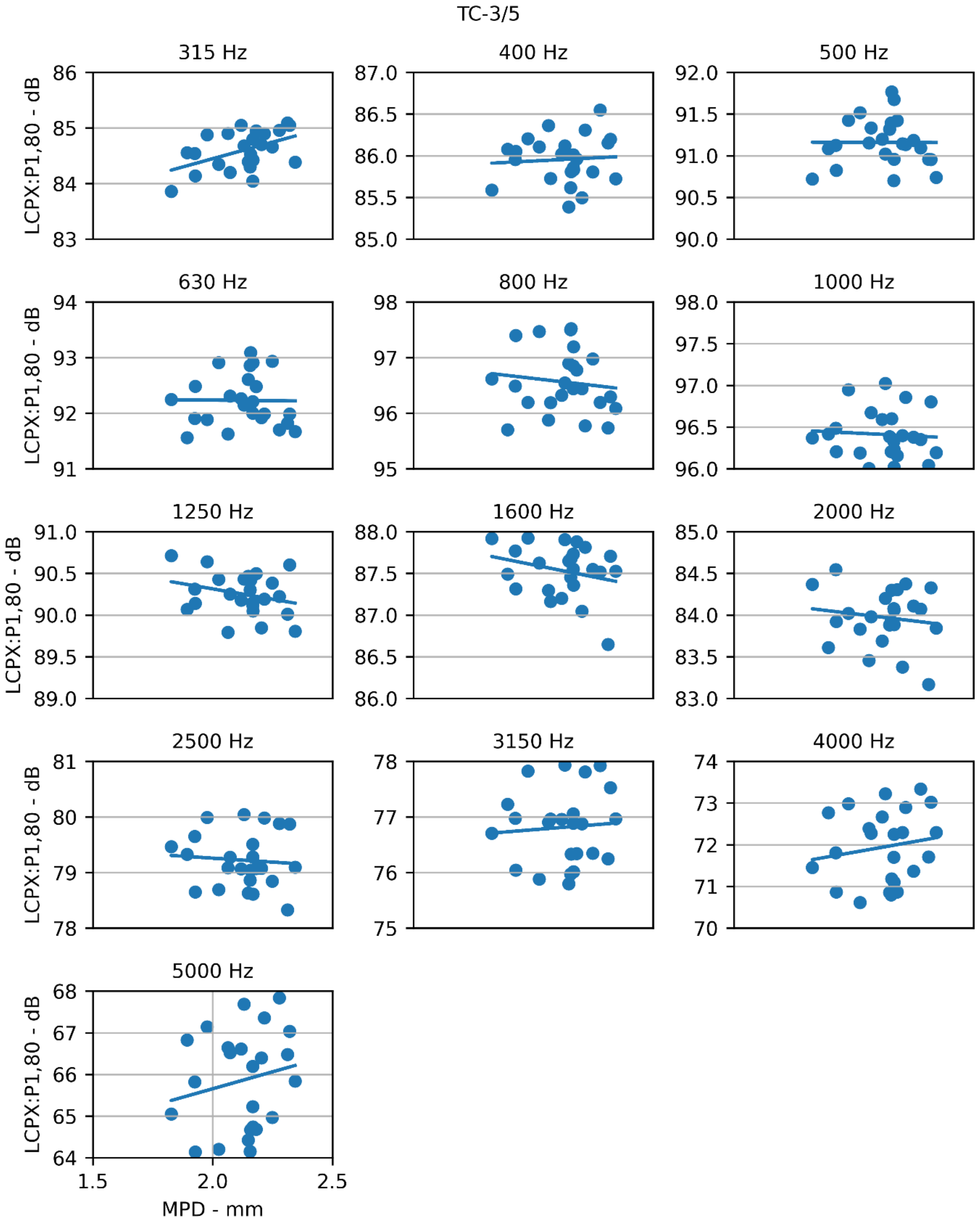

FIGURE 18. ONE-THIRD OCTAVE BAND L_{CPX} VERSUS MPD FOR TWO-COAT GRADE 3/5 FIVE MONTHS AFTER RESEALING.

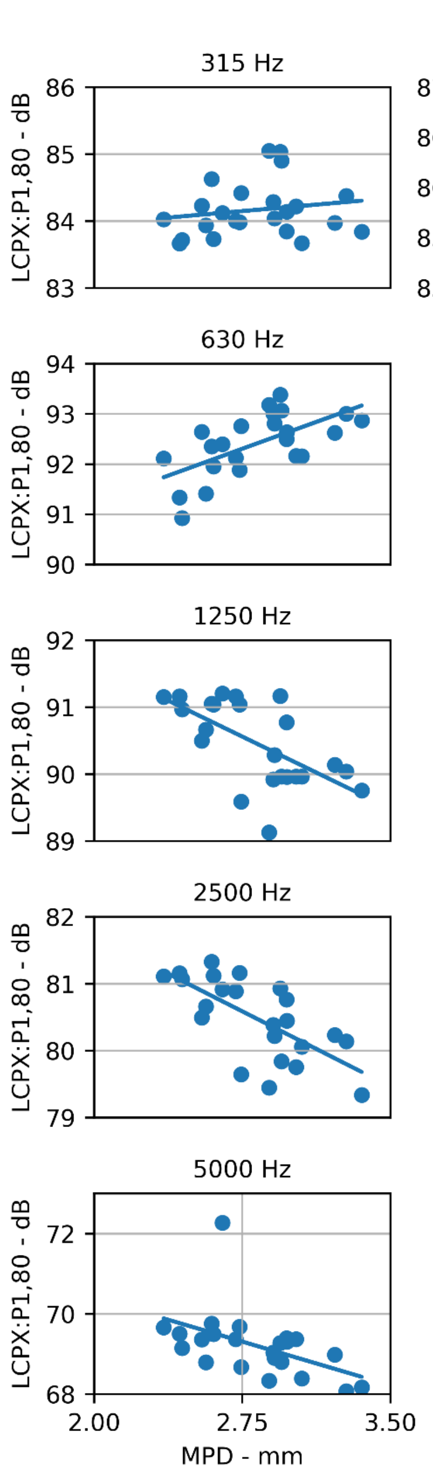

FIGURE 19. ONE-THIRD OCTAVE BAND L_{CPX} VERSUS MPD FOR SINGLE-COAT GRADE 2 FIVE MONTHS AFTER RESEALING.

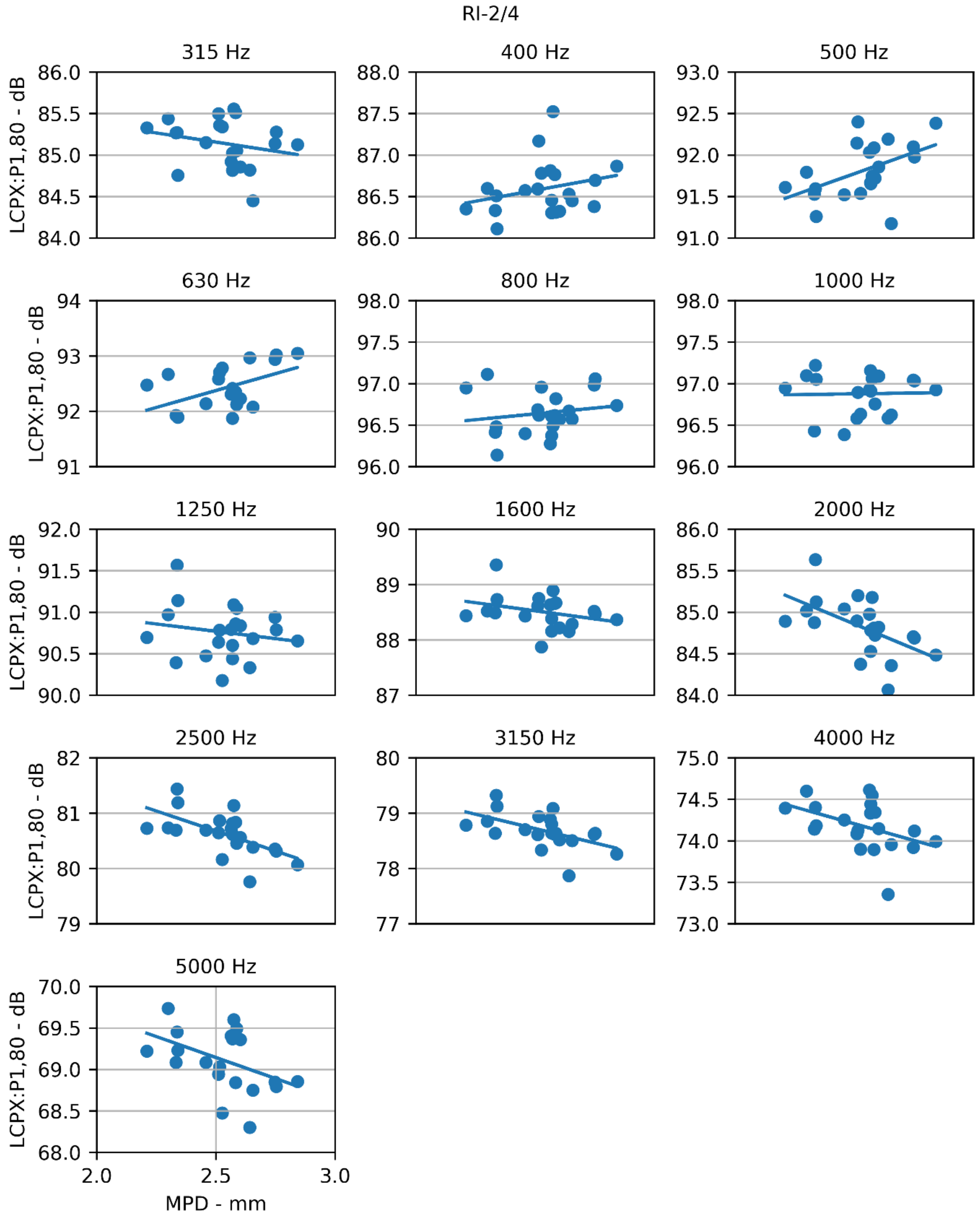

FIGURE 20. ONE-THIRD OCTAVE BAND L_{CPX} VERSUS MPD FOR RACKED-IN GRADE 2/4 FIVE MONTHS AFTER RESEALING.

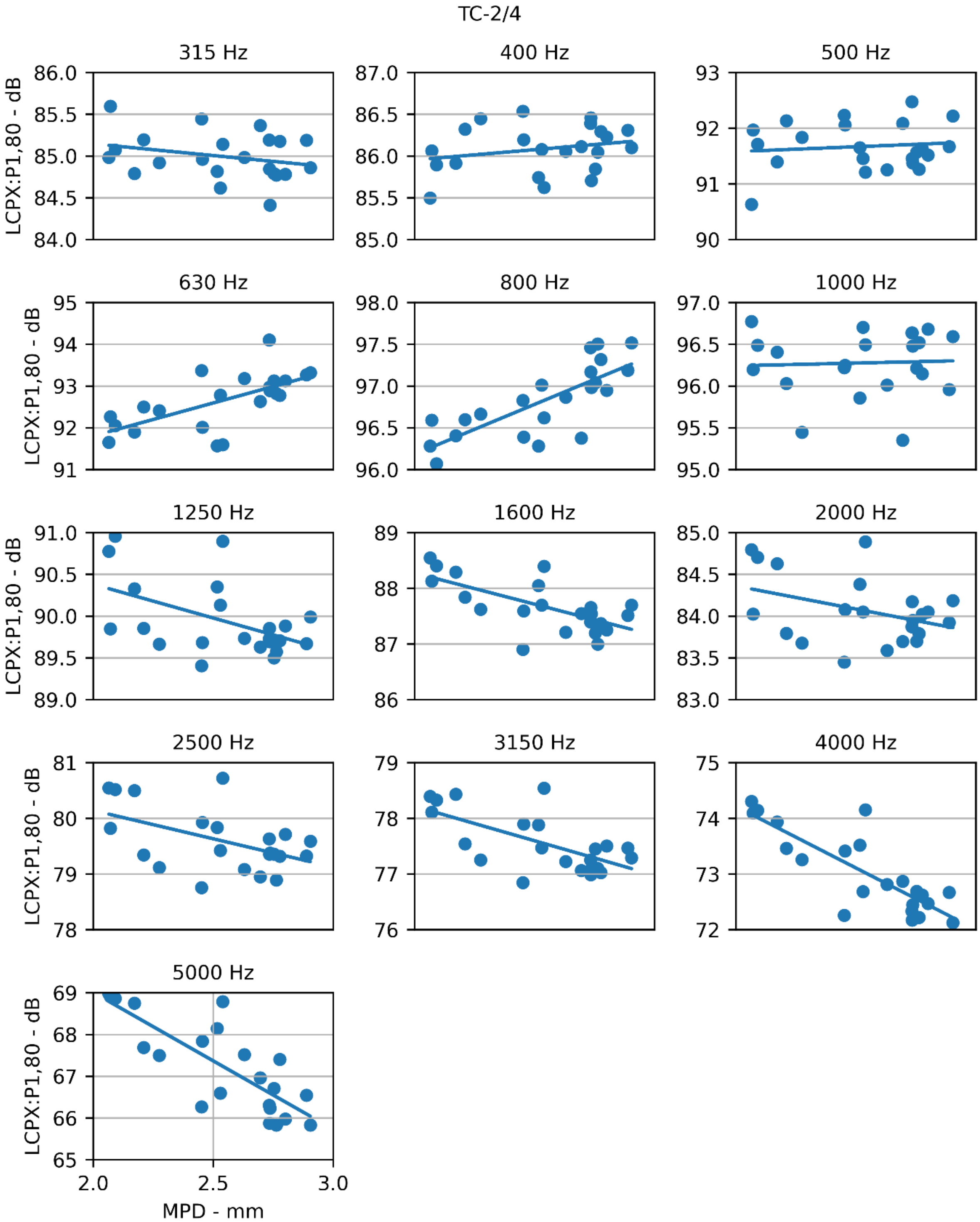

Figure 21. One-third octave band L_{CPX} versus MPD for Two-Coat Grade 2/4 five months after resealing.

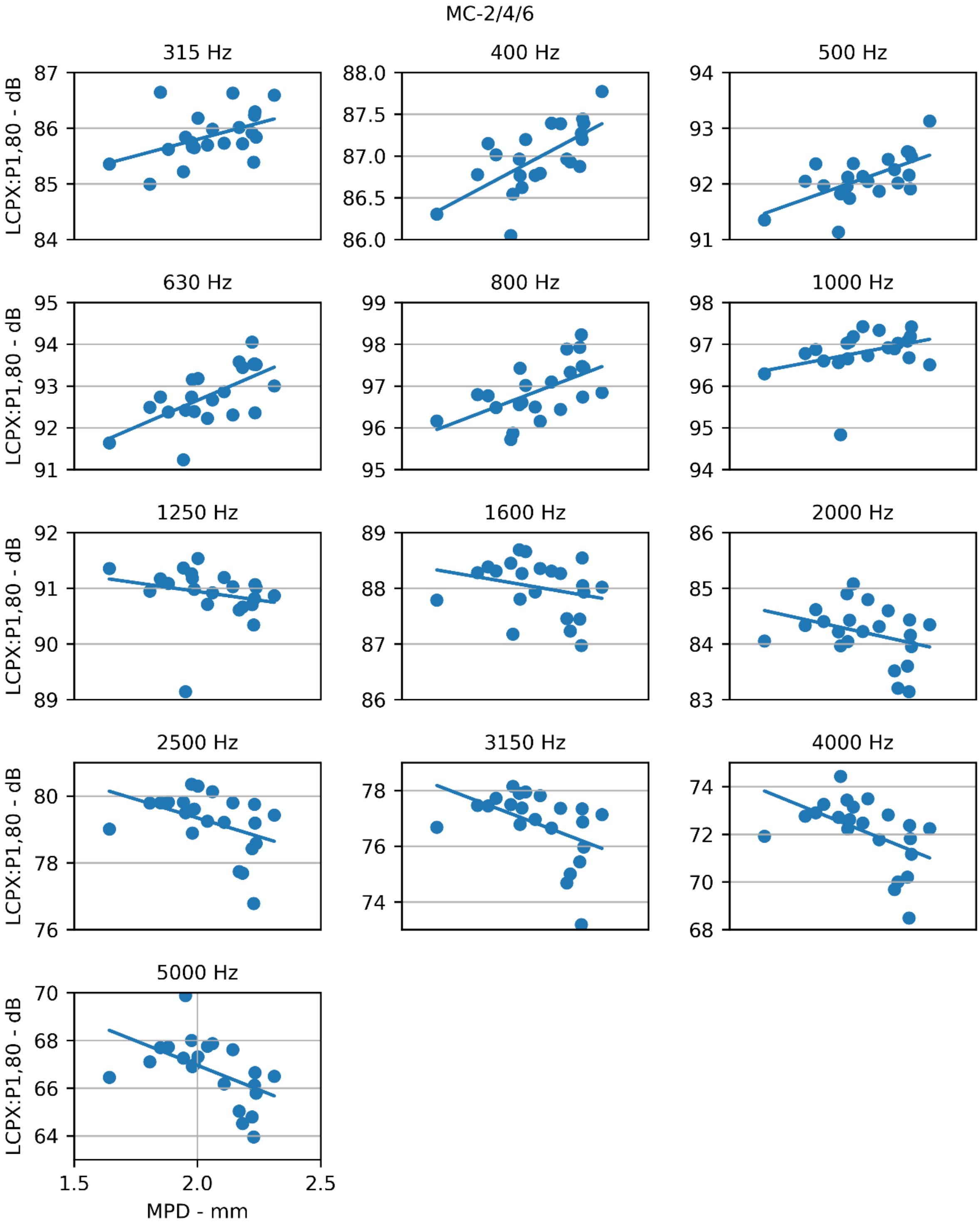

Figure 22. One-Third OCTAVE band L_{CPX} versus MPD for Multi-Coat Grade 2/4/6 five months after resealing.

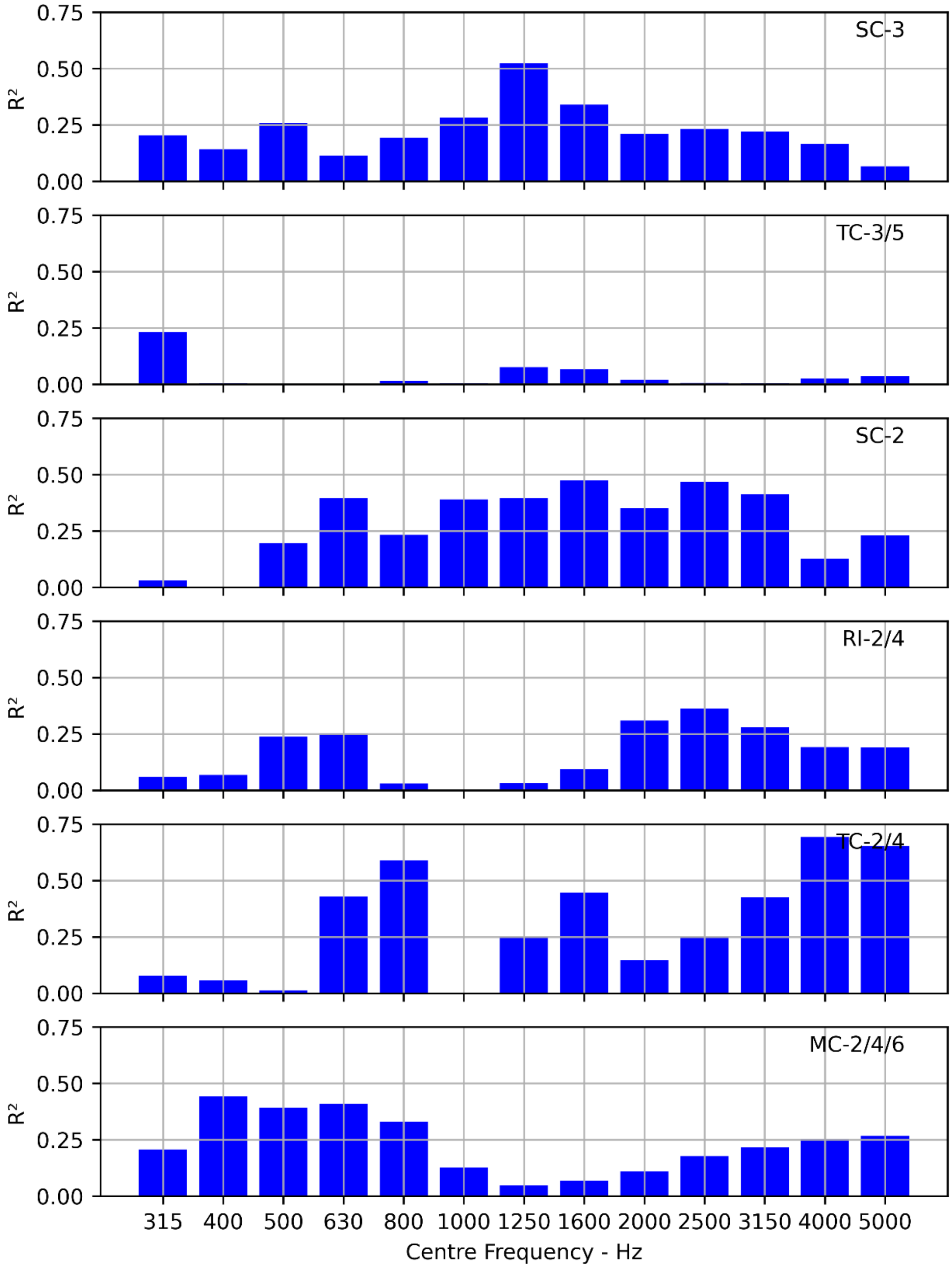

Figure 23. Coefficients of determination (R^2) for correlations between one-third octave L_{CPX} and MPD for each surface type five months after resealing.

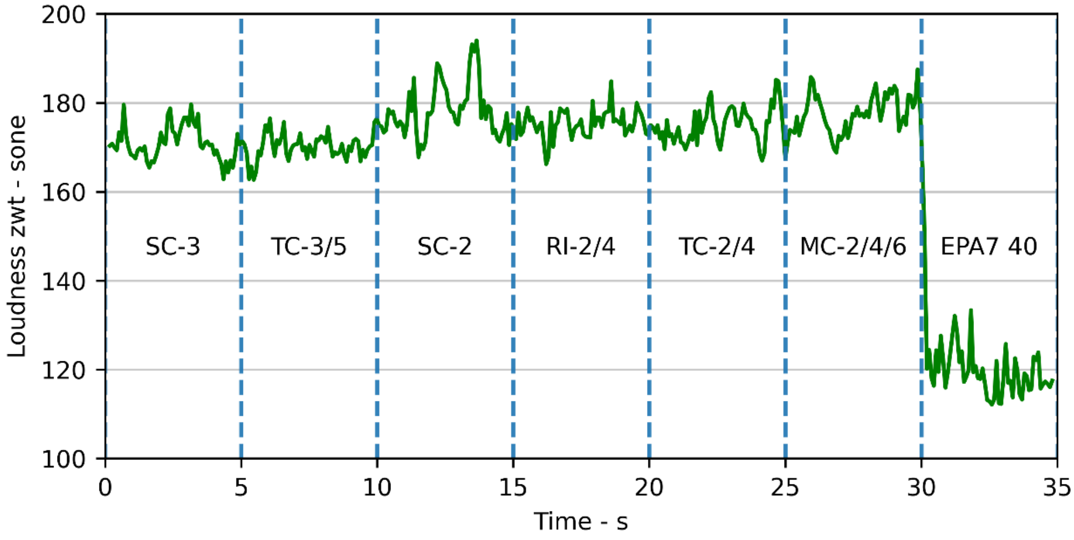

FIGURE 24. ZWICKER LOUDNESS FOR ALL CHIPSEAL SURFACES AND EPA 7 – 40 MM ON CSM2.

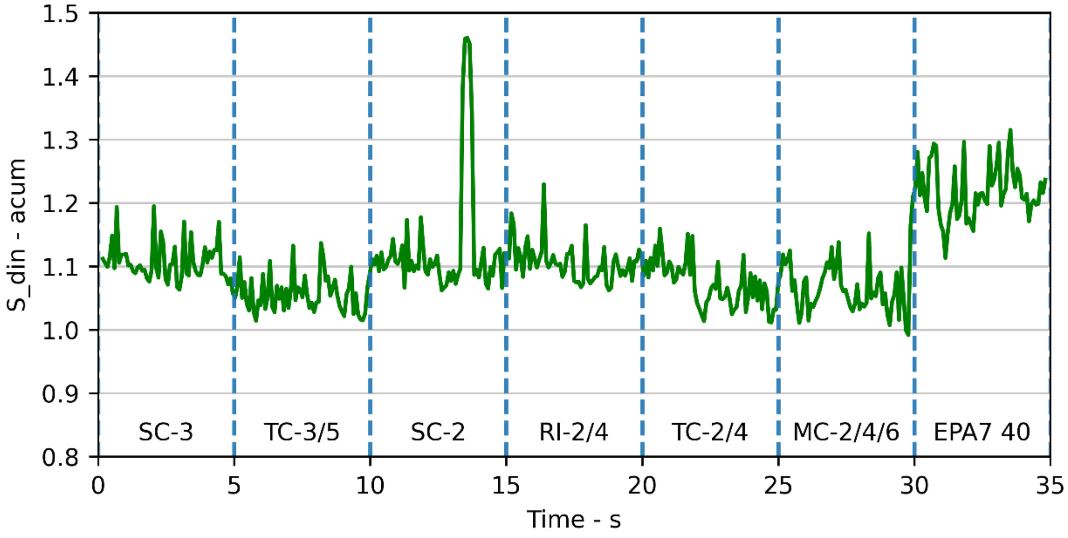

FIGURE 25. SHARPNESS FOR ALL CHIPSEAL SURFACES AND EPA 7 – 40 MM ON CSM2.

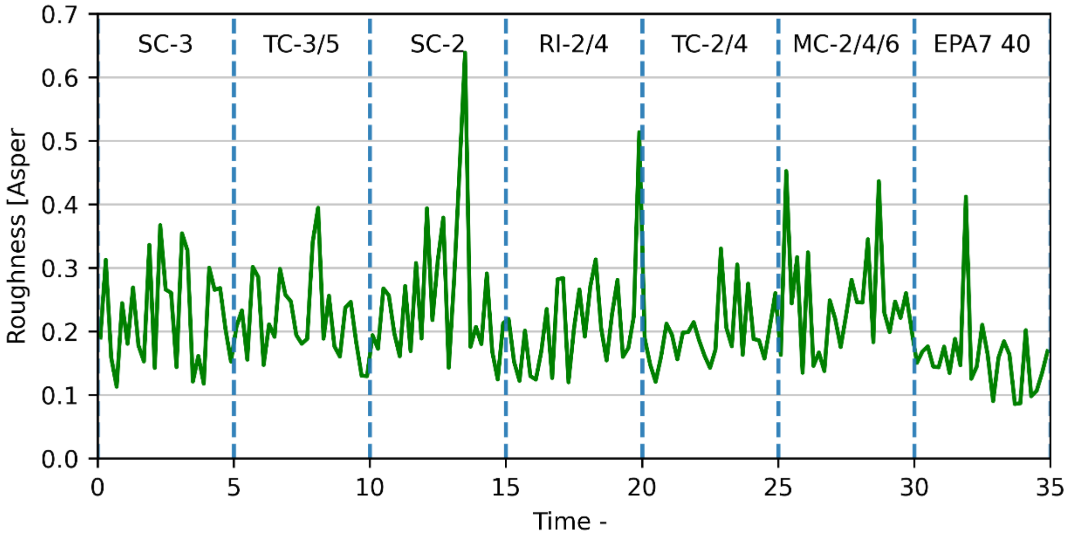

FIGURE 26. ROUGHNESS FOR ALL CHIPSEAL SURFACES AND EPA 7 – 40 MM ON CSM2.

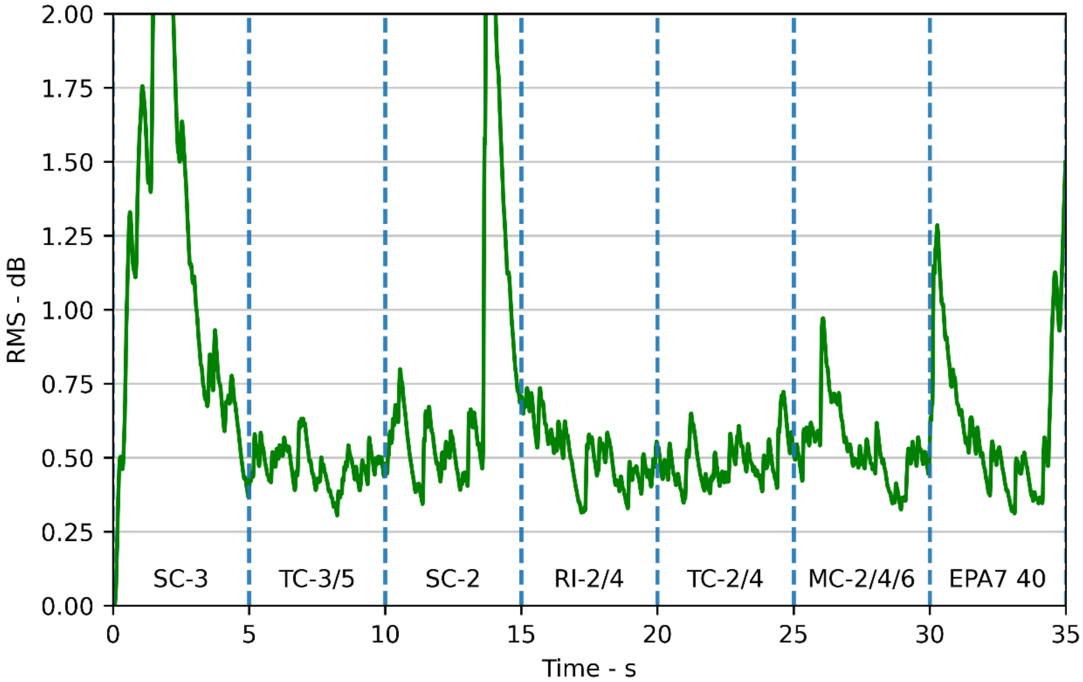

FIGURE 27. MODULATION FOR ALL CHIPSEAL SURFACES AND EPA 7 – 40 MM ON CSM2.

8 Appendix B - Sound Quality Metrics

Sound quality metrics aim to provide an objective measure of how a sound is perceived. Several metrics have been standardised, while others are still in development and require adaption during application. The sound quality metrics used in the present analysis are described below.

8.1 Zwicker Loudness

Zwicker loudness is a quantified measure of the perceived impact of a sound on the ear. The calculation method is defined in ISO 532-1. The method accounts for the impact of tones and how sounds of different frequencies are perceived.

The reference level for loudness is a 1 kHz tone with a sound pressure level of 40 dB; this is said to have a loudness of 40 Phons. A Sone accounts for the variation in perceived loudness with different frequencies and has a linear scale. One Sone is equal to 40 Phones. A Bark is the critical frequency width that tones can be individually distinguished; this is similar to the one-third octave bands. The loudness for each frequency band is calculated in Sones per Bark. The final value for loudness is the integrated area under the Sones per Bark curve and has the units of Sones (Cox, 2023).

MOSQITO calculates loudness following the method described in (Zwicker, Fastl, Kurakata, Kuwano, & Namba, 1991).

8.2 Sharpness

The sharpness of a sound is the high-frequency content and its perception as sounding “sharp” or “hissing”. The calculation method for sharpness is defined in DIN 45692.

The unit of sharpness is acum. One acum as a narrow band sound one critical band wide with a 1,000 Hz centre frequency having a level of 60 dB (Cox, 2023).

MOSQITO uses the ‘din’ weighting function and Zwicker loudness for the computation of sharpness.

8.3 Roughness

Roughness quantifies the subjective effect of rapid fluctuations (15 to 300 Hz) of a sound. There is presently no standardised method for quantifying roughness.

The unit of roughness is the asper. One asper is defined as a 60 dB 1,000 Hz tone that has a modulation of 100% at 70 Hz. A listener can distinguish between roughness values that differ by more than 17% (Cox, 2023).

MOSQITO’s implementation of roughness is based on the algorithm described in (Daniel & Weber, 1997).

8.4 Fluctuation Strength / Modulation

Fluctuation strength or modulation is the low-frequency (<20 Hz) change in noise. It is similar to roughness, but at a lower frequency that can be heard as changes by an observer.

The methodology for calculating modulation can be found in (National Transport Commission, 2007).

9 Appendix C – Trial Site Map

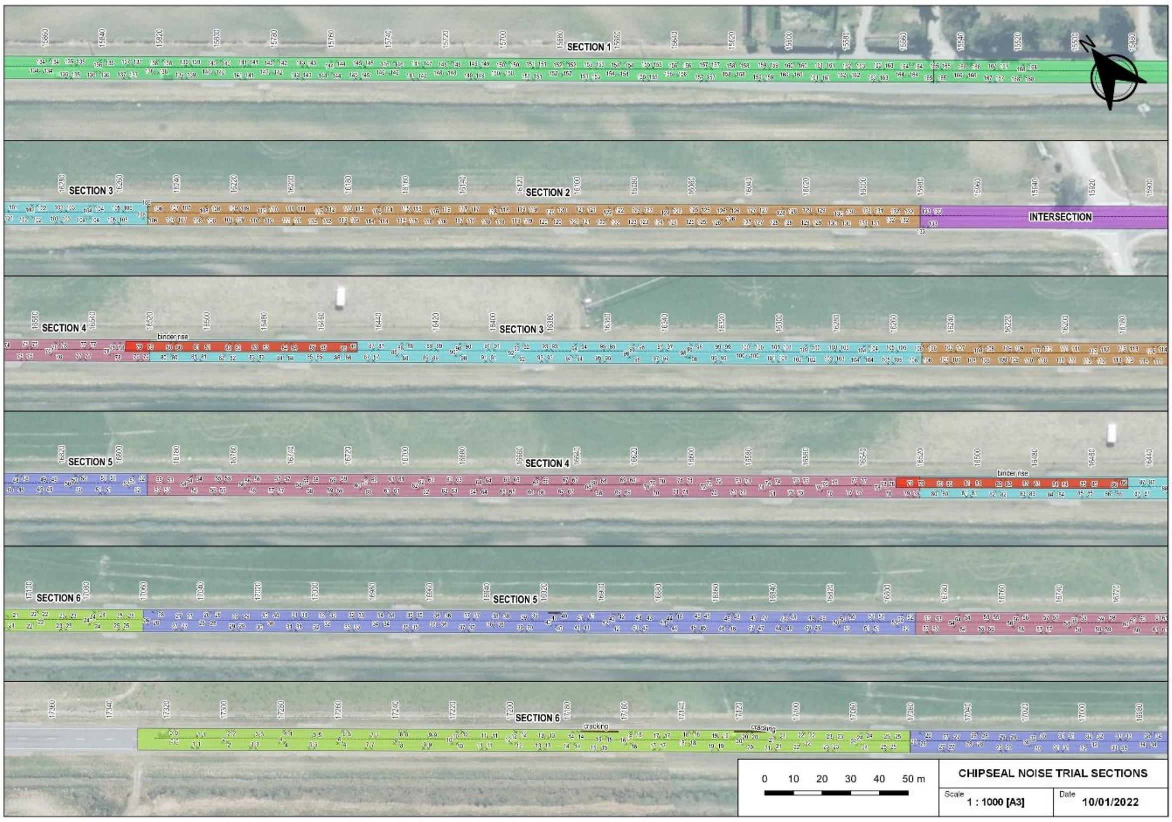

FIGURE 28. MAP OF SH73 CHIPSEAL TRIAL SITES.