RONDA CPX Trailer Measurements Along the Hunter Expressway

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ABSTRACT

RONDA (ROad Noise Data Acquirer) is a CPX trailer conforming to ISO/CD 11819-2 intended for measuring tyre-pavement noise. The trailer is of the open frame type without an enclosure. Tyre-pavement noise measurements along the recently constructed Hunter Expressway were conducted using the RONDA CPX trailer to quantify noise levels for various pavement types along the expressway, which include a variety of concrete and asphalt pavement types. Results from measurements were analysed to determine the tyre-pavement noise levels for each specific pavement type.

1 INTRODUCTION

The Hunter Expressway is a 40km dual carriageway road located between the M1 Pacific Motorway near Seahampton and the New England Highway west of Branxton. Tyre-pavement noise measurements using the RONDA CPX trailer have been undertaken over the full length of the Hunter Expressway to determine the variability of noise results within and between the seven pavement wearing surfaces.

2 EQUIPMENT AND INSTRUMENTATION

The RONDA (ROad Noise Data Acquirer) CPX trailer conforms to Draft ISO 11819-2 'Measurement of the influence of road surfaces on traffic noise - Part 2: The close-proximity method' and is intended for measuring tyre-pavement noise. The trailer is of the open frame type without an enclosure.

RONDA incorporates two independent tyres (of the same type) fitted to a frame with no common axle. For the purpose of the noise measurements presented in this paper, SRTT tyres (Uniroyal Tigerpaw P225/60-R16) have been used with a minimum tread depth of 7mm in accordance with Draft ISO 11819-3, which represent typical light vehicle tyres. The wheel-to-wheel spacing between the tyre centres is 1,690mm, which is in accordance with Draft ISO 11819-2, and the distance between the centre of the RONDA tyres and the centre of the tyres of the towing vehicle is approximately 3,970mm. Each tyre can be independently aligned for toe and camber with variances of better than 0.2%. For each tyre, there is a microphone located 200mm front of centre and one 200mm back of centre, spaced 200mm horizontally from the tyre sidewall and 100mm vertically from the road surface.

Trailer speed is measured using a Kistler Microstar II non-contact microwave sensor type CMSTRA with an operating range of 0.5-400kph and a variance of 0.5%.

Tyre and road surface temperature are measured using Optris CT LT laser thermometers with tolerances of ±1degC. Ambient air temperature is measured using a Dwyer RHP OSA temperature transmitter with a tolerance of ±0.3degC. A laboratory surface thermometer type Measurement Specialties 4600 Precision Thermometer is used to measure the surface temperature of the tyres when testing durometer hardness with a tolerance of ±0.12degC. It is noted that no correction for temperature variances were applied to the measurement results as the coefficients incorporated in the ISO standard are yet to be verified for Australian conditions. Studies to obtain coefficients relevant to Australian conditions are currently planned. Nevertheless, temperature corrections would be minimal and would not affect the comparison of tyre-pavement noise levels for the various pavement types.

Tyre hardness is measured at 20±2degC using a Bareiss HP-AS Shore A Durometer. This instrument has been calibrated using a set of three test blocks for Shore A 40/60/80 duro.

The load on each tyre is measured using a Nuweigh MIL 589 weigh beam scale with has a range of 1000kg and 0.2kg resolution. The static load of the test tyres is 3200N ±200N per tyre.

The tyre and airbag inflation pressures are measured using a Dwyer DPG-200 digital pressure gauge which has a tolerance of ±0.7%. The tyres and airbag are inflated to 200kPA ±10kPa at normal ambient temperature.

The precision of all measurement equipment on the RONDA CPX trailer and the methods of measurements comply with the ISO standard.

Noise level measurements are made using a Sinus Soundbook Mark II and four GRAS 46AE microphones. This instrumentation meets the requirements of IEC 61672-1:2002 as a Type 1 instrument. The frequency range of measurements as specified in the standard is 315Hz-5kHz. The microphones are fitted with Bruel & Kjaer UA1650 90mm foam windscreens.

At the beginning of any measurement and at the end, the measurement instrumentation is calibrated using a GRAS 42AA pistonphone sound level calibrator. The calibrator meets the requirements of IEC 60942 Class 1.

The precision of all measurement equipment complies with the ISO standard.

Figure 1: CPX Trailer RONDA Open Frame Design

Figure 2: Microphone Setup

Figure 3: 16" SRTT Tyre and Tread Pattern

3 MEASUREMENTS AND DATA ANALYSIS

The vehicle was driven at three speeds (70m/h, 90km/h and 110km/h) along each carriageway of the Hunter Expressway. All measurements were conducted along the same single lane in each direction in order to maintain consistency in the wearing courses measured for the three speeds.

The recordings of the noise levels at the four microphone locations are made at 100ms intervals. During the mobile data capture the following information is recorded:

- tyre temperature;
- road surface temperature;
- ambient temperature;
- speed; and
- GPS location.

The energy average spectrum at the microphone positions is calculated in each one-third octave band centre frequency.

Regression analysis is conducted for each road segment of wearing course on pavement to determine the relationship between noise level and speed so that noise levels can be corrected to a reference speed.

The arithmetic average noise level is then determined over each road segment for each tyre and the arithmetic average of the left and right tyre is determined. The A-weighted arithmetic average noise level is termed the CPX noise level and is expressed in decibels.

The reported noise levels in this paper are designated as $L_{CPX:P,vr}$ where;

- L_{CPX} is the time averaged A-weighted sound pressure level of the tyre-pavement noise levels averaged for the four microphones (two per tyre) as determined by the CPX method as defined in the ISO standard, expressed in decibels,
- *P* designates that the standard light vehicle tyre (SRTT) was used for the measurements, and
- *vr* is the reference speed. The reference speed is in km/h and has been designated to be 100km/h.

4 TYPES OF PAVEMENTS

RONDA was used to conduct tyre-pavement noise measurements along various types of wearing courses on pavements along the Hunter Expressway. Measurements were undertaken on both the westbound and east-bound carriageways of the road. The types of wearing courses on pavements along the Hunter Expressway were as follows.

Table 1: Types of Wearing Courses on Pavements along the Hunter Expressway

Location ID	Detailed Pavement Description
	Westbound (Prescribed) Direction
PW1	Full depth asphalt (FDA) with 50mm DGAC14[1] wearing surface
PW2	Full depth asphalt (FDA) with 40mm SMA14[2] wearing surface
PW3	Plain concrete pavement (PCP) with transverse tining wearing surface
PW4	Continuously reinforced concrete pavement (CRCP) with CDG wearing surface (original longitudinal tining required grinding to improve ride-ability or smoothness: CDG[4])
PW5	Continuously reinforced concrete pavement (CRCP) with 40mm SMA14[2] wearing surface
PW6	Full depth asphalt (FDA) with 30mm SMA10[5] wearing surface
PW7	Continuously reinforced concrete pavement (CRCP) with 30mm SMA10[5] wearing surface
PW8	Plain concrete pavement (PCP) with transverse tining wearing surface
PW9	Plain concrete pavement (PCP) with LNDG[3] wearing surface
PW10	Full depth asphalt (FDA) with 30mm SMA10[5] wearing surface
PW11	Plain concrete pavement (PCP) with transverse tining wearing surface
PW12	Continuously reinforced concrete pavement (CRCP) with 30mm SMA10[5] wearing surface
PW13	Plain concrete pavement (PCP) with transverse tining wearing surface
PW14	Full depth asphalt (FDA) with 30mm SMA10[5] wearing surface
PW15	Full depth asphalt (FDA) with 45mm DGAC14[1] wearing surface
	Eastbound (Counter) Direction
PE1	Full depth asphalt (FDA) with 50mm DGAC14[1] wearing surface
PE2	Full depth asphalt (FDA) with 40mm SMA14[2] wearing surface
PE3	Plain concrete pavement (PCP) with CDG[4] wearing surface
PE4	Plain concrete pavement (PCP) with transverse tining wearing surface
PE5	Plain concrete pavement (PCP) with CDG[4] wearing surface
PE6	Continuously reinforced concrete pavement (CRCP) with CDG[4] wearing surface
PE7	Continuously reinforced concrete pavement (CRCP) with LNDG[3] wearing surface
PE8	Continuously reinforced concrete pavement (CRCP) with 40mm SMA14[2] wearing surface
PE9	Full depth asphalt (FDA) with 30mm SMA10[5] wearing surface
PE10	Continuously reinforced concrete pavement (CRCP) with 30mm SMA10[5] wearing surface
PE11	Plain concrete pavement (PCP) with transverse tining wearing surface
PE12	Plain concrete pavement (PCP) with LNDG[3] wearing surface
PE13	Full depth asphalt (FDA) with 30mm SMA10[5] wearing surface
	Eastbound (Counter) Direction

Location ID	Detailed Pavement Description
PE14	Plain concrete pavement (PCP) with transverse tining wearing surface
PE15	Continuously reinforced concrete pavement (CRCP) with 30mm SMA10[5] wearing surface
PE16	Plain concrete pavement (PCP) with transverse tining wearing surface
PE17	Full depth asphalt (FDA) with 30mm SMA10[5] wearing surface
PE18	Full depth asphalt (FDA) with 45mm DGAC14[1] wearing surface

Notes:
1. DGAC14 – Dense Grade Asphalt with 14mm aggregate
2. SMA14 – Stone Mastic Asphalt with 14mm aggregate
3. LNDG – Low Noise Diamond Grinding (longitudinal grooved surface) achieved by 1 pass method; ie. newly paved concrete with hessian drag finish then diamond grinding (or grooving) to provide 3.2mm sawcuts at 14.5mm centres into the surface. No preliminary CDG or flush grind passes of the diamond grinder used
4. CDG – Conventional Diamond Grinding
5. SMA10 – Stone Mastic Asphalt with 10mm aggregate

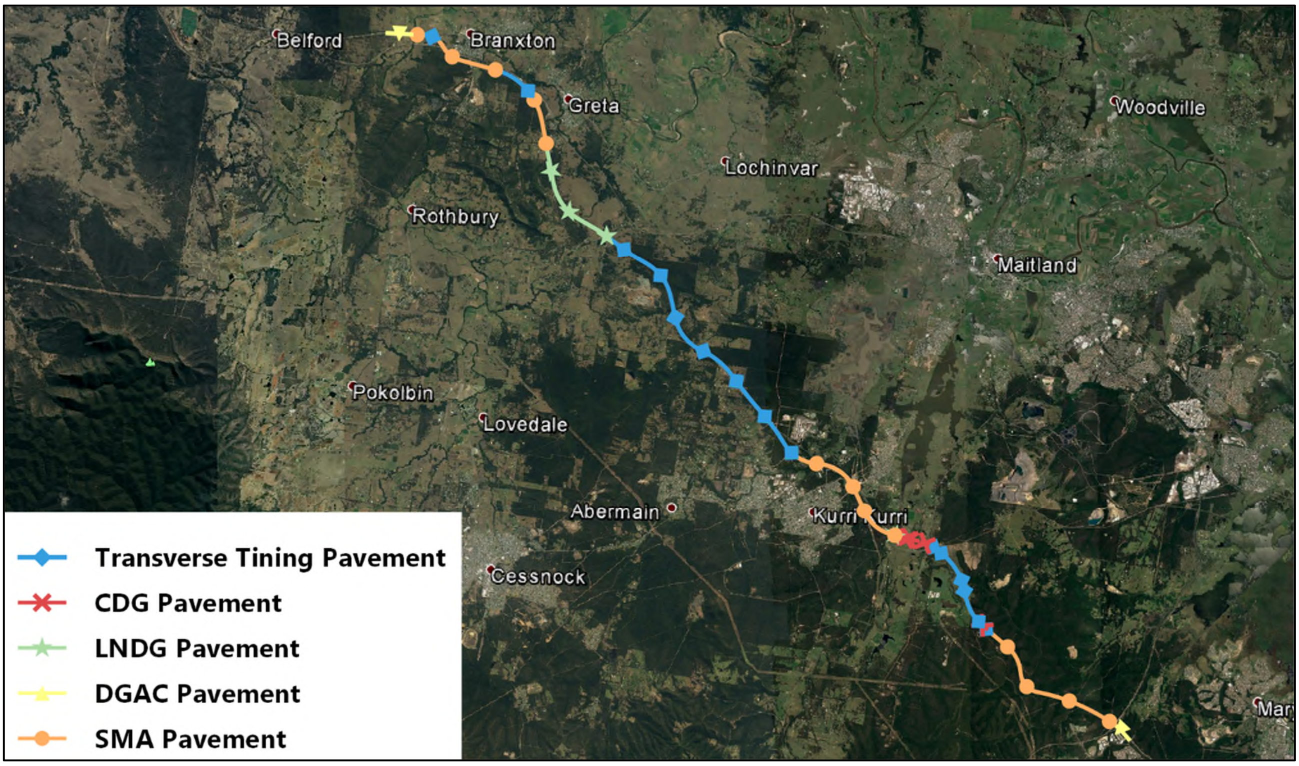

Figure 4: Hunter Expressway Location and Wearing Coarse on Pavement Types

In addition to the measurements of the pavements along the Hunter Expressway, a considerable number of tyre-pavement noise measurements using RONDA have been undertaken by Renzo Tonin & Associates along numerous pavements in NSW where dense grade asphalt (DGA) wearing courses have been laid. Acoustically, dense grade asphalt (DGA) is accepted as the reference pavement (ie. 0dB(A) noise correction) when determining the noise performance of different pavements. The noise level data from the dense grade asphalt (DGA) measurements underwent regression analysis so that $L_{CPX:P,vr}$ noise levels at the reference speed can be determined for the reference dense grade asphalt (DGA) pavement and used compared to the $L_{CPX:P,vr}$ noise levels for the various wearing courses along the Hunter Expressway.

5 MEASUREMENT RESULTS

Regression analysis was conducted for each wearing course using the RONDA measured data for the various speeds. Results indicate high correlation coefficients; therefore, the regressions determined were appropriate in correcting noise levels to the reference speeds.

Using the results of the regression analysis for each wearing course, the noise level comparisons at the reference speed of 100km/h are provided below.

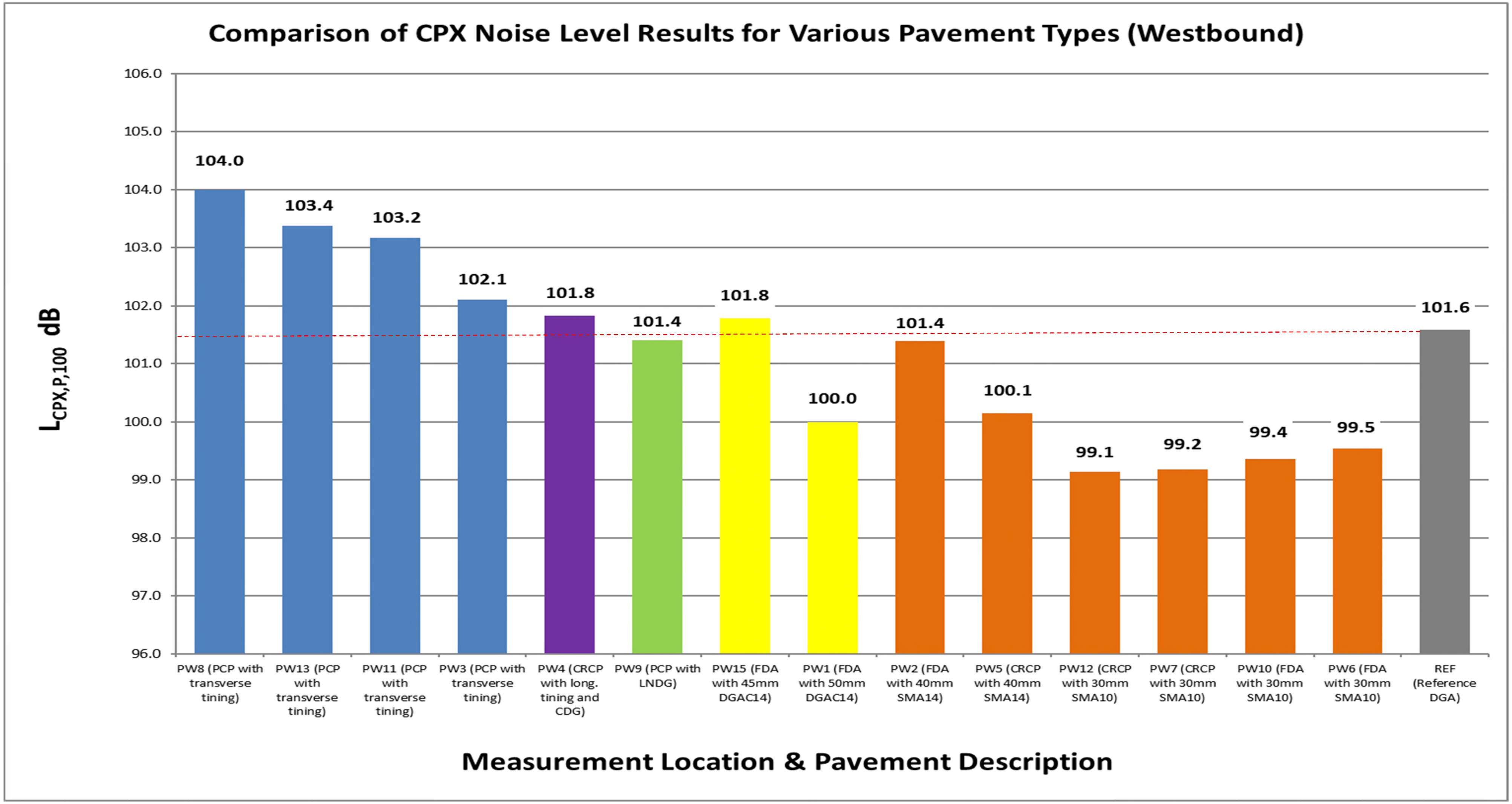

Figure 5: Comparison of Tyre-Pavement Noise Levels (Westbound Carriageway)

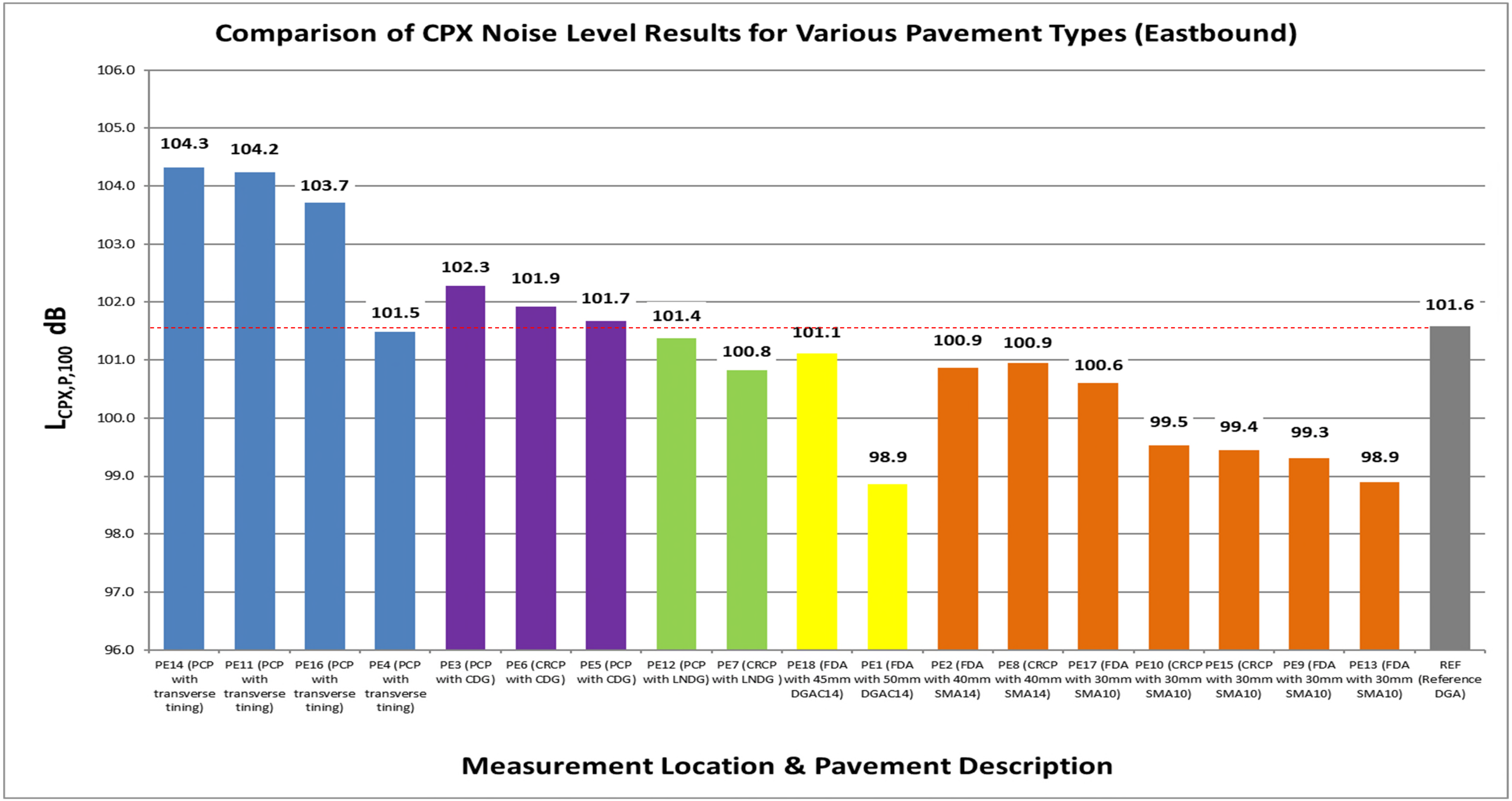

Figure 6: Comparison of Tyre-Pavement Noise Levels (Eastbound Carriageway)

From the above figures, the CPX results show that the transverse tined concrete pavements produced the highest tyre-pavement noise levels, which are up to 2.6dB(A) and 3.5dB(A) higher than the non-tined concrete pavements (with LNDG) for the westbound and eastbound carriageways, respectively, along the Hunter Expressway. Tyre-pavement noise levels for the transverse tined concrete pavements were up to 4.5dB(A) and 5.4dB(A) higher than the asphalt pavements (SMA) for the westbound and eastbound carriageways, respectively.

The conventional diamond grinding (CDG) concrete pavements on the westbound and eastbound carriageways were shown to produce tyre-pavement noise levels within 1dB(A) and up to 1.5dB(A) of those from low noise diamond grinding (LNDG) concrete with longitudinal grooves, respectively.

Tyre-pavement noise levels of low noise diamond grinding (LNDG) concrete pavements with longitudinal grooves were generally comparable with the dense grade asphalt (DGAC) on the Hunter Expressway and SMA14 wearing surfaces.

The stone mastic asphalt (SMA) typically produced the lowest tyre-pavement noise levels. It is notable that the SMA10 wearing surfaces, which has less macrotexture than SMA14, produced tyre-pavement noise levels that are approximately 2dB(A) lower. This is likely to be due to the larger aggregate used for the SMA14 asphalt surface (14mm compared to 10mm) resulting in a higher macrotexture.

In comparison to the reference dense grade asphalt (DGA) pavement, transverse tined concrete pavements and conventional diamond grinding (CDG) concrete pavements are up to 2.7dB(A) and 0.7dB(A) higher than the reference DGA pavement, respectively. Low noise diamond grinding (LNDG) concrete pavements are generally comparable with the reference DGA pavement, while SMA14 and SMA10 pavements are up to 1.5dB(A) and 2.7dB(A) lower than the reference DGA pavement, respectively.

Further to the above comparisons, the tyre-pavement noise level variability of each pavement type along the westbound and eastbound carriageways of the Hunter Expressway are presented in the following figures.

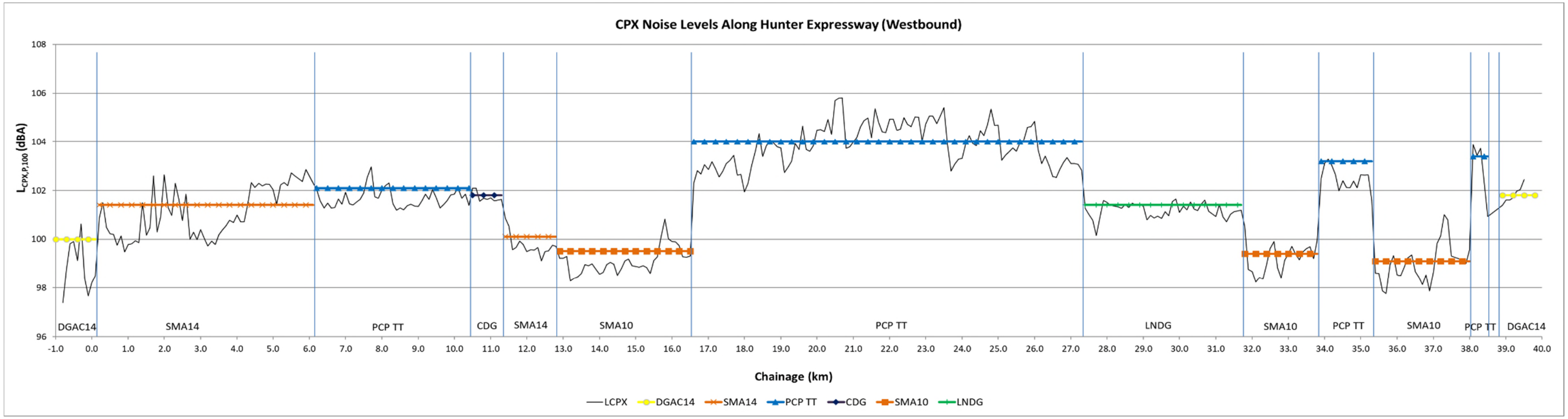

Figure 7: CPX Noise Level Variability for Various Pavement Types (Westbound)

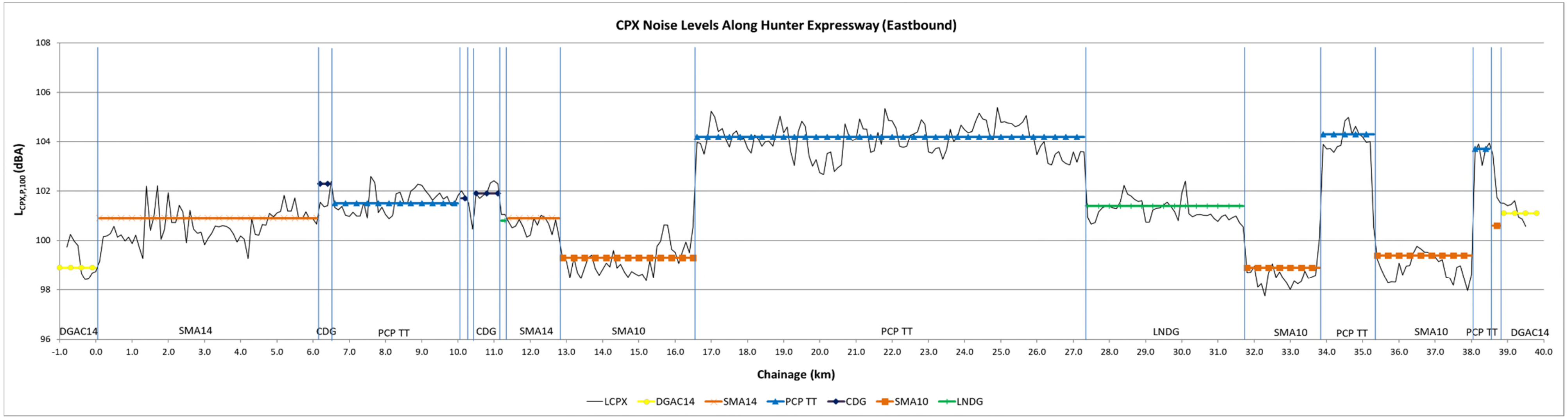

Figure 8: CPX Noise Level Variability for Various Pavement Types (Eastbound)

Road designers and builders are interested in the reliability of noise outcomes for any given pavement type. As such, it is important to know what is the likely level of consistency of a particular pavement noise outcome. There are many variables which impact on the cumulative impact of pavement noise to provide a spectrum of noise volumes for any given wearing course. For example, due to the variable nature of the texturer / curer operator that provides the raked finish on the wet concrete, some tines are heavier and produce greater macrotexture, whilst others are much lighter resulting in inherent variation in the noise levels produced by the pavement. Likewise, the matrix of asphalt wearing courses is influenced by the percentage of binder, air voids and also the rolling pattern all giving rise to variable macrotexture and hence noise outcomes. The variability in any given pavement surface is a function of the finishing operation, hence some pavements have a larger standard deviation in decibel levels than others.

From Figure 7 and Figure 8, it can be seen that LNDG pavements have a lower band of variability of noise outcome than SMA14 pavements. This means that although the average noise outcome for SMA14 is slightly lower than for LNDG, the maximum measured noise level in SMA14 tends to be greater. Based on this outcome there is a lower standard deviation for LNDG pavements than SMA14, which is likely due to the more uniform and consistent manner of the diamond grinding process.

The following table demonstrates the variability outcomes of the different pavement types.

Table 2: Variability Outcomes for Pavement Types along the Hunter Expressway

Surface Type	Lower Bound Average	Upper Bound Average	Variability
LNDG	100.2	102.2	2.0
SMA10	97.8	100.6	2.8
SMA14	99.5	102.8	3.3
DGA – AC14	98.4	101.8	3.4
PCP Transverse tining	101.0	105.8	4.8

6 SPECTRAL ANALYSIS

One-third octave band spectral analysis for the various pavement sections at the reference speed of 100km/h was undertaken for the westbound and eastbound carriageways. The spectral comparisons in one-third octave band frequency detail are presented in Figure 9 and Figure 10 below for the westbound and eastbound carriageways, respectively.

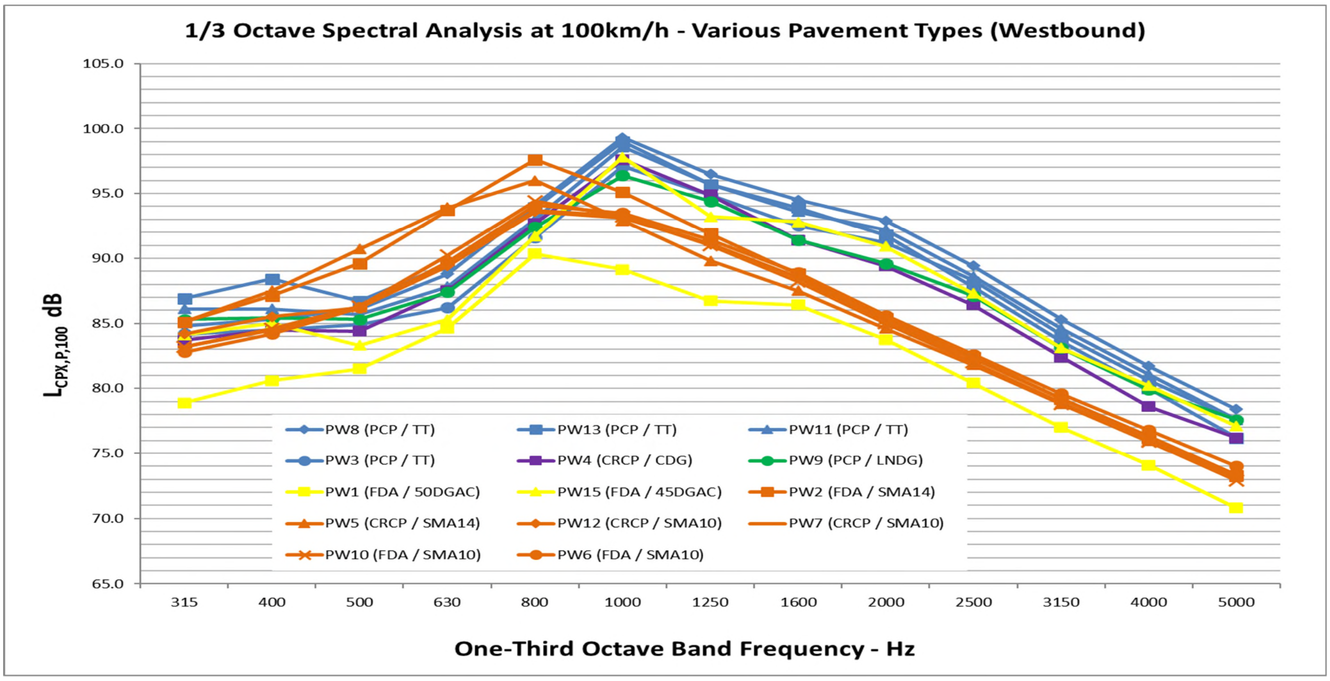

Figure 9: One-third spectral analysis at 100km/h reference speed for various pavement types (westbound)

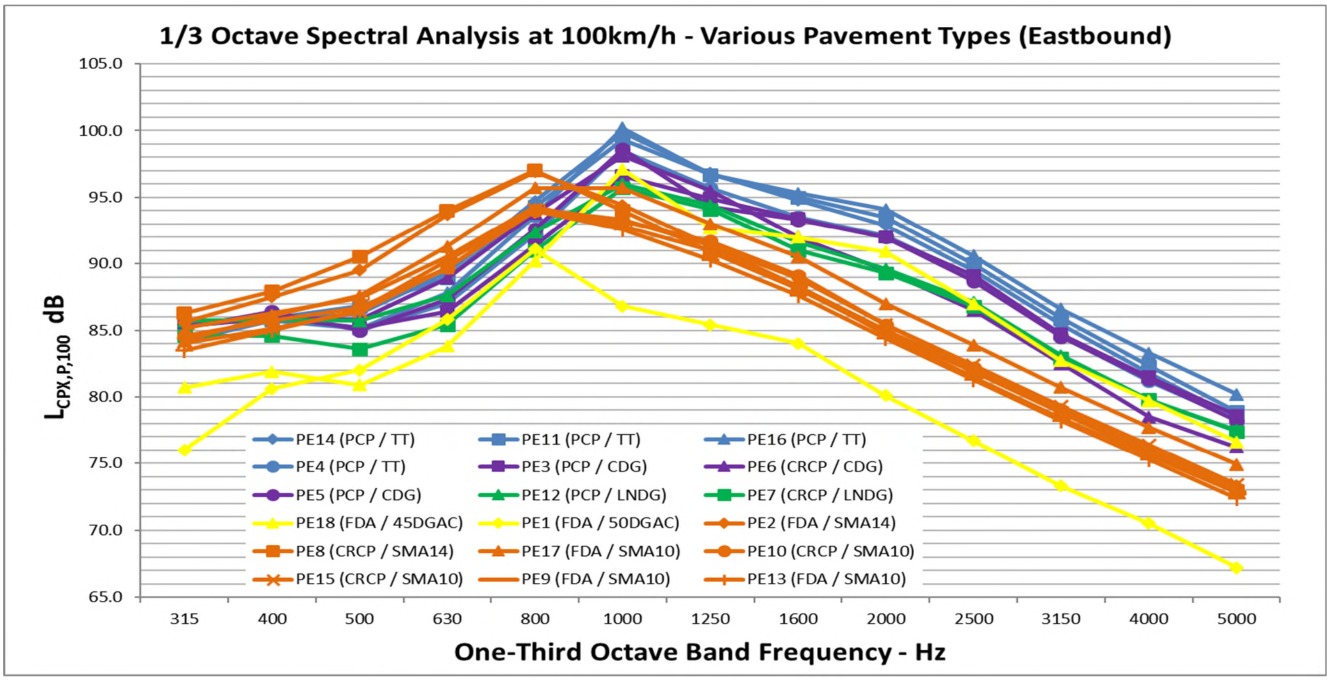

Figure 10: One-third spectral analysis at 100km/h reference speed for various pavement types (eastbound)

From the spectral comparison for the various types of wearing courses on pavements along the westbound and eastbound carriageways of the Hunter Expressway as presented in the figures above, it can be seen that the stone mastic asphalt (SMA) pavements typically produced lower tyre-pavement noise levels compared to the concrete and dense grade asphalt (DGAC) pavements at frequencies from 1kHz upwards. However, at frequencies below 1kHz, tyre-pavement noise levels from the stone mastic asphalt (SMA) pavements were higher than the concrete and dense grade asphalt (DGAC) pavements. This may be due to the “positive” profile produced by the aggregate in the stone mastic asphalt (SMA) pavements, resulting in the tyre to vibrate and emit higher noise at the lower frequency range.

For the transverse tined concrete pavements, tyre-pavement noise levels were generally higher than those of the conventional diamond grinding (CDG) concrete, low noise diamond grinding (LNDG) concrete and the dense grade asphalt (DGAC) pavements for both the westbound and eastbound carriageways.

The low noise diamond grinding (LNDG) concrete pavements which have longitudinal grooves (ie. PW9, PE7 and PE12) generally produced lower or similar tyre-pavement noise levels at frequencies from 1kHz and above, when compared to the dense grade asphalt (DGAC) pavements, but slightly higher tyre-pavement noise levels at frequencies below 1kHz. This has been found to occur from previous RONDA measurement studies.

It is noted that the dominant frequencies of the tyre-pavement noise levels were between 800Hz and 1kHz, which is typical of the characteristics of road traffic noise.

7 CONCLUSION

Tyre-pavement noise measurements along the Hunter Expressway have been undertaken by Renzo Tonin & Associates using the RONDA CPX trailer which conforms with the draft international standard ISO/CD 11819-2.

Measurements of various pavement types along the Hunter Expressway on both the westbound and eastbound carriageways were conducted and results were analysed to determine the L_{CPX} tyre-pavement noise levels. Results indicate that transverse tined concrete pavements along the Hunter Expressway produced the highest tyre-pavement noise levels, while stone mastic asphalt (SMA10) with 10mm maximum aggregate size pavements produced the lowest, which is typically expected. SMA10 wearing course pavements were shown to produce lower tyre-pavement noise levels than SMA14. Low noise diamond grinding (LNDG) concrete pavements have a low standard deviation for variability and similar tyre-pavement noise levels to SMA14 or dense grade asphalt.

In comparison to the reference DGA pavement, transverse tined and conventional diamond grinding concrete pavements produced higher tyre-pavement noise levels, low noise diamond grinding (LNDG) concrete pavements had similar noise levels and stone mastic asphalt (SMA14 and SMA10) pavements had lower noise levels.

Furthermore, spectral analysis of the noise measurement data was also undertaken in one-third octave band frequency detail. Results of the spectral analysis were as follows:

- Stone mastic asphalt (SMA) pavements produced lower overall pavement noise levels; however, at the lower frequencies (ie. below 1kHz) the stone mastic asphalt (SMA) pavements produced higher tyre-pavement noise levels. This may be due to the positive surface profile produced by the aggregate in the pavement resulting in tyre vibrations producing low frequency noise.
- Transverse tined concrete pavements produced the highest tyre-pavement noise levels generally throughout the one-third octave band spectra.
- Low noise diamond grinding (LNDG) pavements typically produced lower or similar tyre-pavement noise levels to that of dense grade asphalt (DGA) pavements at frequencies of 1kHz and above, with higher noise levels at frequencies below 1kHz.
- The dominant frequencies of the tyre-pavement noise levels were between 800Hz and 1kHz, which is typical of the characteristics of road traffic noise.

It is recommended that further tyre-pavement noise measurements using the RONDA CPX trailer be undertaken to obtain further understanding of the various types of road pavements used to mitigate tyre-pavement noise.

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