Acoustics 2008
Geelong, Victoria, Australia 24 to 26 November 2008

Acoustics and Sustainability:

How should acoustics adapt to meet future demands?

CPX tyre/road noise measurements in Queensland – Noise characteristics of various road surfaces

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ABSTRACT

Tyre/road noise measurements conducted using the close proximity (CPX) method provide a useful means of assessing road surfaces and tyres, and particularly the variation of noise along the length of a road surface. In this paper we present results of recent CPX tyre/road noise measurements undertaken with the ROAD-EAR trailer in and around Brisbane and Townsville, Queensland. Testing was performed over short (100 m) distances and a long (5000m) distance. Measurements were conducted on 22 road surfaces including chip seal, OGA, DGA, SMA & PCC, and used three tyres, including two candidate tyres for ISO 11819-2, as well as the Australian made (passenger car) tyre Bridgestone RE92. Most of the SMA and OGA surfaces showed the lowest overall noise levels, although some of these road surfaces provided relatively high emissions of noise. The range in CPXI noise levels over the 100m test sections was 5 dB(A). The local Bridgestone RE92 tyre was found to be substantially quieter than both the Continental and BFGoodrich candidate tyres for all road surface types tested. Long distance measurements using the ROAD-EAR trailer showed considerable variability in concrete (PCC) and asphalt surfaces to the degree that some transverse tyned PCC sections proved equal in overall noise level emissions to the normally quieter asphalt (OGA & SMA) surfaces. This paper presents an assessment of these variations, and suggests explanations for the results.

INTRODUCTION

The main contributing components of road traffic noise include noise from the tyre/road interaction; engine noise; exhaust system noise; and intake system noise. Tyre/road interaction noise is the dominant traffic noise source for speeds above 40-50 km/h for cars and 60-70 km/h for trucks (Sandberg 2001). Tyre/road noise, under most highway conditions, is the dominant contributing factor to road traffic noise and therefore has been the focus of many international studies, (Sandberg and Ejsmont (2002), Jones (2005) and Bennert, Hanson and Maher (2004), and ongoing design of 'quiet, hush, low-noise' pavements/road surface finishes.

This paper deals with tyre/road noise measurements conducted at twenty-two (22) sites in Queensland, with 14 located in and around Brisbane and 8 in Townsville (North Queensland). The measurements were conducted using the Close Proximity (CPX) method as outlined in draft versions of International Standard ISO 11819-2 (2000) and (2007). The latest version used in this assessment is Working Draft (09/28/2008) for 3rd ISO/CD 11819:2 (2000), hereafter referred to as the draft CPX ISO Standard.

Tyre/road noise measurements were undertaken to determine the noise emission properties of vehicle road tyres rolling on various types of road surfaces. For this paper, the main focus is the noise emissions characteristics of various road surfaces.

This paper:

- Presents an overview of the CPX tyre/road noise measurement methodology, and the *ROAD-EAR* measurement trailer;
- Provides results of CPX measurements conducted using 3 different vehicle tyres on 22 road surfaces in Queensland; and
- Discusses the results in light of potential areas for further research within Australia.

MEASUREMENT DESCRIPTION

Measurement Methodology

The general CPX measurement methodology used for this project was as follows:

- Twenty-two (22) suitable road sections, of varying road surface type, were identified for CPX testing;
- Prior to testing at each site, measurements of air and road temperature were conducted, and the site and road pavement photographed;
- The test tyre was warmed up for a period of at least 15 minutes, as per the draft CPX ISO Standard;
- CPX test runs of 100m length, with 2 runs per test tyre were conducted. If the average noise level on each of the two runs differed by more than 0.5 dB(A) then the measurement was repeated;
- The CPX test runs were repeated with each of three (3) tyres.

The CPX noise level results are provided for each standard test tyre (CPXL for the Type A car tyre and CPXH for the Type D off-road/truck tyre), and are the linear average of the measured noise levels over each 100m run, as per the draft CPX ISO Standard.

The CPXI noise level is calculated as an average of the CPX noise level results for the Type A and Type D tyres.

Table 1 shows the measurement site details, including the road surface type and road surface sub-type (where relevant). The road surface identified as DGA2 has been nominated as a datum surface for the project. This section of road pavement is considered to be of high quality and likely to remain in good condition for a reasonable length of time. All other road surfaces will be compared with DGA2.

Measurements were conducted at a test speed of 80 km/h for all but site SMA8 (this test site SMA8 is located in a traffic speed zone of 60 km/h). The lower CPX reference test speed of 50km/h was used for site SMA8. Results for site SMA8 are presented for (i) the test speed of 50 km/h, and (ii) a corrected speed of 80 km/h using the standard speed correction relationship as per the draft CPX ISO Standard.

Table 1: Measurement Site Details

Road Surface Type	Road Surface Sub-Type	Road Surface Identifier	Posted Traffic Speed Km/h
Chip Seal	N/A	CS2	80
	N/A	CS3	100
	N/A	CS4	100
Dense Graded Asphalt	Datum	DGA2	100
	N/A	DGA3	100
	N/A	DGA4	80
	N/A	DGA10	80
Open Graded Asphalt	N/A	OGA1	110
	N/A	OGA2	110
	N/A	OGA3	110
	N/A	OGA4	110
Portland Cement Concrete with Transverse Tyning	N/A	PCC1	110
	N/A	PCC2	110
	N/A	PCC3	110
Stone Mastic Asphalt	Lo Noise	SMA1	100
	Unknown	SMA2	100
	Novachip	SMA5	80
	Hushphalt	SMA6	80
	Lo Noise	SMA7	80
	Lo Noise	SMA8	60
	Pioneer SMA14	SMA9	100
	Boral SMA14	SMA10	100

For this project the CPX measurements were conducted with the test tyre located in approximately the middle of the road lane. The reasons for this approach were twofold:

- It was expected that there are less lateral variations in noise levels around the centre of the lane, compared with variations experienced around the wheel tracks. Thus measurements in the centre of the lane were likely to be more repeatable; and
- The tyre is located centrally on the *ROAD-EAR* and thus it simplified the measurement procedure. On narrow roads, measuring in the wheel track would have required driving the vehicle across the centre line of the road.

As the CPX test tyre was located centrally in the lane, the test results could be considered to generally exclude the effect of tyre wear on the road surface, but include the effect of environmental weathering of the road surface. Supplementary measurements have been conducted on an SMA road surface at different lateral positions within the traffic lane, including in the wheel track, to assess the noise impact of lateral position the traffic lane. These measurements found minimal variation in noise levels with lateral location, but this result could differ for other less homogenous road surfaces, roads with higher traffic volumes, or road surfaces with higher wear rates.

MEASUREMENT EQUIPMENT

The most significant part of the CPX measurement equipment is the *ROAD-EAR* trailer, as shown in **Figure 1**. The *ROAD-EAR* trailer includes an acoustic enclosure housing the test tyre. The enclosure includes significant damping and absorptive treatments, so that the resulting acoustic environment complies, Adams, Kamst, Pugh & Claughton (2006), with the requirements of the Second ISO/CD 11819:2 (2000).

The test tyre is mounted on an operable suspension arm, which permits the test tyre to be loaded to the required CPX load of 3200N as per the draft CPX ISO Standard.

The front of the trailer includes storage compartments for the electronics, gauges, batteries, and spare test tyres.

Figure 1: *ROAD-EAR* CPX Trailer Developed by ASK Consulting Engineers

Electronics

The CPX trailer electronics include a multi-channel sound level analyser (Sinus Soundbook) with Type 1 microphones and preamplifiers. This analyser permits recording of multi-channel one-third octave band, video, audio and additional inputs.

The measurement is triggered using an optical sensor mounted at the side of the road and on the trailer. The sensor is distance accurate to within approximately 1m, thus ensuring each 100m long measurement run covers at least 99% of the same surface as the other runs.

Distance is recorded from a high speed GPS speed sensor, which outputs a digital pulse for every unit distance. Measurements by ASK have found that this system is accurate to within approximately 1m over test measurements of several kilometres. This distance measurement method is considered more accurate than wheel rotation counters, since there is no need to adjust for tyre circumference variations.

Speed is also measured using the aforementioned Racelogic GPS speed sensor. During the 100m long test runs the speed variation is generally less than 2% from the reference speed when the vehicle is held on cruise control. The use of cruise control is standard practice.

On the latter measurements in this project, a real-time temperature sensor was connected into the analyser to provide air temperature measurements. The temperature probe was mounted on the side of the tow vehicle, and included a Stephenson screen to protect the sensor from direct sunlight. Earlier measurements included a handheld digital temperature gauge.

Road surface temperature measurements were conducted with a hand-held infrared temperature probe. Tyre pressure was recorded with a hand-held digital pressure gauge.

All instrumentation was selected on the basis of compliance with the accuracy requirements of the draft CPX ISO Standard.

Test Tyres

The CPX measurement procedure requires the use of specific test tyres. At the time of the commencement of this project, the selection of the standard Type A and D test tyres had not been finalised. Therefore, candidate Type A and D tyres that were readily available in Australia were used. A local test tyre was also chosen for the measurements.

The selected tyres were as follows:
- Type A: Continental Eco Conti Contact 3 195/65 R15. This is understood to be an Original Equipment (OE) tyre for Volkswagen Golf cars;
- Type D: Goodrich M+T 215/75 R15. This is an off-road tyre; and
- Australian Type A: Bridgestone RE92 205/65 R15. This “Made in Australia” tyre is used on locally made family cars.

The CPX noise level determined with the Bridgestone RE92 tyre is differentiated from the CPX noise level determined with the candidate Type A tyre using the subscript RE92 on the CPXL noise level, i.e. $\mathrm{CPXL}_{\mathrm{RE92}}$.

MEASUREMENT RESULTS

Temperature Correction

The draft CPX ISO Standard recognises that both air and road temperature have an effect on the measured tyre/road noise levels. Hence, the standard states that air temperature measurement is mandatory and road surface temperature measurement is recommended.

It is also recommended that measurements be corrected to an air temperature of 20 degrees Celsius, although it is acknowledged that a formalised method for these corrections has not yet been established.

It would be possible to conduct CPX tyre/road noise measurements on each of the road surfaces with the standard test tyres to establish typical temperature corrections, but this work has not yet been undertaken in Australia. In the absence of local data, reference is made to international work. It has been reported, Sandberg (2004), that *”the effects of temperature may typically amount to –0.05 to –0.10 dB per degree Celsius, but effects twice as large, and even with a positive sign have been recorded.”*

A comprehensive review of this topic was not undertaken for this project, and therefore it is simply intended to present the appropriate semi-generic temperature corrections relevant for this project [8], as follows:

- Chip seal: -0.12 dB/degree Celsius;
- DGA: -0.06 dB/degree Celsius;
- OGA: -0.06 dB/degree Celsius;
- PCC: -0.09 dB/degree Celsius; and
- SMA: -0.09 dB/degree Celsius (based on an average SMA chip size of 11mm).

Uncorrected and Corrected Results

The CPX noise level result for each tyre and for each 100m long road section has been determined in accordance with the calculation methodologies in the draft CPX ISO Standard.

The overall CPX noise level results are presented in **Table 2** as standard (i.e. without a temperature correction) and temperature corrected. The results are presented in terms of the standard descriptors CPXL, CPXH, and CPXI, as well as the $\mathrm{CPXL}_{\mathrm{RE92}}$ for tests using the “Made in Australia” Bridgestone RE92 tyre. The temperature corrected values are presented in **Figure 2** in terms of the standard descriptors CPXL, CPXH, and CPXI.

The CPX noise level results relative to the datum surface DGA2, are summarised in **Table 3** and **Figure 3**.

ANALYSIS OF RESULTS

Effect of Temperature Correction

A comparison of the corrected results with the non-corrected results in **Tables 2 & 3** indicates that the effect of temperature correction is to raise the calculated CPXL, CPXH and CPXI values. This occurs because the temperature during CPX noise testing was consistently higher than the 20 degrees reference value. There is little difference between uncorrected and corrected noise levels when assessing the range of noise levels for each road surface, and similarly there is little difference in the relative noise levels of each road surface.

Ultimately it would be preferable to undertake testing over a range of temperatures for each road surface, so that individual temperature correction values can be determined. Further research into Australian temperature influence on measurement results has been identified for future work.

Tyre Selection

Based on the results of this study, there are several observations that can be made regarding tyre selection and its effect on the results:
- The RE92 tyre is consistently quieter than the CPXL and CPXH tyres. On average the RE92 is 2.6 dB(A) quieter than the CPXL tyre and 3.0 dB(A) quieter than the CPXH tyre;
- The RE92 tyre is similar to the CPXL tyre in terms of the relative difference between road surfaces; and
- The CPXH tyre shows less variation in noise levels than the CPXL and RE92 tyres.

Overall Review

From **Table 2** and **Figure 2** it can be seen that the chip seal (CS) and Portland cement concrete (PCC) surfaces are generally the noisiest, the dense and open graded asphalts (DGA & OGA) are similar (except for OGA3 which was noticeably noisier), and the stone mastic asphalt (SMA) results show a wide range of levels.

Surface-by-Surface Review

Chip Seal (CS)

The measurement results in **Tables 2** and **3** indicate that the 3 chip seal surfaces are quite similar in terms of overall noise emission levels. The levels are higher for the car tyre (CPXL) than the heavy vehicle tyre (CPXH).

Dense Graded Asphalt (DGA)

The measurement results in **Tables 2** and **3** indicate that the 4 DGA surfaces are quite similar in terms of overall noise emission levels. The levels are higher for the heavy vehicle tyre (CPXH) than the car tyre (CPXL).

Open Graded Asphalt (OGA)

The measurement results in **Tables 2** and **3** indicate that the 4 OGA surfaces vary noticeably in terms of overall noise emission levels. The levels are generally higher for the heavy vehicle tyre (CPXH) than the car tyre (CPXL), except for surface OGA3 where the levels are similar.

Portland Cement Concrete (PCC)

The measurement results in **Tables 2** and **3** indicate that the 3 PCC surfaces are reasonably similar in terms of the overall noise emission levels. The levels are higher for the heavy vehicle tyre (CPXH) than the car tyre (CPXL) for PCC1 & PCC2, whilst the opposite relationship occurs for PCC3.

Stone Mastic Asphalt (SMA)

The measurement results in **Tables 2** and **3** indicate that the 8 SMA surfaces very significantly in overall noise emission qualities. This is not entirely unexpected as the surfaces are known to consist of different specification mixes. There is no consistent relationship between the heavy vehicle tyre (CPXH) and the car tyre (CPXL). The SMA14 surfaces (SMA9 & SMA10) are both at the upper end of the SMA results.

Comparison of Relative CPX Noise Level Results with Tyre/Road Noise Correction Factors

A comparison of the temperature corrected relative CPXI noise levels with standard tyre/road noise correction factors used by Queensland Department of Main Roads (QDMR 2008) and New South Wales Road Traffic Authority (NSW RTA 2001) has been conducted on a surface-by-surface basis and is presented in **Table 4**.

Table 4: Comparison of Relative CPX Noise Level Results with QDMR & NSW RTA Tyre/Road Noise Correction Factors

Road Surface Type	QDMR (2008) Corrections	NSW RTA (2001) Corrections	Relative CPXI Levels*
CS	+2.3[#]	+4.0**	+1.8 to +2.4
DGA	0	0	0 to +0.5
OGA	-2.5	0 to –4.9	-0.2 to +1.8
PCC	+3.8	-1.0 to +3.5	+1.8 to +2.5
SMA	-0.9	-2.0 to –4.3	-1.7 to +2.0

Note: * Based on temperature corrected values.
[#] Using correction value for 10mm BS.
** Using correction value for 14mm chip seal.

Based on the comparison in **Table 4**, there are several observations that can be made:

- The relative CPXI levels for Chip Seal (CS) are similar to the QDMR correction but lower than the NSW RTA correction, possible due to the chip seal size on which the NSW RTA correction is based.
- The relative CPXI levels for Dense Graded Asphalt (DGA) are set to the datum as per the QDMR and NSW RTA corrections. The relative CPXI levels showed little variation.
- The relative CPXI levels for Open Graded Asphalt (OGA) are generally higher than the corrections proposed by both the QDMR & NSW RTA.
- The relative CPXI levels for Portland Cement Concrete (PCC) are within the wide range of corrections proposed by NSW RTA but lower than the QDMR corrections.
- Some of the relative CPXI levels for Stone Mastic Asphalt (SMA) are similar to the QDMR and NSW RTA corrections, but other SMA CPXI levels are noticeably higher than the QDMR and NSW RTA corrections.

MEASUREMENT OVER A LONGER TEST SECTION

The majority of CPX measurements were conducted with a test section length of 100m, being the minimum measurement length that only requires two passes. A minimum measurement length was considered to be appropriate for comparison with statistical passby measurements (SPB) which had been conducted by other consultants at approximately the same date as the CPX measurements. However, an advantage of the CPX measurement method over the SPB method is the ability to measure tyre/road noise variation over long distances of road, thereby enabling assessment of the homogeneity of the road surface.

CPX measurements were conducted on a 5000m section of a major highway, from approximately 1500m before the OGA1 test site, to approximately 3400m after the OGA1 test site. The run was conducted twice with a reference speed of 80 km/h, using the Type A tyre. After measurements were conducted a visual inspection of acoustically notable sections of the measurement test site was undertaken. The overall results of each of the two runs are presented in **Figure 4** as a trace of noise levels versus distance.

Also shown on **Figure 4** are sections of road with a PCC road surface, the locations of four bridges (labelled bridge 1 to bridge 4), and the approximate location of OGA1 test site. The sections of road between the PCC surfaced sections had asphalt surfaces.

From **Figure 4** it can be observed that the CPX noise level varies significantly on the concrete and asphalt surfaces. A few of the interesting aspects of **Figure 4** are as follows:

- The noise level on bridge 2 is particularly high with notable peaks due to the bridge joins;
- The noise level after bridge 2 drops significantly and this is the location of the OGA1 test site;
- After the OGA1 test site, the road surface changes to PCC and the noise levels increase sharply, but then decrease over the next 150m or so. From Google Earth aerial photography, it is noted that this 150m section of road is notably blackened, presumably from the previous OGA surface treatment and/or from traffic traversing this PCC section to exit via the slip lane. This blackening and the traversing may be connected with the change in tyre/road noise values;
- The asphalt section on bridge 4 appears to consist of two different surface treatments, as the CPX noise level changes noticeably mid-bridge. Visual inspection con-

firms two different road surface treatments present on the bridge surface;

- Throughout the PCC section of the measurement the results vary between approximately 96dB(A) to 103 dB(A). From visual inspection of the test section of PCC it is evident that the uneven wearing of the tyning treatment and changes to the tyning pattern on the PCC road surface may be causes of this. A key example of this is at about the 4000m mark of the noise level trace, the CPX noise level decreases by approximately 3.5 dB(A) for approximately 100 to 150m of PCC road surface. The dip is quite distinctive in **Figure 4** and occurred during each of the two runs.

  This point in the road shows as a slight road surface colour change in Google Earth, and thus the noise level change was considered to be likely to be due to an actual road surface change.

  Upon a detailed inspection of this road surface, it was noted that the PCC surface is relatively smooth in this section of road where the CPX noise level reduces sharply.

Overall, the CPX method has found significant variations in tyre/road noise levels on this 5km test section, particularly within the PCC surface type. Such variations have been measured by others (Parnell and Samuels 2006) whilst testing PCC surfaces in New South Wales. These variations should be considered when evaluating the tyre/road surface corrections for the road surfaces, and selecting tyre/road noise measurement sites.

CONCLUSION

The purpose of this paper was to present the methodology of CPX tyre/road noise measurement system using the *ROADEAR* trailer, the results of said measurements, and to assist in directing further tyre/road research.

Based on the results, the following points were noted:

- Due to all measurements occurring with temperatures above the reference temperature of 20 degrees Celsius, the corrected CPX measurements were above the uncorrected values. However, the relative differences between CPX noise levels for each surface type was generally unchanged.
- Further research of the temperature effect of tyre/road noise should be conducted for Australian road surfaces and climate conditions, to enable more accurate correction for future tyre/road measurements. Temperature correction is recommended in the ISO standards for both CPX and SPB type measurements.
- The Australian-made Bridgestone RE92 tyre was consistently quieter than the CPX candidate tyres. However, the relative difference between RE92 results was similar to the CPX candidate car tyre.
- The CPX candidate heavy vehicle tyre produced a lower range of noise levels than both the car tyres.
- The chip seal (CS) and Portland cement concrete (PCC) surfaces are generally the noisiest, the dense and open graded asphalts (DGA & OGA) are similar (except for OGA3 which was noticeably noisier), and the stone mastic asphalt (SMA) results show a wide range of levels.
- The CPXI noise levels on the chip seal (CS), dense graded asphalt (DGA) and Portland Concrete Cement were relatively similar between sample surfaces. Conversely. the CPXI noise levels on the OGA and SMA surfaces varied noticeably.
- The relative CPXI noise level differences were compared to the QDMR and NSW RTA tyre/road standard correction values. It was found that CS, DGA and PCC were generally similar between measurement and the standard correction values, however, the CPXI results for OGA and SMA were generally higher than the QDMR and NSW RTA standard tyre/road correction values.
- Test runs on a longer 5000m section of the Pacific Highway showed the significant longitudinal variations. Whilst some variations were expected due to the change between surface types and noticeable structural road joins, there were significant variations that appear to be due to differing wearing effects and changes to the tyning pattern.
- The longitudinal variations in road surface noise should be considered when selecting tyre/road noise measurement sites, and evaluating the tyre/road surface corrections for the road surfaces.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of the Queensland Department of Main Roads in funding this project.

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APPENDIX

Table 2: Overall CPX Results

Test Site & Road Surface Type	Air Temp. degrees C	Reference Speed Km/h	CPX Noise Level Result for Each Test Tyre, dB(A)				Close-Proximity Sound Index, dB(A) CPXI		CPX Noise Level Result for Australian Car Tyre: Bridgestone RE92 CPXL$_{RE92}$	
			CPXL Type A: Continental Eco Conti Contact 3		CPXH Type D: Goodrich M&T					
			Standard*	Temperature Corrected	Standard*	Temperature Corrected	Standard *	Temperature Corrected	Standard*	Temperature Corrected
CS2	26.0	80	100.3	101.1	98.6	99.4	99.5	100.2	98.1	98.9
CS3	25.5	80	100.0	100.6	98.4	99.0	99.2	99.8	97.7	98.4
CS4	30.0	80	100.1	101.3	98.3	99.5	99.2	100.4	97.8	99.0
DGA2	**34.5**	**80**	**96.9**	**97.8**	**97.3**	**98.2**	**97.1**	**98.0**	**94.2**	**95.1**
DGA3	33.3	80	96.9	97.7	98.5	99.3	97.7	98.5	95.1	95.9
DGA4	27.3	80	96.6	97.0	99.0	99.4	97.8	98.2	94.4	94.9
DGA10	31.2	80	95.9	96.6	99.0	99.7	97.4	98.1	93.7	94.4
OGA1	24.9	80	96.5	96.8	98.8	99.1	97.7	98.0	94.5	94.8
OGA2	30.0	80	96.9	97.5	97.6	98.2	97.2	97.8	94.8	95.4
OGA3	26.4	80	99.6	100.0	99.3	99.6	99.4	99.8	96.6	97.0
OGA4	26.4	80	98.1	98.5	98.9	99.3	98.5	98.9	95.8	96.1
PCC1	28.0	80	99.1	99.8	100.3	101.0	99.7	100.4	96.2	96.9
PCC2	33.2	80	98.6	99.8	100.0	101.2	99.3	100.5	95.9	97.0
PCC3	31.1	80	99.2	100.2	98.3	99.3	98.8	99.8	97.8	98.8
SMA1	32.6	80	99.0	100.1	98.4	99.6	98.7	99.8	95.4	96.5
SMA2	33.6	80	98.5	99.8	98.3	99.5	98.4	99.6	95.4	96.6
SMA5	30.9	80	97.2	98.2	97.4	98.4	97.3	98.3	93.9	94.8
SMA6	32.4	80	94.0	95.1	96.6	97.7	95.3	96.4	91.1	92.2
SMA7	31.0	80	95.1	96.1	97.1	98.1	96.1	97.1	92.0	93.0
SMA8$^{\#}$	35.2	50	89.4	90.8	88.9	90.2	89.2	90.5	86.9	88.3
	35.2	80	96.6	96.6	96.0	96.0	96.3	96.3	94.0	94.0
SMA9	33.1	80	99.5	100.7	98.1	99.3	98.8	100.0	95.8	96.9
SMA10	30.5	80	98.2	99.1	99.2	100.1	98.7	99.6	95.2	96.2

Note: * These results have not been corrected for air or road surface temperature.

$^{\#}$ This road surface was tested at a reference speed of 50 km/h but has been corrected to 80 km/h for comparison with other SMA road surfaces. CPX noise levels are presented for both 50 km/h and 80 km/h.

Cells are shaded by pavement type for ease of reading.

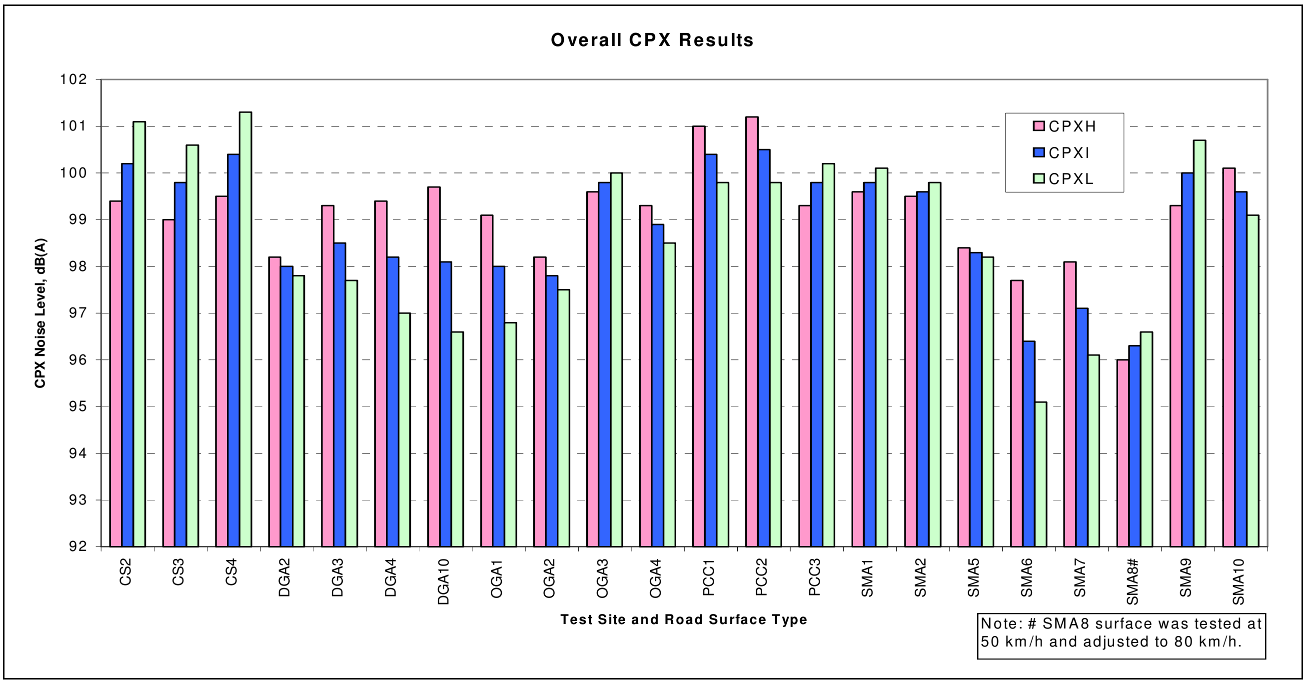

Figure 2: Graph of Overall CPX Results

Table 3: Overall CPX Results Relative to DGA2 Datum Surface

Test Site & Road Surface Type	Air Temp. degrees C	Reference Speed Km/h	CPX Noise Level Result for Each Test Tyre Relative to Result at DGA2, dB(A)				Close-Proximity Sound Index Relative to Result at DGA2, dB(A) CPXI		CPX Noise Level Result for Australian Car Tyre: Bridgestone RE92, Relative to Result at DGA2, dB(A) CPXL$_{RE92}$	
			CPXL Type A: Continental Eco Conti Contact 3		CPXH Type D: Goodrich M&T					
			Standard*	Temperature Corrected	Standard*	Temperature Corrected	Standard *	Temperature Corrected	Standard*	Temperature Corrected
CS2	26.0	80	3.4	3.2	1.3	1.2	2.4	2.2	3.9	3.7
CS3	25.5	80	3.0	2.8	1.1	0.9	2.1	1.8	3.5	3.3
CS4	30.0	80	3.2	3.5	1.0	1.4	2.1	2.4	3.6	3.9
DGA2	**34.5**	**80**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
DGA3	33.3	80	0.0	-0.1	1.2	1.1	0.6	0.5	0.8	0.8
DGA4	27.3	80	-0.3	-0.8	1.7	1.2	0.7	0.2	0.2	-0.2
DGA10	31.2	80	-1.1	-1.2	1.7	1.5	0.3	0.1	-0.5	-0.7
OGA1	24.9	80	-0.5	-1.0	1.5	1.0	0.5	0.0	0.2	-0.3
OGA2	30.0	80	-0.1	-0.4	0.3	0.0	0.1	-0.2	0.6	0.3
OGA3	26.4	80	2.6	2.1	2.0	1.5	2.3	1.8	2.4	1.9
OGA4	26.4	80	1.2	0.7	1.6	1.1	1.4	0.9	1.5	1.0
PCC1	28.0	80	2.1	2.0	3.0	2.8	2.6	2.4	2.0	1.8
PCC2	33.2	80	1.7	2.0	2.7	3.0	2.2	2.5	1.6	1.9
PCC3	31.1	80	2.3	2.4	1.0	1.2	1.7	1.8	3.6	3.7
SMA1	32.6	80	2.0	2.3	1.1	1.4	1.6	1.8	1.2	1.4
SMA2	33.6	80	1.6	1.9	1.0	1.4	1.3	1.7	1.2	1.5
SMA5	30.9	80	0.3	0.4	0.1	0.2	0.2	0.3	-0.4	-0.3
SMA6	32.4	80	-2.9	-2.7	-0.7	-0.5	-1.8	-1.6	-3.1	-2.9
SMA7	31.0	80	-1.9	-1.7	-0.2	-0.1	-1.0	-0.9	-2.3	-2.1
SMA8#	35.2	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	35.2	80	-0.4	-1.2	-1.3	-2.2	-0.8	-1.7	-0.2	-1.1
SMA9	33.1	80	2.6	2.9	0.8	1.1	1.7	2.0	1.5	1.8
SMA10	30.5	80	1.3	1.3	1.9	2.0	1.6	1.6	1.0	1.1

Note: * These results have not been corrected for air or road surface temperature.

\# This road surface was tested at a reference speed of 50 km/h but has been corrected to 80 km/h for comparison with other SMA road surfaces. CPX noise levels are presented for both 50 km/h and 80 km/h.

Cells are shaded by pavement type for ease of reading.

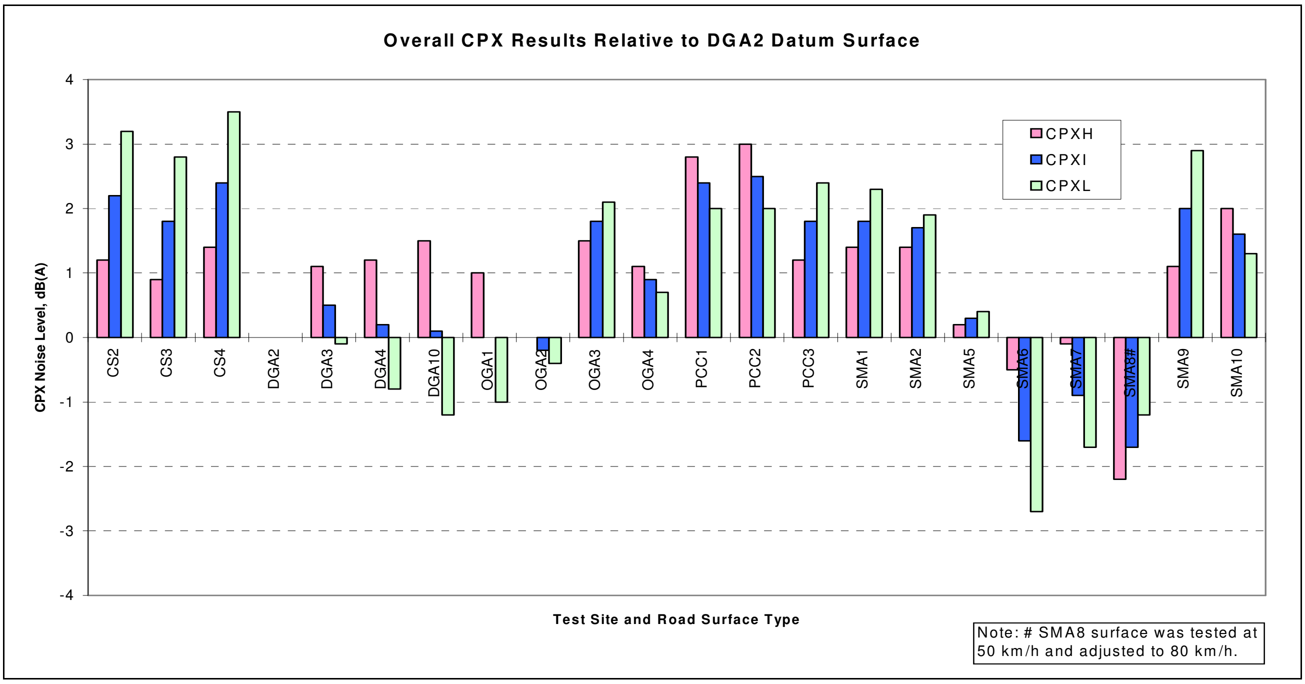

Figure 3: Graph of Overall CPX Results Relative to DGA2 Datum Surface

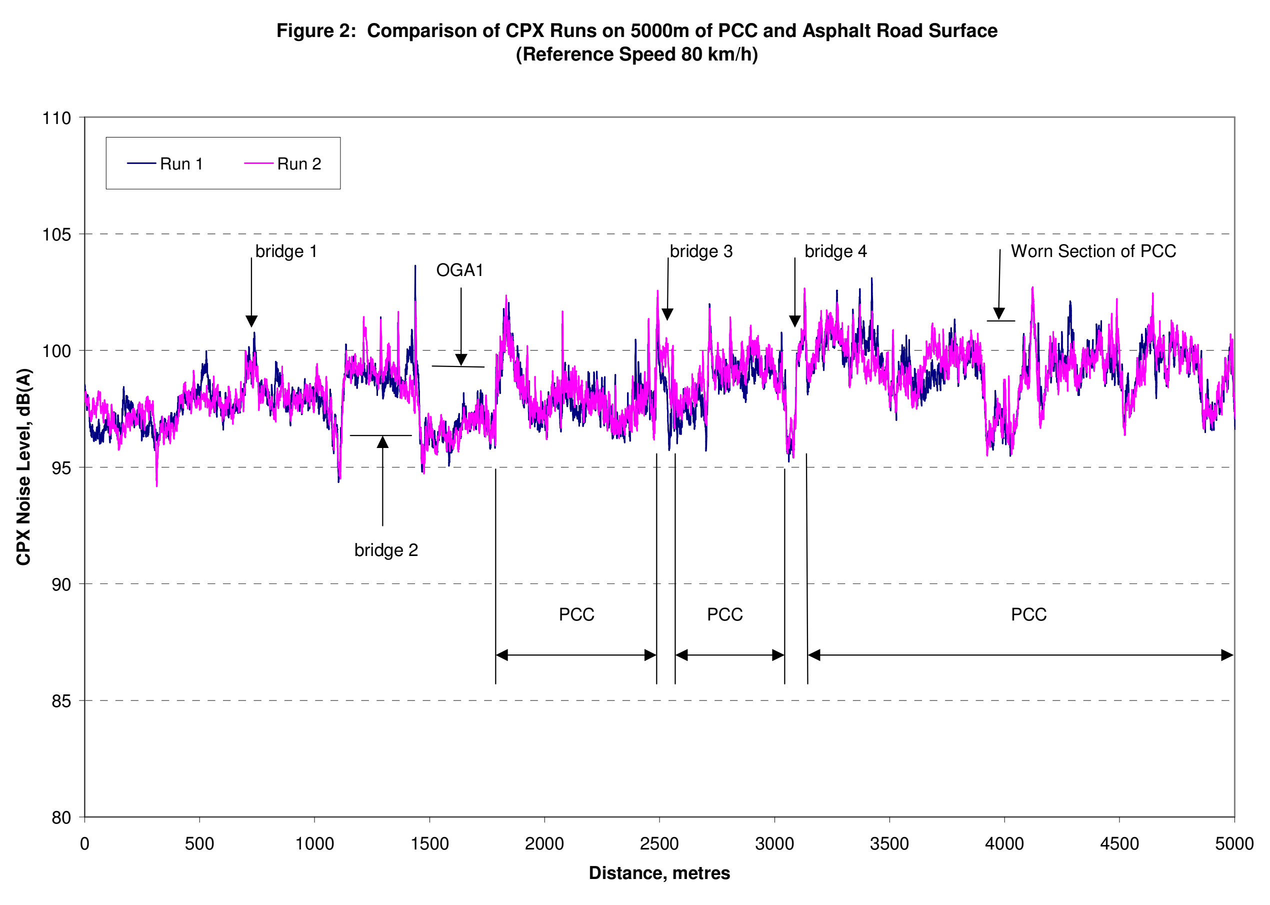

Figure 4: CPX Noise Level Variation with Two Runs over a 5000m Length of the Pacific Highway