A comparison of tyre/road noise generated on NSW pavements to international studies

Jeffrey Parnell (1) and Stephen Samuels (2)

(1) Manager Environmental Monitoring, RTA NSW, Australia.
(2) Principal, TEF Consulting and Visiting Research Fellow, UNSW, Australia.

ABSTRACT

A study of the tyre/road noise generated by 20 pavements surfaces representing a wide range of construction materials, techniques and surface textures constructed in NSW was undertaken and compared against the results of similar studies of 75 pavements constructed overseas. A range of more than 14 dB in passby noise levels was reported over the pavement types investigated with the NSW data being consistent with international data for similar pavement types. In general a range of low noise asphalts were found to return the lowest overall noise levels followed by concrete pavements that had minimal surface texture. Dense grade and stone mastic asphalts, and exposed aggregate concrete were found to perform better than randomly transverse tyned concrete pavements. Longitudinally tyned concrete pavements are not a design that is used in NSW however in international studies they were found to return noise levels similar to that of dense graded asphalts. Uniformly tyned pavements and those which generate acoustic energy in discrete frequency bands were found to be amongst the loudest pavements.

INTRODUCTION

This paper reports the results of a Roads and Traffic Authority of NSW (RTA) funded study into the noise generated by a passenger vehicle travelling under controlled conditions over a number of pavements constructed in NSW. It has long been acknowledged that the different materials and techniques used in the construction of road pavements are significant contributors to the varying levels of road traffic noise that are generated (Samuels 1982 a & b, Samuels 1996, Samuels and Parnell 2001, Dash, Bryce, Moran and Samuels 2002, Sandberg & Ejsmont 2002). More recently there has been a general awareness that the noise generated from certain types of pavements was being found to be more annoying than that generated on other types of pavements despite similar overall noise levels. In particular, complaints to the RTA indicated that noise generated on concrete pavements were considered to be the most annoying. In some cases, the level of complaint has been such that concrete pavements have been overlaid with a thin layer asphaltic wearing surface to reduce the noise generation.

Some research work has also been reported on the most annoying characteristics of road traffic noise generated by concrete pavements. The majority of this research has been performed in the USA and Europe with a frequency spectral energy analysis being the key to identifying the most annoying characteristics. A comprehensive study undertaken in the USA by the Wisconsin Department of Transport (Kuemmel, Sontag, Crovetti, Becker, Jaeckel, and Satanovsky 2000) investigated both internal and external vehicle noise levels as well as undertaking an analysis of the texture characteristics of the concrete pavements examined. In this particular study, frequency spectral analyses were conducted on a substantial set of empirical data. It was found that the presence of tonal components in these frequency spectra, which resulted from energy being focused in discrete frequency bands, appeared to be the cause of increased annoyance compared to that associated with more broad-band road traffic noise.

Confirmation of the results of studies such as those of Kuemmel et al (2000) along with determination of the practical feasibility of constructing what they identified as "quieter" pavements would potentially deliver considerable benefits in terms of acoustic, economic and resource use to the RTA and its stakeholders. These potential benefits were considered sufficient enough to warrant further investigation and the RTA subsequently funded a study to conduct insitu empirical testing of several pavement surfaces in current use. This study was designed to examine a total of 20 pavements. Furthermore, it was set up to develop a data analysis procedure that would allow the outcomes of the study to be compared with those of other Australian and overseas studies. In addition, the analysis procedure would also provide a uniform method of ranking pavement noise attributes against various acoustical performance criteria. In this way detailed assessments of the performance of concrete pavements in terms of noise generating potential might be obtained in order to develop methods to optimise their acoustic performance.

ASPECTS OF ROAD TRAFFIC NOISE

Noise generation

The type of road pavement surface is a significant factor in the process by which tyre/road noise is generated (Samuels 1982a & b, Samuels 1994, Samuels and Hall 2005). Sandberg and Ejsmont (2002) describe in detail the mechanisms of tyre/road noise generation, however it is generally accepted that an air pumping mechanism is the primary mechanism involved. The roadside noise produced by a vehicle under constant speed, free flow operating conditions is dominated by tyre/road generated noise at speeds above a certain value. For passenger vehicles in reasonably maintained condition this will usually be around 30 - 35 km/h while for heavy vehicles it is typically around 40 - 50 km/h (Sandberg & Ejsmont 2002). Above these speeds all other noise sources become negligible contributors to overall level of roadside noise produced by the vehicle. The RTA (Campbell & Isles 2001) nominates that for traffic as a whole, tyre/road noise begins to dominate the noise catchment at around 70 km/h. As a consequence of this, reduction in tyre/road generated noise is an effective source control treatment for high speed highways.

Pavement surface textures

Pavement design guidelines for Australian roads are given in the Pavement Technology Series of publications produced by Austroads and Standards Australia. In particular, Austroads (2004) states that the wearing surface texture specified for the road should "take into consideration the traffic speed, grade, cross-fall, carriageway width and rainfall". Whilst acknowledged as an aspect of pavement design, noise generating potential is not yet a primary consideration in the selection of pavement surfacing.

The orientation of texture can have a significant influence on the noise level that is generated on a particular pavement. Asphalt pavements have a random texture that is similar in all directions and can be considered to be isotropic. The opposite case such as that displayed by transversely or longitudinally tyned concrete is known as anisotropic and refers to textures that are mostly periodic. When a tyre passes perpendicularly over a transversely tyned pavement the tyre impact is in phase over the whole width of the tyre which results in a number of air displacement mechanisms such as pumping and pipe resonances (Sandberg & Ejsmont, 2002). It is therefore desirable to avoid construction of anisotropic textures unless they are longitudinally orientated.

Asphalt surfaces and especially the low noise range of asphalts have optimised isotropic surface texture as a result of having a more honeycomb surface with cavities (air voids) that tend to capture rather than reflect noise. Additional texturing is not generally applied to asphaltic pavements, however concrete pavements can be finished with a variety of insitu surface treatments that may be varied to suit anticipated traffic levels and local conditions.

Tyning

Tyning is achieved by dragging a steel comb over the surface of wet concrete. The tyning may be longitudinal or transverse however in Australia longitudinal tyning is not used because of drainage and safety concerns particularly the 'tram tracking' effect that may occur for bicycles. Tyne spacing may be regular or randomised such that average spacing is between 10 mm and 30 mm. A common abbreviation, which is used in this paper, to describe texture is 3/13/LH were 3 stands for 3 mm tyne depth, 13 represents the nominal tyne spacing and LH (or CH) stand for either Light or Course Hessian drag.

Hessian dragging

Hessian dragging is achieved by dragging a wet Hessian cloth along the whole width of the paved area immediately after concrete paving is complete. In some cases the Hessian is given some horizontal movement to create a longitudinal waveform on the surface. It provides adequate skid resistance and aquaplaning performance for vehicle speeds below 80 km/h. Hessian dragging is undertaken prior to any additional tyning.

Low noise pavements

In Australia, the majority of high speed pavements are constructed of concrete or Dense Graded Asphalt (DGA). However, differing construction techniques have contributed to considerable variability in the noise levels generated by particular examples of both these type of pavements (Samuels 2004, Samuels and Hall 2005). There is a range of so called "low noise" pavements available in the market, and these include the following:

- Open Graded Asphalt (OGA)
- The stone mastic range of gap graded asphalts (SMA)
- Proprietary low noise asphalts designs
- Exposed Aggregate Cement Concrete (EAC).

THE EMPIRICAL STUDY

Pavements studied

The empirical study reported in this paper involved an investigation of the roadside noise generated by 20 pavements. Included in this set were 10 conventional type concrete pavements covering a range of textures along with an EAC type. Also included were four hotmix type asphalts including one conventional DGA and one SMA pavement. In addition a proprietary product marketed by Boral under the name of LoNoise was included. This pavement is a DGA type asphalt that incorporates comminuted scrap rubber and which is paved according to a set procedure and was tested 8 months after opening to traffic. Another hotmix type DGA pavement tested that also incorporated comminuted scrap rubber in the bitumen/aggregate mix was also tested.

Three bitumen sprayed seals with varying nominal aggregate sizes were also investigated, firstly because anecdotally they have been subjectively rated by drivers as being noisy surfaces. Secondly, Samuels (1982 a&b and 2004) and Samuels and Hall (2005) had demonstrated the high noise attributes of these pavements. Finally, two sections of conventionally constructed concrete pavement which had been overlaid with a thin layer of OGA were tested. The OGA overlay had significantly deteriorated at the time of testing and for most purposes resembled a DGA. The major problem with this overlay was that reflective cracking from the concrete pavement below had resulted in spalled joints in the asphalt wearing surface. Subsequent crack filling resulted in an uneven transverse joint at regular intervals of around 4 m.

Development of the test procedure

The noise data were collected using a bank of microphones located adjacent to the section of pavement under investigation. This controlled test passby method was based on the Australian Design Rule 28/01 which deals with the external noise levels of motor vehicles (Department of Transport and Regional Services 2003). The microphones were located at a set distance and height in respect to each of the pavements being investigated. For each measurement the test vehicle always travelled at a constant known velocity on the normally travelled wheel tracks and care was taken to ensure that the noise measurements were not influenced by any extraneous noises. This procedure was also very similar to the well known statistical passby method (ISO 1997) where roadside noise levels and speeds are measured for individual vehicles in the traffic stream.

The test vehicle was a 2005 Ford Falcon sedan which was fitted with Goodyear Eagle NTCS 215/60R16 steel belt radial tyres inflated to 290 kPa. Measurements were made at 100 km/h with the velocity of the test vehicle checked externally using a radar speed gun and internally using a Global Positioning System (GPS) receiver. It was determined that all data presented in this study were collected at a test vehicle speed of 100 km/h +/- 2 km/h.

Data were collected by a bank of three microphones, each set at a height of 1.2 m above the pavement and at a setback of 7.5 m from the centre of the lane in which the test vehicle was driven. The use of three microphones allowed for any variations in each pavement surface to be investigated whilst also tripling the amount of data collected. An audio trace of the vehicle passby was captured from each microphone channel to allow post-processing and replaying of the audio signal. Post-processing allowed a vast number of acoustical descriptors to be assessed as well as facilitating spectral analysis of the signal in 5 ms steps.

The majority of passby noise level studies such as Samuels and Parnell (2001) and Abbott and Phillips (1996) have reported the maximum "A" weighted noise levels. In practice the maximum passby noise level occurs when the vehicle is directly adjacent to the measurement point. However, spectral emissions vary as a vehicle passes the measurement point because the noise propagation to the front, side and rear of the passing vehicle varies with acoustic frequency. Moreover, the spectral components of the passby noise signal are also modified by the Doppler effect (Sandberg & Ejsmont 2002, Samuels 1982 a & b). For the present study it was deemed appropriate to report data collected for the NSW sites as the maximum LAeq noise levels measured over a 125 ms period and over a 500 ms period along with the associated spectral data recorded over the same 500 ms interval. This 500 ms average allowed, in the authors' experience, a more reproducible result to be achieved and reduced any other potential data distortion effects associated with discrete frequency analysis. Figure 1 shows the time evolution of the test vehicle passing a single microphone characterised by rapid fluctuations in the acoustic signal. Samuels (1982a) describes how the directivity of the tyre/road generated noise can contribute to the spurious nature of the acoustic wave front as it reaches the recording microphone.

Instrumentation

A 01dB Metravib Harmonie four channel analyser was used to collect and analyse the roadside noise data. This instrument is capable of collecting data from up to four type 1 microphones simultaneously at a sampling rate of 51.2 kHz.

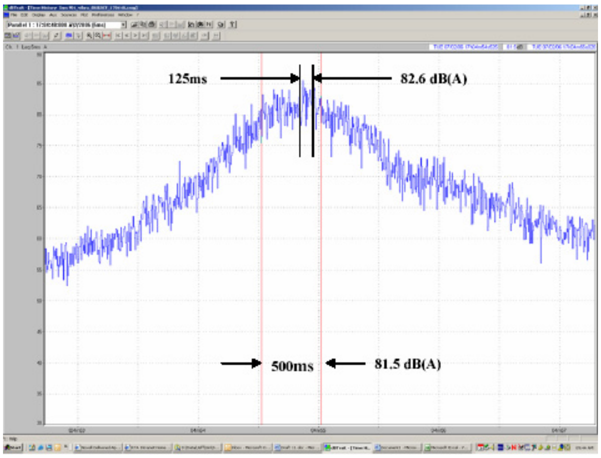

Figure 1. Passby of the test vehicle at 100 km/h on a 7 mm chip seal pavement.

Roadside noise data

Results of the maximum LAeq noise levels in the 125 ms and 500 ms periods averaged from up to five vehicle passbys appear in Table 1. A graph of the 500 ms spectral data for all pavements tested is given in Figure 2.

Table 1. Locations and Results of Data Collected on NSW Pavements.

Site	Location	Surface Texture	Leq Noise Level dB(A)	
			125ms	500ms
Concrete 1	H10 Yelgun - Chinderah	Skewed 1:10 and randomly tyned 3/13/LH	84.6	83.9
Concrete 2	MR23 West Charlestown Bypass	Hessian drag only, no transverse tynes	77.3	76.7
Concrete 3	H10 Raymond Terrace	Random transverse tynes 3/13/LH	82.1	81.4
Concrete 4	H10 Raymond Terrace	Exposed Aggregate Concrete	81.1	80.5
Concrete 5	MR82 Link Road	Turf drag only	80.6	80.0
Concrete 6	H10 Karuah Bypass	Random transverse tynes 3/13/LH	84.0	83.2
Concrete 7	MR617 Foreshore Road	Uniform transverse broom no Hessian drag	88.7	87.9
Concrete 8	F3 Freeway Ph 593	Random transverse tynes 3/13/CH	83.3	82.6
Concrete 9	H10 Coffs Hbr Sth Bound	Random transverse tynes 3/13/LH	83.1	82.3
Concrete 10	H10 Coffs Hbr Nth Bound	Random transverse tynes 3/13/LH	81.8	81.2
Concrete 11	F3 Freeway Dora Ck Ph 565	Random transverse tynes 3/26/LH	85.5	84.6
Asphalt 1	H10 Raymond Terrace Ph 627	14 mm Dense Graded Asphalt	80.5	79.9
Asphalt 2	H1 Nth Distributor Sth Bound	Boral Crumbed Rubber Asphalt	77.4	76.8
Asphalt 3	H1 Nth Distributor Nth Bound	Boral Lo Noise Asphalt (New)	73.5	72.8
Asphalt 4	H1 Nth Distributor Nth Bound	Boral Lo Noise Asphalt (8 months old)	75.5	74.6
Asphalt 5	H10 Coopernook	Stone Mastic Asphalt	81.7	81.2
Seal 1	MR24 Snowy Mtns Hwy, Tumut	7 mm Chip Seal	81.5	80.6
Seal 2	MR24 Snowy Mtns Hwy, Tumut	14 mm Chip Seal	84.6	83.5
Seal 3	H10 Pacific Hwy, MacLean	14 mm Chip Seal with a 7 mm scatter	83.2	82.6
Overlay 1	F3 Freeway Ph 434	Open Grade Overlay on Concrete	85.5	84.3
Overlay 2	F3 Freeway Ph 436	Open Grade Overlay on Concrete	86.6	85.6

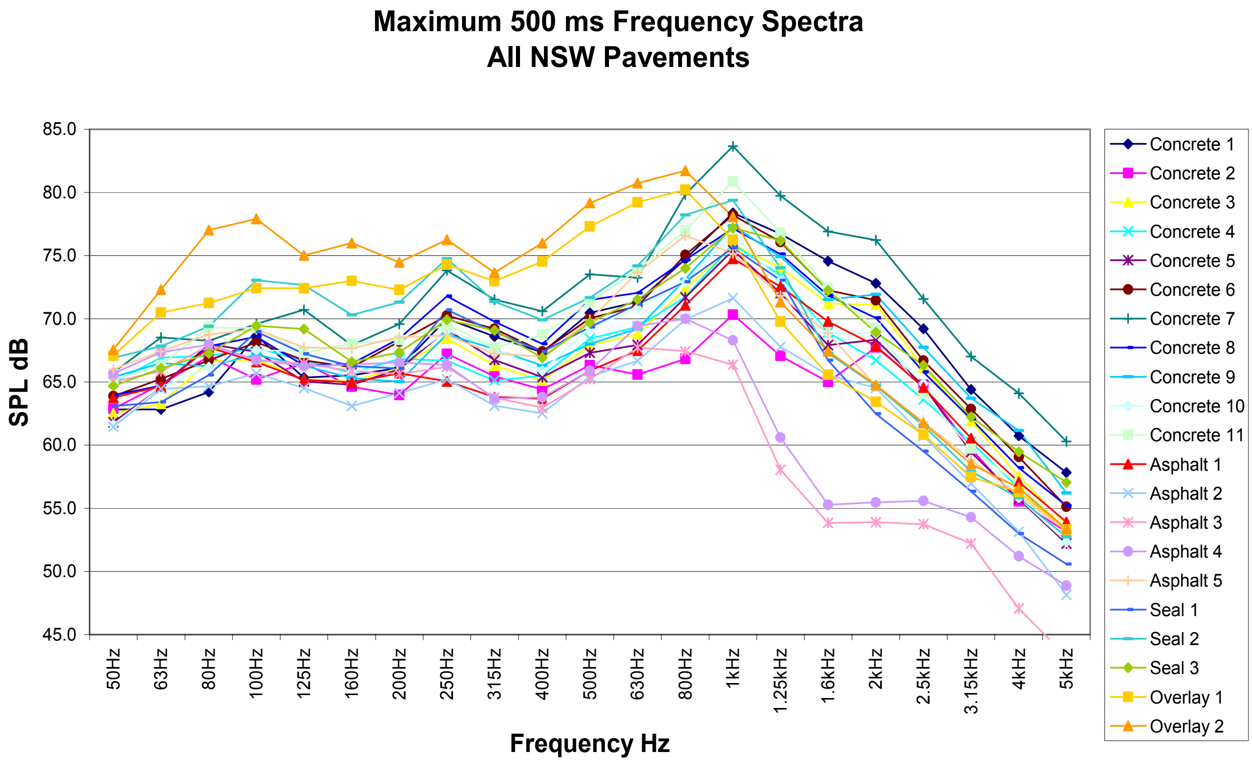

Figure 2. Frequency Data from NSW Pavements

Statistical Variation

Statistical deviations and variations are to be expected in all forms of data collection. For this study three variables were identified and are identified as:

- 'within pavement' variation which is defined as the difference between measurement locations (represented by the 3 microphone locations) on the one individual pavement surface;
- 'test run' variation which is the variation at one single measurement point (represented by an individual microphone) over the multiple test runs that are recorded at that location on the one pavement;
- 'within pavement type' variation which is the variation between pavements of similar construction, texture and type.

Whist an objective of most pavement noise studies is to compare a range of different pavements, it has been found that there can be considerable variations in acoustic attributes within one pavement. 'Within pavement' variability can be as much as 2 to 3 dB(A) (Samuels, 2005), (Sandberg & Ejsmont, 2002). To reduce sampling error the present study utilised a bank of three microphones that were nominally spaced 10 m apart. This had the advantage of testing three sections of the pavement under investigation as well as collecting three wave files for each controlled passby by the test vehicle. Visually it was obvious that surface texture was often quite variable over the section of pavement adjacent to the bank of microphones, a consequence of which could be observed as the magnitude of the resultant 'within pavement' variation in passby noise level.

Figure 3 shows graphically the 'within pavement' variability over short sections between microphone locations. Of particular interest is the large variability associated with concrete pavements, several of which exhibited a range of more that 2 dB(A) between highest and lowest recordings. The 'within pavement' variability is also more significant because other sources of error such as that caused by fluctuations in speed are largely eliminated by the close proximity of the microphones to each other ensuring minimal opportunity for fluctuations in speed between measurement locations.

Visually the asphalt pavements appeared more uniform, an observation that was confirmed acoustically as they also showed much less variation with a range of 2.0 dB(A) or less being recorded for all pavements tested.

In a study of pavement noise in Texas (McNerney et al, 1998) it was also noted that there was an average pavement variation of 0.5 dB(A) between two microphones spaced 15 m apart with no valid runs exhibiting a variation of more than 1.2 dB(A). These findings are consistent with those found in the present study.

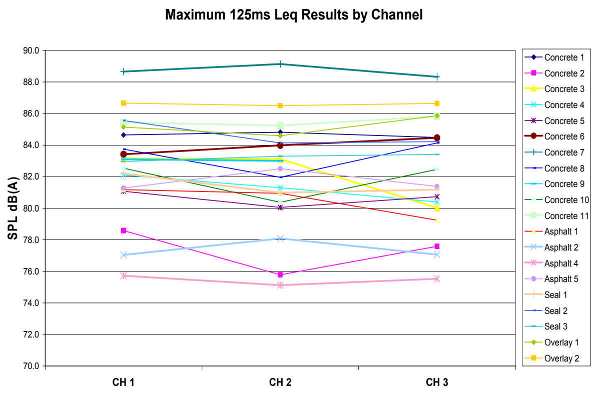

Figure 3. Within Pavement Variation for NSW Data

Table 2. Results of Data from all Studies

Location	Road	Surface	Texture	Max 500ms Leq dB(A)
Nth Distributor Nth Bound	**H1**	**Asphalt**	**Boral Lo Noise 8 months old**	**74.6**
South Africa		Asphalt	Whisper Course	76.6
West Charlestown Bypass	**MR23**	**PCC**	**Hessian drag only, no transverse tynes**	**76.7**
Nth Distributor Sth Bound	**H1**	**Asphalt**	**Boral Crumbed rubber**	**76.8**
US 281 Sth of SH46, San Antonio		Asphalt	Novachip Old	78.9
South Africa		Asphalt	Open Grade Asphalt	79.1
South Africa		Asphalt	Dense Graded Asphalt	79.2
Wisconsin	I-43	Asphalt	Std. ACP	79.4
Iowa	I-163	PCC	19mm uniform long. (1.5 mm d)	79.5
MOPAC @ 45th - Austin		Asphalt	DGA + Microsurfacing	79.5
Raymond Terrace Ph 627	**H10**	**Asphalt**	**14 mm Dense Graded Asphalt**	**79.9**
Link Road	**MR82**	**PCC**	**Turf drag only**	**80.0**
Colorado	I-70	PCC	19mm uniform long. saw cut	80.1
Mopac Sth of Slaughter Lane		Asphalt	DGA Course Matrix	80.1
Iowa	I-163	PCC	19mm uniform long. (1.5 mm d)	80.4
Wisconsin	I-43	Asphalt	Std. ACP	80.4
Raymond Terrace	**H10**	**PCC**	**Exposed Aggregate Concrete**	**80.5**
Snowy Mtns Hwy, Tumut	**MR24**	**Chip Seal**	**7mm Chip Seal**	**80.6**
Loop 1604 - San Antonio		Asphalt	Dense Graded Asphalt New	80.9
Wisconsin	I-43	Asphalt	SMA, 9mm stone	81.0
Padre Is Dr, Corpus Christi		Asphalt	Novachip New	81.0
Coffs Hbr Nth Bound	**H10**	**PCC**	**Random transverse tynes 3/13/LH**	**81.2**
Coopernook Bypass	**H10**	**Asphalt**	**Stone Mastic Asphalt**	**81.2**
Bergstrom AFB, Runway		PCC	JRCP Ungrooved	81.3
Colorado	I-70	PCC	19mm uniform long.	81.4
Raymond Terrace	**H10**	**PCC**	**Random transverse tynes 3/13/LH**	**81.4**
North Dakota	I-94	PCC	Trans., var., 26,51,76,102mm	81.5
Wisconsin	I-43	Asphalt	SHRP ACP	81.6
Wisconsin	I-43	PCC	Ground PCCP	81.7
Fort Worth		Asphalt	Dense Graded Asphalt	81.8
Padre Is Dr, Corpus Christi		Asphalt	DGA + Microsurfacing	81.9
North Dakota	I-94	PCC	19mm uniform long.	82.0
Wisconsin	STH 29	PCC	25mm uniform long.	82.0
Wisconsin	I-43	Asphalt	SMA, 16mm stone	82.1
Minnesota	US 169	PCC	19mm uniform long.	82.2
Coffs Hbr Sth Bound	**H10**	**PCC**	**Random transverse tynes 3/13/LH**	**82.3**
Wisconsin	STH 29	PCC	13mm uniform trans., (1.5mm d)	82.4
MOPAC @ Braker - Austin		Asphalt	Dense Graded Asphalt Old	82.5
Wisconsin	STH 29	PCC	13mm uniform trans.	82.6
F3 Freeway Ph 593	**F3**	**PCC**	**Random transverse tynes 3/13/CH**	**82.6**
Pacific Hwy, Maclean	**H10**	**Chip Seal**	**14mm Chip Seal with a 7mm scatter**	**82.6**
North Dakota	I-94	PCC	13mm uniform trans.	82.7
New Wisconsin	STH 29	PCC	19mm random skew 1:6, LHF	82.9
Minnesota	US 51	PCC	38mm random trans.	83.1
New Wisconsin	STH 29	PCC	25mm random long.	83.2
North Dakota	I-94	PCC	25mm uniform skewed 1:6, RHF	83.2
Karuah Bypass	**H10**	**PCC**	**Random transverse tynes 3/13/LH**	**83.2**
Houston		PCC	Uniform transverse tynes Old	83.2
Iowa	I-163	PCC	13mm uniform trans. (3-5mm d)	83.3
Houston		PCC	Uniform transverse tynes New	83.3
Colorado	I-70	PCC	13mm uniform trans.	83.5
North Dakota	I-94	PCC	19mm uniform trans.	83.5
Snowy Mtns Hwy, Tumut	**MR24**	**Chip Seal**	**14mm Chip Seal**	**83.5**
New Wisconsin	STH 29	PCC	19mm random skew 1:4, LHF	83.6
Iowa	I-163	PCC	19mm uniform trans., (IA. Std.)	83.8
SH16 northwest of Helotes		Chip Seal	10mm Chip Seal	83.8
Decker Lane		PCC	CRCP Untyned	83.8
Wisconsin	US 151	PCC	25mm random trans. (Zignego)	83.9
Yelgun - Chinderah	**H10**	**PCC**	**Skewed 1:10 and randomly tyned 3/13/LH**	**83.9**
South Africa		Chip Seal	19mm Chip Seal	83.9
New Wisconsin	STH 29	PCC	25mm random skew 1:4, LHF	84.0
Minnesota	US 169	PCC	LTD only	84.2
North Dakota	I-94	PCC	25mm uniform trans.	84.2
Bergstrom AFB, Runway		PCC	JRCP Transversely grooved	84.2
Iowa	I-163	PCC	Milled PCCP	84.3
New Wisconsin	STH 29	PCC	25mm random skew 1:6, LHF	84.3
Wisconsin	STH 29	PCC	25mm random trans. (Trierweiller)	84.3
F3 Freeway Ph 434	**F3**	**Overlay**	**Open Grade Overlay on PCC**	**84.3**
Minnesota	US 12	PCC	19mm random trans.	84.4
New Wisconsin	STH 29	PCC	25mm uniform long.	84.4
Wisconsin	STH 29	PCC	Manuf. random trans.	84.4
Wisconsin	STH 29	PCC	25mm uniform skewed 1:6, LHF (1.5mm d)	84.4
Wisconsin	STH 29	PCC	19mm uniform trans.	84.5
Colorado	I-70	PCC	Random trans. saw cuts (16,22,19 mm)	84.6
F3 Freeway Dora Ck Ph 565	**F3**	**PCC**	**Random transverse tynes 3/26/LH**	**84.6**
Minnesota	US 169	PCC	19mm Unif. Long.	84.8
Colorado	I-70	PCC	Random trans. (16,22,19 mm)	84.9
Iowa	I-163	PCC	13mm uniform trans., sawcut	85.1
Wisconsin	STH 29	PCC	Skidabrader, PCCP	85.1
Wisconsin	US 51	PCC	25mm random trans. (Vinton)	85.3
Minnesota	US 169	PCC	19mm random trans.	85.4
Mueller Airport Runway		Asphalt	DGA Transversely grooved	85.4
F3 Freeway Ph 436	**F3**	**Overlay**	**Open Grade Overlay on PCC**	**85.6**
New Wisconsin	STH 29	PCC	19mm random long.	85.8
Wisconsin	STH 29	PCC	21mm truly random trans	85.9
Iowa	I-163	PCC	19mm random trans. (3-5 mm d)	86.0
New Wisconsin	STH 29	PCC	19mm random trans.	86.8
Wisconsin	STH 29	PCC	25mm uniform trans.	86.8
Colorado	I-70	PCC	25mm uniform trans. (CO. Std.)	86.9
New Wisconsin	STH 29	PCC	25mm random trans.	87.1
New Wisconsin	STH 29	PCC	25mm uniform trans.	87.1
Minnesota	US 169	PCC	38mm random trans.	87.8
Foreshore Road	**MR617**	**PCC**	**Uniform transverse broom no Hessian drag**	**87.9**
South Africa		PCC	JRCP	88.4
South Africa		Chip Seal	13mm Chip Seal	88.8

All Studies Data

🟦 **NSW Data**

⬛ **Wisconsin Data**

🟥 **Texan Data**

🟩 **South African D**

Comparisons with other international studies

Comparisons were made of the outcomes of the present study with those of the aforementioned Wisconsin study (Kuemmel et al 2000) along with those from a Texan/South African study (McNerney, Landsberger, Turen & Pandelides 1998). In order to effect these comparisons, the data from these two other studies were reprocessed, taking into account differences in data collection procedures. In this way, comparisons were made of 500 ms maximum LAeq levels, as presented graphically in Figure 4 and in more detail in Table 2. It is apparent that the noise data determined in present study in NSW fits well with those of the other two international studies.

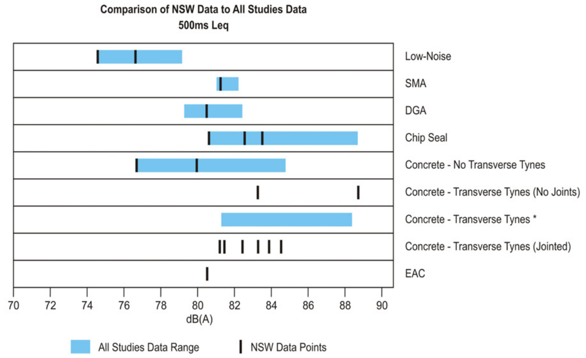

Figure 4. NSW Data Compared to Other Referenced Studies.
* Information was not available from the international studies on the types of contraction joints used in concrete pavements

CONCLUSIONS

The acoustic properties of 20 pavements, representing examples of most of the rigid and flexible pavement types constructed in NSW, were examined in the study reported in this paper. While two OGA overlays were included in the study, they were compacted and resembled DGAs in poor condition. Consequently the outcomes for these pavements were not included in the conclusions of the study. Unfortunately no other examples of OGA pavements in reasonable condition were available at the time of conducting the study. The authors plan to investigate the acoustic properties of OGA pavements in NSW in the future and thus to expand the outcomes of the present study.

In summary the key conclusions of the present paper are as follows:

- The 13 mm transversely tyned concrete pavements studied produced the highest noise levels, followed by the 14 mm chip seal and then the concretes with no transverse tynings. The 7 mm chip seal and the EAC produced similar noise levels, marginally greater than the DGA. Finally, the so called low noise asphalts could produce the lowest noise levels, although this was not always the case.
- Noise levels on concrete pavements tested with transverse tyning were considerably higher than those on other concrete pavement surfaces tested. Based on 'within pavement' variation and visual inspection, prominent tyning appeared to be a major cause of this.
- It was not possible to make definitive conclusions on how to optimise the acoustic performance of pavement surfaces studied, particularly the concrete pavements. Methods and quality control of the application of pavement surface texturing are not at a standard of consistency whereby such conclusions could be drawn from the outcomes of the present study. It is therefore recommended that pavement engineers investigate methods for achieving a more uniform tyne depth and desired texture.
- The frequency spectra of the randomly tyned concrete pavements exhibited a rather prominent peak at around 1 kHz with other discrete peaks at lower frequencies bands. These peaks were substantially greater than any apparent in the spectra of the asphaltic pavements tested. This observation led to the tentative conclusion that the presence of these peaks in the concrete spectra, particularly those around 500 Hz and below, might be responsible for the annoying "whine" often associated with noise generated on concrete pavements. While this conclusion is consistent with the findings of Kuemmel at al (2000) in the USA, it has not yet been possible to identify any particular frequencies as being directly responsible for the "whine".
- LoNoise asphalt performed acoustically well compared to all the other pavement surfaces tested.
- The outcomes of the present study compared well with those of other international studies.
- Overall, stone mastic asphalt did not perform as well as expected in either NSW or overseas studies and this may warrant further investigation.
- Given the good results achieved for longitudinal and skewed tyned concrete pavements overseas it was intuitively expected that the NSW skewed and randomly tyned pavement would perform better than was recorded. This may have been as a result of the quality of the tyning process.

ACKNOWLEDGEMENTS

The work reported in the present paper was conducted under instruction from and commission by NSW RTA as part of the Authority's ongoing Research and Development program. Both authors acknowledge these arrangements and express their appreciation to the Chief Executive of the RTA for being able to conduct the work and for permission to publish the present paper. Any opinions expressed are those of the authors.

REFERENCES

Abbott, P.G. and Phillips, S.M. (1996). *Vehicle noise levels derived from the statistical pass-by method and road surface texture*. Proc. 1996 Nat. Conf. on Noise Control Engineering, Bellevue, Washington, USA.

Austroads (2004). Pavement Design - A Guide to the Structural Design of Road Pavements, Austroads, Sydney.

Campbell, J.A. and Isles, S. (2001). *RTA Environmental Noise Management Manual.* RTA Sydney, Australia.

Dash, D., Bryce, C., Moran, J. and Samuels, S.E. (2002). *Road trial of a low noise concrete pavement with exposed aggregate surfacing.* Road and Transport Research, Vol. 11 No 1, pp6-21. ARRB Transport Research, Vermont South, Victoria, Australia.

Department of Transport and Regional Services (2003). *Australian Design Rule 28/01. External Noise of Motor Vehicles,* DoTaRS Canberra.

International Standards Organisation (1997). ISO 11819-1, Acoustics – Methods for measuring the influence of road surfaces on traffic noise. Part 1 – the statistical passby method. ISO, Geneva.

Kuemmel, D.A.,. Sontag, R.C., Crovetti, J.A., Becker, Y., Jaeckel, J.R. and Satanovsky, A. (2000). *Noise and Texture on concrete Pavements – Results of a Multi-State Study*. Wisconsin DoT Research Report. Wisconsin, USA.

McNerney, M.T., Landsberger, B.J., Turen, T. and Pandelides, A. (1998). *Comparative Field Measurements of Tire Pavement Noise of Selected Texas Pavements*. Centre for Transport Research, University of Texas, Austin.

Samuels, S.E. (1982a). *The generation of tyre/road noise.* Australian Road Research Board. Research Report, ARR No. 121. Australian Road Research Board, Vermont South, Victoria.

Samuels, S.E. (1982b). *Tyre/road noise generation.* Proc. 11th ARRB Conf. 11(6), pp.18-29. Australian Road Research Board, Vermont South, Victoria.

Samuels, S.E. (1994). *The development of low noise surface textures for rigid pavements.* Proc. 17th ARRB Conf. Pt. 7, pp. 47-61. Australian Road Research Board, Vermont South, Victoria.

Samuels, S.E. (1996). *Some aspects of tyre/road noise from rigid pavements*. Proc. 1996 Nat. Conf. on Noise Control Engineering, Bellevue, Washington, USA.

Samuels, S.E. (2004). *The long term road traffic noise attributes of some pavement surfaces in Townsville.* Proc. Annual Conf. Australian Acoustical Society, Gold Coast, Queensland. pp549 – 553. Australian Acoustical Society, Brisbane, Queensland, Australia.

Samuels, S.E. and Hall, A.M. (2005*). The acoustic attributes of Queensland pavement surfaces – the QDMR Pavement Surface Noise Resource Manual*. Proc. Australian Acoustical Society Annual Conference, Busselton, Western Australia. pp 259 – 263. Australian Acoustical Society, Perth, Western Australia.

Samuels, S.E. and Parnell, J. (2001). *Some recent Australian developments in the reduction of road pavement noise.* Proc. Annual Conf. Australian Acoustical Society, ppA3.2/1-A3.2/12. Canberra, November 2001. Australian Acoustical Society, Sydney, NSW, Australia.

Sandberg, U. and Ejsmont, J. A. (2002). *Tyre/Road Noise Handbook.* Informex, Kisa, Sweden.