Pavement surfaces and in-cabin noise levels

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

This paper deals with a Roads and Traffic Authority of NSW funded study of the resultant in-cabin noise levels generated by a passenger vehicle travelling under controlled conditions. The objective of the study was to investigate the relationship between externally and internally measured noise levels and to compare the internally measured noise levels with those recorded in overseas studies. The study investigated 20 pavement surfaces that represented a wide range of construction materials and techniques and surface textures adopted in NSW.

A range of purportedly low noise asphalt and a dense graded asphalt were found to return the lowest overall noise levels followed by a concrete pavement that had minimal surface texture. A stone mastic asphalt along with an exposed aggregate concrete were found to perform better than randomly transverse tyned concrete pavements. Uniformly tyned concrete pavements and chip seal pavements were found to be amongst the loudest pavements.

The present study found that generally, trends in internal noise levels followed those measured externally; however there were some exceptions such as chip seal pavements that recorded higher internal noise levels than did concrete pavements with comparable external noise levels.

INTRODUCTION

This paper reports the results of a Roads and Traffic Authority of NSW (RTA) funded study into the in-cabin noise levels generated by a passenger vehicle travelling under controlled conditions over a number of different pavements. Whilst in-cabin noise levels are of great interest to the automotive industry and continual research is being undertaken to reduce tyre/road noise, mechanical noise and aerodynamic noise the driver for designing lower noise pavements has been to reduce external noise. Intuitively it is expected that a pavement that generates low external noise levels will also return low internal noise levels however this is not widely confirmed.

The objective of the present study was to confirm if there is a direct correlation between internal and external noise levels and determine whether NSW data is comparable to overseas studies.

In the present study the noise levels were recorded both internally and externally as a test vehicle was driven under controlled conditions over a range of 20 pavements surfaces that represented a wide range of construction materials, techniques and surface textures adopted in NSW. Analysis of data collected allowed conclusions to be drawn on the relationship between internal and external noise levels as well as comparing this data to a comprehensive study undertaken in the USA by the Wisconsin Department of Transport (Kuemmel, Sontag, Crovetti, Becker, Jaeckel, and Satanovsky, 2000) which investigated both internal and external vehicle noise levels as well as undertaking an analysis of the texture characteristics of the concrete pavements examined.

ASPECTS OF ROAD TRAFFIC NOISE

Noise generation

Figure 1 identifies the major sources of generated noise from the operational use of a vehicle. By collecting data under controlled conditions mechanical and aerodynamic noise could be kept at a constant with tyre/road generated noise being the only variable.

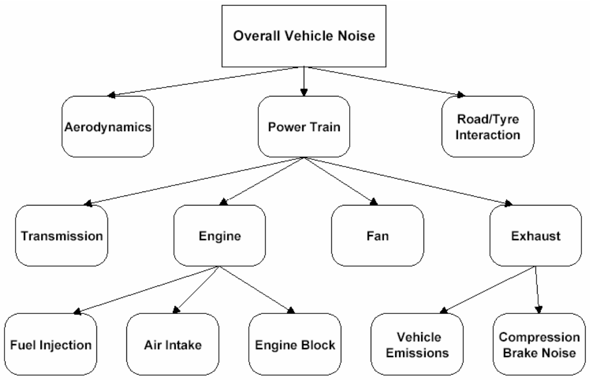

Figure 1 Noise Sources from a Vehicle (sources may not be applicable to all vehicles)

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. There is a substantial body of research which has been undertaken to reduce tyre/road noise at the source and this is divided into one of two options. Firstly, tyre design can have significant influence on the generation of noise. Samuels (1982) discusses the influence of tread patterns and there have been subsequent advances in tyre technology that have further reduced tyre generated noise levels. Tyre design is largely commercially driven and is outside the scope of this study.

The objective of the study is to examine the influence of the second major variable being pavement design and the aspects that determine generated noise levels.

Pavement surface textures

Pavement design guidelines for Australian roads are given in the Pavement Technology Series of publications produced by

Austroads and Standards Australia. The publication *Guide to the Selection of Road Surfacings* (Austroads, 2003) provides the options available for selection of a wearing surface for a range of design and traffic requirements. The most important aspect of pavement texture is in the provision of adequate skid resistance particularly in wet conditions when drainage of the pavement surface is critical to prevent aqua-planing.

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 and 2004) and Samuels and Hall (2005) had demonstrated the high external 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 which resulted in a high periodic impact noise within the cabin.

Test procedure

External noise data were collected using a bank of three microphones, each set at a height of 1.2 m above the pavement level and at a setback of 7.5 m from the centre of the lane in which the test vehicle was driven. 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.

Internal noise data were collected by following SAE Standard J1477 *Recommended Practice for Measurement of Interior Sound Levels of Light Vehicles* with microphones mounted in the passenger position and in the central cabin position. Data were collected at 80 km/h and 100 km/h, but for the purposes of this paper only the 100 km/h data collected on channel 1 (passenger seat position) have been presented. Audio files were collected in the vehicle over varying time intervals which were determined by the length of consistent pavement surface available for testing. To allow qualitative comparison, single representative sub-intervals of 5 seconds were selected for each pavement type and LAeq (5s) values calculated.

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

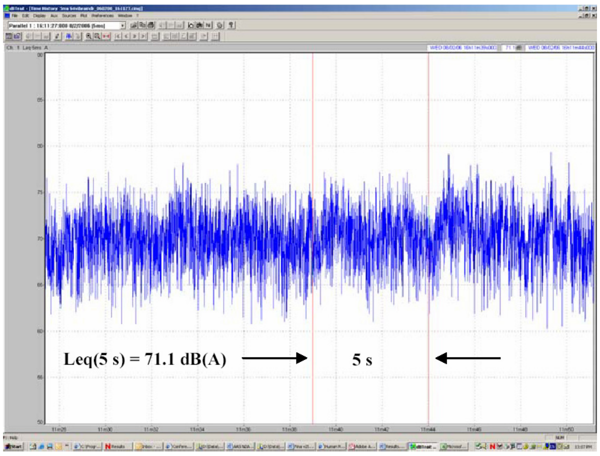

Figure 3. Internal histogram of the test vehicle at 100 km/h on a 7 mm chip seal pavement.

data presented in this study were collected at a test vehicle speed of 100 km/h +/- 2 km/h.

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). 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 2 shows the time evolution of the test vehicle passing a single microphone characterised by rapid fluctuations in the acoustic signal. Samuels (1982) 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 both the external and internal 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.

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. Figure 3 shows the histogram pf the test vehicle travelling on a 7 mm chip seal pavement along with the 5 s cut taken to represent the pavement. 5 seconds was deemed to be of sufficient duration to return a reproducible result. In this case a 5 s cut returned an Leq result of 71.1 dB(A) whereas analysis of the whole file (almost 30s) returned a result of 71.0 dB(A).

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). Apart from the use of a different test vehicle the procedures followed for both studies were almost identical and therefore no reprocessing of data was undertaken. Table 2 allows comparison of the results of the two studies. From Table 2 it can be seen that the noise data determined in present study in NSW fits well with those of the other two international studies.

While no defined correlation exists, there is a trend towards the externally quieter pavements exhibiting a smaller difference between internal and external noise levels with the externally noisier pavements exhibiting the largest internal/external differences. Of particular interest are the chip seal pavements which were found to rate internally as some of the noisiest yet performed much better externally.

It is not known if pavement roughness is responsible for influencing internally noise levels and this is one aspect that will be investigated in future studies.

Of additional interest is the level of 75 dB(A) recorded internally as the test vehicle travelled on a 14mm chip seal pavement is only 10 dB below the NSW recommended occupational Leq(8h) level of 85 dB(A) set by clause 49 of the NSW Occupational Heath and Safety Regulation 2001.

CONCLUSIONS

Following SAE standard J1477, the internal in-cabin noise levels of a test vehicle travelling over 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. These internal noise levels were also compared against the external noise levels measured on the same pavement to determine if any direct correlation exists. Furthermore comparison was made with the internal noise levels reported from 20 pavement surfaces constructed in the mid western states of America (Kuemmel et al, 2000).

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

- Internal Leq noise levels recorded for NSW pavements covered a range of 9.0 dB from 66.0 dB(A) to 75 dB(A) whilst the maximum 500 ms levels ranged 13.1 dB from 74.6 dB(A) to 87.9 dB(A).
- Generally asphalt pavements returned the lowest internal noise levels followed by non-transversely tyned concrete pavements, transversely tyned concrete pavements and

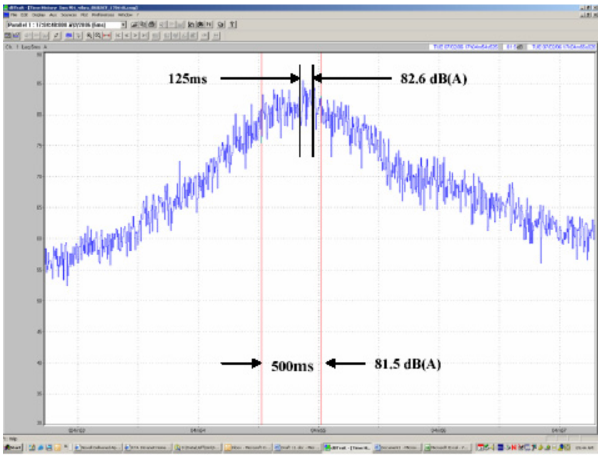

Figure 2. External passby of the test vehicle at 100 km/h on a 7 mm chip seal pavement.

chip seals.

- Chip seal pavements produce high internal noise levels that do not match its external noise level performance. In particular, 7 mm chip seal rates well based on externally generated noise levels yet is one of the poorest performers in terms of internal noise levels.
- Internal noise levels from the asphalt overlay pavements were found to be high particularly for Overlay 2 site which exhibited a higher level of pavement deterioration. The annoying periodic impact noise associated with tyre contact on the spalled pavement joint is not obvious in the Leq(5s) and may be best presented as a maximum noise event.
- The outcomes of the present study compared well with those of other international studies.

ACKNOWLEDGEMENTS

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

Site	Location	Surface Texture	Leq Noise Level dB(A)			
			External		Internal 5s	
			125ms	500ms	CH1	CH2
Concrete 1	H10 Yelgun - Chinderah	Skewed 1:10 and randomly tyned 3/13/LH	84.6	83.9	69.7	69.1
Concrete 2	MR23 West Charlestown Bypass	Hessian drag only, no transverse tynes	77.3	76.7	67.2	67.9
Concrete 3	H10 Raymond Terrace	Random transverse tynes 3/13/LH	82.1	81.4	68.8	67.6
Concrete 4	H10 Raymond Terrace	Exposed Aggregate Concrete	81.1	80.5	67.7	66.7
Concrete 5	MR82 Link Road	Turf drag only	80.6	80.0	67.9	68.3
Concrete 6	H10 Karuah Bypass	Random transverse tynes 3/13/LH	84.0	83.2	69.3	68.7
Concrete 7	MR617 Foreshore Road	Uniform transverse broom no Hessian drag	88.7	87.9	71.6	71.8
Concrete 8	F3 Freeway Ph 593	Random transverse tynes 3/13/CH	83.3	82.6	71.8	70.9
Concrete 9	H10 Coffs Hbr Sth Bound	Random transverse tynes 3/13/LH	83.1	82.3	68.2	67.2
Concrete 10	H10 Coffs Hbr Nth Bound	Random transverse tynes 3/13/LH	81.8	81.2	70.4	69.5
Concrete 11	F3 Freeway Dora Ck Ph 565	Random transverse tynes 3/26/LH	85.5	84.6	70.0	70.0
Asphalt 1	H10 Raymond Terrace Ph 627	14 mm Dense Graded Asphalt	80.5	79.9	66.5	66.2
Asphalt 2	H1 Nth Distributor Sth Bound	Boral Crumbed Rubber Asphalt	77.4	76.8	66.8	66.0
Asphalt 3	H1 Nth Distributor Nth Bound	Boral Lo Noise Asphalt (New)	73.5	72.8	66.0	65.0
Asphalt 4	H1 Nth Distributor Nth Bound	Boral Lo Noise Asphalt (8 months old)	75.5	74.6	NT	NT
Asphalt 5	H10 Coopernook	Stone Mastic Asphalt	81.7	81.2	67.5	66.6
Seal 1	MR24 Snowy Mtns Hwy, Tumut	7 mm Chip Seal	81.5	80.6	71.1	69.3
Seal 2	MR24 Snowy Mtns Hwy, Tumut	14 mm Chip Seal	84.6	83.5	75.0	73.6
Seal 3	H10 Pacific Hwy, MacLean	14 mm Chip Seal with a 7 mm scatter	83.2	82.6	71.4	70.4
Overlay 1	F3 Freeway Ph 434	Open Grade Overlay on Concrete	85.5	84.3	68.0	67.8
Overlay 2	F3 Freeway Ph 436	Open Grade Overlay on Concrete	86.6	85.6	73.1	73.2

NT Not taken.

Table 2. Internal Noise Levels Ranked According to Loudest LAeq (5 s) on Channel 1.

Location	Road	Surface	Texture	Leq (5 s) dB(A)	Max 500ms dB(A)
Wisconsin	I-43	Asphalt	SHRP ACP	65.9	79.4
Nth Distributor Nth Bound	**H1**	**Asphalt**	**Boral Lo Noise**	**66.0**	**74.6**
Raymond Terrace Ph 627	**H10**	**Asphalt**	**14 mm Dense Graded Asphalt**	**66.5**	**79.9**
Nth Distributor Sth Bound	**H1**	**Asphalt**	**Boral Crumbed rubber**	**66.8**	**76.8**
Minnesota	MN 55	Concrete	38mm random trans.	66.9	83.1
New Wisconsin	STH 29	Concrete	19mm random skew 1:4, LHF	67.2	83.6
West Charlestown Bypass	**MR23**	**Concrete**	**Hessian drag only, no transverse tynes**	**67.2**	**76.7**
Michigan	I-75	Concrete	Exposed Aggregate Concrete	67.5	-
Coopernook Bypass	**H10**	**Asphalt**	**Stone Mastic Asphalt**	**67.5**	**81.2**
New Wisconsin	STH 29	Concrete	19mm random skew 1:6, LHF	67.6	82.9
North Dakota	I-94	Concrete	Trans., var., 26,51,76,102mm	67.7	81.5
Raymond Terrace	**H10**	**Concrete**	**Exposed Aggregate Concrete**	**67.7**	**80.5**
Link Road	**MR82**	**Concrete**	**Turf drag only**	**67.9**	**80.0**
New Wisconsin	STH 29	Concrete	25mm uniform long.	68.0	83.2
F3 Freeway Ph 434	**F3**	**Overlay**	**Open Grade Overlay on Concrete**	**68.0**	**84.3**
Iowa	I-163	Concrete	13mm uniform trans. (3-5mm d)	68.2	83.3
Coffs Hbr Sth Bound	**H10**	**Concrete**	**Random transverse tynes 3/13/LH**	**68.2**	**82.3**
Wisconsin	US 151	Concrete	25mm random trans. (Zignego)	68.6	83.9
Colorado	I-70	Concrete	Random trans. saw cuts (16,22,19 mm)	68.6	84.6
New Wisconsin	STH 29	Concrete	19mm random trans.	68.7	86.8
Raymond Terrace	**H10**	**Concrete**	**Random transverse tynes 3/13/LH**	**68.8**	**81.4**
New Wisconsin	STH 29	Concrete	25mm random trans.	68.9	87.1
Wisconsin	STH 29	Concrete	19mm uniform trans.	69.1	84.7
Wisconsin	I-43	Concrete	Ground PCCP	69.2	81.7
Iowa	I-163	Concrete	13mm uniform trans., sawcut	69.2	85.1
Wisconsin	STH 29	Concrete	13mm uniform trans.	69.3	82.6
Karuah Bypass	**H10**	**Concrete**	**Random transverse tynes 3/13/LH**	**69.3**	**83.2**
Minnesota	US 169	Concrete	38mm random trans.	69.4	87.8
Wisconsin	STH 29	Concrete	25mm uniform trans.	69.5	87.1
Colorado	I-70	Concrete	25mm uniform trans. (CO. Std.)	69.7	86.9
Yelgun - Chinderah	**H10**	**Concrete**	**Skewed 1:10 & randomly tyned 3/13/LH**	**69.7**	**83.9**
Iowa	I-163	Concrete	19mm random trans. (3-5 mm d)	70.0	86.0
F3 Freeway Dora Ck Ph 565	**F3**	**Concrete**	**Random transverse tynes 3/26/LH**	**70.0**	**84.6**
Coffs Hbr Nth Bound	**H10**	**Concrete**	**Random transverse tynes 3/13/LH**	**70.4**	**81.2**
Snowy Mtns Hwy, Tumut	**MR24**	**Chip Seal**	**7mm Chip Seal**	**71.1**	**80.6**
Pacific Hwy, MacLean	**H10**	**Chip Seal**	**14mm Chip Seal with a 7mm scatter**	**71.4**	**82.6**
Foreshore Road	**MR617**	**Concrete**	**Transverse broom no Hessian drag**	**71.6**	**87.9**
F3 Freeway Ph 593	**F3**	**Concrete**	**Random transverse tynes 3/13/CH**	**71.8**	**82.6**
Iowa	I-163	Concrete	Milled PCCP	72.0	84.3
F3 Freeway Ph 436	**F3**	**Overlay**	**Open Grade Overlay on Concrete**	**73.1**	**85.6**
Snowy Mtns Hwy, Tumut	**MR24**	**Chip Seal**	**14mm Chip Seal**	**75.0**	**83.5**

NSW Data Wisconsin Data