The long- term acoustic performance of New Zealand standard porous asphalt
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Contents

Executive summary

The NZ Transport Agency, which is responsible for the New Zealand state highway road network, commissioned Opus International Consultants to investigate the long-term acoustic performance of New Zealand standard porous asphalt manufactured in accordance with *TNZ P/11 Specification for open graded porous asphalt* (OGPA).

OGPA in New Zealand, and certainly on the state highway network, is predominantly used in high-speed environments with speed limits of 80 to 100 km/h and often in expressways and motorways. OGPA is selected for its 'functional' attributes of macrotexture and porosity, which promote removal of water from the top road surface, enhance skid resistance and reduce splash/spray during wet conditions, and for its smoothness or low roughness, which provides better ride quality and fuel savings. OGPA also has better acoustic performance than other New Zealand road surfaces and so it is known in New Zealand as a 'low-noise road surface'.

To measure the long-term acoustic performance of OGPA, the most practicable approach for the research project was to measure the tyre/road noise on a set of OGPA sections of different ages and from this infer the effect of age on acoustic performance. A method for acoustic measurement was selected, developed and applied, using for guidance *ISO 11819-2 Acoustics – method for measuring the influence of road surfaces on traffic noise – part 2: close-proximity method* (2012 and 2015 drafts). A microphone rig was externally mounted adjacent to the rear wheel of a passenger car fitted with standard reference test tyres. It was able to measure average sound pressure levels and spectra for each 20-metre long road segment, in one wheel-path, over any length of road. This system closely followed ISO 11819-2, without achieving 100 % compliance.

A series of commissioning studies were undertaken to understand and establish the reliability of the measurement system and methodology. Repeatability was impressive, finding very little difference between repeated runs, even over the course of several weeks. The system was able to distinguish between acoustic emissions of different surface type and tyre combinations, in overall level and in spectra. The effects of vehicle test speed and ambient temperature were quantified, and found to be typical of international experience. A short study looking at correlation with wayside measurements was inconclusive. Overall the measurement system performed very well, and was appropriate for the chosen methodology.

One hundred and fifty OGPA-paved road sections were measured across four New Zealand regions and across a range of different ages between newly laid and nine years old. The dataset was not evenly distributed across regions and ages but allowed comparisons of particular regions and age bands, facilitating some broad interpretation of the long-term acoustic performance of New Zealand OGPA. There was no indication of dramatic deterioration of OGPA acoustic performance prior to the time at which aged OGPA sections are currently being replaced (8 to 10 years), but instead a gradual deterioration of the order of two decibels over the life of the pavement, after the first year. Note that based on the dataset achieved, the research findings should be considered applicable only to New Zealand OGPA laid in high-speed environments, defined as where speed limits are 80 to 100 km/h.

Literature and experiences were studied to understand the factors affecting the functional life of OGPA and those affecting the acoustic performance of OGPA. It appears current practices of asset management for OGPA functional life are in line with what would be prescribed if considering asset management for OGPA acoustic life. Therefore, the research makes no recommendation for changes to asset management of OGPA in high-speed environments, but supports current practices.

Abstract

Research was commissioned to investigate the long-term acoustic performance of New Zealand standard porous asphalt made to *TNZ P/11 Specification for open graded porous asphalt* (OGPA). The research findings should be considered applicable only to New Zealand OGPA laid in high-speed environments (speed limits of 80 to 100 km/h).

A method for acoustic measurement was selected, developed and applied using drafts of ISO 11819-2 for guidance. Measurements were made of a set of OGPA sections of different ages from four regions of New Zealand. The oldest OGPA sections were around 8 to 10 years old, which matches current expectations of OGPA 'life'.

The measurements show OGPA acoustic performance deteriorating at a steady but slow rate over time, yielding about 2 dB(A) deterioration of acoustic performance over 8 to 10 years.

Current asset management of OGPA is largely driven by functional attributes of smoothness and porosity, which also deliver OGPA's acoustic performance. It appears that current practices of asset management for OGPA functional life are synchronised with what would be prescribed if considering asset management for OGPA acoustic life. Therefore, the research makes no recommendation for changes to asset management of OGPA in high-speed environments, but supports current practices.

1 Introduction

The NZ Transport Agency, which is responsible for the New Zealand state highway road network, commissioned Opus International Consultants to investigate the long-term acoustic performance of New Zealand standard porous asphalt and any implications of that for asset management practice.

New Zealand standard porous asphalt is manufactured in accordance with the *TNZ P/11 Specification for open graded porous asphalt* (OGPA) (Transit NZ 2007). It is laid as a single layer asphalt usually 25 to 50 mm deep. The aggregate is open graded and the designed void content is usually about 20 percent. The binder has traditionally been unmodified bitumen (grade 60–70 or 80–100) with some use of polymer modified bitumen where the inclusion of polymers is intended to provide improved performance such as additional flexibility/elasticity or stress/strain resistance.

OGPA in New Zealand, and certainly on the state highway network, is predominantly used in high-speed environments with speed limits 80 to 100 km/h, including on motorways and expressways. OGPA is selected for its ‘functional’ attributes of:

- macrotexture and porosity, which promotes removal of water from the top road surface, enhances skid resistance and reduces splash/spray during wet conditions
- smoothness or low roughness, which provides better ride quality and fuel savings.

OGPA also has better acoustic performance than other New Zealand road surfaces and so is known in New Zealand as a ‘low-noise road surface’. OGPA acoustic performance is sometimes a significant factor in its selection but often this attribute is incidental to its other functional attributes.

Other research has focused on the construction, maintenance and failure of the functional attributes of New Zealand OGPA, but this research project focused on acoustic performance and management of that performance to current OGPA asset management practices.

The report is structured as follows:

- investigation and selection of a method appropriate for measuring the acoustic performance of OGPA
- setup and commissioning of the chosen measurement method
- results of the measurements
- implications and relationships important for OGPA asset management.

This report is not intended as a comprehensive summary of tyre/road noise concepts or international experience and literature. It is a report of New Zealand-specific research. Some concepts and literature are used to expand the interpretation of the New Zealand-specific findings.

2 Methods for tyre/road noise measurement

To measure the long-term acoustic performance of OGPA, it may seem obvious to perform repeat measurements on a sample of road sections at intervals over their service life until replacement. This approach would provide control of many variables; however, it was not practicable for this research project as the service life typically expected of OGPA (as defined by parameters excluding acoustic performance) is around eight years (Fletcher and Theron 2011). The more practicable approach for the research project was to measure the tyre/road noise on a set of OGPA sections of different ages and infer the effect of age on acoustic performance.

A number of tyre/road noise measurement methods are available. Objectives for this research project were not only to select a method appropriate for the research project but also to consider methods useful to the Transport Agency for future management/monitoring of acoustic performance of road surfaces, particularly OGPA.

The expectation is that OGPA laid on the state highway network should deliver a certain acoustic performance. For that acoustic performance to become a contractual requirement, a well-recognised reliable road surface noise measurement, such as an international standard from ISO or AASHTO or equivalent, would be suitable.

International standards for road surface noise measurement methods are developed to produce repeatable and reproducible results. To deliver this, the methods (including equipment and procedures) are necessarily highly specified and comprehensive. For results from the current research project to be meaningful, the road surface noise measurement method would also need to meet a high degree of repeatability and reproducibility. Obviously, an international standard would meet these needs. However, full compliance with an international standard was not practicable within the current research project's time and budget constraints. Therefore, the research project's immediate requirement of a road surface noise measurement method was defined as: 'The road surface noise measurement method needs to follow an international standard as far as practicable'.

There are existing road surface noise measurement methods that require measurements in a laboratory or in a simulated setting. These methods do not meet the critical needs of the Transport Agency and this research project for in situ measurements and therefore were not considered in this work.

2.1 Methods for measurement of road surface acoustic properties

2.1.1 Technical standards

The International Organization for Standardization (ISO) standard for 'Measurement of the influence of road surfaces on traffic noise' is numbered ISO 11819 and has four parts:

- 11819-1 for the statistical pass-by (SPB) method
- 11819-2 for the close-proximity (CPX) method[1]
- 11819-3 for the reference test tyres

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[1] The 2012 draft of ISO 11819-2 was the most recent version when much of this work was undertaken. Since then 2015 and 2016 drafts have been released. It is understood the differences between the 2012 draft and 2016 draft do not affect the work reported here, but the original documents should be consulted for full confirmation.

- 11819-4 for the SPB method using a backing board and serving as a complement to 11819-1.

The American Association of State Highway Transportation Officials (AASHTO) standard methods relating to road surface acoustic properties are:

- TP 76 for the 'Standard method of test for measurement of tire/pavement noise using the on-board sound intensity (OBSI) method' (AASHTO 2015)
- TP 98 for the 'Standard method of test for determining the influence of road surfaces on vehicle noise using the statistical isolated pass-by (SIP) method' (AASHTO 2013a)
- TP 99 for the 'Standard method of test for determining the influence of road surfaces on traffic noise using the continuous flow traffic time-integrated method (CTIM)' (AASHTO 2013b).

Work in progress by the Society of Automotive Engineers (SAE) International (nd) includes Standard J2920 for the 'Measurement of tire/pavement noise using sound Intensity'. The American Society for Testing and Materials (ASTM) International (nd) has a work item 'New practice for measurement of tire/pavement noise using the on-board sound intensity (OBSI) method'.

2.1.2 Methods

For the purposes of the research, the above technical standards provide the following options for the measurement of noise:

- wayside (far-field) measurements vs close-proximity (near-field) measurements
- sound pressure measurements vs sound intensity measurements.

2.2 Consideration and selection of methods

This section does not give a full description of the approaches to measuring road surface acoustic properties but instead focuses on the defining nature of each approach with regard to its particular advantages or disadvantages.

2.2.1 Wayside vs close-proximity measurements

Wayside measurements use a microphone at the side of the road, positioned at a defined distance from the vehicle path. They record all sources of road traffic noise: engine (power train) noise, exhaust noise, aerodynamic noise and tyre/road noise, and wayside measurements and can accurately obtain measurements across the full frequency spectrum. The results are taken as representative of how people hear road traffic noise and can be input directly into noise models.

Procedures for wayside measurements require measuring a specified number of vehicles from a specified set of vehicle classes. For example, the ISO 11819-1 method requires measurement of at least 100 passenger cars, at least 30 dual-axle heavy vehicles with more than four wheels, and at least 30 multi-axle heavy vehicles with more than two axles, with the additional requirement that the total number of heavy vehicles should be at least 80. Whether obtaining the sample of vehicles from the 'natural' vehicle fleet or from a set of 'controlled' vehicles, changes to these vehicles over time may confound assessment of the tyre/road noise over time.

For wayside measurements, the procedures set requirements for the characteristics of the travel of passing vehicles, conditions of the testing site and weather conditions. Within New Zealand, meeting these requirements may significantly lengthen the time for obtaining the measurement and severely restrict the availability of fully compliant testing sites.

As noted previously, wayside measurements record all sources of road traffic noise. Due to the ‘control’ provided by the procedures, the influence of the road surface on the noise level can be determined through comparison with wayside measurements performed at a testing site with a reference road surface. However, as wayside measurements require static setup, the results describe only one point (± about 20 metres) of road surface. This is a significant limitation to assessing variability of road surface influence, especially since noise reduction of porous surfaces is known to vary substantially from spot to spot.

Close-proximity measurements are taken by microphones located at or near the tyre/road interface as the tyre/wheel moves over the road surface. From this measuring position, the tyre/road noise dominates any other road traffic noise source. Thus, the noise captured is not an exact representation of that heard externally and cannot be input directly into noise models; but the measurements are appropriate for isolating the tyre/road contribution. The frequency range over which a microphone accurately measures is related to aspects of the microphone itself and the distance between the microphone and the noise source, particularly where that distance is near to or less than the wavelength of the sound being measured. At 1,000 Hz the wavelength of sound is about 340 mm, thus the close-proximity measurements have the microphones mounted in a near-field position for some frequencies, but the lower frequencies contribute little to the A-weighted sound levels. Close-proximity measurements effectively travel with the tyre/road noise source, allowing efficient measurement of continuous lengths of road and the variability of the results can be readily assessed.

Procedures for close-proximity measurements require the tyre to be very close to the microphones from which measurements are made. Reference tyres representing different vehicle types, such as light and heavy vehicles, are used. These are not necessarily tyres typically used by the vehicle fleet but are specified according to their ability to produce results that represent the tyre/road noise of certain types of vehicle, are responsive to road surface changes, and most importantly will remain in production in the same specification for the foreseeable future. Procedures set the reference tyres to be used and those selected are periodically reviewed to ensure they are appropriate for the intended purpose (and still available from manufacturers). The properties of the tyre at the time of measurements are critical to the measurements obtained; and requirements are set in ASTM F2493 and ISO 11819-3 for storage and handling and replacement of reference tyres.

The equipment for close-proximity measurements is more expensive to obtain and technically demanding to maintain, with a minimum starting cost of about $40,000 compared with about $5,000 for wayside measuring equipment. However, performing wayside measurements to assess the variability of the road surface’s influence along an extended section would entail much more time and high labour costs. These would probably make the wayside measurement method impracticable, as it would require four to six hours per site, and three to five sites per km, or twice this for dual carriageways. Close-proximity measurements on the other hand are extremely efficient for long road sections, as two people can cover 30 km across four lanes within a day, with perhaps an additional day for data processing. In per kilometre terms, it would be approximately 40 person hours per kilometre for wayside measurements versus less than an hour per kilometre for close-proximity measurements.

The correlation between wayside and close-proximity measurements has been studied and found to be acceptable (Skov 2016).

Wayside measurements may better represent the human experience of road traffic noise but for a focus on tyre/road noise, the close-proximity method is recommended for long-term road surface measurements. Close-proximity measurements were also the best method for the research project.

2.2.2 Sound pressure vs sound intensity

A sound source radiates a certain amount of sound power. Sound power is the total power produced by the source in all directions. A sound intensity level is a measure of the sound power transmitted over an area or in a certain direction. A sound pressure level is a measure of pressure fluctuations caused by the transmission of sound power.

Either sound pressure or sound intensity can be used in close-proximity measurements.

For close-proximity sound pressure measurements, typically two (or more) closely spaced microphones are used. The microphones need to be shielded from airflow and extraneous noise. This is achieved using a special ‘enclosed’ trailer or vehicle to protect the microphones; or windscreens/nose cones to protect ‘unenclosed’ microphones mounted on a normal vehicle, which would otherwise be open to airflow.

In close-proximity sound intensity measurements, a ‘sound intensity probe’ is used. This consists of two closely spaced microphones measuring both the amplitude and phase of the sound power from which the sound intensity can be determined. The directional characteristic of sound intensity makes it suited for measuring a specific direction (or sound source) while attenuating sound from other directions, such as airflow-induced noise (although microphone windscreens or nose cones should still be used). As the sound intensity microphones require less shielding they are commonly used without being enclosed, but attached to the outside of the vehicle and positioned very close to a tyre/road contact point.

Sound intensity is more complicated to measure and analyse than sound pressure and also requires more expensive equipment. Comparisons between measurements using the CPX and OBSI methods have been made and found to give almost perfect correlations (Oddershede et al 2013).

For the research project, the cost of the equipment for sound intensity measurements exceeded constraints so close-proximity sound pressure measurements were used instead.

2.3 Close-proximity mounting

There are three approaches to close-proximity measurements of road surface noise:

1. The microphones and subject wheel, whose tyre/road interface is to be measured, can be contained within an enclosed trailer towed by a vehicle, or
2. The microphones and subject wheel can be on an open trailer towed by a vehicle, or
3. A test vehicle’s wheel can be used for the subject tyre and the microphones can be mounted ‘on-board’ the outside of the test vehicle adjacent to the tyre.

Vehicle excluded, initial setup costs for the on-board approach should be lower than the costs for an open CPX trailer, which would be lower than the costs for an enclosed CPX trailer. Our investigation indicated an enclosed trailer from Europe would cost $110,000, with an additional $50,000 necessary for equipment. On the other hand, a car-based system using a sound pressure approach would cost $40,000 and an on-board sound intensity system would cost $50,000.

Of the three approaches, the enclosed trailer approach provides the greatest protection or control for the measurements. Robust operation of the enclosed trailer approach has reduced the need for operators with specialty skills. Data from the enclosed trailer should be relatively ‘clean’ allowing consistency between test runs and assisting subsequent processing of the data.

The on-board approach puts extra requirements on the host vehicle to avoid unwanted vehicle noise and aerodynamic influences. It is difficult to find a vehicle that can host both reference tyres proposed in ISO/TS 11819-3 (which have different dimensions) and can supply the loading required in the standard.

Some procedures require measurements in both wheel paths. Using the on-board approach, the microphones would be outside the body of the test vehicle and so more vulnerable to contact than the microphones using either an open or enclosed trailer. This vulnerability is reduced when measuring the kerbside wheel path but increased if measuring the wheel path adjacent to other traffic.

Therefore, operation of the enclosed noise trailer approach would be more efficient than operation of the open trailer, which would in turn be more efficient than operation of the on-board approach.

From the review of standards and literature, the enclosed trailer appears most appropriate for the Transport Agency's long-term needs. Higher initial setup costs would be offset by the long-term usage. The overall recommendation is to build an enclosed noise trailer and use it in accordance with ISO 11819-2.

For the research project, time and cost constraints governed which approach to employ. At the time of selecting the measurement method, there was no CPX trailer in New Zealand and the development and construction of a trailer would have been specialised tasks beyond the resources of the research project. Purchase or leasing of a trailer from an overseas source was also beyond the resources of the research project. Thus, the on-board approach was selected. Some of the identified operation inefficiencies of the on-board approach were considered less prohibitive in the context of the research project's distinct purpose and short usage. ISO 11819-2 provides for use of the on-board approach. Although the research project was unable to resource full compliance with ISO 11819-2, the standard was used as a guide and benchmark.

The on-board approach may offer nimbleness and flexibility for other research purposes as well as the current project. For example, many CPX trailers cannot be adapted to enable measuring with a tyre of a different dimension, such as a truck tyre. With a slight modification of the mounting system, the on-board approach could readily accommodate any vehicle load/tyre type to be investigated. However, as expressed above, there are several extra constraints regarding the host vehicle that must be observed when the on-board method is selected. Also, a greater vulnerability to noise from adjacent traffic and possible acoustic reflections must be taken into account.

2.4 Conclusion on methods

An enclosed noise trailer built and used in accordance with ISO 11819-2 is recommended as a reliable measuring method that complies with an international standard.

This research project needed to follow an international standard as far as practicable. The conclusion was to use the on-board approach for sound pressure measurements and consult ISO 11819-2 for guidance on the setup and method.

3 Research project measuring method

3.1 Equipment and methodology

3.1.1 Equipment

Figure 3.1 shows the frame and microphones essential to the research project measurement method. Appendix A provides detail of the equipment setup including notes on the requirements of ISO 11819-2.

Figure 3.1 Mounting of microphones for close- proximity measurements

A frame was manufactured to mount directly onto the hub of the rear passenger-side wheel of the test vehicle. The mounting plate was machined to match the hub of the test vehicle.

The frame held two half-inch free-field microphones, each 200 mm away from the wall of the tyre. The microphones were spaced 400 mm from each other, centred on the hub of the wheel, so one microphone was in front and the other microphone behind the tyre/road contact patch.

The frame allowed vertical adjustment of the microphones and was set so the microphones were 100 mm above the road surface (measured with the correct tyre pressure and vehicle loaded ready for measuring).

The tyre on the test wheel was selected following ISO 11819-2. For measurements representing passenger cars, ISO 11819-2 requires a special tyre called the standard reference test tyre (SRTT), with properties and dimensions as per ASTM F2493. Figure 3.2 shows the tread pattern of the SRTT for a tyre in new condition.

Figure 3.2 Tread pattern of the standard reference test tyre

The SRTT is specifically sized with nominal section width of 225 mm, aspect ratio 60 percent (meaning a tyre undeflected sidewall height of 135 mm) and to fit a wheel diameter of 16 inches. The total diameter of the tyre is 676 mm. This tyre size is atypical of the tyres predominant on New Zealand passenger cars, and cannot be fitted to the vast majority of the fleet. A test vehicle was sourced specifically to fit the SRTT, with a 2008 Holden VE Commodore Omega sedan meeting requirements.

This relatively large passenger car contributed a higher tyre loading than provided for by ISO/TC 11819-2 (4,600 N vs 3,200 N), but was run at the designated pressure (200 kPa cold, nitrogen), which would have caused a higher deflection in the tyre than anticipated by the standard. To understand the implications for the accuracy of the CPX measurements, a short study was undertaken to quantify the influence of tyre inflation, and by extension, tyre deflection, on the measured CPX sound pressure levels (appendix D). The results indicated that no strong relationship existed between tyre inflation pressure and measured CPX sound pressure level, within the statistical power of the study, for this vehicle on a sample section of OGPA. The higher loading was accepted as an unfortunate consequence of the on-board CPX method (in New Zealand at least), and a source of some error, but was not likely to contribute a significant or invalidating level of bias to the outcomes of the research.

3.1.2 Data collection, undertaking measurements

Road sections were selected for measurement and each drive over the road section was used as a measurement run. The driver maintained the test vehicle in the leftmost lane travelling with the passenger side wheels in the left-hand wheel path and steady at the intended test speed of 80 km/h (unless noted otherwise). The driver used cruise control during the measurement runs to assist in maintaining the steady and correct vehicle speed. Prior to commencing the measurements, the accuracy of the car speedometer was verified via the Police Calibration Services (± 1 km/h at 80 km/h) and the precision of the cruise control was also tested and did not contribute significant error. ISO 11819-2, section 10.7.2 applies a ± 15 % tolerance to the target reference speed, corresponding to a speed range of ± 12 km/h, which the chosen method was comfortably able to meet.

During each run the GPS position was acquired at a rate of five readings per second, and this data was used to calculate the actual speed of the vehicle during post-processing, facilitating the speed correction required by section 11.1 of the standard. Where the GPS-derived speed differed from the target speed by more than 3 km/h the affected measurements were discarded.

Three repeat measurement runs were undertaken for each road section. During and after each measurement run, the driver and passenger noted any disturbances or events that might affect results and a measurement run was repeated if considered necessary.

At intervals, the outdoor air temperature was manually noted via a sensor mounted on the outside of the car near the rear passenger wheel, approximately one metre above the ground.

3.1.3 Data logging and processing

During measurement runs, the GPS position of the test vehicle was logged at a rate of 5 Hz and the output of each microphone was recorded at a sampling rate of 20,000 Hz. Data was subsequently processed within the mathematical analysis software package, Matlab, and the spreadsheet software, MS Excel.

GPS positions were converted to state highway route positions[2] for matching with the route positions of the road sections identified for measurement. To allow for potential latency of the GPS-acquired positions, a short 'lag' was allowed for at the start and end of each road section and only sound levels obtained within the slightly abridged length were used for sound level calculations for that road section. The uncertainty in car speed associated with this method was estimated to be ± 0.7 km/h, or approximately 1 % of the 80 km/h target speed.

Prior to analysis, the sound samples were filtered into third-octave frequency bands from 315 Hz to 5,000 Hz.

For analysis, sound pressure levels were computed for 20-metre road segments. For the selected test vehicle speed of 80 km/h (or 22.2 m/s), and using the sampling rate of 20 kHz, 18,000 samples were obtained (per microphone) during 20 metres of test vehicle travel, corresponding to 0.9 seconds of elapsed time. Measured sound pressure levels from the front microphone were averaged with the levels from the rear microphone to produce the combined sound pressure levels at each third-octave band and the overall A-weighted sound pressure level.

An example output file is shown as figure 3.3.

Figure 3.3 Example output file

Folder:	**005 SH16NboundRun3 100930**
Files:	**RNOISE2 D25-07-15 T10-09-30.TXT**

Combined MicFront and MicRear microphones

Seg.	Frequency Hz													Overall dB(A)
	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	
1	72.0	78.7	82.8	89.3	92.4	90.6	88.2	84.4	82.7	81.0	79.2	75.8	73.8	97.3
2	72.6	79.5	83.6	88.4	92.0	90.6	88.6	84.7	82.6	80.8	79.2	75.8	74.0	97.2
3	71.4	77.7	83.1	87.5	91.5	89.5	87.8	84.7	84.0	82.1	79.7	75.9	74.5	96.6
4	72.3	79.1	84.2	89.0	92.7	90.7	88.0	84.1	82.8	81.2	79.5	76.1	74.1	97.5
5	72.1	78.9	84.0	89.0	93.2	91.2	87.8	83.7	82.9	81.4	79.5	75.4	73.4	97.7
6	73.4	79.6	84.7	89.3	92.7	91.3	88.3	83.9	82.5	81.5	80.1	76.1	73.7	97.7
7	71.7	78.0	83.4	88.5	93.1	91.5	87.9	83.5	82.9	81.3	79.6	75.6	73.8	97.6
8	73.2	79.7	84.0	89.5	93.4	92.0	88.7	83.4	82.2	81.1	79.8	76.1	74.1	98.1
9	72.5	78.9	83.8	89.5	92.8	91.3	88.6	84.2	82.6	81.3	80.0	76.3	74.5	97.7
10	72.7	80.4	84.5	89.0	93.4	91.0	88.9	84.7	83.5	81.7	79.3	76.0	74.6	98.0
11	72.6	79.1	83.9	88.6	92.3	90.5	87.5	84.3	83.6	82.0	79.1	75.4	74.5	97.2
12	72.3	78.6	84.0	89.0	93.0	91.0	86.9	82.8	81.8	80.8	79.3	75.0	73.1	97.4
13	71.6	78.3	83.8	88.7	93.6	91.2	86.4	83.2	82.0	80.3	78.0	74.0	72.7	97.5

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[2] Via mobileroad.org

Each 20-metre segment was matched to its determined state highway route position. If the state highway route position corresponded to a road surface section identified for measurement (and the 20-metre measurement was acceptable in terms of test vehicle speed and other parameters) further calculations were performed on the data for that 20-metre segment.

Following ISO 11819-2, the median overall sound level for the section was calculated from all 20-metre segments measured within a selected road surface section. Any 20-metre segment with an overall sound level outside the median ±1.5 dB(A) was discarded, following the ISO 11819-2 comment that it is assumed any such measurement of a segment 'shall be considered as having been disturbed'.

Three measurement runs were made on each remaining test road section and the results from the measurement runs were averaged to obtain the average overall sound level for each section. The average overall sound level calculated for each test road section of the research project sample are used in chapter 4, in discussing and comparing the results.

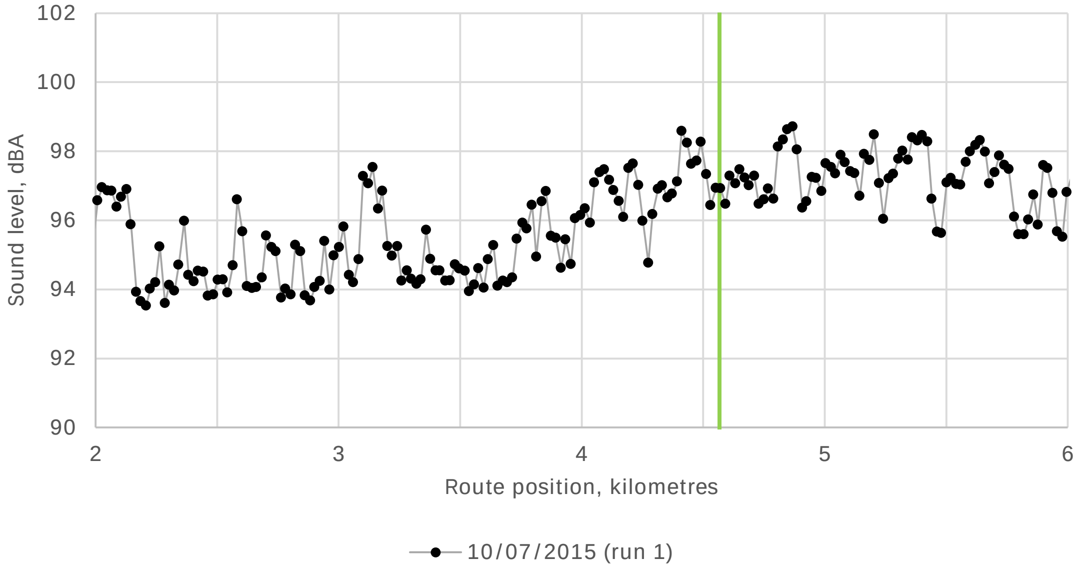
3.2 Commissioning the measurement method

A series of measurements were undertaken to understand and establish reliability of the research project measurement method.

3.2.1 Repeatability

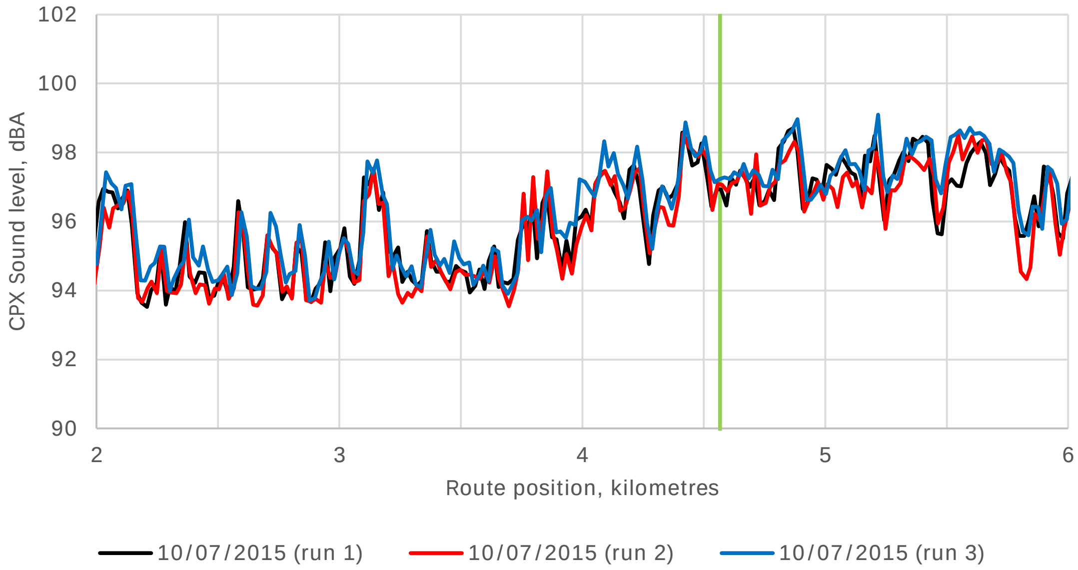
Figure 3.4 is constructed by plotting the overall sound level for each 20-metre segment obtained consecutively during a measurement run (the vertical green line represents a change in surface age, discussed later). The longitudinal variability within a single measurement run is immediately noted. The literature confirmed that this type of variability is not unexpected. See figure 2 in ISO 11819-2 (2012 draft), table 10 in Hanson et al (2004), figure 4 in Bueno et al (2014) and figure 4 in Pugh et al (2008).

Figure 3.4 Example longitudinal record of overall sound levels measured for 20- metre segments (OGPA)



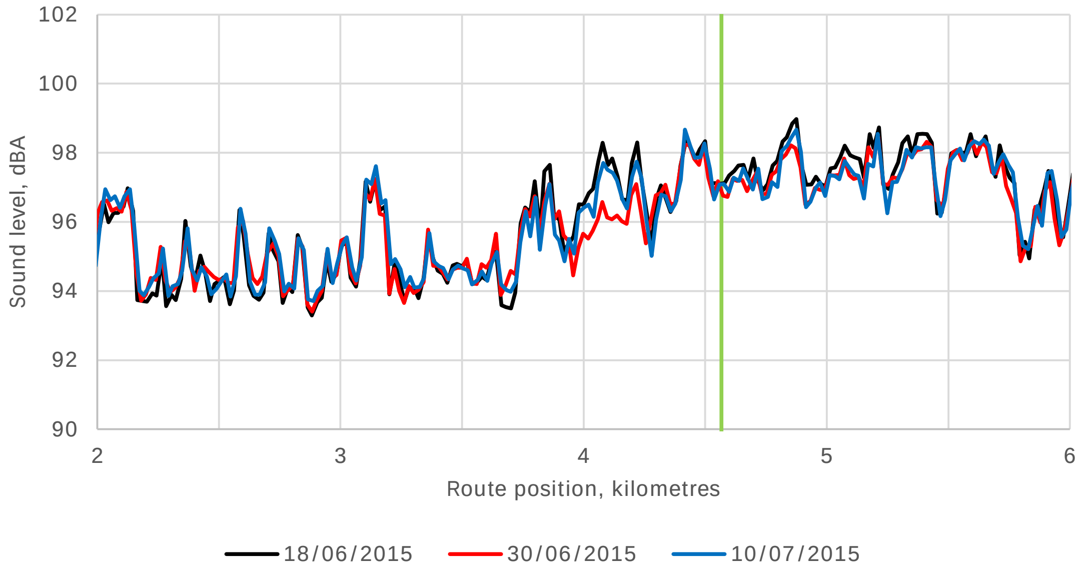
The research project conducted three measurement runs on each test road section. Figure 3.5 represents the same road section as for figure 3.4 but shows three measurement runs conducted on the same day (with an ambient temperature range of 2 °C). For the research project, the overall sound level for a test road section was an average calculated using three such measurement runs.

Figure 3.5 **Example of three longitudinal records of overall sound levels measured for 20- metre segments**



For commissioning and understanding of the research project measuring method, two further sets of three measurement runs were undertaken on the same road section as figures 3.4 and 3.5. The blue line in figure 3.6 shows the 'average record' calculated from the three measurement runs shown in figure 3.5 and also shows the average record calculated from three measurement runs undertaken on each of two other days.

Figure 3.6 **Example of three average records of overall sound levels measured for 20- metre segments**



Figures 3.5 and 3.6 show the extent of variability and particular aspects are found largely replicated in other repeat measurement runs over the same section within the same day and over separate days. Although the microphones are mounted in an 'open' position, if exposure to wind, engine noise and other extraneous noise sources were dominant, the observed replication would not occur and the 'shape' of repeat measurement runs would be inconsistent.

On figures 3.4 to 3.6, the green vertical line at route position 4.567 kilometres indicates a transition between two road sections. The road section leading to route position 4.567, left of the green line, is OGPA laid on 22 April 2015 and the calculated overall sound pressure level is 95.3 dB(A). The following road section, right of the green line, is OGPA laid less than two weeks later on 1 May 2015 and the calculated overall sound pressure level is 97.1 dB(A). It appears these two OGPA sections are different even though laid at approximately the same time and under the same contract. This feature was not investigated in this research project; however, it was noted and it highlighted that only repeat measurements over time of the same road section would track how that road section aged. Using the research project method, measurements were made of aged OGPA sections without any information on the initial acoustic performance.

3.2.2 Distinction between road surface types

Having verified that the research project method could produce stable results, commissioning included verification that the research project method could distinguish between road surface types.

Three road sections with different surfaces and with a speed limit of greater than or equal to the test speed (80 km/h) were located and measured. The road surface types were:

- a cape seal (CS) laid in February 2013[3]
- a two-coat (grade 2/4) chipseal laid in March 2009
- an OGPA surface laid in January/February 2008.

The average sound spectra obtained from each road surface measured is shown in figure 3.7. The research project measurement method clearly distinguishes between the three different road surface types.

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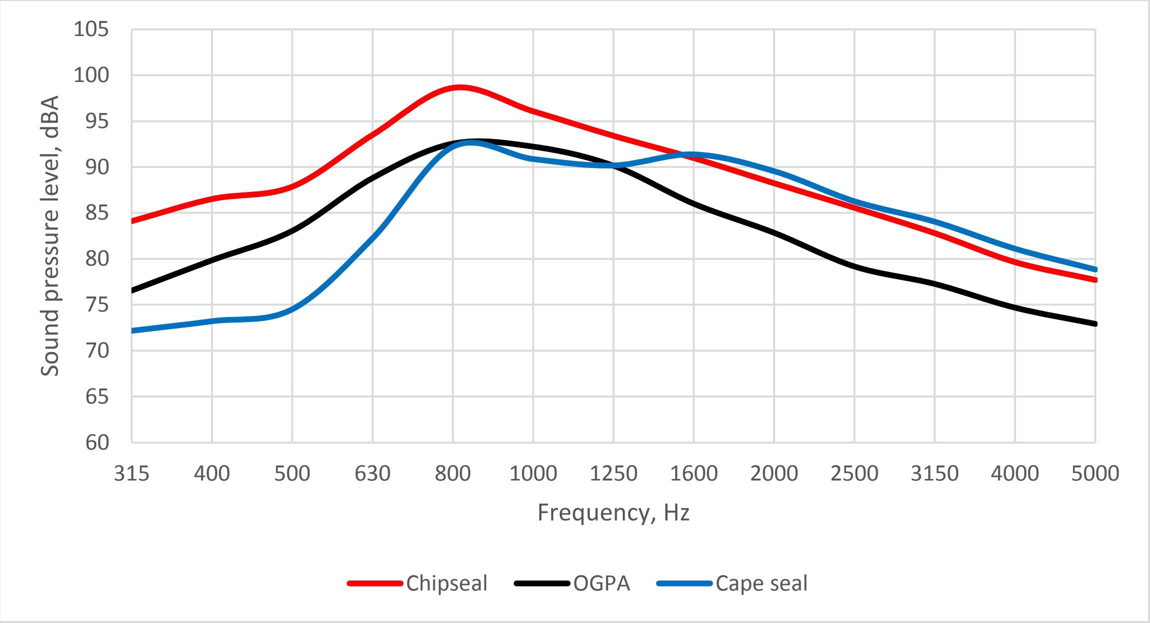
[3] Ideally a ‘pure’ dense graded asphaltic concrete (AC-10) road surface would have been located as this road surface type is used in New Zealand as the ‘reference acoustic performance’ to which other road surfaces are compared. However, there is very little AC-10 laid where traffic speeds are 80 km/h or greater. A cape seal was the best match available. A cape seal is made with a chipseal layer covered with a slurry layer to fill the texture of the chipseal. In this case, the chipseal layer used grade 4 sized chips and the slurry layer used mix DG10 with nominal size 10 mm. At least visually, the final top road surface appears very similar to a pure AC-10 asphaltic concrete.

Figure 3.7 Average sound spectra from three road surface types (as measured with the SRTT)



Note that this investigation was only for the purpose of commissioning the research project measurement method and so it was not an extensive investigation and was not intended to ‘characterise’ the relative acoustic performance of the road surface types. However, the measurements for just one example of each road surface tyre gave a sound level on the OGPA road surface that was 0.6 dB less than the CS road surface, and a sound level on the two-coat (grade 2/4) chipseal road surface that was 4.3 dB greater than the CS road surface (section 3.2.3 discusses this further).

3.2.3 Effect of tyre type

Section 3.1.1 stated the research project measurement method used a SRTT on the wheel to which the microphones were mounted. Figure 3.2 shows the tread pattern of the SRTT. Though the New Zealand fleet of passenger cars is fitted with a variety of tyres, the SRTT appears substantially different in terms of tread pattern and dimensions. The SRTT is 225 mm wide and 676 mm diameter whereas passenger car tyres in New Zealand are predominantly 195 to 205 mm wide and 615 to 648 mm diameter on newer passenger cars or 175 mm wide and 575 to 583 mm diameter on older passenger cars (Prebble 2014).

There is considerable literature and discussion on the effect of tyre type on the generated tyre/road noise, which was outside the scope of this research project. However, for the three road sections measured for section 3.2.2 using the SRTT, the measurements were repeated using a ‘regular’ road tyre. The size of this tyre matched the SRTT (225/60 R16). Figure 3.8 shows the tread pattern on the ‘regular’ tyre in its worn condition (3 mm tread depth) as used for the set of measurements reported here. ISO 11819-2 notes tyres with worn treads may be relatively ‘quiet’ on smooth surfaces and relatively ‘noisy’ on rough-textured surfaces.

Figure 3.8 Tread pattern of the 'regular' tyre

The OGPA section measured for section 3.2.2 was located immediately adjacent to the two-coat (grade 2/4) chipseal section. Figure 3.9 shows two longitudinal records from the consecutive road sections, with the solid line for measurements with the SRTT and the other broken line for measurements with the regular tyre. (A short section of the records is omitted around route position 11.3 km at the transition between the two road surface types.) Figure 3.10 shows corresponding average sound spectra.

Figure 3.9 Longitudinal records of sound levels from two road surface types as measured with two tyre types (overall A- weighted level given in parentheses in legend)

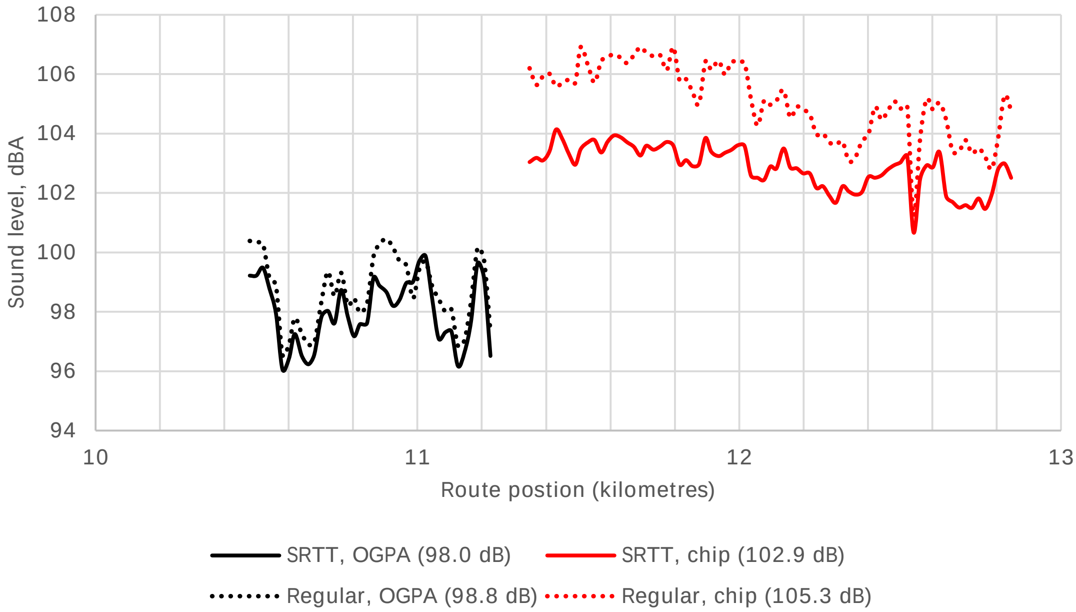


Figure 3.10 Average sound spectra from three road surfaces types as measured with two tyre types[4]

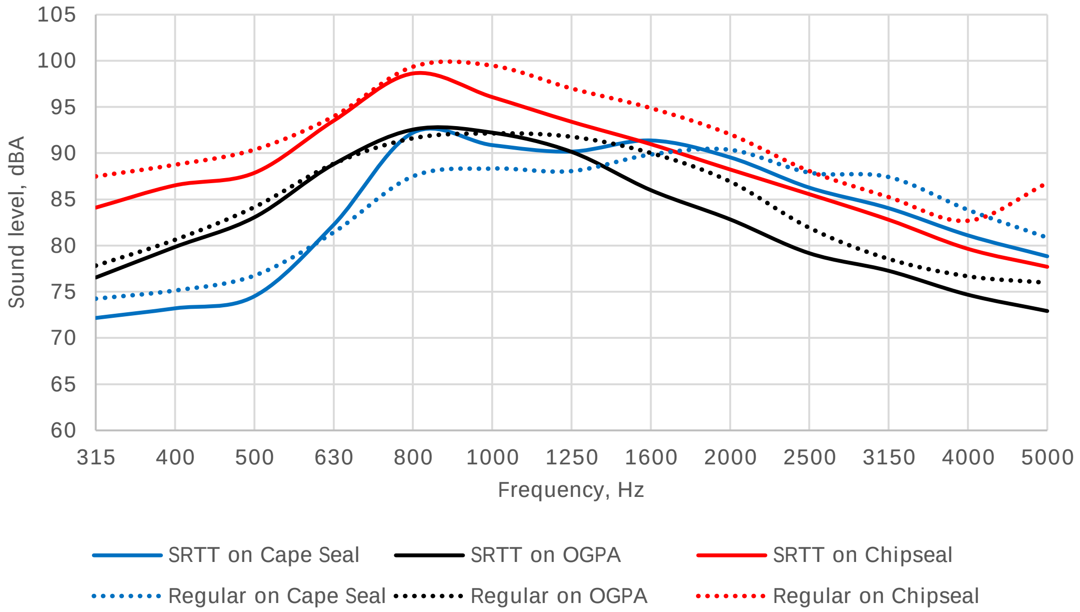


Figure 3.10 shows the relative acoustic performance of the three road surface types as measured with the two tyre types. Table 3.1 provides a summary but it is noted that the measurements are from just one example of each of the three road surfaces so should not be taken as characteristic of the tyre/road acoustic performance.

Table 3.1 Summary of relative tyre/road acoustic performance. Levels are A- weighted

	Measured example, dB		**Guide to state highway road surface noise**
	SRTT	**Regular tyre**	**Adjustment for cars, dB, relative to AC**
Two-coat (grade 2/4) chipseal	102.9	105.3	+6
Cape seal	98.6	97.6	≈ +2
OGPA (PA-10)	98.0	98.8	0
∆ OGPA to chipseal	4.9	6.5	6.0

The ‘measured example’ columns of table 3.1 show the acoustic performance measured from one example of each of the three road surface types. The measurements with the SRTT rank the tyre/road noise level on cape seal greater than the tyre/road noise level on OGPA, whereas the measurements with the regular tyre rank the OGPA tyre/road noise level greater than the cape seal tyre/road noise level.

The rightmost column of table 3.1 contains reference road surface adjustments as provided in NZ Transport Agency (2014). The road surface adjustments are expressed in decibels relative to the acoustic performance of AC-10. The guide includes three grades of cape seal but none to match the surface measured in this study and the guide also notes the adjustments are indicative only, due to the data

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[4] Figure 3.10 indicates a sudden rise at 5,000 Hz in the measurement of the chipseal road surface with the regular tyre. This feature was not present in the measurement of the OGPA road surface immediately prior to the measurement of this chipseal road surface and this sudden rise was also observed in measurements of other chipseal road surfaces with the regular tyre and so is not disregarded here as an error.

coming from a small sample. The bottom row of table 3.1 shows the size of the difference between the OGPA acoustic performance and chipseal acoustic performance. For the measurements with the SRTT the range is 4.9 dB, whereas the range from measurements with the regular tyre is 6.5 dB, which is closer to the 6.0 dB range from the road surface adjustments in the guide.

In the CPX standard, in J.3 of annex J, referencing Sandberg et al (2009), it is recognised worn tyres are more sensitive to the surface macrotexture than tyres in a new condition. Therefore, since tyres in actual traffic flow are a mix of new and worn tyres, it would also be desirable to use a worn tyre to classify road surface acoustic properties. However, it is currently not possible to define the grade of wear on a tyre, and consequently no reproducible tyre is available for this purpose. Figures 3.9 and 3.10 illustrate the shortcomings of the method.

These differences were not significant for this research project. However, they are noted as a potential area of future investigation where a worn tyre with reproducible and defined features is used in addition to the SRTT.

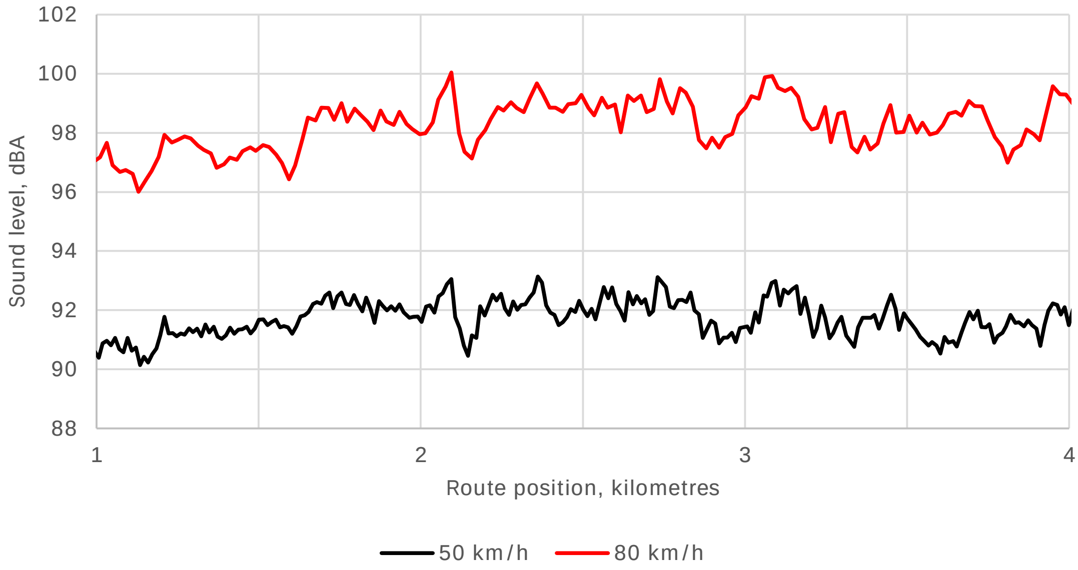
Coinciding with the time of writing this report, ISO published a draft technical specification ISO/DTS 11819-3, which specifies two reference tyres for the CPX method. This is expected to be published by ISO as ISO/TS 11819-3 in January or February 2017. Naturally, as the specification did not exist when the project was planned and when the measurements were conducted, it could not be taken into account. However, in all essential ways, the SRTT tyre used in this project meets the requirements of the tyre designated P1 in ISO/DTS 11819-3.

3.2.4 Effect of test vehicle speed

For one length of road with multiple consecutive OGPA sections, measurement runs were made at the test speed of 80 km/h for the research project dataset, and also for information measurement runs were made at the speed of 50 km/h. Section 3.1.2 described the algorithm for processing the logged data into results for 20-metre segments, which was developed based on a test speed of 80 km/h. Using the same algorithm but with data logged with a speed of 50 km/h, the results were for 12.5-metre segments. The comparison between test speeds was for information only so the algorithm was not adjusted and different segment lengths were accepted.

Figure 3.5 shows the data obtained for a road section from three measurement runs using a test speed of 80 km/h. In figure 3.11 the data is paired with data obtained for the road section from three measurement runs using a speed of 50 km/h.

Figure 3.11 Longitudinal records of total sound levels measured with two test speeds (80 km/h and 50 km/h)



Acknowledging the different segment length for each speed (20 metres for 80 km/h and 12.5 metres for 50 km/h), the shape of the longitudinal variability is seen to be similar for the two speeds, except the peak-to-trough variation is slightly smaller at 50 km/h than at 80 km/h (1.4 vs 2.0 dB(A)). This may be an indication that there is unwanted external noise that increases the lower levels at 50 km/h or that the noise generation mechanisms differ in some respects between the speeds.

Within the subject road section, five OGPA sections were identified for study. Table 3.2 summarises the average median sound levels calculated for the OGPA sections for 80 km/h and 50 km/h,

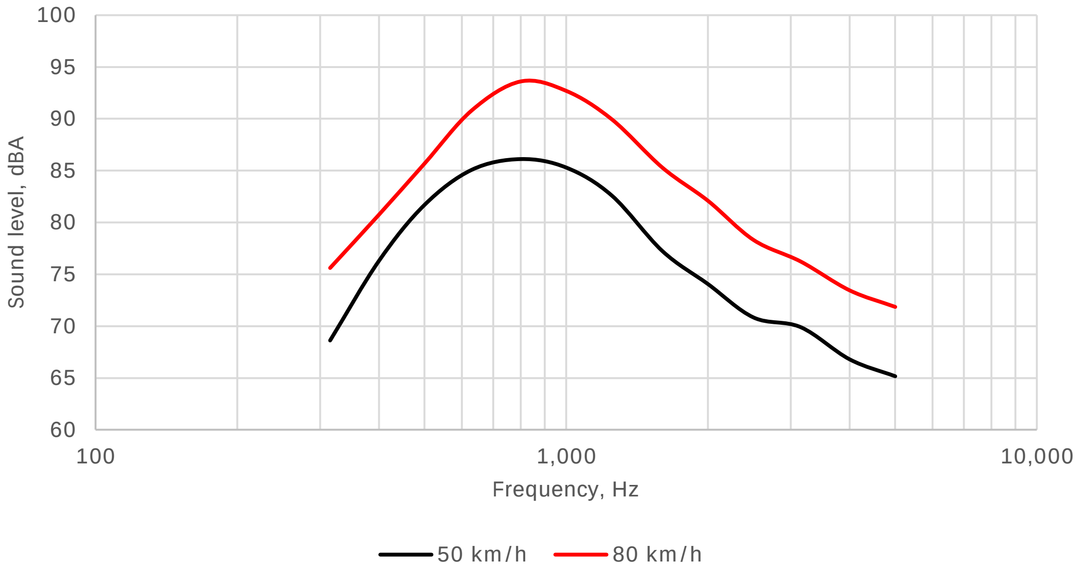
Table 3.2 Average overall sound level, dB(A), from measurement runs at different test speeds

OGPA section	Average overall sound level, dB		Change in average overall sound level, dB
	80 km/h	50 km/h	
1	99.7	93.0	6.7
2	99.0	92.6	6.4
3	98.2	92.1	6.1
4	97.9	91.7	6.2
5	98.8	91.9	6.8
	Average change		6.5

Using table 3.2 to compare each pair of OGPA sections, the overall sound level obtained using an 80 km/h test speed is on average 6.5 dB(A) greater than the overall sound level obtained using a 50 km/h test speed.

The average sound level difference varies across the frequency bands, being greatest around 800 Hz to 2,500 Hz, and least between 400 Hz and 630 Hz, as indicated in figure 3.12 for one sample OGPA section. Below 630 Hz is a common range for contribution of power unit noise from the vehicle, although it should be particularly evident in the 315 Hz band, which it is not. ISO 11819-2 states ‘wind noise manifests itself mainly at low frequencies’ and notes the effect particularly for non-enclosed systems, such as the research project measurement method. However, wind noise should be much more significant at 80 km/h than at 50 km/h, which is not observed in our measurements. It is therefore not clear whether the difference in spectra is a real speed effect of the tyre/road noise or an artefact of the measurement system, but it is noted that our results are broadly consistent with overseas experience that the spectra generally narrow with increasing speed, particularly in the lower frequencies (Sandberg and Ejsmont 2002, p47). Even so, the potential for power unit and wind noise contributions is one of the weaknesses of the CPX variant where a tyre on-board the driving vehicle is used instead of an enclosed trailer.

Figure 3.12 Average sound spectra from measurements with two test speeds (80 km/h and 50 km/h)



ISO 11819-2 suggests a speed correction calculated as –*B*.log($speed_1/speed_2$) where *B* is 25 dB/decade for a porous road surface in a new/unclogged condition or 30 dB/decade for a clogged porous road surface. Therefore, for the test speeds of 80 km/h and 50 km/h, depending on the extent of clogging, the standard estimates the overall sound level obtained using an 80 km/h test speed would be between about 5.1 dB(A) and 6.1 dB(A) greater than the overall sound level obtained using a 50 km/h test speed. ISO 11819-2 also notes 'the experience is that *B* varies over a range 20 to 40 depending on test tyre and pavement type'.

3.2.5 Temperature

Tyre/road noise is known to be affected by temperature. In general terms and within typical ambient or operating temperatures, the rubber compound of the tyre is more flexible when warmer, and stiffer when colder, making less tyre/road noise when warmer and greater tyre/road noise when colder. The temperature effect on tyre/road noise is different across the third-octave frequency bands but here temperature correction is considered only with regard to the overall sound level.

From related literature, it seems quantification of the temperature effect on tyre/road noise appears equivocal, including the factors that should be accounted for in determining the temperature correction to be applied. However, the relationship is generally represented as:

Sound level = Uncorrected sound level + Temp. coefficient (Temp. – Ref. Temp.)

Literature contains discussion about whether the most relevant temperature is that of the road surface, the ambient air, or the tyre. ISO 11819-2 uses the ambient air temperature and the reference temperature is taken as 20°C.

In the 2012 draft of ISO 11819-2 the temperature coefficient for the SRTT is given as 0.03 dB/°C with the note that this may be considered a conservative value. For the 'moderate and continental' climatic zone, the temperature range for measurements is 5 to 30 °C. Therefore, the upper limit on the magnitude of the temperature correction back to reference conditions would be 0.03 x (5 – 20) = -0.45 dB.

The development of the temperature coefficient was undertaken between the 2012 and 2015 drafts of ISO 11819-2. The 2015 draft refers to ISO/TS 11819-3[5] and ISO/TS 13471-1[6] for the temperature coefficient and notes the temperature effect may 'frequently amount to as much as 1 dB per 10 °C deviation in air temperature' and so 'substantial errors' may occur if no temperature correction is applied.

Coinciding with the time of writing this report, ISO published a draft technical specification ISO/DTS 13471-1, that specifies temperature corrections to noise levels measured with the two reference tyres for the CPX method specified in draft technical specification ISO/DTS 11819-3. This is expected to be published by ISO in final form as ISO/TS 13471-1 in March or April 2017. Naturally, as the specification did not exist when the project research was planned and when the measurements were conducted, this document could not be considered earlier in this project.

The temperature corrections originally presented in ISO/DTS 11819-3 have remained unchanged but have been moved to ISO/TS 13471-1. The reference temperature is 20 °C. For 'porous asphalt surfaces (not seriously clogged)' the temperature coefficient is $-0.08 + 0.0004v$ dB/°C and for non-concrete road surfaces or clogged porous asphalt surfaces the temperature coefficient is $-0.14 + 0.0006v$ dB/°C, where v is the test speed in km/h. Inclusion of the test speed as a factor reflects that the tyre rubber compound response also depends on the stresses and stress frequency experienced. Following ISO/TS 13471-1, for the research project measurement method test speed of 80 km/h, the temperature coefficient is -0.048 dB/°C for 'not seriously clogged' porous asphalt surfaces and -0.092 dB/°C for other road surfaces. ISO 13471-1 states the temperature correction procedures are for air temperatures between 5 °C and 35 °C. Using that range, the maximum magnitude of the temperature correction would be 0.72 dB for 'not seriously clogged' porous asphalt surfaces and 1.38 dB for other road surfaces.

Section 2.1.1 mentions the AASHTO standard TP-76 for the on-board sound intensity method for measuring tyre/road noise. This standard also uses a reference temperature of 20 °C. The temperature coefficient is 0.072 dB/°C. TP-76 limits testing to an ambient air temperature range of 4 to 38 °C, corresponding to a maximum temperature correction magnitude of 1.30 dB. Because this is a sound intensity-based method, there is some doubt over whether it is an appropriate correction for a sound pressure-based method.

Table 3.3 summarises the overall sound level from such measurements and then demonstrates the effect of applying various temperature coefficients. The coefficients have a mixture of signs, reflecting the lack of consensus on whether noise increases or decreases with increasing temperature.

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[5] ISO/TS 11819-3 (2016 draft) This was not publicly available at the time of conducting the measurements in this project, and is expected to be published in March or April 2017.

[6] ISO/TS 13471-1 (2016 draft) This was not publicly available at the time of conducting the measurements in this project, and is expected to be published in March or April 2017.

Table 3.3 Investigation of temperature correction

OGPA section	Temperature range of measurements (˚C)		OGPA section overall sound level, dB(A)							
			No temperature correction		2012 draft ISO 11819-2 (0.03 dB/˚C)		ISO 11819-3 and ISO 13471-1 (-0.048 dB/˚C)		AASHTO (0.072 dB/˚C)	
	Max.	Min.	μ	σ	μ	σ	μ	σ	μ	σ
1	15.0	12.1	96.6	0.28	96.4	0.28	96.9	0.27	96.2	0.30
2	15.0	12.1	96.6	0.20	96.4	0.22	96.9	0.19	96.1	0.24
3	15.0	12.1	97.7	0.19	97.6	0.20	98.0	0.17	97.3	0.22
4	15.0	12.1	97.3	0.08	97.1	0.11	97.6	0.05	96.9	0.14
5	15.0	13.0	96.0	0.23	95.9	0.23	96.3	0.22	95.6	0.25
6	15.0	13.0	95.3	0.19	95.1	0.19	95.5	0.19	94.9	0.19
7	15.0	13.0	97.1	0.18	96.9	0.19	97.4	0.18	96.7	0.20
8	17.8	11.8	97.2	0.37	97.0	0.38	97.4	0.36	96.8	0.42
9	17.8	11.8	96.7	0.14	96.6	0.16	96.9	0.14	96.4	0.21
10	17.8	11.8	97.5	0.21	97.4	0.25	97.8	0.15	97.2	0.32
11	17.8	11.8	98.2	0.19	98.1	0.23	98.4	0.14	97.9	0.30
12	18.6	14.7	97.8	0.34	97.7	0.36	98.0	0.32	97.6	0.39
13	17.2	14.7	98.2	0.49	98.0	0.49	98.3	0.49	97.9	0.50
14	18.6	14.7	96.8	0.20	96.7	0.19	97.0	0.24	96.5	0.17
15	18.6	14.7	97.5	0.14	97.4	0.15	97.7	0.14	97.2	0.18
16	18.6	14.7	97.8	0.20	97.6	0.21	97.9	0.20	97.5	0.23
17	18.6	14.7	97.8	0.27	97.7	0.28	97.9	0.25	97.5	0.31
Root mean variance				**0.25**		**0.26**		**0.24**		**0.28**

- The first column lists the OGPA sections measured multiple times and the next two columns show the maximum and minimum temperatures of measurement runs for those OGPA sections.
- Sound pressure levels in the remaining columns of the table are expressed in dB(A). The average and standard deviation are calculated from the set of overall sound levels measured for the OGPA section.
- The overall sound levels are as measured with no temperature correction applied, then with temperature corrections calculated using three different temperature coefficients.
- The bottom row on the table is the sum of the standard deviations for the OGPA sections for an impression of the combined effect of the temperature correction on the set of 17 OGPA sections.

For the research project, a set of OGPA sections were measured multiple times (two to four) on each of multiple (two to three) days which were of different temperatures ranging from 11.8 °C to 18.6 °C. This fairly narrow range of measurement temperatures close to the reference temperature would ordinarily be beneficial to the study of tyre/road noise as it minimises the uncertainty contributed by temperature effects and correction. However, for an analysis of temperature corrections it is of limited value, since when temperatures differ by only a few degrees the uncertainties in measurements become similar to or higher than the (assumed) true temperature effects. Ideally a data set encompassing a temperature range of 15 °C or more would be employed, but this has not been possible to attain.

Another issue is that it is uncertain how porous the OGPA test sections are. For porous surfaces there is typically a dip in the frequency response in the range 630 Hz – 1,000 Hz, which is caused by sound absorption. There is no strong evidence of a dip in the measured spectra, which may indicate that the road surface is clogged, or more likely, had a negligible porosity from the beginning. As discussed, the surface characteristics determine the coefficient to be used in the calculation of the temperature correction, and therefore the magnitude of the correction itself, with an influence of approximately a factor of 2.

None-the-less, an attempt was made to derivate a temperature correction coefficient from this set of 17 OGPA-paved road sections. Using a least squares approach (on the standard deviation from each section, eight passes per section), the optimal temperature coefficient was computed to be -0.049 dB/°C, applicable to the range 12 ºC to 19 ºC. This is strikingly similar to the value of -0.048 dB/°C put forward by ISO/TC 11819-3 and ISO/TC 13471-1 for porous asphalt, although our research tested a reduced temperature range compared with the standards. This is encouraging, as the international standards are expected to receive more usage in New Zealand than the equivalent American standard.

The researchers chose a temperature coefficient of zero for the sound pressure levels. The justification for this decision came from the high amount of uncertainty about which temperature coefficient value to employ, specifically:

1. Until the international standards are confirmed and published, the range of possible coefficients (-0.048 to +0.072) provided by the three available sources is large and contradictory with respect to the physical effects of temperature.
2. There was uncertainty surrounding the amount of porosity of the OGPA surfaces measured in this study, which can have an effect on the value of the temperature coefficient of up to a factor of 2.
3. The brief temperature study conducted within this project was consistent with ISO/TC 11819-3 and ISO/TC 13471-1, but over a very limited temperature range, and included no measurements above the reference temperature, in contrast with the measurements made for the main part of the research project.
4. The temperature coefficients in the literature continued to develop over the course of the study, so committing to one value of the correction posed a risk of invalidating earlier data analysis.
5. The range of temperatures experienced during the main part of the research was relatively modest, ranging from 9 ºC to 24 ºC, or a maximum ISO/TC 13471-1 correction of about 0.5 dB. The project team considered the risk of applying an erroneous temperature correction or porosity multiplier outweighed the potential benefits.

3.2.6 Wayside vs on-board

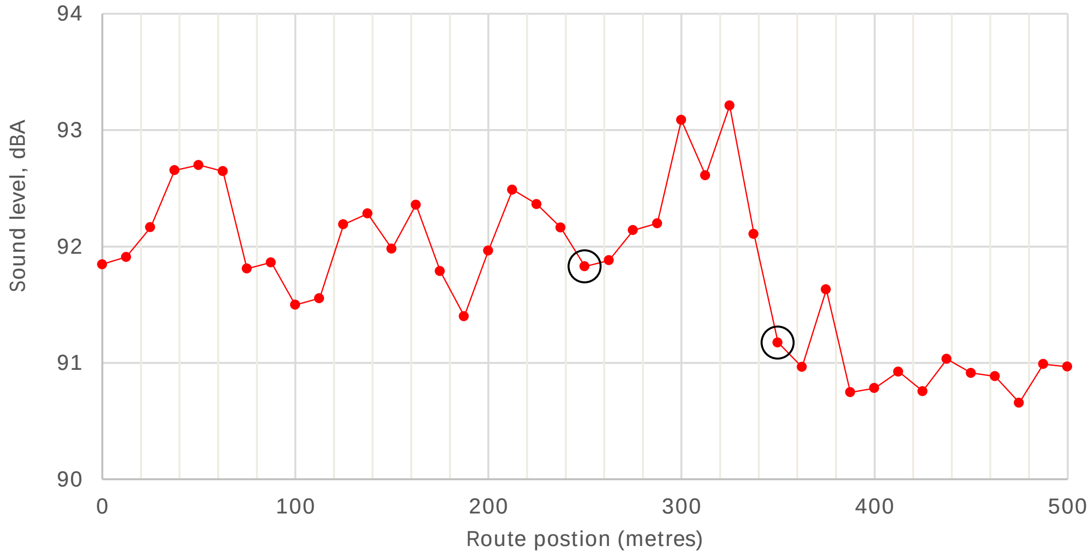
The data processing algorithm for the research project's on-board sound measurements was set up to average measurements over 20-metre segments using a test speed of 80 km/h, which is equivalent to averaging measurements over 0.9 seconds. Thus, each on-board measurement point represents 0.9 seconds of vehicle travel.

Wayside sound measurements used to characterise road surface noise performance often report the A-weighted sound level averaged over one second of measurement centred on the subject vehicle passing directly by the sound level meter, or (in ISO 11819-1) the maximum A-weighted sound level during the passage with a time constant 'F' corresponding to 0.125 s.

An experiment was set up to investigate if any of the longitudinal variability in road surface acoustic performance revealed by on-board measurements was detectable in wayside sound measurements.

While the research project test speed is generally 80 km/h, for practicability the experiment was undertaken using a test speed of 50 km/h. As noted in section 3.2.4, the research project measuring method algorithm for processing the logged data into results for 20-metre segments was developed for a test speed of 80 km/h. The same algorithm was used for this experiment but with a 50 km/h test speed so the results were calculated for 12.5-metre segments. A straight and level section of road with wide roadside verges was chosen as the location for the experiment. The road surface was asphaltic but not OGPA.[7] On-board measurements were taken along the section to identify longitudinal variability. The results are shown in figure 3.13.

Figure 3.13 Longitudinal record of overall sound levels measured at 50 km/h for 12.5- metre segments. Circles show locations of wayside measurements.



Two route positions were selected by considering where the on-board measurements were indicating contrasting sound levels but there was no visible road surface feature to which the contrasting sound level could be attributed and also where wayside measurements would be practicable. The route positions are indicated by the black circles on figure 3.13 at route positions 250 and 350 metres.

A sound level meter was set up wayside at each of the two route positions, targeting 1.3 metres above the left-hand wheel path and five metres lateral displacement from the same path. The clocks on the two wayside sound level meters and the clock of the on-board measurement system were synchronised to within one second accuracy. The wayside sound level meters were set continuously recording while the test vehicle repeated six on-board CPX measurement runs along the road past the wayside sound level meters. The wayside sound level meter results were inspected to determine the one second continuous equivalent sound pressure level (Leq) during each test vehicle pass and the on-board measurements were inspected to determine the 0.9 second Leq corresponding with each test vehicle pass by the wayside sound level meters.[8] The results are shown in table 3.4.

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[7] Port Road, Lower Hutt, with a speed limit of 50 km/h and an asphaltic concrete road surface laid in 2002. The experiment was conducted over two days, with initial on-board measurements on 17 May 2016 and synchronised wayside/on-board measurements on 27 May 2016.

[8] The research project on-board measurement system was not specifically designed for this purpose and the processing of results into 0.9 second segments (12.5 metres at 50 km/h) is automated so would not have consistently aligned with passing the wayside sound level meters. This is likely to have contributed to the variability seen in the set of on-board noise measurements.

Table 3.4 Comparison of overall sound levels measured wayside and on-board

	250 metres route position		350 metres route position		Difference between route positions	
	Wayside, dB(A) $L_{eq(1.0s)}$	On-board, dB(A) $L_{eq(0.9s)}$	Wayside, dB(A) $L_{eq(1.0s)}$	On-board, dB(A) $L_{eq(0.9s)}$	Wayside, dB(A) $L_{eq(1.0s)}$	On-board, dB(A) $L_{eq(0.9s)}$
Run 1	73.4	92.3	73.6	91.8	0.2	-0.5
Run 2	73.2	93.3	73.7	91.7	0.5	-1.6
Run 3	73.2	91.6	73.5	90.9	0.3	-0.7
Run 4	72.6	92.2	73.2	91.2	0.6	-1.0
Run 5	73.3	92.4	73.3	90.9	0.0	-1.4
Run 6	73.3	92.1	73.1	91.7	-0.2	-0.4
Average	**73.2**	**92.3**	**73.4**	**91.4**	**0.2**	**-0.9**

For the 250 metres route position, on average the on-board measurement is 19.1 dB(A) greater than the wayside measurement. For the 350 metres route position, on average the on-board measurement is 18.0 dB(A) greater than the wayside measurement. This indicates the offsets between wayside sound level meters and the test vehicle's left-hand wheel path were slightly different at each route position. This is noted but not considered to affect the observation that the wayside measurements show the one-second Leq sound level at the 350 metres route position is 0.2 dB(A) greater than the one-second Leq sound level at the 250 metres route position whereas from the on-board measurements show that the 0.9-second Leq sound level at the 350 metres route position is 0.9 dB(A) greater than the 0.9-second Leq sound level at the 250 metres route position.

The on-board measurements clearly show greater distinction between the two route positions. There are many studies comparing wayside measurements and on-board measurements but such comparisons were not the focus of this research project. However, undertaking this investigation reinforced some of the concepts discussed in section 2.2.1 where wayside and close-proximity measurements were compared. Wayside measurements receive a wider angle and range of inputs, including the tyre/road noise from the front wheel fitted with a 'regular' tyre as in this research, than the standard reference test tyre fitted on the rear wheel. On-board microphones are subject to wind noise due to the movement of the test vehicle and are in a 'near field' position but these factors have greatest effect on the lowest frequencies which are suppressed by the A-weighting. The tyre/road noise measured on-board has a very short transmission distance compared with wayside noise which has approximately a five-metre transmission distance to the sound level meter.

4 Tyre/road noise measurements and results

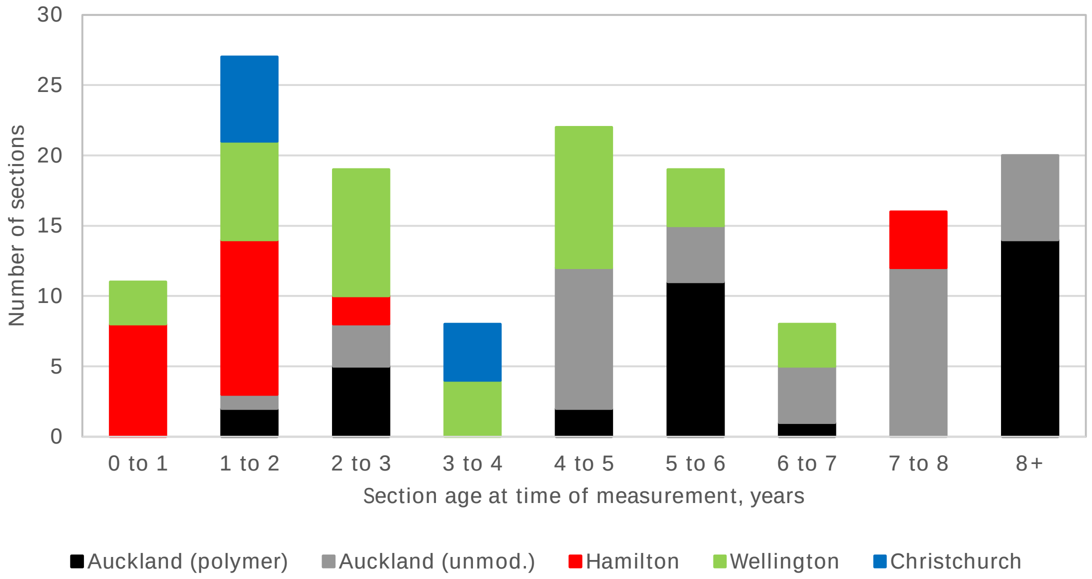
4.1 Sample

The New Zealand Road Assessment and Maintenance Management (RAMM) database was used to identify locations and attributes of OGPA sections. It was quickly evident that most of the OGPA sections are in the North Island main centres of Auckland, Hamilton and Wellington. To expand the study of potential regional differences, OGPA sections from the South Island main centre of Christchurch were also included. In terms of the number of sections or age of sections, there was not an equivalent sample of OGPA sections available from each of the four main centres.

Figure 4.1 summarises the 150 OGPA sections of the dataset, categorised by age and region. Age is calculated as the elapsed number of years between the date of laying and the date of measurement. For the Auckland OGPA sections, RAMM showed some were made with polymer modified bitumen to provide greater strength or durability. The effect of polymer modified bitumen on acoustic performance is not known and so, as figure 4.1 shows, the Auckland sample was split according to whether the binder was polymer modified or unmodified.

Measurements were undertaken on a greater number of OGPA sections, but only those with three successful measurement runs were included in the dataset.

Figure 4.1 Distribution of age and regions for the total research project dataset of OGPA sections measured



Appendix B provides details of the sample achieved.

The Auckland sample was measured in July 2015. All the OGPA sections of the Auckland sample were on motorways, being multi-lane and generally straight roads with little or gradual change in gradient so the road geometry readily allowed achievement of the test speed. The Auckland sample included OGPA sections from SH 1 near Bombay and Drury. The nature of the environment adjacent to these OGPA sections was quite rural or open relative to the generally urban or built-up nature of the environment adjacent to the other OGPA sections of the Auckland sample which were on SH 16 and SH 20. Speed limits for all these OGPA sections was 100 km/h. The test speed of 80 km/h was readily attainable near Bombay and Drury and reasonably attainable on SH 20. Some of the OGPA sections on SH 16 were near the centre of Auckland and the 80 km/h steady test speed was difficult to attain due to congestion from other traffic using the road. Some SH 16 measurements were undertaken early on a Saturday morning to attempt to find a period with lower traffic volumes.

The Hamilton sample was measured in June 2015. The Hamilton sample included OGPA sections from SH 1 near Ngaruawahia, Te Rapa and Tamahere. The setting for these OGPA sections was quite open and in some cases a rural environment adjacent to the road. The roads were generally straight and flat. The RAMM database identified a short length of OGPA with an 80 km/h speed limit in an urban setting in Hamilton. In reality, the site was not ideal, affected by gradient and intersections at the start and end of the length. Measurements were attempted but the data was discarded as it was considered non-representative.

The Wellington sample was measured in March and April 2015. The Wellington sample included OGPA sections on SH 2 near Upper Hutt and Lower Hutt and OGPA sections on SH 1 between Paremata and Ngauranga, all with 80–100 km/h speed limits.

The Christchurch sample was measured in September 2015. From the Christchurch region, there were only a limited number of OGPA sections measurable with a test speed of 80 km/h. Other OGPA sections could be measured at 50 km/h but these were excluded from the total sample discussed here.

The RAMM database identified other OGPA sections in Christchurch on SH 74 near Lyttelton. These sections were found to include both horizontal and vertical curvatures which were not ideal for on-board tyre/road noise measurements. These geometric elements also affected the speed chosen by other traffic on the road so during measurement runs at the test speed of 80 km/h (20 km/h below the speed limit of 100 km/h) the test vehicle was often impeded by other traffic. Also during the time of the Christchurch measurements there were long-term roadworks affecting a central portion of the intended SH 74 measurement route. These created visibly extra dust and loose material on the road surface and there was a temporary speed limit for the area of the roadworks. Measurements were undertaken but the results had to be discarded from the sample as they appeared anomalous and the measurement operators considered them non-representative.

The RAMM database identified other OGPA sections in Christchurch on SH 1 that should have been feasible for measurements but were affected by long-term roadworks during the intended measurement period. The Christchurch road network has been subject to substantial roadworks since earthquakes in 2010 and 2011 affected the region.

In all four main centres, the RAMM database identified other OGPA sections that were not included in the sample due to practicability. For example, if the test speed would be compromised due to intersections or there was a high risk of being impeded by other traffic. Either prior to attempting measurements or after review of the obtained measurements, some other sections, usually less than 200 to 300 metres long, were discarded as they were too short for the research project measurement method to achieve a useful number of segments.

There are porous asphalt variants other than NZTA P/11 specified OGPA on the state highway network but these comprise only very short or isolated lengths and largely represent road surface trials. These porous asphalt variants were excluded from the research project's focus on the TNZ P/11 specified OGPA.

4.2 Regional comparison of OGPA 1 to 2 years old

Figure 4.1 shows the section age of 1 to 2 years, which is the only age band including OGPA sections from each of the regions (including for Auckland both OGPA sections with polymer modified binder and OGPA sections with unmodified binder). This age band was selected for comparison of regional OGPA acoustic performance.

The average sound spectra for OGPA sections aged 1 to 2 years at the time of measurement are shown in figure 4.2 with a different line for each region. Table 4.1 shows the number and average age of OGPA sections within the 1 to 2-year age band and the calculated average overall sound level for each region. The bottom line of table 4.1 is for the average standard deviation, calculated from the standard deviation of the sound level for all 20-metre segments of each OGPA section within that region/age band. ISO 11819-2 states this standard deviation indicates road surface homogeneity and notes 'this variability is normally dominated by road surface variations, though random errors could add a little. Measurement speed and wheel tracks normally do not influence this value significantly'.

Figure 4.2 **Average sound spectra for OGPA sections measured at 1 to 2 years old (overall Leq level in dBA given in parentheses in legend)**

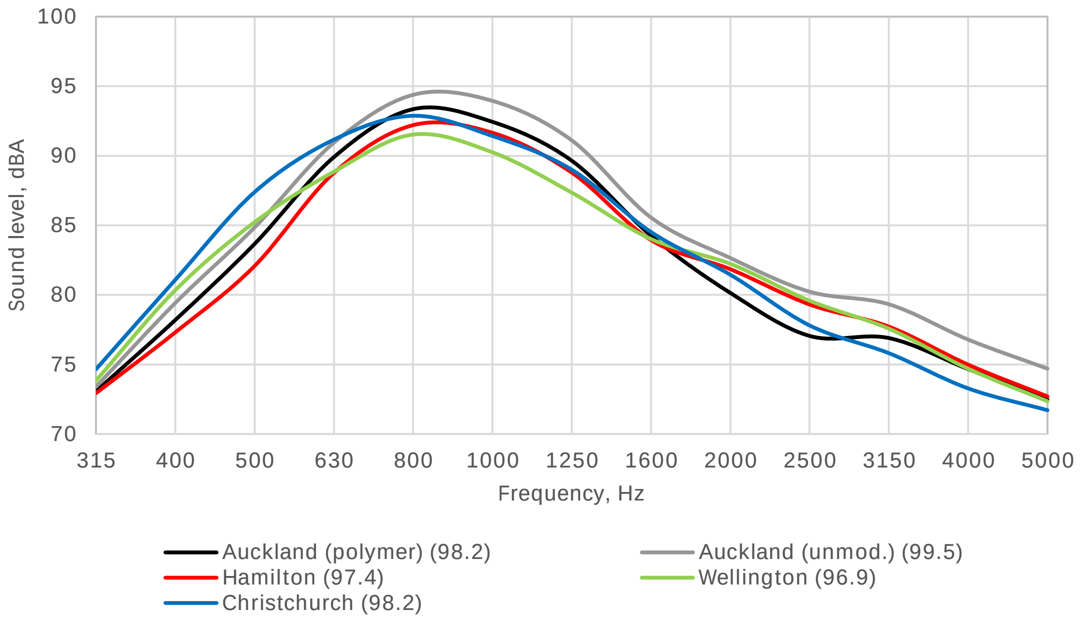


Table 4.1 **Summary of results and the set of OGPA sections measured at 1 to 2 years old**

	Auckland (polymer)	Auckland (unmod.)	Hamilton	Wellington	Christchurch
Number of sections	2	1	11	7	6
Average age, years	1.9	1.6	1.5	1.5	1.6
Average overall sound level, dB(A)	98.2	99.5	97.4	96.9	98.2
Average standard deviation, dB(A)	0.52	0.51	0.56	0.53	0.66

From figure 4.2, the general shape of the average sound spectra is the same across all regions. The Auckland OGPA with unmodified binder clearly stands out as having the greatest average overall sound level, though it is noted that there is only one OGPA section in this region/age band.

The Wellington OGPA has the lowest average overall sound level. Section 3.2.5 discussed the decision to apply no temperature correction though noted agreement with the concept that tyre/road noise decreases with increasing temperature. Therefore, it is noted that the Wellington measurements were made in March/April during late-summer, compared with June/July during early/mid-winter for the Hamilton and

Auckland measurements, and late winter/early spring for the Christchurch measurements. The potential influence of higher temperatures on the apparently lower average overall sound level for Wellington is noted though not quantified.

Following ISO 11819-2, the recommended time period of 48 hours was allowed between rainfall and measurement of the OGPA sections. ISO 11819-2 notes allowing 24 hours may be acceptable if there is sunshine during the day and air movement over the surface whether by wind or by traffic. Hamilton and Auckland have relatively high levels of dampness/humidity during June/July when the measurements were made. Some OGPA measurements in Hamilton and Auckland were made in the early part of the day. Though there was no rain in the 48 hours prior to measurements, cool mornings and the potential for overnight dew could have affected the wetness of the OGPA sections, though this small amount of moisture was unlikely to have had a significant influence on measured levels. ISO 11819-2 suggests blowing compressed air into the road surface to reveal moisture in the road surface. This was not practicable for the research project considering the lengths of road surface to be measured and the presence of traffic, plus the additional health and safety management such measurements would require.

4.3 Comparison of Wellington OGPA 0 to 7 years old

Figure 4.1 shows Wellington OGPA sections in all age bands from 0 to 7 years at the time of measurement. Therefore, the Wellington region was selected for some comparisons of OGPA acoustic performance over time.

Figure 4.3 shows the average sound spectra for the Wellington OGPA sections and table 4.2 provides a summary of the results and set of Wellington OGPA sections.

Figure 4.3 Average sound spectra for measured Wellington OGPA sections of varying age in years (overall Leq level in dBA given in parentheses in legend)

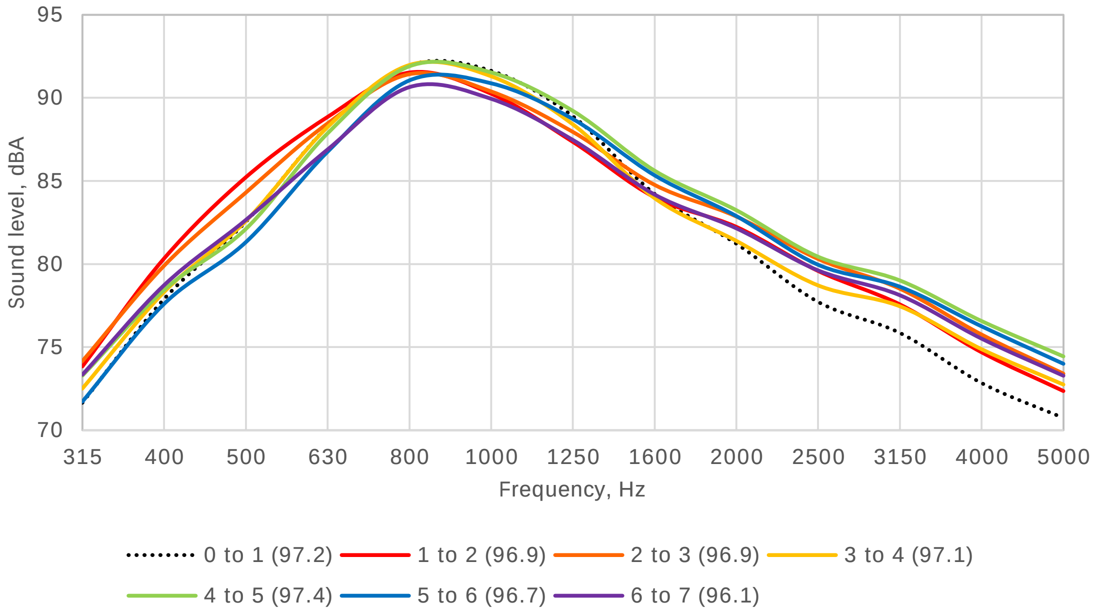


Table 4.2 Summary of results and the set of measured Wellington OGPA sections

Wellington OGPA sections	Section age at time of measurement, years						
	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7
Number of sections	3	7	9	4	10	4	3
Average age, years	0.4	1.5	2.5	3.8	4.5	5.3	6.3
Average overall sound level, dB(A)	97.2	96.9	96.9	97.1	97.4	96.7	96.1
Average standard deviation, dB(A)	0.65	0.53	0.61	0.73	0.63	0.68	0.63

Table 4.2 shows from 0 to 6 years, the average overall sound levels are very similar, with a range of only 0.7 dB(A). With regard to the overall sound level, no ageing effect is readily apparent. One interpretation is that porosity is low from the outset, so additional clogging over time has little influence on the acoustic properties of the surface.

The average sound spectra in figure 4.3 indicate the OGPA sections aged 0 to 1 year at the time of measurement have a slightly different spectral response compared with the older OGPA sections.

The average overall sound level calculated for the Wellington OGPA sections aged 6 to 7 years at the time of measurement is lower than that calculated for ages 0 to 6 years. Given the similarity of the results for the other six age bands, this result is likely to be a consequence of the small sample size rather than a real ageing effect.

4.4 Comparison of Auckland (unmodified binder) OGPA 1 to 8+ years old

Figure 4.1 shows Auckland OGPA with unmodified binder in seven of the nine age bands. Therefore, this group of OGPA sections was also selected for some comparisons of OGPA acoustic performance over time.

Figure 4.4 shows the average sound spectra for the Auckland OGPA sections with unmodified binder and table 4.3 provides a summary of the results and a set of sections.

Figure 4.4 Average sound spectra for measured Auckland OGPA sections with unmodified binder of varying age in years (overall Leq level in dBA given in parentheses in legend)

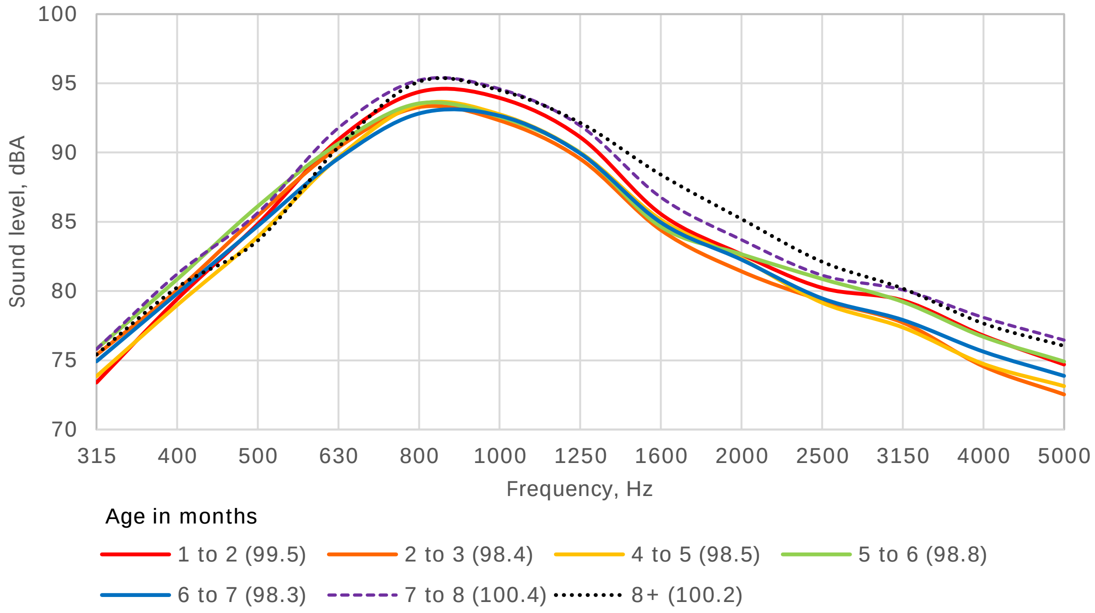


Table 4.3 Summary of results and the set of measured Auckland OGPA sections with unmodified binder

Auckland (unmodified binder) OGPA sections	Section age at time of measurement, years						
	1 to 2	2 to 3	4 to 5	5 to 6	6 to 7	7 to 8	8+
Number of sections	1	3	10	4	4	12	6
Average age, years	1.6	2.6	4.3	5.6	6.3	7.5	9.3
Average overall sound level, dB(A)	99.5	98.4	98.5	98.8	98.3	100.4	100.2
Average standard deviation, dB(A)	0.51	0.57	0.65	0.68	0.60	0.52	0.54

From table 4.3 the acoustic performance for Auckland OGPA with unmodified binder shows no strong ageing effect up to seven years. Following seven years, the average overall sound levels appear to increase.

In figure 4.4 the average sound spectra for the OGPA sections oldest at the time of measurement are shown with broken lines. (A line of purple dashes for 7 to 8 years age band and a line of black dots for the 8+ years age band.) This highlights the slightly different spectral response for these OGPA sections around the 1,250 Hz frequency band.

4.5 Comparison of early OGPA

Anecdotally, sometimes the sound experience of driving on OGPA during the first week after its laying has been noted as a ‘swishing’ sound but this lasts only a short while. Following this observation, special inspection was made of the ‘early’ acoustic performance of OGPA sections. Figure 4.5 shows the average sound spectra for the OGPA sections measured at ages up to 24 months old and table 4.4 provides a summary of this set of OGPA sections.

Figure 4.5 Average sound spectra for OGPA sections measured at ages (in months) up to 24 months old (overall Leq level in dBA given in parentheses in legend)

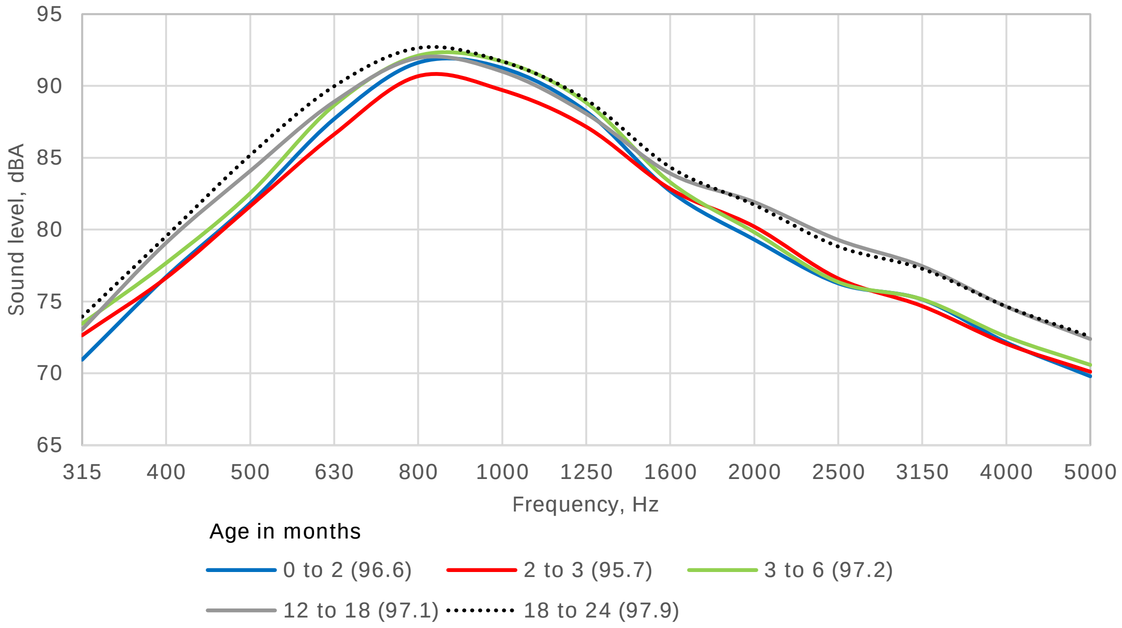


Table 4.4 Summary of results and the set of OGPA sections measured at ages up to 24 months old

'Early' OGPA sections (only Wellington and Hamilton)	Section age at time of measurement, months				
	0 to 2	2 to 3	3 to 6	12 to 18	18 to 24
Number of sections	3	2	5	10	17
Average age, months	1.4	2.3	3.4	16	20
Average overall sound level, dB(A)	96.6	95.7	97.2	97.1	97.9
Average standard deviation, dB(A)	0.70	0.88	0.61	0.55	0.58

The availability of OGPA sections aged less than six months was limited and observations should be treated accordingly. From both the average sound spectra shown in figure 4.5 and the average overall sound levels shown in table 4.4, the two OGPA sections in the 2 to 3 month age band appear anomalous relative to the other OGPA sections in this 'comparison of early OGPA'; however, it is noted that the first two age groups contain very few samples and may not be representative of the population.

From the other age bands, it appears the average overall sound level may gradually increase over the first 12 to 24 months. From the average sound spectra in figure 4.5, there is a notable difference between the OGPA sections aged less than six months at the time of measurement and those aged between 12 and 24 months. It is proposed that this spectral difference during the first six months or so may be affected by the film of bitumen binder present on the top surface of the OGPA at the tyre/road interface when the OGPA surface has been freshly laid. On well-trafficked roads, this film typically wears away after about six months (Abbott et al 2010). The change may also indicate the open texture has become less open during the period 6 to 12 months after laying.

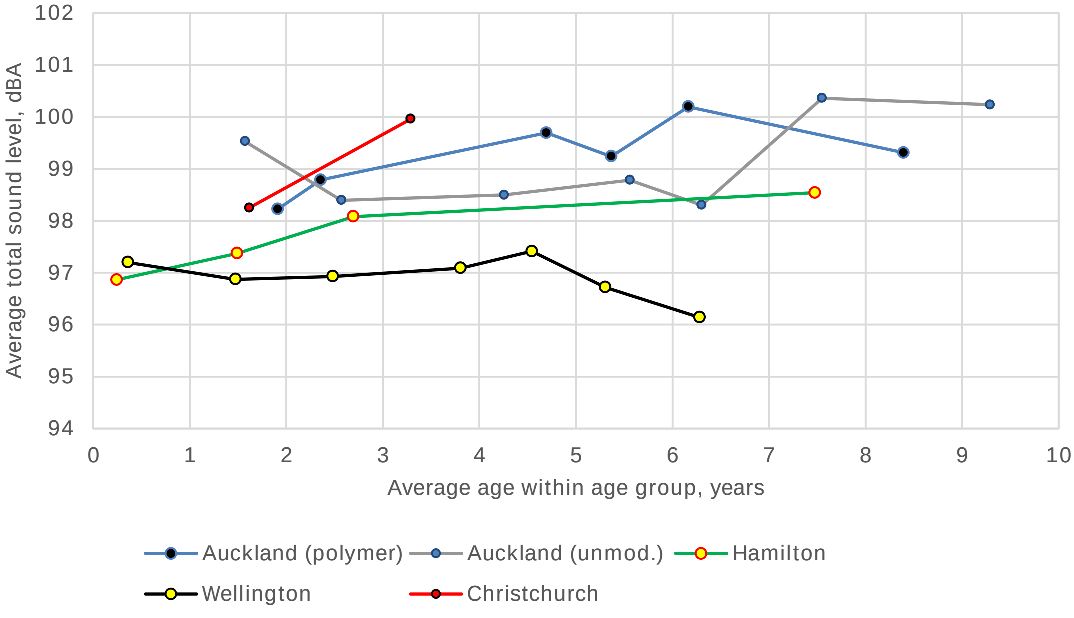
4.6 Comparison of region/age band for full research project dataset

An amalgamation of data from the individual regions to create a single large dataset would achieve better statistical power, but would introduce some limitations on its interpretation. First, the temperature coefficient for New Zealand OGPA is not definitive, so with the range of ambient temperatures encountered during measurement (in various regions and at different times of year) some error would be introduced that could bias the findings. Second, and more importantly, the sound emission levels and ageing properties of OGPA vary between regions, and the sampling with respect to surface age is not uniform across regions. This can have a strong biasing effect. For example, the Wellington OGPA is quieter and the sample is generally younger than the other regions. If all regions were combined into one dataset, the Wellington data would lower the average emission of the younger surfaces without affecting the oldest average surface emissions at all, which could lead to the incorrect conclusion that there is a strong ageing effect.

Figure 4.6 shows a separate line for each of the regions (including a separate line for each of the Auckland OGPA sections with polymer modified binder and Auckland OGPA sections with unmodified binder). The lines follow a general trend over time with a shallow or slight increase in average overall sound level, generally 1 to 2 dB(A) over the six to eight years of ageing represented within the dataset. The overall impression from figure 4.6 is of a fairly steady but minor increase in acoustic emission over time, without any sudden deterioration in performance at any age (at least within the available eight or nine years of ageing data).

The results and details of each region for each age band, as summarised graphically in figure 4.6 are tabulated in appendix C.

Figure 4.6 Average overall sound level versus OGPA section age



The lines/time series only go as far as a maximum age band of 8+ years and for any OGPA section measured the greatest age at the time of measurement was 11 years 5 months. This reflects current OGPA asset management practices. For OGPA sections with speed limits 80 to 100 km/h, there is no dramatic deterioration of OGPA acoustic performance prior to the time at which aged OGPA sections are currently being replaced.

Without repeat measurements over time of the same OGPA sections, it cannot be conclusively determined whether the aged OGPA sections had initial acoustic performance substantially different from those OGPA sections measured in the ‘early’ years. However, a similar ageing effect is observed across the different regions and so the effect is considered reliable.

The data from the Christchurch OGPA sections are noted, first for having just two plotted points in figure 4.6 and second for the apparently rapid deterioration of acoustic performance. The difficulties of locating Christchurch OGPA sections for measurement have already been explained in section 4.1. It is not possible to fully explain the rate of acoustic performance deterioration as indicated by the two points and it has not been specifically investigated further. However, the effect of many aftershocks continuing since the aforementioned earthquakes and the effect of reconstruction activity in the area could be a factor.

5 Implications for asset management of OGPA as a low- noise road surface

The research project measured OGPA sections only on roads with speed limits 80 to 100 km/h, for which the term 'high-speed environments' is used here. This provides important context and limitations to the following discussion.

OGPA acoustic performance over time is not just of academic interest but pertinent to OGPA asset management practices. Chapter 1 of this report uses the term 'functional attributes' to indicate the special OGPA attributes of surface porosity and smoothness. These functional attributes are significant to the reasons for selecting use of OGPA and then maintenance or degradation of those functional attributes are significant to the OGPA asset management practices currently employed.

At the outset of the research project there was knowledge and experience of the 'functional life' of OGPA but there was a lack of knowledge about the duration of OGPA 'acoustic life'. Now, for OGPA sections in high-speed environments, the research project results indicate the acoustic life is not generally less than the functional life.

Literature reinforces that the mechanisms triggering deterioration of functional attributes are also those that trigger deterioration of acoustic performance.

Surface porosity can deteriorate if the pores become clogged. Clogging degrades the drainage capability of OGPA, leaving water on the road surface, which decreases its functional attributes of enhanced wet skid resistance and splash/spray suppression. Clogging also degrades the acoustic performance of OGPA.

Clogging can be caused by a build-up of tyre rubber, windblown detritus, and wear of aggregate material or movement of other fine materials within the pores. Clogging of porous road surfaces can begin immediately after trafficking begins but the extent and rate of clogging depends on a wide range of factors including the mix design, initial porosity, the traffic volume and composition, environmental factors including rainfall, and traffic speed. It is noted that high traffic speeds are considered to help reduce clogging by 'self-cleaning' through the suction effects that occur at the back of the tyre/road contact patch (Welker et al 2013; Ripke et al 2008; Sandberg 1999; Bendtsen 2008). In New Zealand trials in high-speed and motorway environments, machine-cleaning/vacuuming does not appear to offer substantial benefits to acoustic performance and variable effects on measured permeability (Patrick and Kvatch 2014; NZ Transport Agency 2014; Fletcher and Theron 2011). As a general rule, France and Italy also do not clean their similar porous asphalts as the practice has not been found to be beneficial (Gibbs et al 2004).

From international and local information, it is unlikely the functional attributes or long-term acoustic performance of OGPA in high-speed environments will be substantially degraded through clogging and so there seems no basis for including cleaning in OGPA asset management practices.

Note that mechanisms other than clogging can cause void content to vary over the life of the OGPA. For example, the mix design has an impact on the structure and elasticity; and traffic volumes, particularly heavy traffic, can influence the loading of the structure.

OGPA smoothness can deteriorate through chip loss, called ravelling or fretting, and can be measured as increased macrotexture depth. Macrotexture operates at the scale of 0.5 to 50 mm. Chip loss is the most common form of OGPA damage and it arises as the binder hardens and becomes brittle through oxidation. (Herrington et al 2005; Fletcher and Theron 2011). OGPA smoothness at a larger megatexture scale can also deteriorate, measured as increased roughness. Roughness is often represented by variance of road profile at wavelengths of 3, 10 and 30 metres. Three-metre variance is typically influenced by features such as potholes or severe cracking; 10-metre variance is typically influenced by short undulations from localised subsidence; and 30-metre variance typically indicates pavement deformation or distress.

Tyre/road noise is generated through tyre/road contact and deterioration of smoothness (in the macro- and megatexture ranges) can alter the frequency or forces of tyre/road contacts to generate greater levels of tyre/road noise. The nature of the 'excitation' forces on the tyre can depend on the frequency and size of the road texture or roughness, features of the tyre and the vehicle speed.

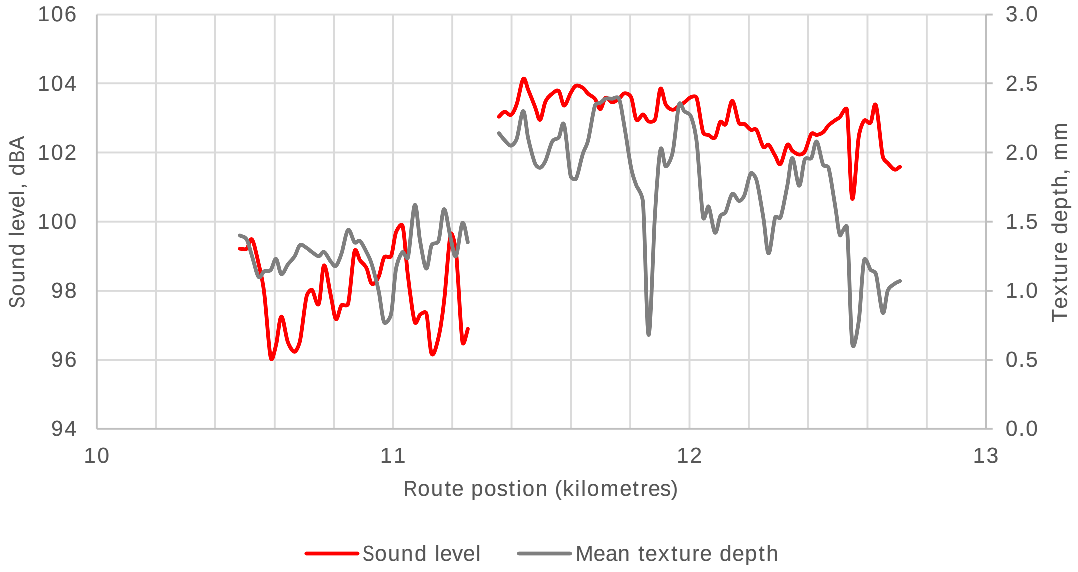
There is no simple general relationship between overall tyre/road noise levels and smoothness; different frequencies of the tyre/road noise are affected by particular wavelengths of texture/roughness (Wayson 1998; Sandberg and Ejsmont 2002; Ongel and Harvey 2011; Pratico and Anfosso-Ledee 2012; Rasmussen et al 2007; Kragh et al 2013).

Each year, a high-speed data survey of the New Zealand state highway road network is undertaken where lasers measure road surface texture and roughness. Macrotexture is reported for 10-metre sections as the mean, minimum and maximum texture depth over the 10-metre section. Roughness is reported as a variance (3, 10, 30 metres) and using other recognised indices.

In figures 5.1 and 5.2, data from the survey[9] is shown on a shared x-axis with sound level measurements obtained with the research project measurement method. The road section represented is the same as used for figure 3.6 where there is an OGPA section located immediately adjacent to a two-coat (grade 2/4) chip seal section.

- In figure 5.1 the red line shows overall sound levels (left hand y-axis) and the grey line shows mean texture depth (right-hand y-axis); and
- In figure 5.2 the red line shows overall sound levels (left-hand y-axis) and the grey line shows roughness reported as three-metre variance.

Figure 5.1 Longitudinal record of overall sound levels and texture depth as measured along OGPA (left) and two- coat 2/4 chipseal (right).



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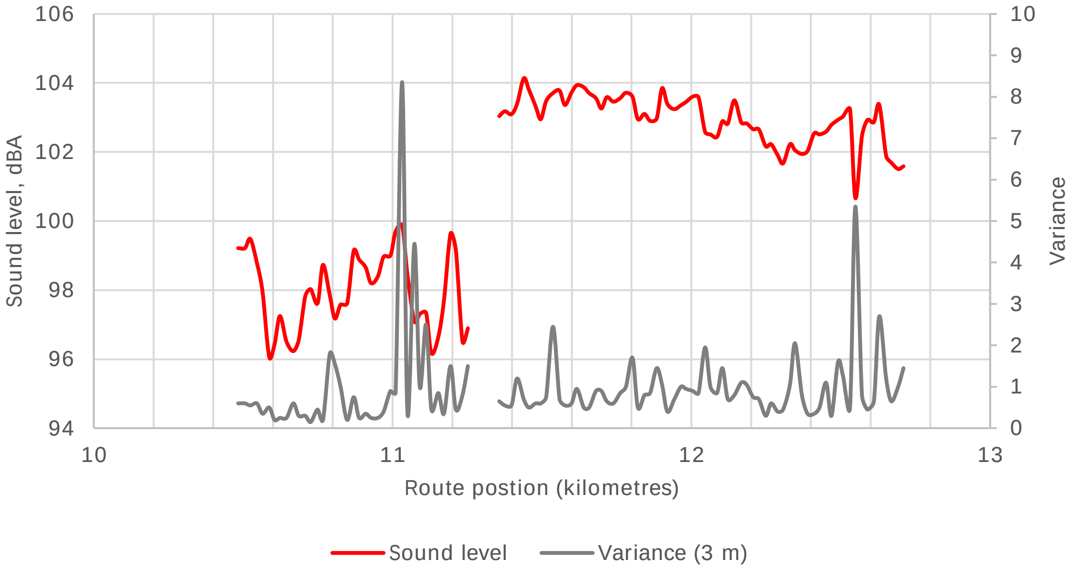
[9] 2015 survey data, chosen as that obtained closest to the date of the sound level measurements

Figure 5.2 Longitudinal record of overall sound levels and roughness (3m variance) as measured along OGPA (left) and two- coat 2/4 chipseal (right).



Detailed investigation of the relationships was beyond this research project but there appears to be some correlation between the overall sound levels and texture depth for the coarser chipseal section, and perhaps to a lesser extent for the smoother OGPA surface. There does not appear to be any relationship between road roughness and sound levels for either surface. The figures show the OGPA section and chipseal sections together but a fuller analysis would be needed to separately consider correlations for different road surface types (Berge and Viggen 2014).

These comparisons are somewhat limited by the data collected traditionally for the management of functional attributes. It may be that data separated for different wavelengths gives greater correlation to acoustic performance, as demonstrated by Sandberg and Ejsmont (2002, chapter 7). This is also the subject of an international study (Kragh et al 2013).

Overall, current OGPA asset management practices have been developed with a focus on the functional attributes of OGPA and deliver a functional life of 8 to 10 years in high-speed environments. The research project noise measurements show through the 8 to 10 years of functional life, there is no sudden change but rather a steady and shallow deterioration of acoustic performance. If the research project noise measurements had shown a sudden change in acoustic performance, this could have been interpreted as an indication that traditional OGPA asset management practices are not adequately addressing acoustic performance. However, from the research project noise measurements and understanding that the surface properties affecting functional attributes also affect acoustic performance, the research concluded that current OGPA asset management practices can be continued, as these do not appear to have a negative impact on the observed acoustic life.

6 Summary and conclusions

Research was commissioned to investigate the long-term acoustic performance of New Zealand standard porous asphalt made to TNZ P/11 specifications. The research findings should be considered applicable only to New Zealand OGPA laid in high-speed environments, defined as where speed limits are 80 to 100 km/h.

For the research project, a method for acoustic measurement was selected, developed and applied using ISO 11819-2 for guidance. The research project measurement method followed many of the ISO 11819-2 requirements for setup of equipment, undertaking of measurements and processing of data; but the research project measurement method was not fully compliant with ISO 11819-2.

OGPA sections were measured across four New Zealand regions and across a range of different road ages. The research project dataset achieved is not evenly distributed across regions and ages but allows comparisons of particular regions and age bands so interpretation of the long-term acoustic performance of OGPA can be made.

The research project dataset has given no indication of sudden deterioration of OGPA acoustic performance prior to the time at which aged OGPA sections are currently being replaced (8 to 10 years).

It was not practicable to make repeat measurements of a set of OGPA sections over their functional lives and so it could not be conclusively determined whether the initial acoustic performance of aged OGPA sections would have been substantially different from the newer OGPA sections measured in the research. However, a similar ageing effect was observed across the different regions so the methodology is considered reliable.

Literature and experiences were consulted to understand the factors affecting the functional life and acoustic performance of OGPA. It appears current practices of asset management for OGPA functional life are in line with what would be prescribed if considering asset management for OGPA acoustic life. Therefore, the research makes no recommendation for changes to asset management of OGPA in high-speed environments, but supports current practices.

7 References

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Appendix A: Research project measurement method

This section lists the parameters of the measurement equipment and method used for this research project, with notes on alignment or departure from ISO 11819-2 (2012 draft).

The shown order and numbering matches ISO 11819-2 (2012 draft).

6 Measuring instruments	
6.1 Sound level instrumentation	
Two type 1 sound level meters to measure frequency range of 315 Hz to 5,000 Hz, at least.	✓ as per standard
A windscreen for each sound level meter, having diameter at least 90 mm.	By error, 65 mm windscreens were used
6.2 Frequency analysis instrumentation	
One-third-octave band frequency analysis of the measured sound	✓ as per standard
6.3 Sound calibration	
Calibrated sound calibration device	Microphone calibration results were consistent throughout measurements
6.4 Vehicle speed measuring instrumentation	
Speed measured with accuracy better than ±1% of the indicated value.	Vehicle speedometer was verified as accurate and speed fluctuation in cruise control mode was verified as within acceptable precision
Speed will be averaged for each measured 20 m road segment (10.7.1).	As far as practicable, driver and assistant monitored speed was within desired range and supplementary check was performed based on the GPS
6.5 Temperature measuring instrumentation	
Air temperature measured (non-infrared) with accuracy of at least ±1°C.	Temperature sensor was mounted near the rear passenger door handle and temperature was recorded at intervals
Each temperature measurement shall have a duration of at least 15 seconds (10.10.1).	✓ as per standard
Air temperature sensor is to be located exposed to airflow and protected from direct solar radiation, 0.5 m to 1.5 m above road surface level.	✓ as per standard
If road temperature is measured, it will be measured in the left hand wheel path.	Not measured
6.6 Tyre load measuring equipment	
Measure load of the test tyre ±5%	Performed with scales accurate to 5 kg (49 N)
6.7 Inflation measuring equipment	

Inflation pressure of the test tyre measured with accuracy at least ±4%	Initial tyre inflation pressure was supplied correct from tyre specialist. Throughout measurements, that tyre inflation pressure was maintained and typically measured using service station pumps
7 Test sites	
7.1 Selection of measurement site	
Reference speed to be reached before the measurement begins	✓ as per standard
At least 10 m of the same surface type before the measurement begins	✓ as per standard
Measurement sections shall be at least 20 m and preferably longer than 100 m	✓ as per standard
Measurement sections shall be nominally straight	'Curves' were not excluded however curvature encountered was generally such that reference speed was readily maintained
At least 0.5 m of the same surface type adjacent to the wheel path of the measurement section.	✓ as per standard
At least 2 m to any reflective surface adjacent to the measurement section. This includes guard rails, jersey barriers, parked vehicles, bridges, embankments.	This was not specifically targeted but it is considered that it was generally achieved and any effect included in measurements could be considered negligible
8 Meteorological conditions	
8.1 Wind	
Wind speed should not exceed 5 m/s at the microphone height	Wind speed was not measured
8.2 Temperature and other weather-related issues	
Air temperature shall be 5°C to 30°C	✓ as per standard
Measurement sections shall be dry (being no rainfall for 24 to 48 hours for porous asphalt)	✓ as per standard with regard to rainfall but 'dryness' was not measured or closely inspected
9. Test vehicle	
9.1 General design	
Self-powered vehicle on which at least one of its tyres is a reference (test) tyre, close to which the microphones are mounted.	✓ as per standard
9.2 Microphone positions	
The two mandatory positions are mounted at angles of 45° ±5° and 135° ±5° to the rolling direction, at a horizontal distance 0.20 m ±0.01 m from the tyre, and at a vertical height 0.10 m ±0.01m from the pavement level. There are three optional positions: in the rolling direction behind the tyre, 90° to the rolling direction, and reverse to the rolling direction in front of the tyre. The mandatory positions are obviously preferred, however "in the case of non-enclosed systems, it may be preferable to mount the microphones parallel to the driving direction."	The two mandatory positions were used, with the microphones mounted vertically (to ensure compliance with New Zealand vehicle-dimension requirements), which is preferable to the optional mounting positions from a measurement point of view.
9.3 Performance requirements and conformity of the test vehicle	

The test vehicle was rear wheel drive so the microphones were fitted to a driven wheel, which the standard recommends against. The same test vehicle was used throughout the research project and mileages were low so the tyres remained in a consistently good condition throughout. (The test tyres did not remain on the test vehicle during long-distance transit between measurements sites or during extended periods between measurements.)	
9.4 Reference tyres	
The test tyre shall be the Reference Tyre as specified in ISO/TS 11819-3. This is a standard reference test tyre as specified in ASTM F2493-06 of dimensions 225/60/R16.	✓ as per standard For safety/handling, a test tyre was fitted on both wheels of the rear axle. The “regular” tyres were retained on the wheels of the front axle.
9.5 Tyre mounting	
The test tyres shall be mounted on the rim such that the sidewall with the DOT mark faces out from the test vehicle	✓ as per standard
9.6 Tyre run-in	
The test tyres shall be run-in for a minimum of 100 km before first use.	✓ as per standard
10 Measurement procedure	
10.1 Preparations for measurements	
With vehicle loaded as typical for measurements (fuel and equipment and operators), the microphone position shall be regularly checked as correct.	✓ as per standard
Tyres shall be warmed up to normal operating temperature by at least 15 minutes driving at lower reference speeds and 5 minutes driving at high reference speeds.	✓ as per standard
All four tyres shall be regularly checked as clear from damage to the tread or the presence of foreign objects in the tread.	✓ as per standard
10.2 Measurement of sound	
The A-weighted equivalent one-third-octave band sound pressure level from 315 Hz to 5,000 Hz shall be determined at each microphone position by averaging over each 20 m road segment for which the test requirements are met.	✓ as per standard
10.3 Procedure for study of typical road section	
No less than five road segments shall be measured under equivalent and acceptable conditions and with a reasonable spread over the entire road section. The results shall differ by no more than 0.5 dB (or two more 20-metre segments shall be measured). The final result is the arithmetic average of all the runs.	Selection of road sections for measurement excluded those less than 160-200 metres length. For calculating the average overall sound level for a road section, the result for a 20-metre road segment was excluded if it was outside of ±1.5 dB of the road section’s median result
10.4 Minimum number of runs for very short road sections	
Not applicable for the research project as selection of road sections for measurement excluded those less than 160–200 metres length. Three runs were performed on each road section	
10.5 Lateral position on the road	

The standard would generally expect both wheel paths to be measured, however the test wheel used was only the passenger side rear wheel of the test vehicle and so measurements were made only in the left-hand wheel path. The passenger side/left-hand wheel path was selected with regard to safety and risk of interference as there is more clearance for obstructions on this side.	
10.6 Consideration of disturbing noise	
The standard recognises that a certified system will still be potentially subject to several sources of disturbing noise, including wind noise on non-enclosed systems and background noise from unrelated sources such as passing vehicles and reflections against roadside objects. • Wind noise was managed as far as practicable through the selection of the microphone mounting positions, use of windscreens, and subjective monitoring of wind speeds. • The operators were alert to identifying where measurements may be affected by background noise from unrelated sources, however this was extremely rare given the reference speed and location of the measurements. • Measurements were generally taken in the leftmost lane so the microphones were largely shielded from other traffic and there were some road sections where measurements were specially timed to coincide with times of low traffic volume.	
10.7 Test vehicle speed	
The standard prefers 40 km/h, 50 km/h, 80 km/h, or 100 km/h. For this research project, a reference speed of 80 km/h was used and selection of road sections for measurements was undertaken with regard to this reference speed. (For information, some measurements were undertaken at 50 km/h and this data is separate from the main dataset.)	
10.8 Tyre loads	
With vehicle loaded as typical for measurements (fuel and equipment and operators), the standard requires the static load of the test tyre shall be 3,200 N ±200 N.	4,600 N (see appendix D)
10.9 Tyre inflation	
The test tyre shall be inflated to 200 kPa ±10 kPa (29 psi ±1.5 psi) in cold condition. Nitrogen is the preferred inflation gas, then dry air, then normal air.	✓ as per standard
10.10 Temperature measurement	
Air temperature shall be measured at least one time per each road section.	✓ as per standard

Appendix B: Details of the sample

The details of date of OGPA laying, layer depth, aggregate mix and binder were obtained from the RAMM database. Where these details are missing, the information was not in the RAMM database.

B1 Auckland

The Auckland OGPA sections were measured over two days during early/mid-winter.

- 22 July 2015, 16 to 19 °C during measurements.
- 25 July 2015, 9 to 13 °C during measurements.

Section code	Date laid	Section start			Section end			Layer depth	Mix	Binder
		SH	Station	km	SH	Station	km			
16N01	16/05/2013	16(I)	0	4.186	16(I)	0	5.054	25	M10	Polymer
16N03	16/05/2013	16(I)	0	5.472	16(I)	0	6.032	25	M10	Polymer
16N04	16/05/2013	16(I)	0	6.032	16(I)	0	6.452	25	M10	Polymer
16N05	26/08/2013	16(I)	0	6.452	16(I)	0	6.838	25	M10	Polymer
16N06	26/08/2013	16(I)	0	6.838	16(I)	0	7.827	25	M10	Polymer
16N07	29/10/2009	16(I)	0	8.096	16(I)	0	8.655	31	M10	Polymer
16N08	28/11/2006	16(I)	0	8.655	16(I)	0	9.313	35	M14	Polymer
16N09	5/12/2006	16(I)	7	0.000	16(I)	7	0.800	35	M14	Polymer
16N10	8/12/2006	16(I)	7	0.800	16(I)	7	1.700	35	M14	Polymer
16N11	12/12/2006	16(I)	7	1.700	16(I)	7	2.720	35	M14	Polymer
16N12	1/03/2006	16(I)	7	2.720	16(I)	7	3.517		M15	Unmodified
16N13	18/02/2007	16(I)	7	3.517	16(I)	7	3.960	30	M14	Polymer
16N14	14/12/2006	16(I)	7	3.960	16(I)	7	4.481	30	M14	Polymer
16N15	8/11/2007	16(I)	7	4.481	16(I)	7	5.634	25	M10	Unmodified
16N16	8/05/2007	16(I)	7	5.634	16(I)	7	6.497	35	M14	Polymer
16N17	8/05/2007	16(I)	7	6.697	16(I)	7	8.728	35	M14	Polymer
16N18	1/06/2011	16(I)	7	8.728	16(I)	7	10.902		M15	Unmodified
16N20	1/06/2011	16(I)	7	11.574	16(I)	7	12.662		M15	Unmodified
16S01	1/06/2011	16(D)	7	11.997	16(D)	7	12.644		M15	Unmodified
16S02	1/06/2011	16(D)	7	10.371	16(D)	7	11.807		M15	Unmodified
16S03	1/06/2011	16(D)	7	8.713	16(D)	7	10.093		M15	Unmodified
16S04	16/05/2007	16(D)	7	7.515	16(D)	7	8.713	35	M14	Polymer
16S05	21/02/2006	16(D)	7	6.276	16(D)	7	7.515	40	M14	Unmodified
16S06	21/04/2010	16(D)	7	4.281	16(D)	7	6.190	30	M10	Polymer
16S07	30/11/2010	16(D)	7	3.712	16(D)	7	4.281	30	M10	Polymer
16S08	2/04/2007	16(D)	7	1.105	16(D)	7	3.500	30	M14	Polymer
16S09	26/05/2009	16(D)	7	0.370	16(D)	7	1.105	30	M14	Polymer
16S10	3/05/2007	16(D)	7	0.000	16(D)	7	0.370	35	M14	Polymer

Section code	Date laid	Section start			Section end			Layer depth	Mix	Binder
		SH	Station	km	SH	Station	km			
16S11	25/12/2006	16(D)	0	6.240	16(D)	0	9.312	30	M14	Unmodified
16S12	22/04/2007	16(D)	0	5.775	16(D)	0	6.240	35	M14	Polymer
16S13	26/04/2007	16(D)	0	5.475	16(D)	0	5.775	35	M14	Polymer
16S14	6/05/2007	16(D)	0	5.002	16(D)	0	5.475	35	M14	Polymer
16S15	25/12/2006	16(D)	0	3.378	16(D)	0	5.002		M14	Unmodified
20N02	22/02/2009	20(I)	0	5.070	20(I)	0	6.736	25	M14	Unmodified
20N04	9/02/2004	20(I)	10	0.000	20(I)	10	0.357	25	M14	Unmodified
20N05	25/02/2010	20(I)	10	0.585	20(I)	10	1.014	25	M10	Polymer
20N06	25/02/2010	20(I)	10	1.014	20(I)	10	2.171	25	M10	Polymer
20N08	11/04/2010	20(I)	10	3.793	20(I)	10	4.320	25	M10	Polymer
20N09	11/04/2010	20(I)	10	4.320	20(I)	10	4.784	25	M10	Polymer
20N10	11/04/2010	20(I)	10	4.784	20(I)	10	5.245	25	M10	Polymer
20N11	30/04/2009	20(I)	10	5.795	20(I)	10	6.449	50	M10	Unmodified
20S01	8/12/2009	20(D)	0	4.032	20(D)	0	5.070	28	M10	Unmodified
20S03	13/10/2009	20(D)	0	5.680	20(D)	0	6.694	27	M10	Unmodified
20S04	1/12/2010	20(D)	0	6.694	20(D)	0	9.030	30	M15	Unmodified
20S05	30/05/2011	20(D)	0	9.030	20(D)	0	9.425	25	M10	Unmodified
20S06	10/06/2011	20(D)	10	0.000	20(D)	10	0.367	25	M10	Unmodified
20S07	24/03/2010	20(D)	10	0.367	20(D)	10	0.783	25	M10	Polymer
20S08	4/03/2010	20(D)	10	0.783	20(D)	10	2.131	25	M10	Polymer
20S09	4/03/2010	20(D)	10	2.131	20(D)	10	2.543	25	M10	Polymer
20S15	19/04/2010	20(D)	10	5.350	20(D)	10	5.613	50	M10	Polymer
20S16	30/04/2009	20(D)	10	5.613	20(D)	10	7.078	50	M10	Unmodified
BN1	13/01/2011	1N(D)	461	5.154	1N(D)	461	6.452	30	M10	Unmodified
BN2	11/03/2011	1N(D)	461	6.452	1N(D)	461	9.420	30	M10	Unmodified
BN3	5/06/2013	1N(D)	461	9.420	1N(D)	461	10.396	30	M10	Unmodified
BS1	10/10/2012	1N(I)	461	4.878	1N(I)	461	6.822	25	M10	Unmodified
BS2	11/10/2012	1N(I)	461	6.822	1N(I)	461	8.042	25	M20	Unmodified
BS3	23/02/2010	1N(I)	461	8.042	1N(I)	461	8.608	27	M10	Unmodified
BS4	24/02/2010	1N(I)	461	8.608	1N(I)	461	11.003	27	M10	Unmodified
DN1	10/02/2008	1N(D)	448	6.229	1N(D)	448	6.229	35	M15	Unmodified
DN2	7/02/2008	1N(D)	448	6.920	1N(D)	448	7.720	35	M15	Unmodified
DN3	4/02/2008	1N(D)	448	7.720	1N(D)	448	8.338	35	M15	Unmodified
DN4	3/02/2008	1N(D)	448	8.450	1N(D)	448	8.944	35	M15	Unmodified
DN5	31/01/2008	1N(D)	448	9.057	1N(D)	448	9.655	35	M15	Unmodified
DN6	29/01/2008	1N(D)	448	9.655	1N(D)	448	9.965	35	M15	Unmodified
DN7	23/01/2008	1N(D)	448	10.145	1N(D)	448	10.607	35	M15	Unmodified
DN8	17/01/2008	1N(D)	448	10.607	1N(D)	448	11.488	35	M15	Unmodified

Section code	Date laid	Section start			Section end			Layer depth	Mix	Binder
		SH	Station	km	SH	Station	km			
DN9	17/09/2012	1N(D)	448	11.488	1N(D)	448	13.400	25	M10	Polymer
DN10	23/03/2009	1N(D)	448	13.400	1N(D)	448	13.810	30	M10	Unmodified
DS1	18/11/2007	1N(I)	448	6.384	1N(I)	448	7.297	25	M14	Unmodified
DS2	19/11/2007	1N(I)	448	7.488	1N(I)	448	8.338	25	M14	Unmodified
DS3	20/11/2007	1N(I)	448	8.450	1N(I)	448	9.116	25	M14	Unmodified
DS4	25/12/2013	1N(I)	448	9.116	1N(I)	448	10.360	40	M14	Unmodified
DS5	27/10/2010	1N(I)	448	10.368	1N(I)	448	11.140	30	M10	Polymer
DS6	15/04/2007	1N(I)	448	11.140	1N(I)	448	11.550	25	M15	Unmodified
DS7	13/03/2013	1N(I)	448	11.550	1N(I)	448	14.132	25	M10	Polymer

B2 Hamilton

The Hamilton OGPA sections were measured over four days during early/mid-winter.

- 18 June 2015, 13 to 16 ºC during measurements
- 29 June 2015, 17 to 20 ºC during measurements
- 30 June 2015, 15 ºC during measurements
- 10 July 2015, 12 to 19 ºC during measurements.

Section code	Date laid	Section start			Section end			Layer depth	Mix
		SH	Station	km	SH	Station	km		
NGN1	19/03/2015	1N(D)	534	3.455	1N(D)	534	2.866		
NGN2	1/11/2013	1N(D)	534	2.866	1N(D)	534	2.664		
NGN3	19/03/2015	1N(D)	534	2.664	1N(D)	534	1.110		
NGN4	23/03/2015	1N(D)	534	1.110	1N(D)	527	4.640		
NGN5	25/03/2015	1N(D)	527	4.640	1N(D)	527	1.068		
NGN6	29/03/2015	1N(D)	527	1.068	1N(D)	527	0.050		
NGS7	22/04/2015	1N(I)	527	1.650	1N(I)	527	4.567		
NGS8	1/05/2015	1N(I)	527	4.567	1N(I)	534	1.050		
NGS10	20/04/2015	1N(I)	534	1.136	1N(I)	534	2.753		
NGS11	1/11/2013	1N(I)	534	2.753	1N(I)	534	2.954		
TMN1	9/01/2008	1N(D)	557	5.867	1N(D)	557	2.520	35	M10
TMN2	9/01/2008	1N(D)	557	2.520	1N(D)	557	1.000	35	M10
TMS1	9/01/2008	1N(I)	557	1.000	1N(I)	557	2.520	35	M10
TMS2	9/01/2008	1N(I)	557	2.520	1N(I)	557	5.866	35	M10
TN2	10/12/2013	1N(D)	540	5.522	1N(D)	540	5.048	30	M10
TN3	10/12/2013	1N(D)	540	4.986	1N(D)	540	4.168	30	M10
TN4	4/03/2014	1N(D)	540	4.102	1N(D)	540	0.935	30	M10
TN5	4/03/2014	1N(D)	540	0.720	1N(D)	540	0.000	30	M10

Section code	Date laid	Section start			Section end			Layer depth	Mix
		SH	Station	km	SH	Station	km		
TS6	4/03/2014	1N(I)	540	4.168	1N(I)	540	4.986	30	M10
TS7	4/03/2014	1N(I)	540	5.048	1N(I)	540	5.522	30	M10
TS8	10/12/2013	1N(I)	540	5.522	1N(I)	540	6.359	30	M10
TS9	10/12/2013	1N(I)	540	6.473	1N(I)	540	7.173	30	M10
TS10	10/12/2013	1N(I)	540	0.000	1N(I)	540	0.720	30	M10
TS11	24/10/2012	1N(I)	540	0.935	1N(I)	540	3.140	35	M10
TS12	24/10/2012	1N(I)	540	3.140	1N(I)	540	4.102	35	M10

B3 Wellington

The Wellington OGPA sections were measured over two days during late-summer.

- 21 March 2015, 16 to 22 ºC during measurements
- 15 April 2015, 9 to 11 ºC during measurements.

Section code	Date laid	Section start			Section end			Layer depth	Mix
		SH	Station	km	SH	Station	km		
1N20	1/01/2011	1N(D)	1060	4.255	1N(D)	1060	5.300	25	M14
1N21	1/11/2012	1N(D)	1060	3.400	1N(D)	1060	4.130	40	M14
1N22	1/11/2012	1N(D)	1060	2.800	1N(D)	1060	3.400	40	M14
1N23	1/11/2013	1N(D)	1060	2.000	1N(D)	1060	2.800	40	M14
1N24	1/01/2011	1N(D)	1060	1.160	1N(D)	1060	2.000	25	M14
1N25	1/02/2011	1N(D)	1060	0.480	1N(D)	1060	1.160	25	M14
1N28	1/03/2009	1N(D)	1050	6.300	1N(D)	1050	9.585	25	M12
1N29	1/05/2013	1N(D)	1050	5.032	1N(D)	1050	5.580	40	M14
1S30	1/11/2009	1N(I)	1050	0.400	1N(I)	1050	1.840	30	M12
1S32	1/12/2013	1N(I)	1060	0.000	1N(I)	1060	0.510	40	M14
1S33	1/12/2013	1N(I)	1060	0.510	1N(I)	1060	1.200	40	M14
1S34	1/12/2012	1N(I)	1060	1.200	1N(I)	1060	1.800	40	M14
1S37	1/03/2010	1N(I)	1060	2.468	1N(I)	1060	2.810	25	M12
1S38	1/01/2013	1N(I)	1060	2.865	1N(I)	1060	3.120	40	M14
1S39	1/02/2013	1N(I)	1060	3.120	1N(I)	1060	4.300	40	M14
1S40	1/04/2012	1N(I)	1060	4.300	1N(I)	1060	5.255	25	M10
1S41	1/04/2012	1N(I)	1060	5.255	1N(I)	1060	5.500	30	M14
2N42	1/05/2014	2(D)	962	8.504	2(D)	962	9.206	40	M14
2N43	1/11/2008	2(D)	962	7.515	2(D)	962	8.504	25	M10
2N44	1/11/2008	2(D)	962	4.570	2(D)	962	4.830	25	M10
2N46	1/10/2012	2(D)	962	4.020	2(D)	962	4.330	30	M10
2N47	1/10/2012	2(D)	946	13.863	2(D)	946	14.420	30	M10
2N49	1/10/2013	2(D)	946	13.380	2(D)	946	13.863	30	M10

Section code	Date laid	Section start			Section end			Layer depth	Mix
		SH	Station	km	SH	Station	km		
2N50	1/10/2013	2(D)	946	13.024	2(D)	946	13.380	30	M10
2N51	1/10/2013	2(D)	946	12.865	2(D)	946	13.024	30	M10
2N53	1/04/2010	2(D)	946	7.430	2(D)	946	7.686	25	M12
2N54	1/04/2010	2(D)	946	6.890	2(D)	946	7.430	25	M12
2S11	1/06/2011	2(I)	946	6.890	2(I)	946	7.430	30	M14
2S12	1/06/2011	2(I)	946	7.430	2(I)	946	7.686	30	M14
2S13	1/11/2009	2(I)	946	7.695	2(I)	946	7.840	25	M12
2S15	1/10/2010	2(I)	946	8.143	2(I)	946	8.340	25	M10
2S16	1/10/2010	2(I)	946	8.340	2(I)	946	8.575	25	M14
2S17	1/10/2010	2(I)	946	9.710	2(I)	946	10.025	25	M14
2S18	1/10/2010	2(I)	946	10.025	2(I)	946	10.480	25	M14
2S2	1/04/2010	2(I)	946	10.620	2(I)	946	11.680	25	M12
2S52	1/02/2015	2(I)	962	7.579	2(I)	962	9.197		M10
2S56	1/03/2015	2(I)	962	12.123	2(I)	962	12.324		M10
2S6	1/11/2009	2(I)	962	12.579	2(I)	962	12.850	25	M12
2S7	1/11/2009	2(I)	962	12.850	2(I)	962	13.032	25	M12
2S8	1/06/2011	2(I)	962	13.032	2(I)	962	13.632	30	M14
2S9	1/06/2011	2(I)	962	13.632	2(I)	962	14.551	30	M14

B4 Christchurch

The Christchurch OGPA sections were measured on two days during early-spring.

- 14 September 2015, 12 to 14 ºC during measurements
- 15 September 2015, 21 to 24 ºC during measurements.

Section code	Date laid	Section start			Section end			Layer depth	Mix
		SH	Station	km	SH	Station	km		
6E1	1/06/2012	76(D)	3	5.670	76(D)	3	6.150	40	M11
6E2	1/06/2012	76(D)	3	7.300	76(D)	3	7.530	40	M11
6E3	1/02/2014	76(D)	3	7.530	76(D)	3	7.798		M11
6E4	1/02/2014	76(D)	11	0.050	76(D)	11	2.060		M11
6E5	1/02/2014	76(D)	11	2.075	76(D)	11	4.207		M11
6W1	1/06/2012	76(I)	3	5.195	76(I)	3	5.600	40	M11
6W2	1/06/2012	76(I)	3	6.220	76(I)	3	6.842	40	M11
6W3	1/02/2014	76(I)	3	7.477	76(I)	3	7.782		M11
6W4	1/02/2014	76(I)	11	0.060	76(I)	11	2.070		M11
6W5	1/02/2014	76(I)	11	2.086	76(I)	11	4.230		M11

Appendix C: Additional results tables

These results tables relate to chapter 4.

	Auckland (polymer)	Auckland (unmod.)	Hamilton	Wellington	Christchurch
Sections aged less than 1 year at time of measurement					
Number of sections	0	0	8	3	0
Average age, years			0.2	0.4	
Average overall sound level, dB(A)			96.9	97.2	
Average standard deviation, dB(A)			0.70	0.65	
Sections aged 1 to 2 years at time of measurement					
Number of sections	2	1	11	7	6
Average age, years	1.9	1.6	1.5	1.5	1.6
Average overall sound level, dB(A)	98.2	99.5	97.4	96.9	98.2
Average standard deviation, dB(A)	0.52	0.51	0.56	0.53	0.66
Sections aged 2 to 3 years at time of measurement					
Number of sections	5	3	2	9	0
Average age, years	2.4	2.6	2.7	2.5	
Average overall sound level, dB(A)	98.8	98.4	98.1	96.9	
Average standard deviation, dB(A)	0.61	0.57	0.59	0.61	
Sections aged 3 to 4 years at time of measurement					
Number of sections	0	0	0	4	4
Average age, years				3.8	3.3
Average overall sound level, dB(A)				97.1	100.0
Average standard deviation, dB(A)				0.73	0.55
Sections aged 4 to 5 years at time of measurement					
Number of sections	2	10	0	10	0
Average age, years	4.7	4.3		4.5	
Average overall sound level, dB(A)	99.7	98.5		97.4	
Average standard deviation, dB(A)	0.48	0.65		0.63	
Sections aged 5 to 6 years at time of measurement					
Number of sections	11	4	0	4	0
Average age, years	5.4	5.6		5.3	
Average overall sound level, dB(A)	99.2	98.8		96.7	
Average standard deviation, dB(A)	0.52	0.68		0.68	
Sections aged 6 to 7 years at time of measurement					
Number of sections	1	4	0	3	0
Average age, years	6.2	6.3		6.3	
Average overall sound level, dB(A)	100.2	98.3		96.1	
Average standard deviation, dB(A)	0.70	0.60		0.63	

	Auckland (polymer)	Auckland (unmod.)	Hamilton	Wellington	Christchurch
Sections aged 7 to 8 years at time of measurement					
Number of sections	0	12	4	0	0
Average age, years		7.5	7.5		
Average overall sound level, dB(A)		100.4	98.5		
Average standard deviation, dB(A)		0.52	0.63		
Sections aged 8+ years at time of measurement					
Number of sections	14	6	0	0	0
Average age, years	8.4	9.3			
Average overall sound level, dB(A)	99.3	100.2			
Average standard deviation, dB(A)	0.57	0.54			

Appendix D: Influence of tyre inflation pressure

The vehicle used for CPX measurement contributed a higher tyre loading than provided for by ISO/TC 11819-2 (4,600 N vs. 3,200 N), yet was run at the designated pressure (29 psi cold, nitrogen), which will have caused a higher deflection in the tyre than anticipated by the standard. To understand the implications for the accuracy of the research project's CPX measurements, a short study was undertaken to quantify the influence of tyre inflation on the measured CPX sound pressure levels. The results of the study are presented in this appendix.

D1 Methodology

The testing involved driving a vehicle (the same vehicle from the original testing), instrumented with microphones near the contact point between one of the rear tyres and the road, over a section of road. Noise levels for the section of road were measured multiple times with the pressure in the rear wheels of the car being altered between runs.

D1.1 Test setup and equipment

All the instrumentation used for this testing was the same as that used for the original testing. It was performed driving at a steady speed of 80 km/h with two people in the car and was done on a dry road, with moderate winds developing over the second half of the testing.

Table D.1 below shows the tyre pressures used for the various tests. Tyre pressures were kept constant in the front tyres throughout the testing (36 PSI).

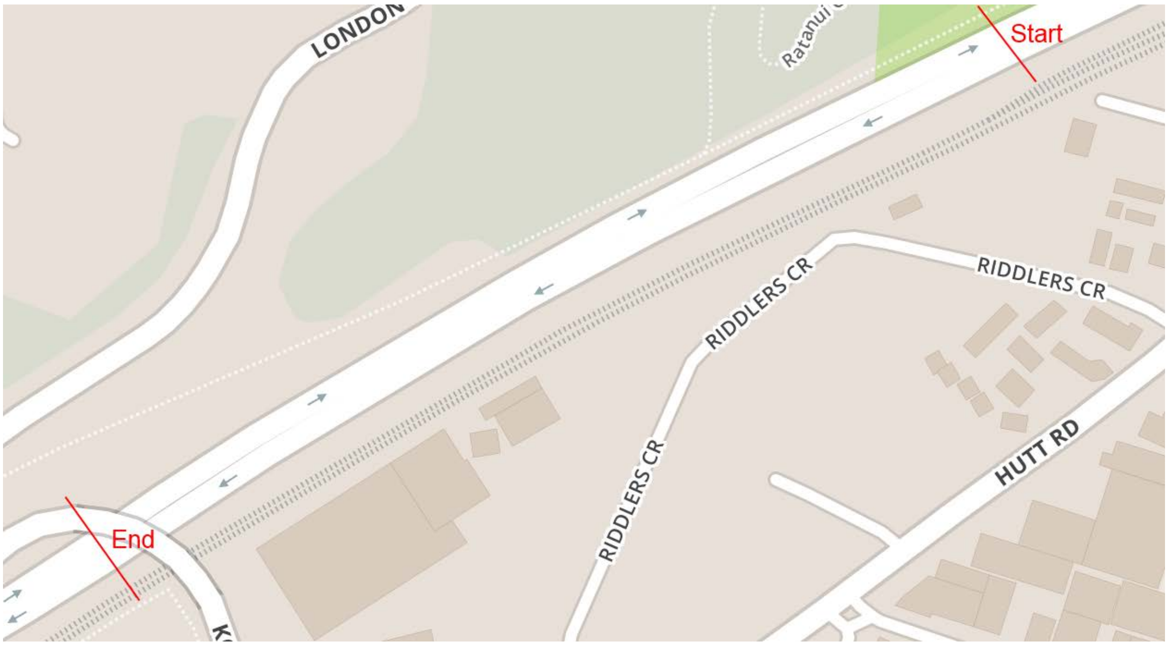
Table D.1 Tyre pressures used in the testing and the air temperature at the time of inflating the tyres

Test number	Number of runs	Rear tyre pressure [PSI]	Air temperature [ºC]	Test time
1	4	25	25.3	13 Dec 2016 – 2.51–3.03pm
2	4	29	24.8	13 Dec 2016 – 2.26–2.38pm
3	4	36	22.3	13 Dec 2016 – 3.18–3.32pm
4	4	42	-	13 Dec 2016 – 1.56–2.10pm

D1.2 Test location

The testing was performed on a section of SH 2 between the Dowse Drive interchange and the Petone railway station. The testing was performed in the slow lane (extreme eastern lane) travelling in a southbound direction. This section of SH 2 is sealed with OGPA. Figure D.1 shows the location of the testing in more detail.

Figure D.1 The location of the test site on SH 2 RS962- I between 10.40 and 10.88



D1.3 Data analysis

The data was analysed using the same MATLAB script used for the original testing. This code breaks the signal down in 20-metre segments and into 1/3 octave bands. For this analysis, the following measures of the noise levels were used:

- average 1/3 octave band noise levels for each tyre pressure
- 20-metre segment average combined noise level for each tyre pressure.

D2 Results

Figure D.2 shows the 20-metre average noise levels for each tyre pressure.

Figure D.2 Plot of the 20- metre average combined noise levels along the route for each tyre pressure

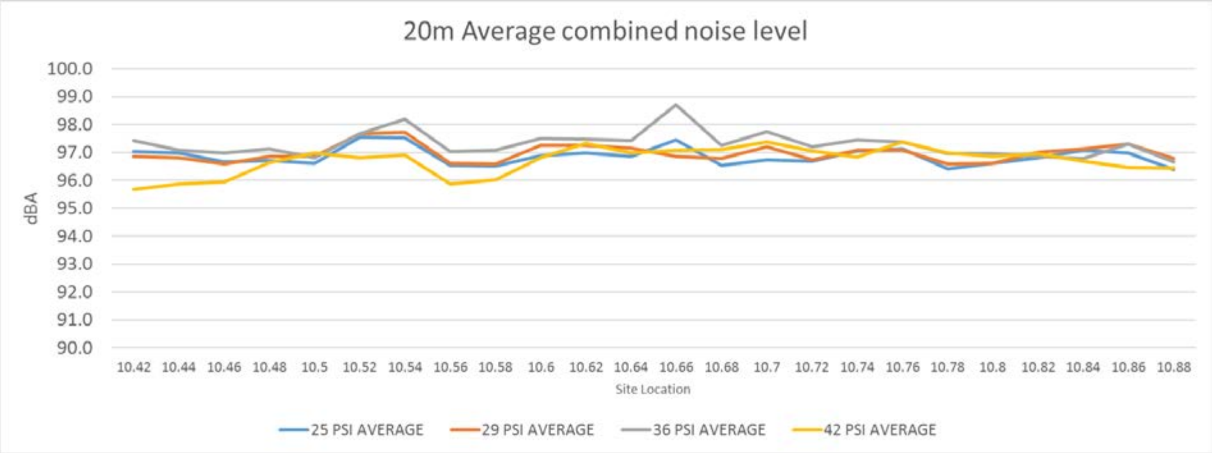
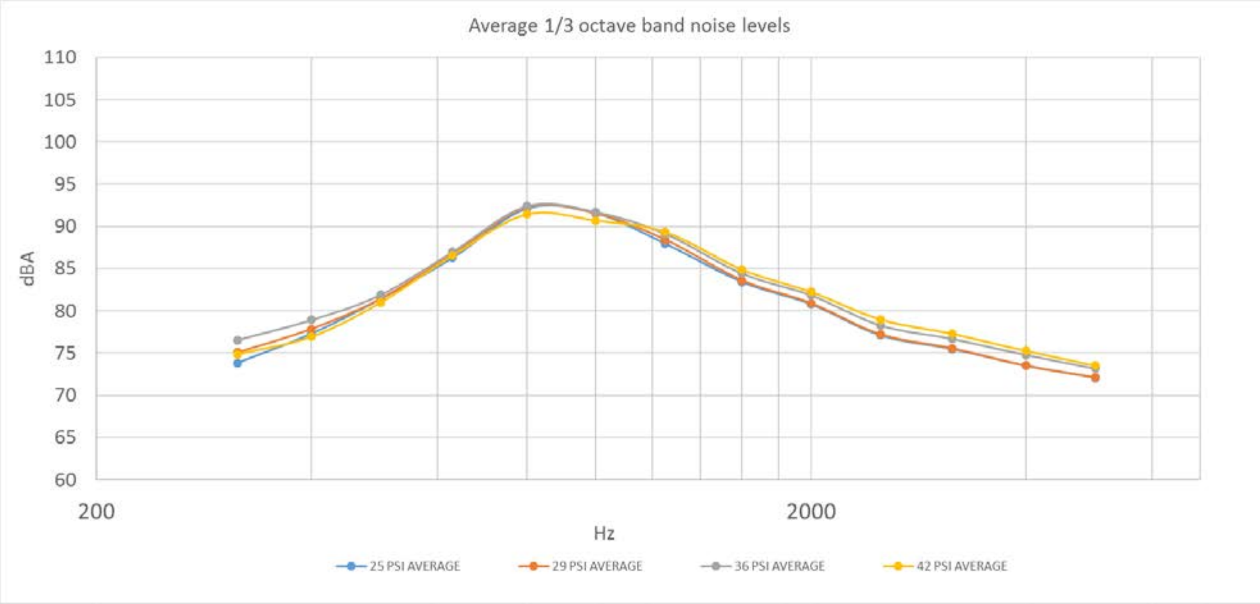


Table D.2 shows the average noise levels (along the entire site length) for the four tyre pressure measurements and figure D.3 shows the average 1/3 octave band spectrum for each tyre pressure.

Table D.2 Table showing the site average noise levels for each tyre pressure

Tyre pressure [PSI]	Site average noise level [dB(A)]
25	96.80
29	96.93
36	97.29
42	96.70

Figure D.3 The average 1/3 octave band spectrum for each tyre pressure



D3 Summary

Testing was performed to measure the effect of tyre pressure on the noise generated by tyre/road-surface interaction. The measurement techniques and analysis were the same as those used earlier in the project. The testing was performed on an OGPA section of SH 2 between the Dowse Drive interchange and the Petone railway station.

The noise measurements found there was very little variation in the 20-metre average noise levels caused by changes in tyre inflation pressure. The average combined noise levels produced by the four different tyre pressures were all covered by a range of 0.59 dB(A) with no clear pattern emerging between tyre pressure and noise level.

There was also little variation in the noise levels when the 1/3 octave band spectra were analysed, although there was a pattern of increased noise levels with increased tyre pressure above 1,000 Hz.

The effect of tyre pressure on the noise levels produced by tyre/road-surface interaction was minimal on this common TNZ P11 OGPA road surface.

Appendix E: Glossary

AASHTO	American Association of State Highway Transportation Officials
AC-10	asphaltic concrete
ASTM	American Society for Testing and Materials
CPX	close-proximity (method)
CS	cape seal
dB	decibel
DG	dense graded
GPS	global positioning system
Hz	Hertz, the unit for frequency (equivalent to 1 cycle per second)
noise/sound	Noise is commonly referred to as 'unwanted sound'. However, within this report, the terms noise and sound are used interchangeably
OGPA	open graded porous asphalt made to *TNZ P/11 Specification for open graded porous asphalt*
RAMM	Road Assessment and Maintenance Management (database)
SAE	Society of Automotive Engineers
SH	state highway
SPB	statistical pass-by (method)
SRTT	standard reference test tyre

For aggregate chip grading/sizing:

ISO 11819-2	acoustics specification for measuring the influence of road surfaces on traffic noise – part 2 close proximity method. Both the 2012 and 2015 drafts are referred to.
NZTA M/6	specification for sealing chip. For the two grades in the text of this report, grade 2 has average least dimension 9.5 to 12.0 mm and grade 4 has average least dimension 5.5 to 8.0 mm.
NZTA M/10	specification for dense-graded and stone mastic asphalts. For the mix in the text of this report, DG 10 has chips of nominal size 10 mm.
TNZ P/11	specification for open graded porous asphalt