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Audio Tactile Profiled Roadmarkings: The Relationships of the Dimensions of the Marking to Noise and Vibration Generated

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ABSTRACT:

This paper describes part one of a research project that is to establish the relationship of the dimensions of audio tactile profiled roadmarkings to the noise and vibration generated when traversed by a vehicle.

Experimentation is using wooden profiles adhered to the road surface to simulate the roadmarking. The wood is being used so that the dimensions of the blocks of the roadmarking can be exactly controlled. Variations being trialled include block height, block width, block spacing, and block shape including rectangular, trapezoid, and rounded from chord to semi-circular.

Noise and vibration is measured in-car as the trial roadmarking is traversed, and subsequent analysis will construct a mathematical model so that the effect of any shape can be predetermined. Some measurements will be made of exterior noise. Coupled with part two of the project, which will assess the subjective effect, part one will allow end of-life dimensions and dimensional tolerances for audio tactile profiled roadmarkings to be established.

Audio tactile profiled roadmarkings: The relationships of the dimensions of the marking to noise and vibration generated.

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This paper describes part of a research project that is to establish the relationship of the dimensions of audio tactile profiled roadmarkings to the in-vehicle noise and vibration generated when those roadmarkings are traversed by the vehicle.

Experimentation is using wooden profiles adhered to the road surface to simulate the audio tactile profiled roadmarking. The wood is being used to form the experimental roadmarking blocks so that the dimensions of the blocks can be exactly controlled. Roadmarking variations being trialled include block height; block width; block spacing; and block shape, including rectangular, trapezoid, and rounded from chord to semi-circular.

Noise and vibration is measured in-car as the trial roadmarking is traversed, and subsequent analysis will construct a mathematical model so that the effect of any block configuration can be predetermined. Some measurements will be made of the exterior noise as the trial roadmarkings are traversed. Coupled with another part of the project, which will assess the subjective effect, this part of the project will allow end-of-life dimensions and dimensional tolerances for audio tactile profiled roadmarkings to be established.

Introduction

Audio tactile profiled roadmarkings are increasingly featured on New Zealand roads. There was a historical but very minor use of these roadmarkings prior to about 2004, then *Transit New Zealand* implemented a major safety initiative and now approximately $4 million of new installations on State highway roads are funded each year. Other road controlling authorities also fund audio tactile profiled roadmarking installations.

At present the dimensions specified for audio tactile profiled roadmarkings are based on the design of a United Kingdom product that has been available in New Zealand since the early 1990s. The use of this design is ad hoc in that it is believed to work but we do not know how its "effectiveness" is influenced by height, width, length, and spacings of the blocks.

There are about four main issues emerging where the relationship of effectiveness to the dimensions of the roadmarking needs to be known.

1. Industry, seeking to use the latest long-life materials with the best economic use of these high-cost materials, is advocating innovative designs. The potential for learning from established overseas experience is therefore reduced. There is a need to have methods to determine which new styles of audio tactile profiled roadmarkings are delivering physical effects that elicit the required driving response.

2. There is uncertainty as to when "end of life" of audio tactile profiled roadmarkings is reached, as the minimum noise and vibration response that delivers an effective subjective performance has yet to be determined. Generally, audio tactile profiled roadmarkings wear by rounding and flattening of the profile, abrasive loss of material, and by separation of pieces of the roadmarking from the roadway. Minimum dimensions need to be defined together with specification of a minimum "degree of intact" blocks. Noise and vibration is experienced relative to the road surface on which the audio tactile profiled roadmarking is placed and so there is the need to identify whether different minimum dimensions are needed on coarse and smooth road surfaces.

3. Applicators of audio tactile profiled roadmarkings cite a need for quite large dimensional tolerances when laying these roadmarkings, for example because it is not an easy task to control the dimensions of the fluid material prior to it hardening. But it is uncertain whether these tolerances allowed for in application are more than a minor part of the dimensions required for the audio tactile profiled roadmarking to remain effective.

4. The roading industries, in general, and the roadmarking industry, in particular, are moving to performance-based specification and contract management. For audio tactile profiled roadmarkings this move has been so far hindered because not enough is known about patterns and dimensions of blocks that are effective in generating the required driver response. This did not begin to emerge as a problem until recently as previously only one type of suitable material dominated and the roadmarking profile design was confined to being of only a few patterns. Methods-based approaches for audio tactile profiled roadmarkings therefore appeared appropriate.

   A complication of using a performance-based approach is the complexity of measurement. Measuring the noise and vibration is reasonably straightforward but it does require skilled personnel using specialist equipment. Measuring "effectiveness" of audio tactile profiled roadmarkings is much more difficult. Measuring driver response requires a complex psychological trial, and the cost and difficulty of this trial would tend to stifle innovation and progressive development of products.

Currently there is no accepted method for testing the resulting roadmarkings for performance - either in terms of audio and tactile response or in terms of effective lifetime with respect to retaining key critical dimensions. This is the context within which audio tactile profiled roadmarkings research projects lie. The first of two completed projects identified methods by which the physical effects of noise and vibration could be measured. The second completed project sought to establish broad relationships between physical dimensions and the noise and vibration generated. The work reported in this paper is for a third project that aims to develop an economical method for determining whether a particular audio tactile profiled roadmarking meets acceptable performance standards, without the need for manufacturers and road agencies to run further complex human response tests for individual roadmarking types and to establish minimum dimensions of the marking for performance and permissible application tolerances.

Previous work

Central Laboratories Report 03-527605 *Guidelines for Performance of New Zealand Markings* describes investigations of the in-vehicle noise experience created when trafficking upon audio tactile profiled roadmarkings. This project was a preliminary study to identify methodologies for measuring the noise and vibration effects so as to consider the potential for performance based measures. The project included driving a test vehicle, instrumented with a sound level meter, upon a type of audio tactile profiled roadmarking, called *Vibraline*, at 100 km/h. Figure 1 and Figure 2 show graphs reproduced from that project. The graphs show the in-vehicle response spectra for a car travelling on *Vibraline* in "good" condition, on *Vibraline* in a "worn" condition, and on typical New Zealand open road surfaces of Grade 3 chipseal and open graded porous asphalt (OGPA). The vibration spectra on Figure 2 are simplified excerpts from the full vibration spectra; concentrating on the area of 40 to 60 Hz, where a clear pattern of difference between markings of different conditions appears to be shown. (The assessments of the *Vibraline* samples as "good" and "worn" were subjective only and not determined by any dimensional measurements.)

Figure 1 In-vehicle noise spectra for a car travelling at 100 km/h

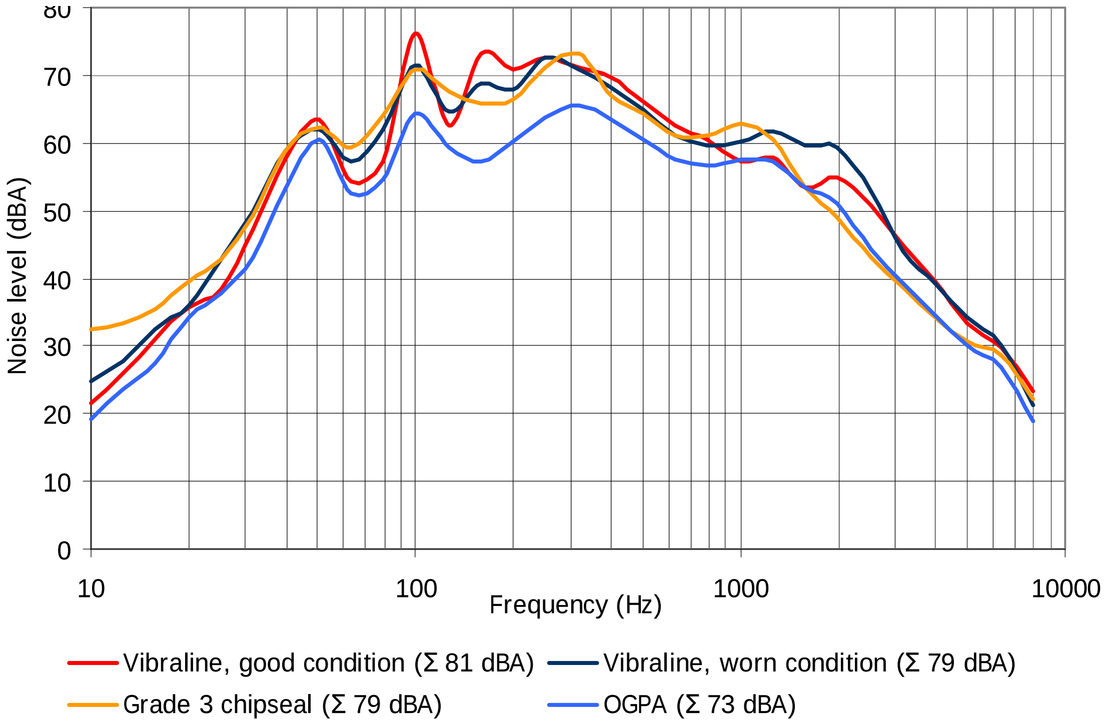
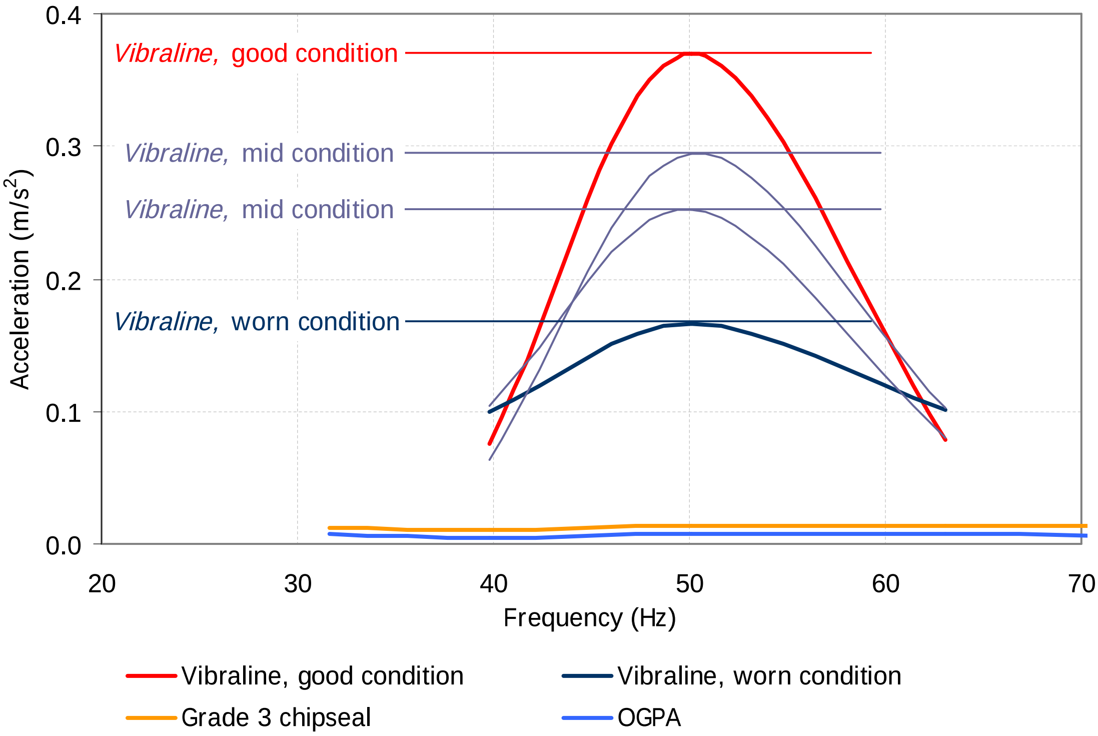


Figure 2 In-vehicle vibration 40 to 60 Hz spectra for a car travelling at 100 km/h



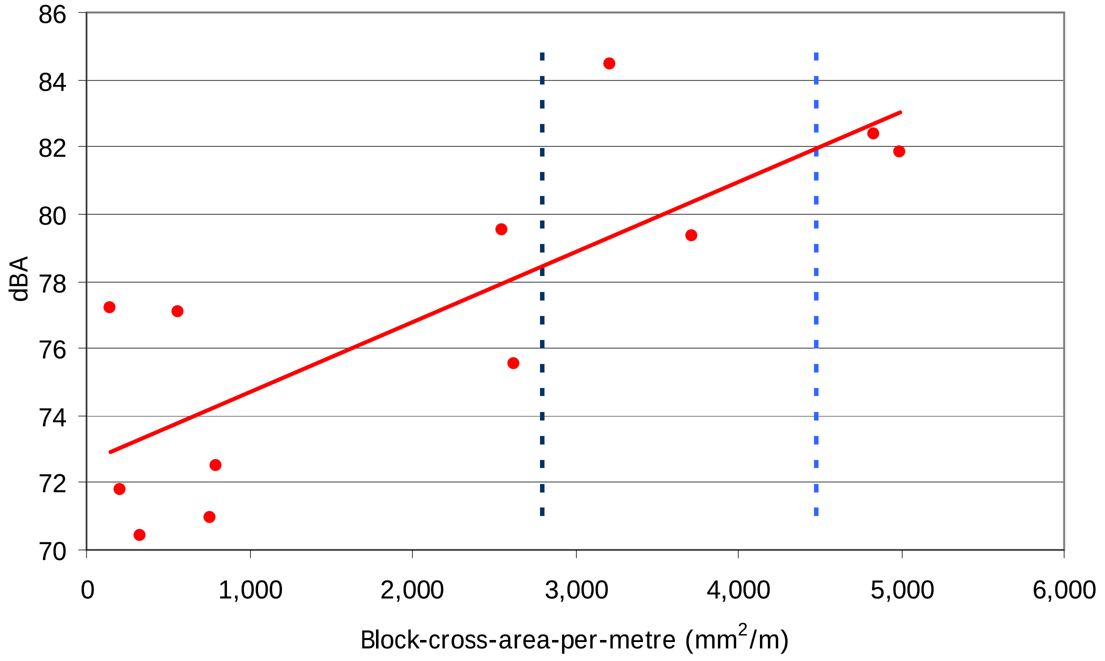
Relating effects and dimensions

The second project extended the work of the first project and sought to establish in broad terms the effect of dimensions on the noise and vibration levels and the extent that these were noticeable. The intent was to develop some initial "end of life" criteria.

An instrumented test car was used to traverse audio tactile profiled roadmarkings and record the sound and vibration levels inside the cabin. Subjective assessment of the audio and tactile effect of the audio tactile profiled roadmarkings was also made by the two in-vehicle occupants as the roadmarkings were traversed. Physical measurements of the dimensions of the audio tactile profiled roadmarkings were taken at a separate occasion as this required partial road closure. The dataset was analysed to determine which physical properties of the audio tactile profiled roadmarkings contributed most to the audio and tactile effects.

Identifying a relationship between noise (or vibration) effects and physical dimensions was complicated by the variability in dimensions of the in situ audio tactile profile roadmarkings. Pitch of the blocks and width of the roadmarking were reasonably consistent but block height was found to be quite variable, with variations of 2 to 3 mm in height for the individual blocks within each cluster of blocks measured dimensionally. This range in block heights can be 30 percent to 50 percent of the average block height. Therefore to develop a relationship between dimensions and effects, several relationships were examined, including block height versus noise; block face area versus noise; block face area per linear metre versus noise; and block volume per linear metre versus noise. The relationship of block face area per linear metre versus noise gave the strongest relationship ($R^2 \approx 0.63$) which is, however, still too weak to be of use. This is shown in Figure 3. (The noise level plotted in Figure 3 is noise of the audio tactile profiled roadmarking being traversed with the effect of the other two tyres on the road surface extracted.)

Figure 3 Block face area per linear metre versus measured audio effect



Several issues arise out of this study.

1. The difficulty of attempting to identify relationships between dimensions and effects when in-situ material shows considerable variation of critical dimensions.
2. The likely bias in subjective response when evaluators are deliberately searching for the effect.

3. The relevance of the vibration response when it appears less readily detectable subjectively and also appears, so far, to be strongly related to the more easily measured and detected noise response.

This third project on audio tactile profiled roadmarkings is intended to resolve a number of these problems encountered earlier.

The project will develop two numerical methods that separately link the dimensions and shape of the audio tactile profiled roadmarkings to the noise response and to the vibratory response, and a further model that relates these noise and vibration effects to the subjective response of drivers. Working from the driver-response thresholds identified, the models will then be used to establish minimum and maximum dimensions as acceptable tolerance limits for audio tactile profiled roadmarking applicators. The models will also be able to be used by the sector in delivering new and innovate audio tactile profiled roadmarking profile designs.

The physical response model is being developed by measuring in-vehicle noise and in-vehicle vibration while the vehicle traverses a special test section of audio tactile profiled roadmarkings. Test runs have varied the parameters of profile height, profile pitch, profile width, and profile shape. To ensure accuracy, first specimens of pre-screeded thermoplastic adhered to the road were used, then test profiles were machined from wood and adhered with double-sided tape to the road surface. Correlation to in-situ audio tactile profiled roadmarkings will be provided by data collected by further field measurements.

The second stage of the project measuring the subjective driver-response will be achieved in two ways. Test subjects will drive over particular profiles known to deliver physical effects ranging from weak to strong, and their response determined. Separately subjects will be played back noise and vibration effects in controlled laboratory conditions, and responses assessed.

From these two sets of experimental results the model that relates subjective response to noise and vibration will be developed.

Method

For road user safety purposes the experimentation needed to be undertaken in private-road conditions and after practice runs in the Central Laboratories yard two main experimental series were conducted on hired roads.

The first series of tests were undertaken at the Manfeild racing circuit near Palmerston North. The second series was at the Paraparaumu airport near Wellington. This use of hired test areas with attendant significant time and hire costs influenced how the experimentation was conducted. In particular, the available time was used to complete tests of as many parameters as possible. The data were post-processed in the following days.

A test car was driven over wooden test blocks of different size and shape, representative of sizes and shapes of audio-tactile road markings, which were stuck to two different flat, uniform road surfaces at a range of spacings. In-vehicle acceleration (vibration) and in-vehicle sound level were measured for each run while the driver controlled the speed to 40, 60 or 100 km/h +/-5 km/h.

The wooden test blocks were cut from pine timber into shapes to give variation in height, width and length of the block and the angle of the rising edge facing towards the oncoming car. Figure 4 shows these dimensions. Table 1 and Table 2 show the combination of dimensions used. Traffic Safety Products Ltd made some additional blocks of thermoplastic by a screeding process over release paper; to represent an ideal audio-tactile profile road marking. A further two sets of wooden markings with a round profile were used to show the effect of a round profile. The test blocks were stuck to the road surface using double sided tape in a single line with block spacings of either all 250mm, or all 500mm, or all 750mm.

The test car was a 1996 Toyota Corolla GL Wagon (front-wheel drive) with less than 20,000 km driven. Figure 5 shows the test car next to a line of test blocks at the Manfeild racetrack. Tyres were inflated to 32 psi when cold.

Sound was recorded through a Rion NL-32 sound level meter mounted behind the driver's left ear. The sound meter outputs an analogue sound pressure signal which was logged on a multi-channel Logbook Data Logger at a rate of 12,500 Hz. A tri-axial accelerometer was mounted in the passenger's footwell on the central partition below the gear lever. Accidentally, the accelerometer only logged in-vehicle acceleration in one dimension, the direction of motion, when at Paraparaumu and the accelerometer did not log at all at Manfeild.

Figure 4 Dimensions of the test blocks.

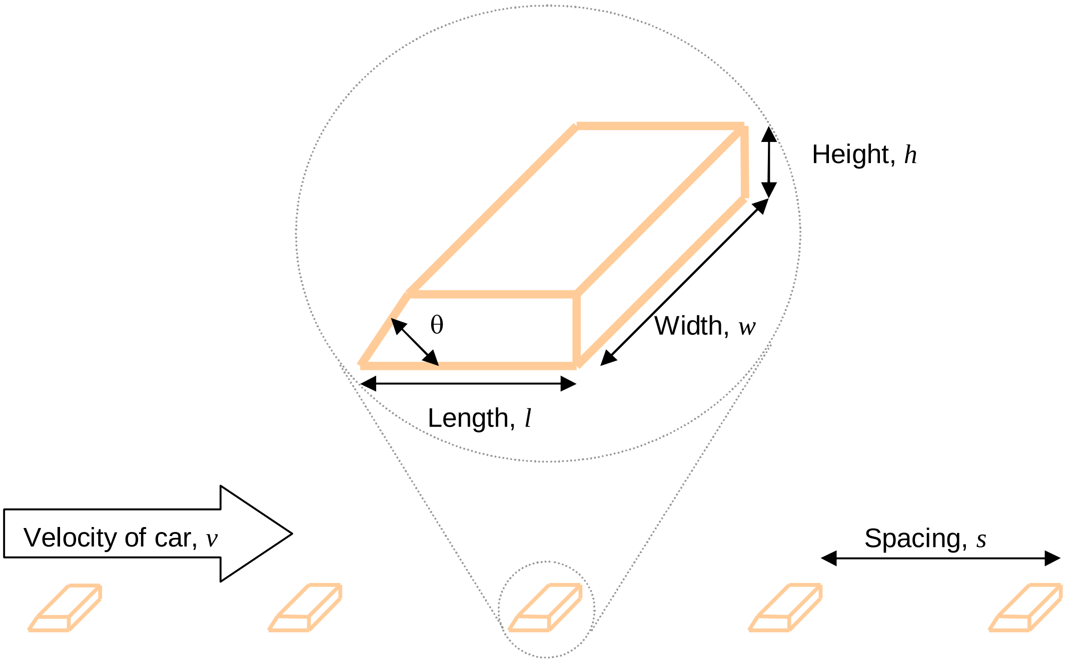


Table 1 Size and shape of blocks used at the Manfeild race track and the speeds and spacing of blocks used at that site.

Height (mm)	Width (mm)	Length (mm)	Angle (deg)	Spacing (mm)	Speed (km/h)
6	100	40	90	250, 500, 750	40, 60, 100
10	100	40	90	250, 500, 750	40, 60, 100
14	100	40	90	250, 500, 750	40, 60, 100
10	100	40	70	250, 500, 750	40, 60, 100
10	100	40	45	250, 500, 750	40, 60, 100
10	100	40	25	250, 500, 750	40, 60, 100

Table 2 Size and shape of blocks used at the Paraparaumu airstrip and the speeds and spacing of blocks used at that site.

Height (mm)	Width (mm)	Length (mm)	Angle (deg)	Spacing (mm)	Speeds (km/h)
14	100	40	90	250	40, 60
10	100	40	30	250	40, 60, 100
10	100	40	45	250, 500	40, 60, 100
10	150	80	45	250, 500, 750	40, 60, 100
14	150	80	45	250	40, 60, 80
10	150	80	90	500	40, 60,100
10	150	80	90	750	40, 60
14	150	40	½ round	250, 500, 750	40, 60, 100
10	150	37	½ round	250, 500, 750	40, 60, 100
8 Thermoplastic	150	60+/-5		250, 500, 750	40, 60, 100

Figure 5 The test car next to a line of test blocks on the Manfeild race track and a selection of four wooden test blocks and a thermoplastic test block that were used in the testing. The car is shown facing the opposite direction to that travelled during the testing.

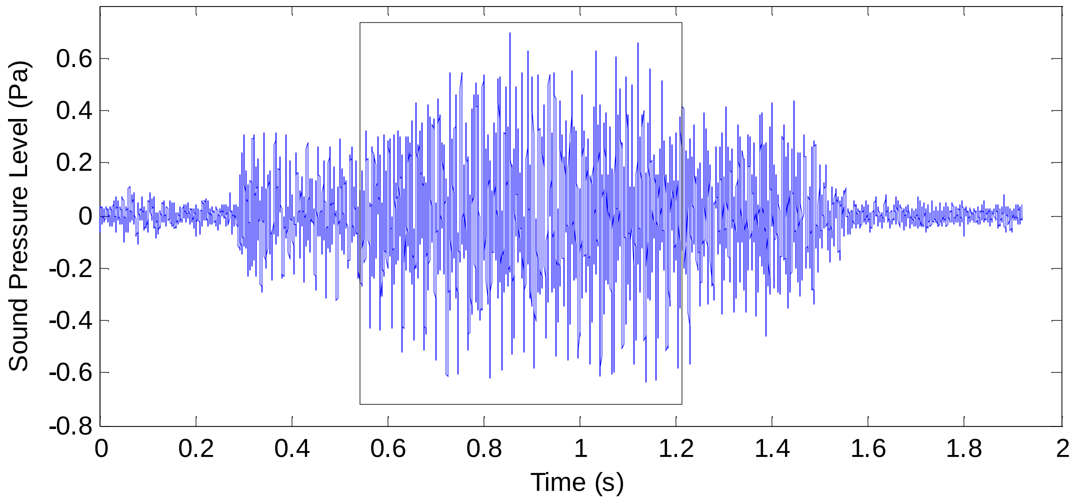
The driver and passenger of the test car assessed whether the wheels hit the full line of test blocks and only the successful runs were used for further analysis.

Results

The loudest section of the sound pressure signal was selected in post processing as shown in Figure 6. This section of the sound pressure represents the time that both tyres hit the full face of the test block. Figure 6 shows the selected loud section of the sound pressure level. The 0.23 seconds before and after the loud section corresponds to the front and rear wheels hitting the trip of blocks separately as the 2.6 metre vehicle wheelbase travels at 40 km/h (11.1 m/s) for this illustrated run.

Figure 6 also shows that there is significant variation in the sound level even within the section where both wheels are thought to be hitting the test blocks. This suggests that while the driver and passenger of the car thought that the car hit the blocks squarely they actually drifted across and back over the blocks along the length of the test line, so that contact oscillates between "full contact" and "partial contact" during the test.

Figure 6 An example of time history of sound pressure level from Manfeild race track. Test blocks were 14 mm high, spaced 250 mm apart. The velocity of the test car was 40 km/h. The loudest section is shown in the box.



The equivalent noise level was calculated from the sound pressure level time series for each test run using Equation 1. Dravitzki et al. (2007) shows there is a good relationship between noise and vibration inside a car travelling over audio-tactile road markings on a road so it is reasonable as a first stage to only analyse noise and not acceleration.

$$L_{eq} = 10\log_{10}\left(\frac{1}{T_2 - T_1}\int_{T_1}^{T_2}\frac{p^2(t)}{\left(20x10^{-6}\right)^2}dt\right)$$

Equation 1

Where: L_{eq} is the equivalent noise level over the loudest section.

T_1 is the time when the noise level first increases above background noise.

T_2 is the time when the noise level first drops below the background noise.

$p(t)$ is the instantaneous sound pressure level.

t is time.

The equivalent noise level was tabulated against block parameters, spacing and velocity. A 6 dimensional non-linear regression analysis was carried out on this tabulated data using the curve fitting program LAB-Fit (Silva and Silva).

Rudder (1987) in Leventhal (1987) gives a formula to predict the dynamic loading on a road from a car travelling over a pot hole or bump as shown in Equation 2.

$$P_0 = kh\frac{v}{lf}\frac{\cos(\pi fl/v)}{\left(\frac{v}{2lf}\right)^2 - 1}$$

Equation 2

Curve fitting to Rudder's (1987) equation gave a very poor correlation (R^2 =0.22) so is considered unacceptable.

Several empirical formulae based on semi-mechanistic principles were tried, in an effort to improve the correlation between the block parameters and the noise level. However even the best fit had a correlation of only R^2=0.68 so is also considered unacceptable.

A correlation analysis between all the block shape parameters, vehicle speed and Noise Level without road markings and the measured equivalent noise level was conducted.

Table 3 Correlation matrix between the test parameters and the equivalent sound level (Leq) near the driver's ear.

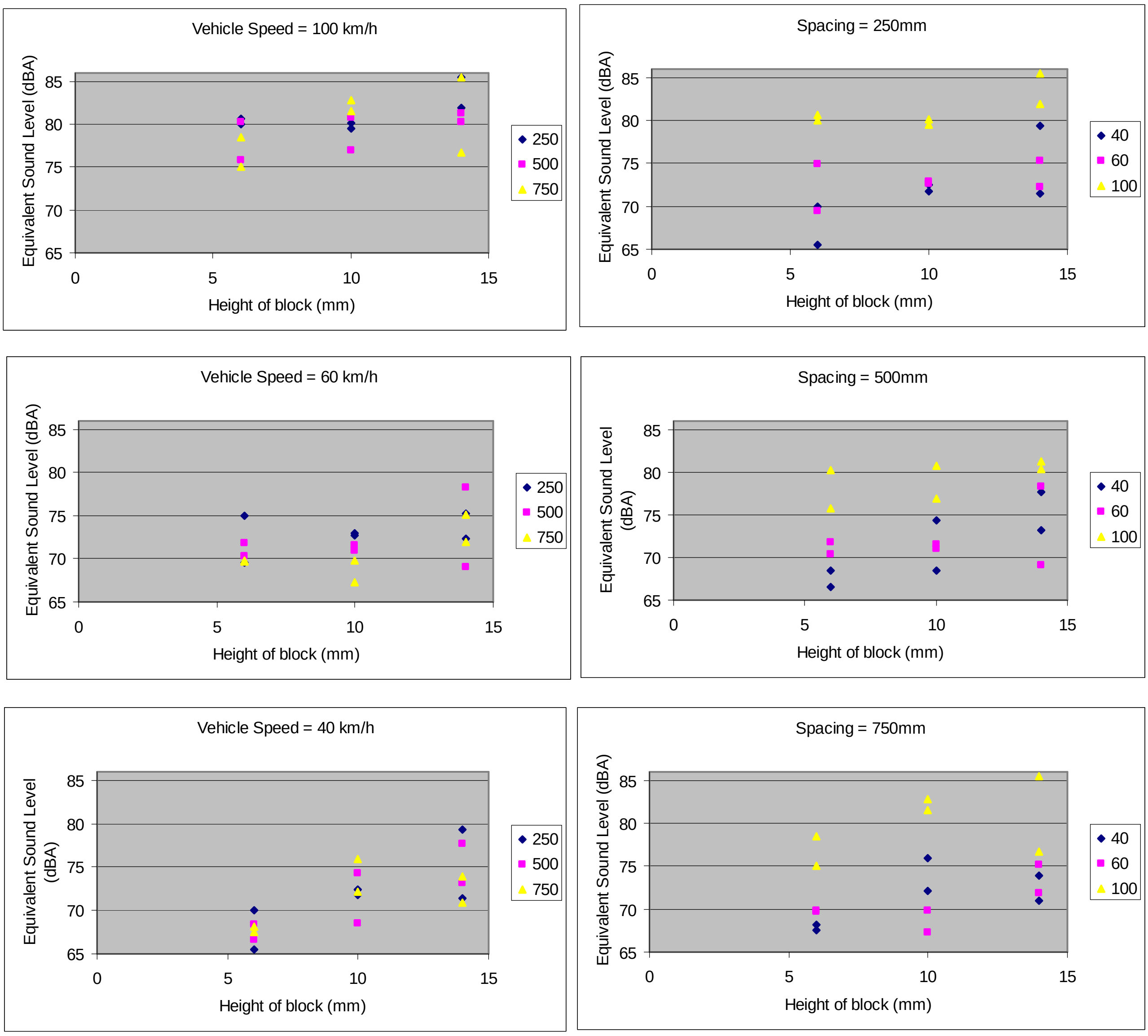
	Speed	**Spacing**	**Length of Block**	**Height of Block**	**Width of Block**	**Angle of Facing Edge**	**L_{eq} with no Test Blocks**
Spacing	0.1						
Length of Block	-0.07	0.14					
Height of Block	-0.11	-0.04	0.15				
Width of Block	-0.09	0.09	0.96	0.19			
Angle of Facing Edge	-0.01	0.01	-0.04	0.05	0.		
Leq with no Blocks	0.93	0.14	-0.28	-0.16	-0.29	0.04	
Equivalent Noise Level	0.65	-0.11	0.15	0.24	0.15	-0.11	0.49

Table 3 shows that there is some weak correlation (R^2 of 0.65 and 0.49) to equivalent noise level from speed of the vehicle and the equivalent noise level from the test surface with no test blocks. The variable of "height of blocks" shows very low correlation with equivalent noise level. The other block parameters show even less correlation with equivalent noise level.

There is significant correlation between speed and the equivalent noise level from the test surface without profiled road markings. This is because this calibration noise level was measured at each of the three test speeds and the relationship of noise with speed is already well established. There is also strong correlation between the length of blocks and width of blocks. This is because only height and width were not varied and tested independently due to time constraints at the test sites.

Plotting height of the test blocks versus sound level, as shown in Figure 7, shows a general trend to higher sound level with higher height of block. However it also shows that there is considerable variability in the equivalent sound level from subsequent test runs over the same blocks at the same spacing and speed. For example, the equivalent sound level from driving over 14 mm high blocks at 500 mm spacing at 60 km/h could be louder or quieter than driving over 6 or 10 mm high blocks in the same conditions. Similarly with blocks spaced at 500 mm and driving at 100 km/h the variation in equivalent noise level inside the car on 6 or 10 mm blocks masks whether there is little to no change in equivalent noise level or there is a significant increase as height of block increases.

Figure 7 Height of block versus equivalent sound level grouped by speed (40 to 100 km/h) of vehicle and spacing (250-750 mm). All from the Manfeild race track.



Vehicle Speed = 100 km/h

Spacing = 250mm

Vehicle Speed = 60 km/h

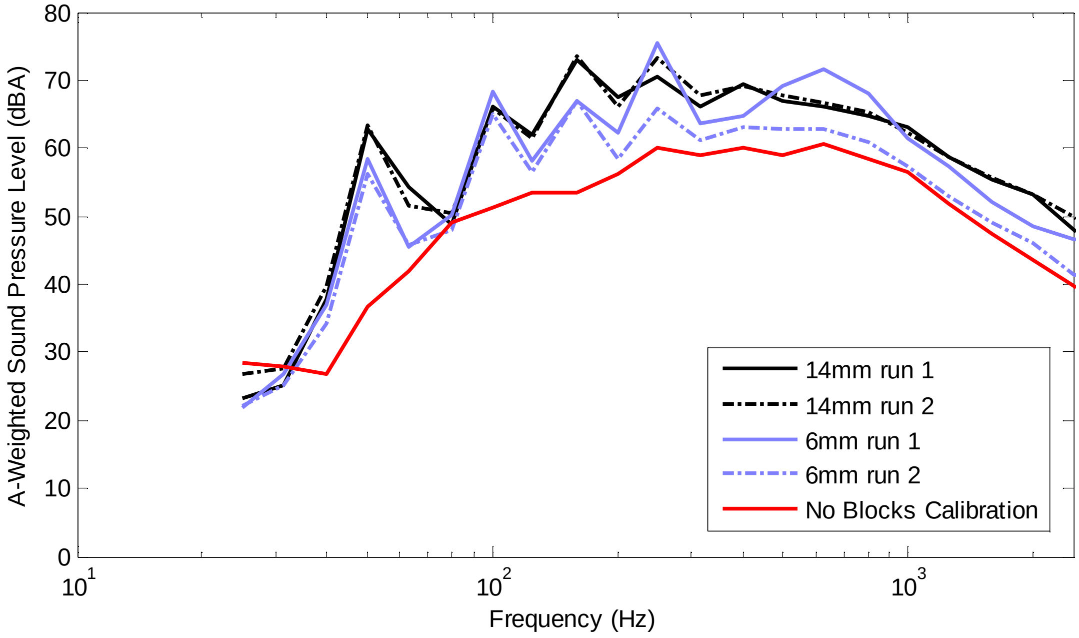
Spacing = 500mm

Vehicle Speed = 40 km/h

Spacing = 750mm

Figure 8 shows further evidence of variation in sound levels between test runs over the same blocks. The 1/3 octave band spectral analysis of A-weighted sound pressure level shows that the two runs over 14 mm blocks are very consistent. However, the two runs over 6mm blocks are not at all consistent. The peak at 230 Hz and a further peak at 620 Hz dominate the calculation of equivalent noise level for the first run over 6 mm blocks. These peaks are higher than the values for the larger blocks confirming that there is more variation between test runs over the same blocks than there is between test runs over blocks of different heights. Figure 8 does show however that any of these blocks have a pronounced effect on noise compared to travelling on the road surface only.

Figure 8 1/3 octave band spectral analysis of A-weighted sound pressure level measured inside the test vehicle while driving at 100km/h over 14mm high blocks 6mm high blocks spaced 500mm apart and the same surface with no blocks laid.



Discussion

The variability between repeat runs on the same block spacing and size obstructs identifying the effect that the block dimensions may be having on the generation of noise and vibration when traversing the simulated audio tactile profiled roadmarking line. Because of this variation there are low levels of confidence (low R^2 values) in relationship identified. The first issue that needs to be addressed therefore is to improve the technique so as to have a reliable measurement for each block size and spacing combination used. At this stage the cause of the low repeatability is not known.

It may be the effect of not being able to keep the tyre in a consistent position on the line. The blocks tested were usually only 100 mm in width though some runs were done with blocks 150 or 200 mm wide. However the tyre is approximately 150 mm wide so there could easily be some sideways wander along the line. The signal obtained does tend to support this. (See Figure 6 and the accompanying discussion. A possible solution is therefore to not attempt to accurately simulate lines of standard width but examine the effects using wider blocks such as up to 300 mm wide so that consistent tyre contact is certain. If this was successful it would identify that the more narrow the block (and line), the more uncertain is its effect in practice.

Another possibility is that the in-car noise measurement is inherently variable, and the solution would be to carry out three to five runs of each variation in block configuration and selection, so as to produce a stable average for comparison with similar stable average results with each variation. Figure 10 and Figure 10 show measurements of repeat runs done out-of-car on two types of road surface, measuring road surface effects only. These multiple runs are consistent within 1 dBA and for the spectral content above 200 Hz. However there is variation at lower frequencies which for this work had no impact on the overall result. Comparison of Figure 10 and Figure 10 with Figure 8

Figure 10 Repeatability of noise measurements of car on AC road surface
Five runs measured outside of vehicle (mean = 68.9 dBA)

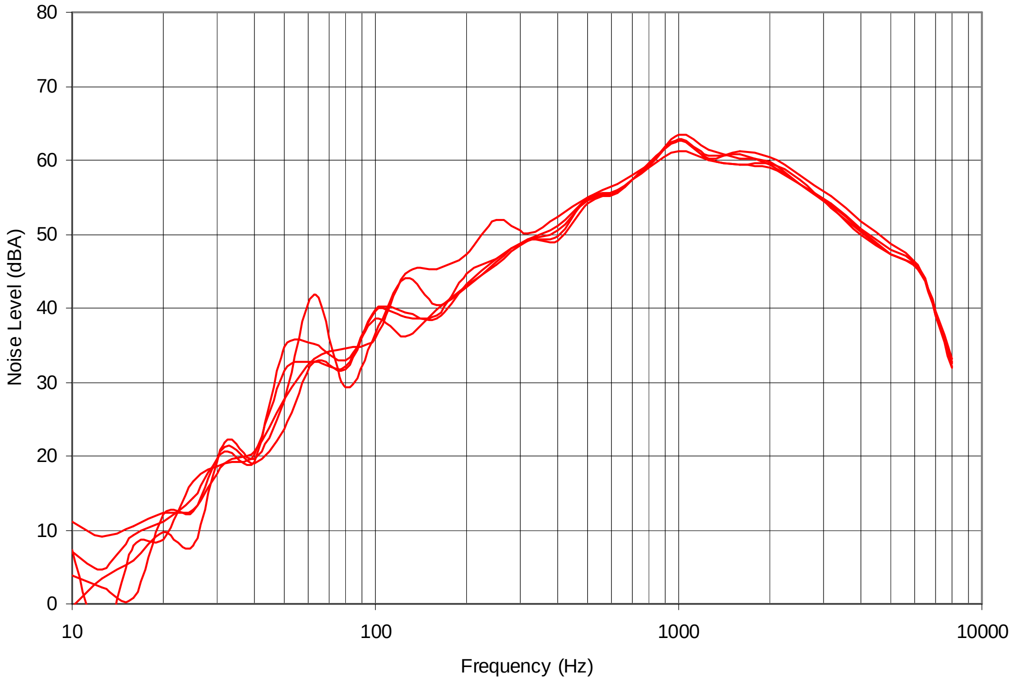
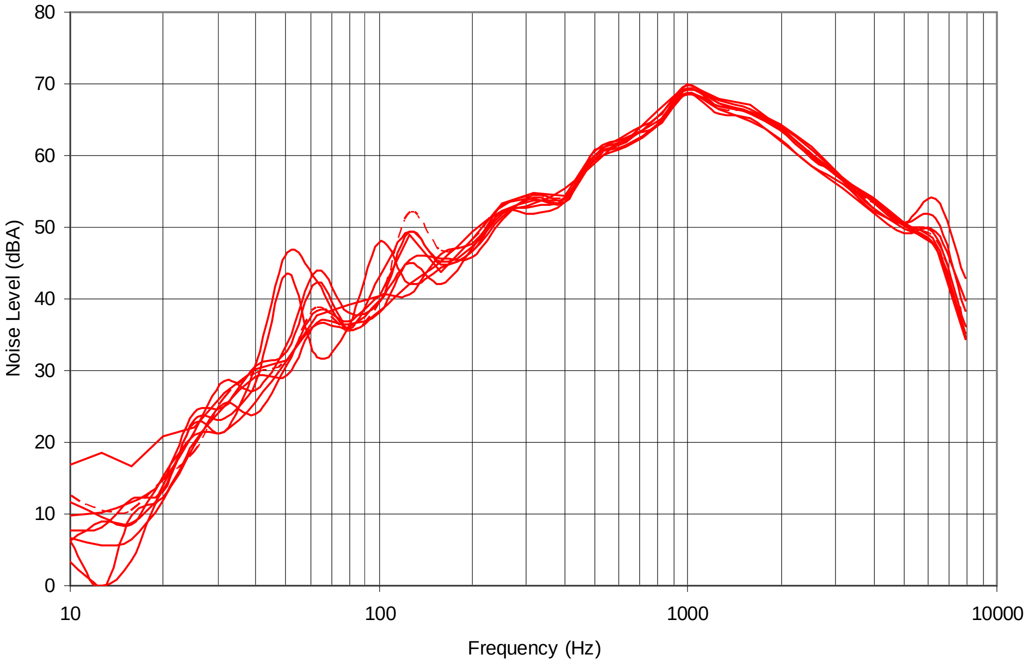


Figure 10 repeatability of noise measurements of car on Grade 3 chipseal road surface
Nine runs measured outside of vehicle (mean = 74.5 dBA)



shows that the in-car noise level is much higher at these lower frequencies especially when the blocks are being traversed.

Another approach may be to measure the dimension effects with noise measurements taken outside of the car, but as Figure 10 and Figure 10 show, noise measurements taken outside of the car on a road surface show variation in the same region of the noise spectra as where the blocks have effect, and where mechanical noise from the car can also be evident.

One significant learning that does come from this work is that a performance based approach to the effect of audio tactile profiled roadmarkings may not be appropriate. This work has shown variability in noise effect which is either inherent in attempting to measure noise within a car where it is subject to interior effects and mechanical noise from the car, or to variability coming from the difficulty of tracking the line. It helps confirm the validity of the intent of this research, that is to develop a knowledge of the dimensions/noise and vibration relationship through controlled experiments so that the performance measure is merely that dimensions are retained.

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