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Measuring the effects of audio tactile profiled roadmarkings

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Abstract

When driven upon, audio tactile profiled roadmarkings provide both audio and tactile feedback to the driver, who then responds to the stimuli and corrects the position of the vehicle on the roadway. Three factors are critical to the success of the interaction: the level of noise generated; the level of vibration generated; and the ability of the driver to detect, interpret, then respond to this audio and tactile information.

This paper describes work in progress establishing the relationship between the dimensions of the roadmarkings, the physical effects that they produce, and the ability of drivers to detect and interpret these effects.

A preliminary study has established a methodology for measuring the physical effects. A second study has measured the effects of a number of audio tactile profiled roadmarkings in situ, and established some relationships between physical effects and dimensions, but these relationships are complicated by the variability of dimensions of these in situ roadmarkings. The subjective assessment of effects is probably of low validity because of the methodology used. A third study is about to take place which will use more dimensionally-consistent test roadmarkings and include a proper psychological study of driver experience.

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, but *Transit New Zealand* have implemented a major safety initiative and now fund approximately $4 million in new installations each year. Other road controlling authorities also fund installations. These audio tactile profiled roadmarkings are typically made out of hard-wearing materials. While the ultimate life is uncertain, three to eight years is the expectation.

Three main issues are emerging.

1. Industry, seeking to use the latest long-life materials, is advocating innovative designs to give the best economic use of these high-cost materials. The potential for learning from established overseas experience is therefore limited. 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. Noise and vibration is experienced relative to the road surface on which the audio tactile profiled roadmarking is placed and so data specific to New Zealand is critical.

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 no more than a minor part of the dimensional changes required for the audio tactile profiled roadmarking to remain effective. These issues need to be resolved as audio tactile profiled roadmarkings are believed to be a valuable safety initiative to promote lane-keeping and avoiding "run off the road" type crashes.

A fourth issue emerging is the viability of a performance-based approach to audio tactile profiled roadmarkings. 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 hindered because not enough is known about patterns and dimensions 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 a few patterns. Methods-based approaches therefore appeared appropriate.

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. 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.

Now, as the demand for audio tactile profiled roadmarkings continues to increase, the roadmarking industry is continually developing new technologies and specifications aimed at providing a better product. However there is currently 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.

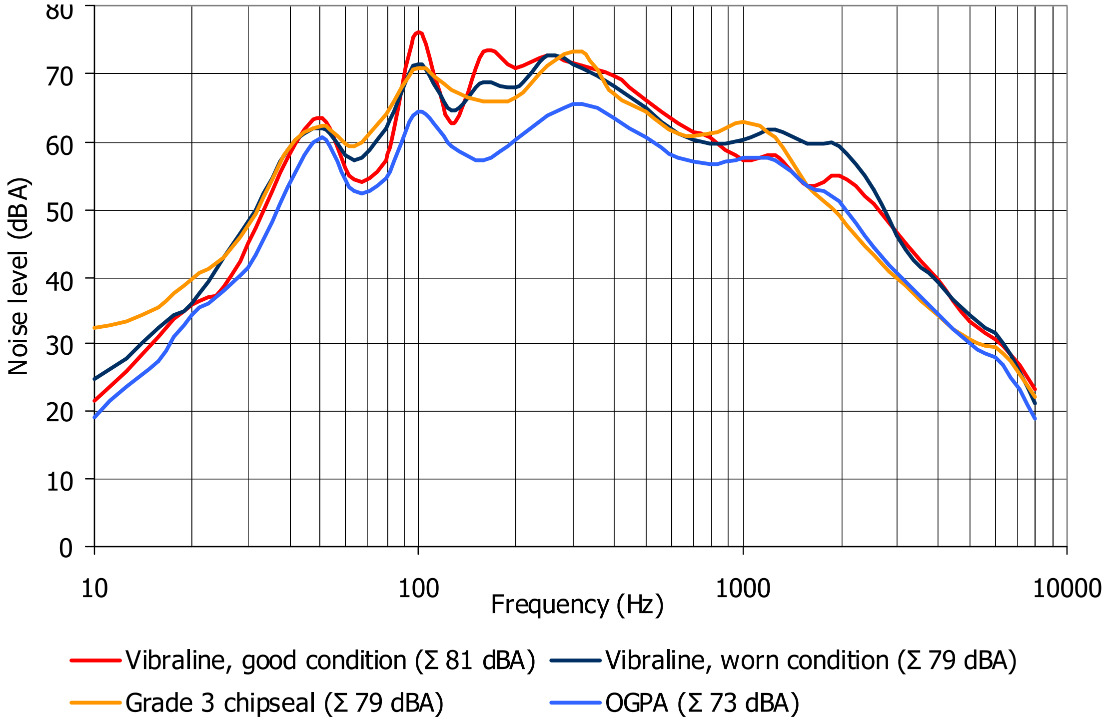
This is the context within which audio tactile profiled roadmarkings research projects lie. The first of two completed projects identified methods by which the physical effects of noise and vibration could be reliably measured. The second project sought to establish broad relationships between physical dimensions and the noise and vibration generated. A third project about to start will 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. Instead modelling of effects will be used.

Measurement of audio and vibratory effects

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. 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 shows a graph reproduced from that project and shows the in-vehicle noise 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 assessments of the *Vibraline* samples as "good" and "worn" were subjective only and not determined by any dimensional measurements.)

In terms of overall noise levels, the *Vibraline* in "good" condition is 9 dBA more noisy than the vehicle on open graded porous asphalt but only 2 dBA greater than the "worn" *Vibraline* and the chipseal road surface. The spectra show the surfaces have different dominant frequencies indicating there would be some tonal distinction between the in-vehicle experiences.

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



As part of the same project, the vibrations inside a car travelling at 100 km/h were recorded as the car trafficked upon *Vibraline* in a "good" conditions, upon *Vibraline* in a "worn" condition, and upon typical open road surfaces of Grade 3 chipseal and open graded porous asphalt. The graph below presents the results over the frequency spectrum up to 200 Hz.

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

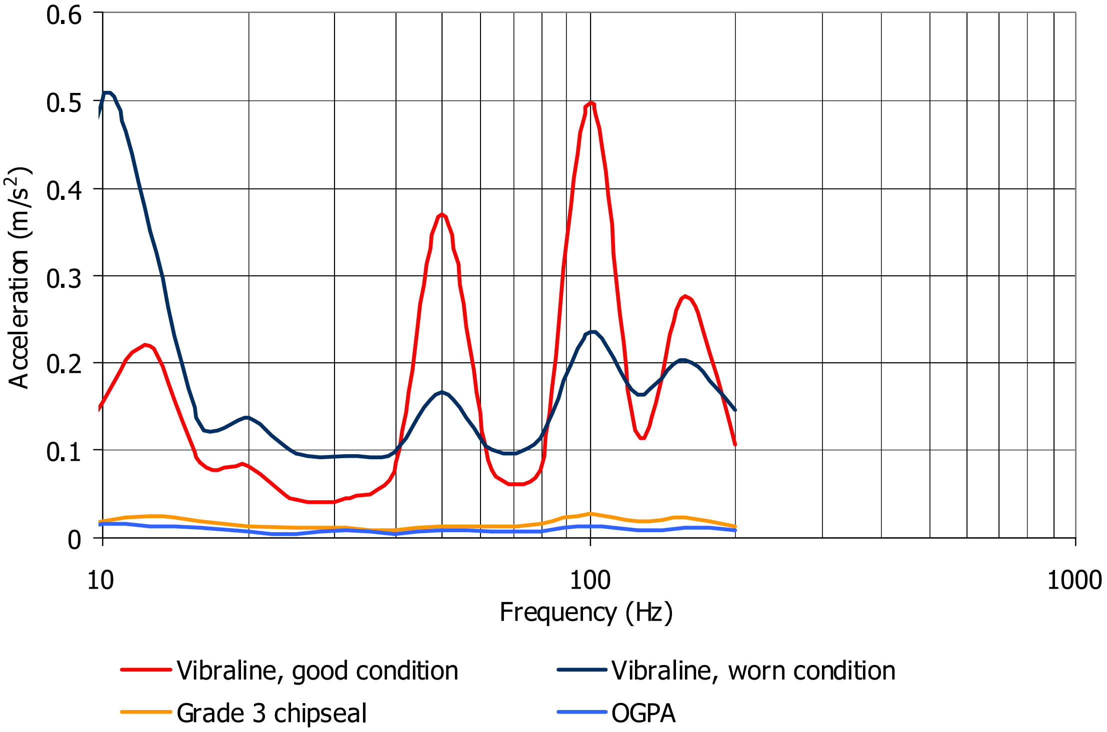
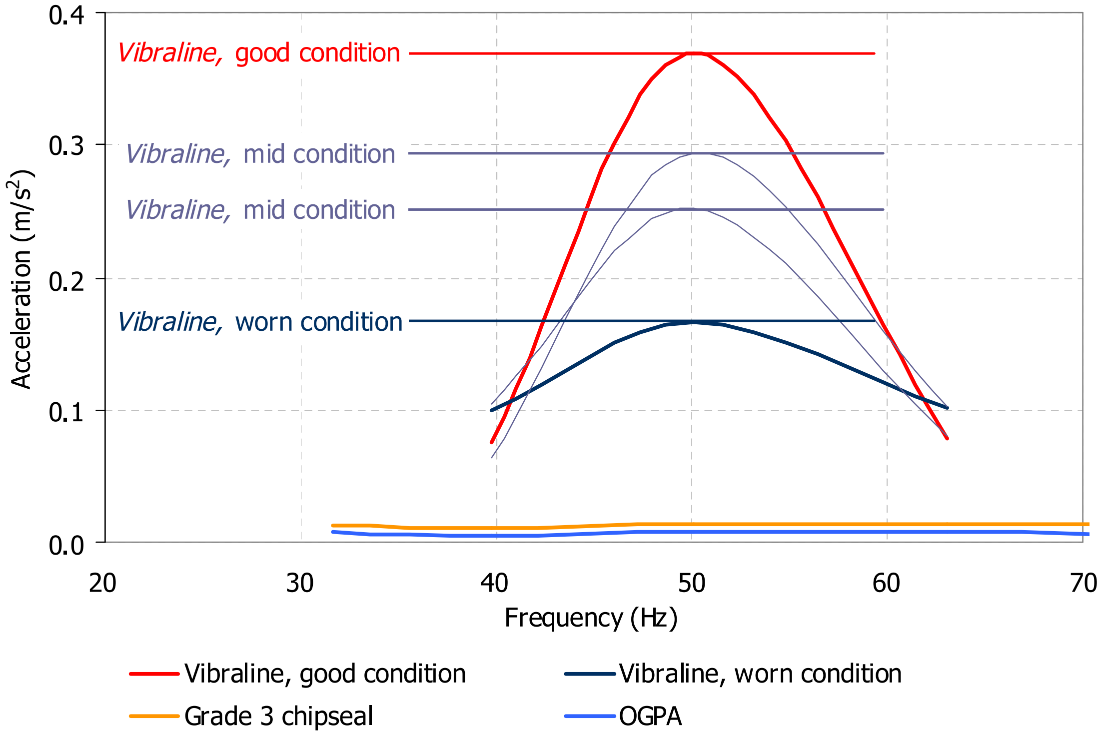


Figure 2 shows a somewhat confusing graph and the approach was to simplify it by focussing on the area that seems to relate to the effects of the audio tactile profiled roadmarking dimensions. Based on the pitch of the *Vibraline* profile design, the in-vehicle vibration experienced due to travel on *Vibraline* at 100 km/h is approximately 50 to 55 Hz. The following graph reproduces Figure 2 around this range of frequencies.

Figure 3 In-vehicle vibration 40 to 60 Hz spectra for a car travelling at 100 km/h



Over the 40 Hz to 60 Hz range, shown in Figure 3, the maximum acceleration experienced in-vehicle while trafficking the audio tactile profiled roadmarkings appears to correlate to the subjective appraisal of their condition. Within this range, the subjective appraisal of road surfaces also correlates with the measured vibration effect.

However, before this observation can be used towards specifying noise and vibration performance criteria, further research would be needed on issues such as:

1. How the pitch of blocks of other audio tactile profiled roadmarking profile designs affects the pertinent frequency range; and

2. How the graphed effect is affected by trafficking conditions, including vehicle type, tyre pressures, and vehicle speed.

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. The intention was to make an assessment of the point at which the audio and tactile responses become inadequate, and this would be linked to the dimensions to produce a physical indicator for the "end of life" of the audio tactile profiled roadmarkings.

Instrumented runs took place on State highway 1 north of Wellington, primarily between Porirua and Tawa, and on State highway 58 Haywards Hill Road. A tri-axial accelerometer was employed to measure the vibration in the cabin of the vehicle, and was placed on a solid portion of the car's interior in the passenger's footwell, so as not to impede the driver's foot movements. This position was found, through pilot study, to be the most appropriate for determining the tactile response. A pilot study had shown that there was no benefit in attaching the accelerometer to the steering column or steering wheel.

Figure 4 In-vehicle positions of accelerometer and sound level meter

The test car was a 2006 Toyota Corolla GL Wagon (front-wheel drive). The car was equipped with power steering and was in near-new condition (less than 5000 kilometres driven) with all tyres inflated to 38 psi. The accelerometer was mounted in the passenger's footwell on the central partition below the gear lever. Due to the mechanics and suspension system of the vehicle, between the wheel and the accelerometer vibrations were both sprung and dampened. Sound was recorded via a Rion NL-32 sound level meter mounted behind the driver's left ear. The sound level meter outputs an A-weighted analogue signal via an AC data connection. A Global Positioning System receiver was placed on the dashboard near the windscreen to record the position and speed of each sampling traverse. The outputs of the accelerometer, sound level meter, and position receiver were logged by a multi-channel Logbook Data Logger at a rate of 12,000 Hz, using a 100 Hz low-pass filter to avoid aliasing.

The sampling duration was fixed at 2 seconds, and a traverse sample was considered valid if the car remained on the subject surface for the entire 2 seconds of the sample and maintained a constant speed for the 2 seconds of sampling. For each valid sampling traverse, the location, speedometer reading, direction of travel, and time of day were recorded, along with subjective assessments, by the two vehicle occupants, of the audio experience, and, separately, the tactile experience. In total 59 traversing samples were recorded of which 46 were considered valid.

The large volumes of data were loaded and processed using the Mathematics package MATLAB, using purpose written scripts, and then loaded into Microsoft Excel for further processing and analysis.

The three acceleration axes and the sound time-series data were mean-removed before analysis. Fast Fourier transforms were computed separately for each of the 3 vibration axes and the sound data, and the vibration axes were combined into a single FFT representing magnitude of vibration.

Single value indicators for sound level and vibration were calculated from the time series data. For sound level this was the familiar Leq (energy equivalent sound pressure level) in dB(A), computed by numerical integration of the time series data using the trapezium method. For vibration, a similar approach was found to provide the best alignment with both sound and subjective responses. The mean of each axis was computed by numerical integration using the trapezium method, the axes combined by a root-mean-of-squares (rms) calculation, and the result converted to decibels with reference value of 1 µg [9.8x10¬-6 ms-2] to produce the energy equivalent vibration indicator in decibels.

The location data was converted from latitude and longitude into eastings and northings for import into the mapping software GPSTrackMaker, and subsequently Google Earth. The maps were necessary to accurately locate the markings for dimension measurement.

The distance travelled during the sample was calculated from the GPS data using the Great Circle Method, and divided by the sample duration to provide the vehicle speed. The resulting speeds appear to be largely accurate, but there are some obvious outliers having unreasonable speeds. The speedometer reading appears to be 5 km/h slower than actual vehicle speed, but was consistent and precise enough for the purposes of this survey, so where speedometer data was recorded that is taken in precedence to GPS derived speed.

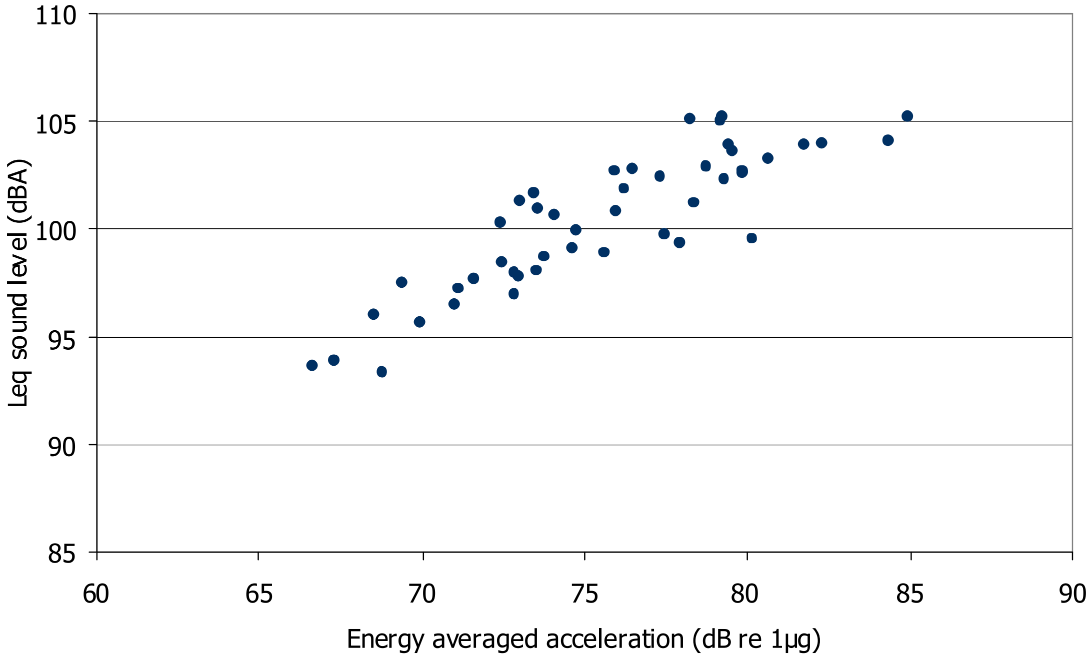
The direction of travel of the vehicle was calculated from the change in angular minutes of latitude and longitude, and presented as a compass direction to aid in determining the exact location of the audio-tactile marking (i.e. it shows which side of the road the marking is on).

After comparing a variety of different measures (single value indicators) of vibration within the car, the most appropriate appears to be the time averaged acceleration, presented in decibels with a reference value of 1 µg ($9.8x10^{-6}$ ms^{-2}).

The single value indicator for sound level is the familiar A-weighted energy equivalent sound level, or L_{Aeq}, in decibels.

Figure 5 shows the excellent correlation between the sound and vibration measurements, indicating that noise and vibration levels change together, at least for the types of markings encountered in the survey. That is to say that samples that provide high levels of tactile feedback generally also provide high levels of audio feedback, and vice versa. It implies that a decrease in the response of either type of feedback is likely to mean that the other type has also decreased. This may have implications for a simplifying the audio tactile profiled roadmarking performance

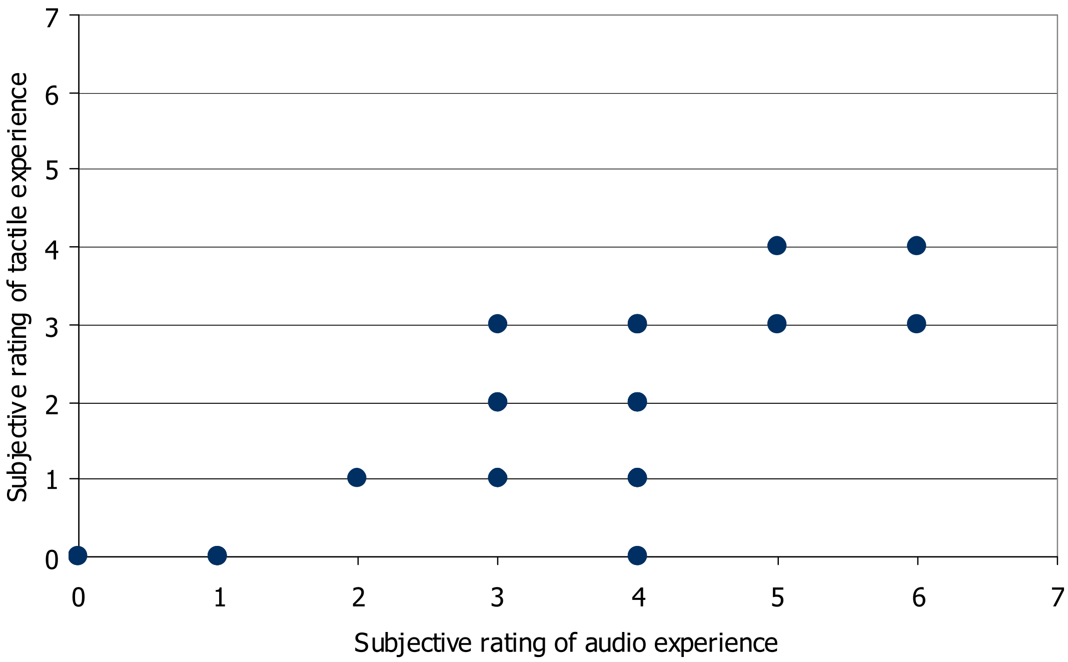
Figure 5 In-car vibration versus sound (from 46 valid traverse samples)



testing procedure, where measurement of only one of vibration or sound is necessary to estimate the overall performance of the roadmarking.

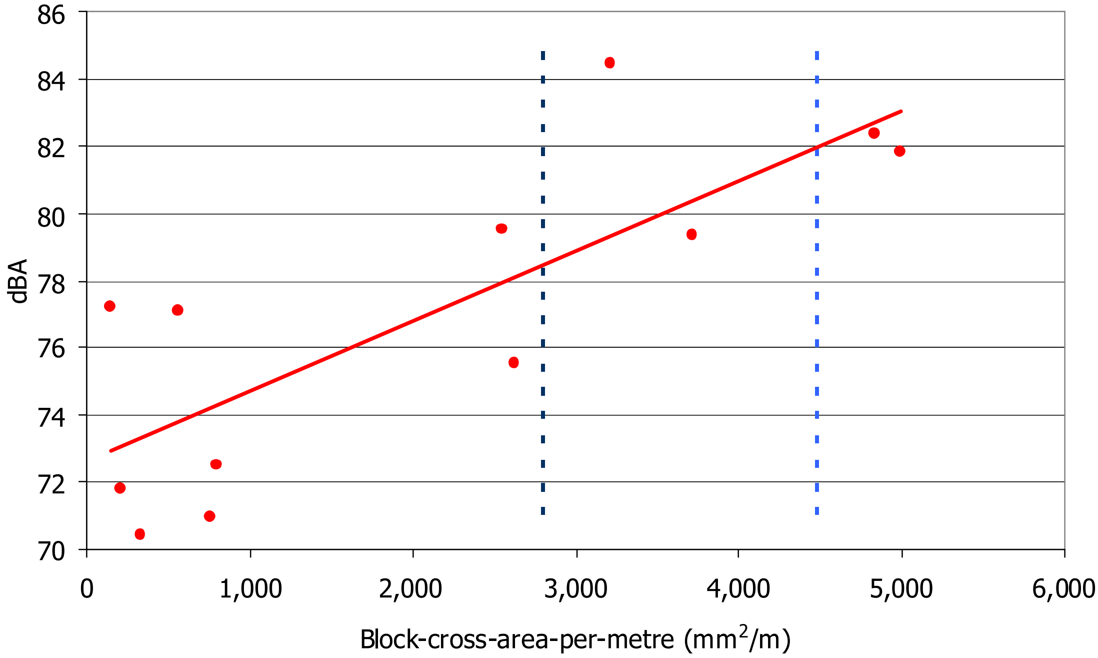
Subjective assessments of the audio effects and of the tactile effects were made by the two in-vehicle occupants while traversing the samples. The subjective assessments were made descriptively, ranging from weak/no effect to noisy/very noticeable, and then subsequently transposed onto a numerical scale. Of the two sensory effects, the audio effect was much more easily discerned and it was easier to notice a wider range of audio effects than for the vibration effects. The distinction between the road and the audio tactile profiled roadmarking was much greater for noise than for vibration. Figure 6 illustrates this distinction. (The figure contains data for 35 pairs but a number of them are coincident.)

Figure 6 Subjective audio experience versus subjective tactile experience



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 ($R^2 \approx 0.63$). This is shown in Figure 7. (The noise level plotted in Figure 7 is noise of the audio tactile profiled roadmarking being traversed with the effect of the other two tyres on the road surface extracted.)

Figure 7 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.

A third project is about to commence which addresses these and other issues. The methodology of this research proposal is based on measurements made on test roadmarking strips where the accuracy of the dimensions of the test profiles is certain. 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 used by the sector in delivering new and innovate audio tactile profiled roadmarking profile designs.

The physical response model will be developed by measuring in-vehicle noise and in-vehicle vibration while the vehicle traverses a special test section of audio tactile profiled roadmarkings. Test sections will vary the parameters of profile height, profile pitch, profile width, and profile shape. A range of vehicle tyre types will also be sampled. To ensure accuracy, the test profiles will be machined. Correlation to in-situ audio tactile profiled roadmarkings will be provided by data collected by further field measurements.

The subjective driver-response will be measured 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.