The Effects and Significance of New Zealand Road Surfaces on Traffic Noise

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ABSTRACT

New Zealand has a wide range of road surface types, ranging from large to small chipseals, and bituminous mixes ranging from 10mm asphaltic concrete to deep depth open graded porous asphalt. This paper describes first the measurement of the noise effect of these surfaces, by a variant of the cruise-by technique. The findings describe how the road surface type had a significant effect on traffic noise at urban driving speeds, and that the effects differed for light and heavy vehicles. The paper then links these findings to previous work on how the change in noise caused by resealing with different surface types could have significant effects on how adjacent communities perceived this noise environment, to produce a guideline of when worthwhile gains in noise environment improvement could be achieved by using a surface type with lower noise levels. This guideline required a new descriptor of community impact, "acutely affected", be derived. The effect that a change in noise has on the percentage of the population that is "acutely affected" was calculated for three characteristic street-noise groupings of suburban streets, distributor roads, and major arterials and an indicative guideline for Road Managers developed.

INTRODUCTION

An earlier paper (Dravitzki, Walton, Wood 2002) reported the noise effects of a small selection of road surface types, covering a broad range of types from low-textured bituminous mix type surfaces, through to large textured surfaces such as one- and two-coat chipseals. It also examined the noise impact on adjacent communities.

This current paper expands on that earlier study and in particular looks in much more detail at the range of low-textured surfaces made from bituminous mixes and the effect that they have on road traffic noise. These surface types are, for example, open graded porous asphalt, stone mastic asphalt, various grades of asphaltic concrete, macadam, and slurry seals. The work sought to identify the noise effect relative to asphaltic concrete made with graded chip sizes but with a maximum size of 10mm,(often referred to as AC-10), and, if possible, to also identify if there was regional variation, within New Zealand, of noise effects within surfaces of the same type.

SURFACE TYPES USED IN NEW ZEALAND

Road surface types used in New Zealand fall into two categories, chipseal or bituminous mix.

Chipseal surfaces (also known in other countries as sprayseals, or surface-dressings) consist of a layer of sprayed bitumen into which is embedded a layer of aggregate of specific size. The nominal aggregate sizes are (with the New Zealand classification shown in parentheses) all passing: 19mm (Grade 2), 16mm (Grade 3), 12mm (Grade 4), 10mm (Grade 5), 7mm (Grade 6). The bitumen layer is only about 30 to 50% of the thickness of the chip diameter so that the travelled surface is the aggregate only.

The aggregates are of a roughly uniform size, formed by crushing to provide mainly broken faces, and shaped so that the longest dimension is about twice the smallest dimension. Most of the stones are within about 65 to 100% of the maximum size for the Grade.

As in other countries, two-coat seals, where a smaller chip is fitted into the matrix of a larger chip, are also used in New Zealand. Common combinations are 19/12mm, 16/10mm, 16/7mm, and 12/7mm.

Bituminous mix surfaces are usually used in urban areas on the higher traffic volume roads, on motorways, and on higher-stress areas where their greater mechanical strength is required.

Bituminous mixes differ markedly from chipseal. They contain a graduation of aggregate sizes from fine to coarse. These stone chips are first mixed together with bitumen before laying on the road surface. This layer contains the bitumen coated chip compacted tightly together to form one or more layers, typically 20 to 40mm thick but 90mm is sometimes used.

Surface types are named according to both their overall design, and the maximum chip size. For example, AC-10 is asphaltic concrete (also known as dense graded asphalt) containing a maximum sized chip of 10mm. The different surface types: asphaltic concrete (AC), stone mastic asphalt (SMA), macadam, open graded porous asphalt (OGPA) (also known as open graded asphalt), and slurry seals differ from each other according to the relative combinations of stone chip sizes and bitumen content.

Figure 1 shows a series of stone chip size distributions for some of the different bituminous surfaces.

The curve denoting maximum density is the "theoretical" most dense combination that would be made from a continuous graded material. AC-10 lies to the left of this and is dense graded but contains a higher proportion of fines and consequently has a very low-textured surface.

The OGPAs lie to the right of the theoretical maximum density curve. These comprise mainly large stone sizes with very small proportions of fines thereby making these surfaces very porous. Compared to AC-10, the surface has a similar level texture at the top as the stones are aligned by the laying machine, but the surface is pitted by the porous texture of the material.

The SMAs are similar to the OGPAs, containing a high proportion of larger aggregate sizes and therefore lying to the right of the theoretical curve. Compared to OGPA, an SMA contains more fines so is not as porous. Compared to AC, an SMA contains larger aggregates and so has a more pronounced texture.

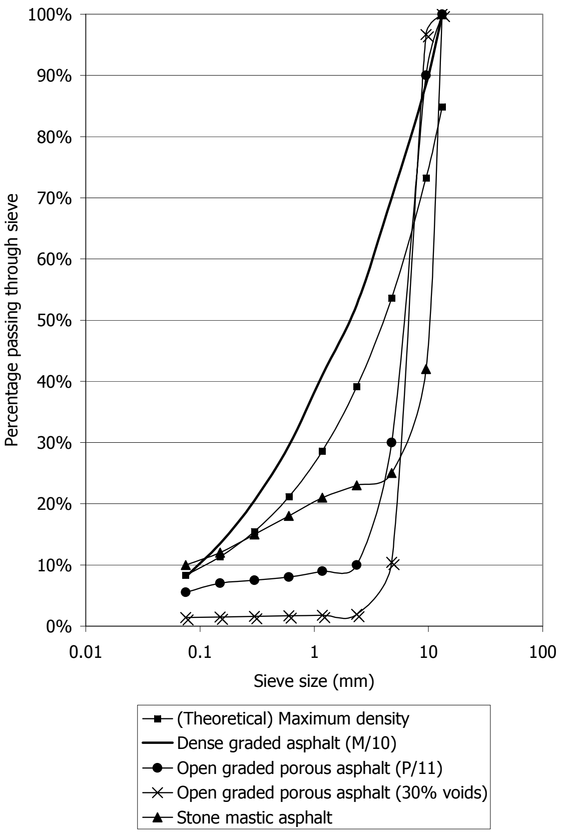

Figure 1. Composition of bituminous road surface mixes

METHODOLOGY

The methodology used followed that of the previous study, being the statistical pass-by method with the vehicle in cruise-by mode, but with some variations.

The first study had used test vehicles for the noise measurements on a selection of test road surfaces, with a 10 to 20 vehicle sampling of the vehicle fleet to ensure that the test vehicle was relevant to the rest of the vehicle fleet. An analysis within that study found that a sample of 5 vehicles of a vehicle type gave a mean noise value within 1dBA of the mean noise value from any other sample of 5 vehicles of that same vehicle type. This illustrated that a viable method of determining road surface noise effects could be based on noise measurements from a sample of passing cars and noise measurements from a sample of passing trucks. In this study, the average noise levels for each surface were calculated based on noise measurements from a sample of 20 to 22 cars and noise measurements from a sample of 10 to 12 heavy trucks.

At all sites the noise meter and microphone were installed 1.2m above the ground level and 2.5m from the edge of the traffic lane. While 5m is a preferable distance to be offset from the edge of the vehicle lane, New Zealand roads present a number of features which impede achieving that distance, such as steep embankments close to the road shoulder, or the presence of roadside furniture.

Trials showed that the distance between the noise meter (microphone position) and the edge of the traffic lane could be reduced to 2.5m without being noise measurements being influenced by aerodynamic effects from the passing vehicles. This was established by measuring noise levels of individual vehicles with two meters, one offset by 5m and one by 2.5m from the edgeline as shown by Table 1. An almost constant relationship between the two meters for both light and heavy vehicles indicated no aerodynamic effects. However at this separation care is needed in that the "real" distance between the vehicle track and the noise meter can vary significantly depending on the vehicle type, road width, and driving conditions. Observations show that this distance can vary from approximately 2.5m to 4m for light cars and from 2.5m to 3.5m for heavy trucks and buses, depending on the position that the vehicle takes in the lane. In the series of measurements made, only vehicles travelling in approximately the centre of the traffic lane were recorded. Vehicles travelling very close to the lane edge or too far from this position towards the centreline were not included, and as far as was practical vehicles included passed at about 3 metres from the microphone.

Table 1. Comparison of noise levels (dBA) at the distances of 2.5m and 5.0m offset from the edge of the traffic lane

Heavy trucks		4WDs, SUVs		Cars	
Vehicle type	Δ(2.5m - 5m)	Vehicle size	Δ(2.5m - 5m)	Vehicle size	Δ(2.5m - 5m)
Art. 7 axle	2.9	3.0 L	2.8	3.0 L	3.1
3 axle	2.8	3.0 L	3.2	2.4 L	3.4
Art. 7 axle	3.3	3.0 L	3.1	3.5 L	2.7
4 axle	2.9	4.0 L	3.5	2.0 L	3.0
5 axle	3.3	4.0 L	2.9	2.4 L	2.8
6 axle	3.1	3.0 L	3.2	1.8 L	3.2
Art. 6 axle	3.0	3.0 L	3.0	2.0 L	2.8
Art .6 axle	2.7	3.0 L	2.5	3.5 L	3.3
5 axle	2.7	4.0 L	3.2	2.0 L	3.0
6 axle	3.1	4.0 L	3.0	2.4 L	3.0
Art. 6 axle	2.9				
Average	**3.0**		**3.0**		**3.0**

Measurements were made capturing 1 second of noise as the vehicle was directly adjacent the meter. The noise was sampled at 16000hz with 0.5 seconds either side of the peak selected for analysis, for both spectral content and total noise level. As Dravitzki, Walton, Wood (2006) reported, the spectral content was used to help confirm that the predominant noise was tyre-road noise, to verify the consistency of measurement, and to assist in identifying trends with speed and between surface types.

"Cruise-by" requires that the vehicle is neither accelerating nor decelerating. Taking a sample of the passing fleet means that driver behaviour cannot be controlled directly so an indirect control is used which is to select a test site that is flat and straight and away, as far as is possible, from intersections. In these situations drivers should be travelling in the "cruise-by" mode. Vehicles that appeared to be behaving erratically, accelerating, or decelerating were also excluded.

Vehicle speeds

Measurements were undertaken on roads with posted speed limits of 50, 60, or 70km/h. However "real" mean driving speed can differ from the posted speed limit. Actual speeds were determined by using a test vehicle driven within the traffic flow passing the site, and repeating this manoeuvre 4 to 5 times. The driving speed of the test vehicle was recorded and used to calculate the average real speed of the traffic flow. The more obvious method of measuring speed using a radar gun was avoided as it was likely that drivers would change their speed if they saw the speed measurement being made.

Adjusting for speeds

Test surfaces were in different speed zones and the mean "real" speed in some of the zones appeared to be greater than the posted speed. Noise levels increase with vehicle speed so to compare surfaces the vehicle speeds on each surface need to be adjusted to a common speed, chosen as 50km/h. The previous study (Dravitzki, Walton, Wood 2006) had shown on New Zealand road surfaces tyre road noise was the dominant source for both cars and heavy trucks at speeds as low as 50kmph, and a little less.

The Nordic road noise model shows the relationship of vehicle noise and speed as being 25log(v/50) for light vehicles and 30log(v/50) for heavy vehicles. The current heavy vehicles relationship has altered since an earlier version of the model which had expected noise of heavy vehicles to be 20log(v/50).

A previous study (Dravitzki, Walton, Wood 2006) measured the noise effect of test vehicles at different speeds on about seven road surfaces. For the light vehicles, the difference between noise levels at 50km/h compared to 100km/h varies between 8 to 11dBA dependent on the road surface. This fits with a speed dependency close to 30log(v/50). For the heavy vehicle, noise increased by 4 to 5dBA as speed increased from 50 to 90km/h indicating a relationship of noise to speed of approximately 20log(v/50). These relationships are closer to those used in the old Nordic model rather than the new one. Noise levels were adjusted using the relationships established by the study.

RESULTS

The effect on noise level of the different road surface types is shown in Table 2. The values appear to hold true for speeds between 50 and 100km/h.

The values of Table 2 can be used to improve the accuracy of noise prediction when using noise models. However, a more important use is to identify the noise improvement that would occur if a road surface was to be replaced by a surface with a lower noise effect. Because the effect is separate for cars and for trucks, the combined surface effect will be specific for particular proportional combinations of cars and trucks that form the vehicle stream on the road under consideration.

The combined effect can be determined by using a noise model such as the Nordic model, which calculates the noise of the streams separately, as follows.

The overall noise level is calculated by combining $L_{eq(light)}$ with $L_{eq(heavy)}$. The appropriate surface corrections can be taken from Table 2.

Table 2. Recommended road surface effects relative to AC-10, for use with New Zealand roads (dBA)

Surface Category	Type	Correction to use for Cars	Correction to use for Trucks
AC	10mm	Ref.	Ref.
	14mm	0	0
	16mm*	0	0
OGPA	OGPA-14, 20% voids	0	-2.0
	OGPA-14, 30% voids	-2.0	-3.0
	70mm double-layer, Wispa	-2.0	-4.0
Capeseal	#2/Type 3*	+3.0	+1.0
	#3/Type 2*	+2.0	-1.0
	#4/Type 1*	0	-1.0
SMA	10	+1.5	-1.5
	11	+1.5	-1.5
	14*	+1.5	-1.5
Slurry seal	Type 3*	+2.0	0
Macadam		+3.0	0
Chipseal	Grade 6	+3.0	-2.0
	Grade 5	+3.0	-2.0
	Grade 4	+3.0	-2.0
	Grade 3	+4.0	+1.0
	Grade 2*	+6.0	+1.0
Two-coat seals	Grade 4/6	+5.0	+1.0
	Grade 3/5	+6.0	+1.0
	Grade 3/6	+6.0	+1.0
	Grade 2/4	+6.0	+1.0

* Results indicative only as data from a very small sample

Noise for light vehicles (cars and vans) is:

$$L_{eq(light)} = 73.5 + 25\log\left(\frac{V_L}{50}\right) + 10\log\left(\frac{Q_L}{T}\right) + \text{surface correction}_{(light)}$$

[Equation 1]

Noise for heavy vehicles (trucks) is:

$$L_{eq(heavy)} = 81 + 30\log\left(\frac{V_H}{50}\right) + 10\log\left(\frac{Q_H}{T}\right) + \text{surface correction}_{(heavy)}$$

[Equation 2]

V_L and V_H are the speeds of the light and heavy vehicles. Q_L and Q_H are the volumes of light and heavy vehicles in time T (seconds) for which the equivalent sound level L_{eq} is calculated.

The effect of a particular road surface on the noise generated by a specific traffic mix can be determined by comparing the total noise for the particular road surface with the noise that would have occurred if the road surface had been AC-10.

Table 3. Combined surface effect on noise from light and heavy vehicles (dBA)

% heavy vehicles	Combined surface effect on noise from light and heavy vehicles (dBA): Dense asphalt	OGPA	Fine chip #4,5,6	Med. chip #3	Coarse chip #2, 2-coat seals
0	0	0	3.0	4.0	6.0
3	0	-0.3	2.4	3.5	5.4
10	0	-0.8	1.3	2.8	4.3
20	0	-1.2	0.4	2.2	3.4

Table 3 has been produced from a series of calculations as outlined above to produce the net surface effect for a selection of road surface types relative to AC-10, for any volume of traffic, with the percentage of heavy vehicles as identified.

For any given road therefore, the road manager can use this type of table to assess the effect (or benefit) of choosing one surface type compared to another.

Table 3 describes the physical changes in noise levels. However it does not describe the community impact of these changes in noise levels.

MEASURES OF REACTION TO CHANGE IN NOISE DOSAGE

Noise annoyance dose/reaction relationships are normally associated to the Shultz Curve (Shultz 1978). However this relationship is for a constant noise exposure and will not be reliable in predicting the change in reaction due to a change in noise dosage, especially in the short to medium term.

The previous paper to this work (Dravitzki, Walton, and Wood, 2002 and 2006) describes how the noise impact of changing noise levels due to changing the road surface was determined by a "before and after survey" of responses to noise carried out on residents adjacent road sections that were being resealed.

The design of the research was a "within subjects" or "repeated measures" experiment. Thus, participants (N=138) were surveyed before and after reseal to determine the influence of any change on their measurable levels on annoyance and behavioural disturbance. The independent variable is the change of the road surface between the first and second interviews. The surveys determined two parameters: the degree of annoyance, as represented by a 10-point continuous scale, anchored at 0 "not at all annoying" and 10 "extremely annoying", and a 13 item "behavioural disturbance" scale on measures that people might react to or take to counter increased noise, such as "shut windows" or "turned radio up".

Correlating the changes in mean annoyance and mean behavioural disturbance found that the behavioural disturbances index, following Job et al. (2001), is a more sensitive measure of noise annoyance than those recommended by Field et al. (1998). When controlling for initial differences in sound levels at the sites the behavioural disturbance scale (r^2(BD)=0.47, F(2,135)=61.45, p.=<0.001) correlates more strongly than the annoyance scale (r^2(A)=0.37, F(2,135)=41.62, p.=<0.001).

Long term habituation

Three of the sites involved in the previous study's "after" surveys were revisited approximately six months after the initial "after" surveys. At these three sites significant improvements in residents' responses to noise immediately after reseal had been recorded. The surveys were reapplied at these three sites to investigate and measure the development of any acceptance or habituation to noise over the intervening six months. The sample was small but within this constraint it appears that initial improvements in community annoyance closely following a reseal can degrade over time to approximately the pre-reseal levels, whereas the improvements of reduced behavioural disturbance appear to have lasted.

IDENTIFYING A MEASURE OF ACCEPTABLE IMPACT

The behavioural disturbance scale (and the annoyance scale) measure a range of responses to traffic noise and used in a before-and-after mode can measure the impact of changing the road surface. However Road Managers need to manage a much wider range of issues than just noise. Cost is important, as the range in costs between the different surface types is about a factor of 10. Inevitably the quietest road surfaces cost the most. There are also engineering constraints on the sequencing of surfaces. Road Managers therefore need to know when a seal change is likely to result in unacceptable change in noise levels, and conversely when a useful noise benefit could be achieved by selecting a quieter road surface.

For the purposes of producing initial guidelines we have defined a new measure of unacceptable impact, which we have called "acutely affected". Further research is however recommended to further develop this measure of "acutely affected" and confirm or revise the initial value that we have set for it. This initial value has been set conservatively at this stage with respect to the outcomes that it will produce for the need for quieter surfaces.

The measure "acutely affected" is formed from the examination of the baseline distributions of behavioural disturbance and noise annoyance scales prior to reseal and has been defined as a value of 6 or more on the 13-point Behavioural Disturbance scale, because this demarcates approximately the 85^{th} percentile of the distribution and so relates to the 90^{th} percentile demarking "population highly annoyed" in Shultz (1978). Figure 2 shows the frequency of the types of disturbances identified by those respondents who reported some disturbance. Many respondents did not identify any disturbance. The responses in Figure 2 were drawn from the 138 participants, who in turn were in one of 12 different road noise environments and the change in noise with re-seal ranged from a 7dBA decrease to a 6dBA increase in noise compared to the noise level prior to the re-seal.

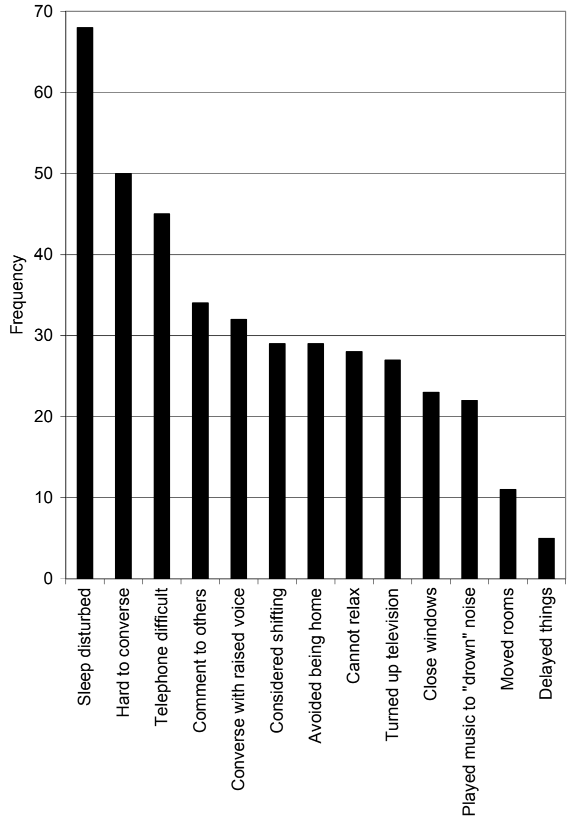

Figure 2. Frequency of response for each of the behavioural disturbance items

Calculating the effect of a change in noise level on changing the percentage of population "acutely affected"

The effect of change in noise in increasing or decreasing the percentage of population "acutely affected" was calculated using the equation:

$$PMBD = 0.697 + 0.69(BD) + 0.153(\Delta L_{eq24}) \quad \text{[Equation 3]}$$

where *PMBD* is the predicted mean level of behavioural disturbance and *BD* is the base level of disturbance. The base disturbance (or mean disturbance) was obtained from the survey of residents' responses to noise changes from resealing the road. The responses were divided into three typical noise environments. These noise environments were chosen arbitrarily but we believe they represent classifications of noise environment/road type equivalent in scale to those used by most Road Managers.

- Local streets are low noise areas, where typically the average noise level is less than 60dBA $L_{eq(24\ hour)}$
- Distributors and smaller arterials are medium noise areas where typically the average noise level is L_{eq} of between 60 to70dBA
- Major arterials are high noise areas where typically the noise level is L_{eq} of greater than 70dBA.

For these three noise environments, the base behavioural disturbance was calculated from the survey results as:

- Low; base disturbance =2.01, SD= (3.02)
- Medium; base disturbance =2.77, SD = (2.94)
- High; base disturbance =5.8, SD = (2.69)

Using these base disturbance levels and standard deviations Equation 3 can be used to estimate the mean, 90% percentile and percentage of the population above the disturbance level that defines the "acutely affected", that is, 6 or more.

Figure 3 summarises this calculation and shows the relationships between the changes in the percentage of people acutely affected by road traffic noise with changes in the noise dosage in the three pre-reseal noise environments. The figure shows the percentage of the population that is above the "acutely affected" level and how this percentage increases or decreases in relation to the extent of change in noise level. The figure illustrates that the change in the percentage of "acutely affected" depends not just on the extent of change in noise but also on the original noise level, and this is significant to the Road Manager as it implies that all roads do not have to be treated the same.

Figure 3 could be used directly when making decisions about selecting surface types. The change in noise level from one surface to another is known, the existing noise environment is known, and then the effect in changing the percentage "acutely affected" can be read directly from the figure. Most roading practitioners however need further guidance in the area of how much of a change in the percentage "acutely affected" is a "significant change" and it is this area which needs further research. Measuring behavioural disturbance and assessing the acceptability of that change to a population appears to be a workable methodology for identifying what is a "significant change".

In the interim we have developed an indicative guideline around some information that we have on complaints to the Local Councils when roads are resealed. It appears that few complaints arise from any resealing when low volume roads are resealed irrespective of the reseal surface used. Nor do many complaints arise around medium volume roads where the change in noise is quite small, in the order of 2dBA or less. In contrast, large increases in noise around medium volume roads and small increases (2dBA) around high volume roads lead to community complaints.

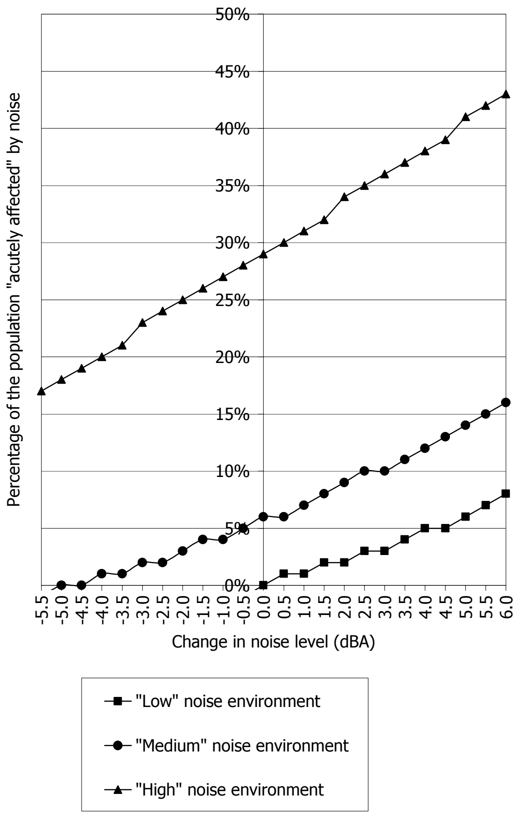

Figure 3. Percentage of the population that are "acutely affected" with related change in noise level

GUIDELINE (INDICATIVE) FOR SELECTING SURFACE TYPES IN RESEALS

We have developed a classification for changes in noise level related to the change in the percentage of the total population being "acutely affected", using, arbitrarily, increments of 5 % of the total population.

- A "big improvement" to the noise environment has 15% fewer of the total population being "acutely affected".
- An "improvement" to the noise environment has 10% fewer.
- A "small improvement" to the noise environment has 5% fewer.
- A "slightly worse" noise environment has 5% more of the total population being "acutely affected".
- A "worse" noise environment has 10% more.
- A "much worse" noise environment has 15% more.

Table 4 below is the indicative guideline derived from Figure 3 and the classification described above. The top part of Table 4 shows the extent that the noise environment is improved for the adjacent community by selecting a more quiet road surface. It also shows the converse where the surface selection results in increased traffic noise. The change in noise is determined as shown by Table 4, or calculated for a specific vehicle stream.

The guideline has been described as indicative because there are several areas needing further definition. It has been set conservatively at this stage and it mirrors current good practice.

Further research is needed to further develop the behavioural disturbance index, both with respect to the items that it con-

Table 4. Guideline (indicative) for selecting surface types in reseals

Change in noise level arising from road surface change		Low noise env. (L_{eq} <60)	Med. noise env. (L_{eq} 60-70)	High noise env. (L_{eq} >70)
Reduction	More than -3.6	Small Improvement	Improvement	Big Improvement
	-1.1 to -3.5	Small Improvement	Small Improvement	Improvement
	0 to -1	Little change	Little change	Small Improvement
No change	0	-	-	-
Increase	0 to 1	Little change	Little change	A little worse
	1.1 to 3.5	A little worse	A little worse	Worse
	3.6 and more	A little worse	Worse	Much worse

tains and the confidence limits. The measure "acutely affected" also needs to be tested against community views as to how it is separating acceptable and unacceptable disturbance. The classification into increments of 5% changes in population being "acutely affected" also needs to be tested. This can come in part from reviewing a more extensive collection of public complaints (or their absence) after reseals are made following this guideline or from further surveys of the public.

CONCLUSIONS

New Zealand road surfaces have a significant effect on the road traffic noise generated. These effects are evident for speeds 50 to 100 kmph.

Compared to dense graded asphaltic concrete with 10mm maximum chip size (AC-10): for cars, the range in noise effect is 8dBA, ranging from -2dBA for highly porous surfaces to +6dBA for highly textured chipseals; for heavy trucks, the range in noise effects is 5dBA, ranging from -4dBA for highly porous surfaces to +1dBA for highly textured chipseals.

Residents adjacent roads that are resealed, notice changes in the noise from the traffic, in some cases when the change is as little as 1dBA. The change is more noticeable the higher the existing traffic noise environment prior to the re-seal. The response is both a change in annoyance, and a change in behaviours needed to cope with the changed noise. The change in annoyance degrades with time but the change in coping behaviours appears ongoing.

A guideline has been prepared to assist road managers in selecting road surfaces when re-surfacing. This guideline identifies the extent of impact on the community of the change in noise level when the road surface is resealed, and relates the extent of impact to both the degree of change in noise level and the traffic noise environment prior to the re-seal.

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