FRICTION COURSE - COMPARISONS OF 20 & 14 mm MIXES

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FRICTION COURSE – COMPARISONS OF 20 & 14 mm MIXES

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EXECUTIVE SUMMARY

Introduction

The two main types of road surface in New Zealand are asphaltic concrete and chipseal, with asphaltic concrete being generally confined to higher volume (approximately 10,000 vehicles average annual daily traffic) urban roads. For areas where the speed limit is greater than 50 km/h, dense-graded asphaltic concrete is regarded as unsuitable, because its poor drainage accentuates the decline in wet skid resistance for higher speeds, and the surface water causes loss of visibility through spray. For these high-volume high-speed areas, open-graded porous asphalt, known in New Zealand as friction course, is the preferred surface. Compared to dense-graded asphaltic concrete, it is believed to offer:

- better retention of wet skid resistance with increasing speed,
- improved driver visibility through reduction of water spray from tyres,
- reduced levels of noise.

Each of these characteristics stems from the drainage properties of the material which arise from its porosity. Economic evaluations are based on friction course having a service life of about 8-12 years. In respect to pavement integrity, such as freedom from rutting or roughness, this expected service life is met. However, observations are that the drainage property of the surface appears to be starting to degrade after about two years, with significant deterioration being evident after 4-6 years. This deterioration is manifested by significant increases in tyre spray, especially from heavy vehicles. This early loss of drainage capability is undesirable, as it implies that for a significant part of its expected life the pavement may not be delivering the main performance characteristics for which it was selected.

The dominant grade of friction course used in New Zealand has a maximum aggregate size of 14 mm. However, because of the short duration of its good drainage properties, a study of international literature was made in 1994-95 to determine if there were means of improving its life. The significant findings of that early study were that:

- the deterioration of the drainage properties is primarily through the clogging of the pores with detritus, and this is worse beyond the wheelpaths (because tyre-water pumping in the wheelpaths in wet weather can help to clean the pores);

- there is also a compaction element in the deterioration, but it is not usually a significant contributor.

The study reported literature that recommended using friction course with a higher level of larger, inter-connecting pores, and a thicker layer than that typically used in New Zealand. This thicker structure could be best achieved with friction course made with larger aggregate, for example friction course with a 20 mm maximum aggregate size. The main advantage of the use of such material is that the larger pores would be less likely to be clogged by dirt. This would increase the capacity of the friction course to buffer the short-term, high-level rainfall, which could then be released to the road shoulders when the rain eased.

Some of the findings suggest that use of the 20 mm aggregate could have disadvantages in that the larger aggregate could generate more tyre noise. Conversely, other literature suggests that the well known ability of a porous road surface to provide at least a small reduction in road noise may be enhanced by a thicker layer of porous material.

Pavement noise has other aspects likely to be affected by the choice of paving material. For car tyres, an increase in speed results in an increasing level of noise, and noise increases with increasing texture depth. Truck tyres have different tread patterns, and it has been argued that increases in texture depth need not result in increased noise levels.

Test Programme

In April 1995, an opportunity arose to examine the possibility of achieving some of the benefits of a larger sized friction course during normal road maintenance. A section of State Highway 1 in the lower Ngauranga Gorge, Wellington, New Zealand, was being re-laid in 14 mm friction course to a depth of 25 mm. A 30 m section within this site was laid in larger 20 mm friction course to a target depth of 50 mm. Monitoring of the water permeability, skid resistance and noise levels at approximately six-month intervals over two years, from the date of the laying of the new material in April 1995 to late March 1997, enabled a comparison of the two types.

Immediately adjacent to this re-laid section was a section of previously laid (approximately eight-year-old) 14 mm friction course of similar construction to the newly laid 14 mm friction course. This section was included in the monitoring to indicate an end point of the monitored properties.

The properties monitored over the 24-month period were:

- *On-site permeability*. Permeability tests were performed by measuring the time taken for 150 ml of free-standing water, constrained within a 150 mm-diameter ring, to drain through the surface.

- *Skid resistance*. This was assessed by the GripTester, at speeds of 35, 65 and 95 km/h, to determine the existence of speed dependence on skid resistance values. The 35 km/h speed was chosen as a point at which drainage properties are regarded as having little influence on skid resistance. The 95 km/h speed is the maximum safe speed for the site.

- *Vehicle noise*. Noise measurements were made both as vehicle drive-by noise and vehicle interior noise levels. The interior levels also enabled the examination of the effects of a wet road surface in comparison to a dry surface. As well as measurements of overall noise levels, subsequent spectral analysis (analysis of the individual components making up the overall noise) of the vehicle noise enabled some insight into the nature of the noise and of any changes that were measured.

  Noise measurements were made for both a car and a truck at three speeds. These speeds were selected from the region of 60-90 km/h where tyre/road noise should dominate over drive-train noise. Drive-train noise is that arising from the engine, gearbox, drive shaft, and engine exhaust. It is the dominant source of noise for cars for speeds up to 40 km/h, and for trucks for speeds up to 50-60 km/h. Car speeds were 60, 80 and 90 km/h. Truck speeds were 60, 70 and 80 km/h. The difference in maximum speeds was a safety consideration.

Results

Permeability

- The permeability of both the 14 mm and the 20 mm friction courses decreased significantly from the initial values.

- Permeability was initially worse outside the wheelpaths. However, at around 14 months after the placement of this material, a changeover occurred for both friction course materials. From this time, the permeability outside the wheelpath was greater than that of the material within the wheelpath.

- The 20 mm friction course was significantly more permeable than the 14 mm for about 12 months. Thereafter they tended to be approximately equal.

Skid Resistance

The skid resistance of the 14 mm friction course showed a speed dependency in the early months, but this progressively decreased and was not evident by 12 months. The 20 mm friction course did not display a similar speed dependency from six months onwards. Skid-resistance data for the freshly laid, untrafficked surface were not obtained.

After 24 months, skid resistance of both the 14 mm and 20 mm friction course surfaces approached that of the older 14 mm friction course (laid around eight years before commencement of this comparison).

Vehicle Noise

The noise results are grouped in three subsets:

- *Vehicle Interior Noise Levels – Dry Pavement*

For the car, the trend for each material, including the 'old' friction course, was for the noise levels to increase gradually over the monitoring period (with the exception of the initial interior measurement). However, these increases were not large, being around 1 to 2 dBA over the 24-month period for each material.

For the truck, there was a significant increase in overall interior noise levels, which was greater at the lower speeds. Over this 24-month monitoring period, interior noise levels increased by 4-6 dBA for each material at 60 km/h, while for the 70 and 80 km/h speeds, levels increased by 3 to 4 dBA for each material.

The internal noise increased with speed and this increase was greater for the truck than for the car. This is typical, and was expected. Less expected was that the 20 mm friction course, instead of significantly decreasing noise, appears to have had only a minor effect on vehicle interior noise levels. The literature had indicated that the larger friction course would provide significant reductions, but this does not appear to have eventuated. There appeared to be a small trend for the 20 mm surface to be noisier for the car (compared to the 14 mm surface), but for the truck this trend appeared to be reversed.

- *Vehicle Interior Noise Levels - Wet Pavement*

In a spectral analysis, the overall noise is grouped into the bands of frequency of its components. Frequency is measured in hertz (Hz) and 24 bands between 31.5 and 10 000 Hz were selected.

Spectral analysis of the vehicle interior noise on the wet friction course material showed a rise in the spectra beyond 1000 Hz (which is the tyre noise component) for the wet road, when compared to the dry road data. This portion of the wet road spectra, particularly for the car, steadily increased with time and is likely to be related to the progressively deteriorating permeability of the friction course material, which in turn allows a greater amount of free water to be present The significance of this aspect of the work is that interior noise of a vehicle on wet friction course could be used as an indicator of its permeability. However, one difficulty is that rainfall is highly variable in its intensity, and driving rain with wind could generate spurious noise.

- *Exterior Drive-by Vehicle Noise*

Expectations were that the 20 mm material would reduce drive-by noise significantly, in comparison to the 14 mm material, and deterioration would mirror reductions in permeability. The 'old' friction course was in turn expected to be noisier than the new 14 mm friction course. It was found, however, that the overall drive-by noise levels did not change by more than 2 to 3 dBA over the full 24-month monitoring period. There appeared to be very little difference in vehicle noise for any of the three test surfaces when measured using either the car or the truck. In the case of the car measurements, the 20 mm may be 1 or 2 dBA quieter than the 14 mm or old 14 mm surface, which is a slight reversal of the trend for the interior noise.

Conclusions

- The hoped-for improvement, that a larger sized friction course may provide a surface which retains its drainage properties possibly 50% longer than the 14 mm aggregate friction course, has not occurred. The 20 mm material is significantly more permeable in the wheeltrack for the first 12 months. However, after 24 months, the drainage properties for both the 14 mm and the 20 mm friction course were similar. This indicates that the predicted better tolerance to detritus accumulation of the 20 mm material has not eventuated.

  Measurements of the skid resistance on the old 14 mm friction course demonstrate that the long-term indication is for skid resistance to regress to a low value at all speeds. Over the 24-month monitoring period, the skid-resistance values for both the 14 mm and the 20 mm materials have gradually converged, approaching values similar to those obtained from the old 14 mm friction course.

- The initial speed dependence of skid resistance observed for the 14 mm friction course had reduced significantly after 24 months.

- No significant noise increase is apparent using the 20 mm friction course, but conversely, the acoustic benefit that was expected from a thicker, more porous material has not occurred.

- Surface permeability may possibly be linked to acoustic properties. This linkage is stronger for vehicle interior noise when measured on wet roads.

Recommendations

- Vehicle interior noise showed some relatively strong trends when measured on wet friction course, and this could perhaps be used to monitor permeability. Development of test equipment to provide controlled water depth, and subsequent vehicle interior noise monitoring, would reduce the possibility of anomalies being introduced into these observations and confirm the existence of such trends.

- A number of the observations made in this study may be partially attributable to site-specific characteristics, such as atypical drainage related to the slope and crossfalls, abnormal noise conditions because Ngauranga Gorge tends to act as a wind funnel. Repeat studies, if undertaken, should be on a level site with more controllable parameters.

- For such a repeat study, the friction course material should have improved quality control, during both manufacture and during laying, so that the specifications are more closely complied with.

- Overseas studies have indicated that many of the (particularly acoustic) advantages of using 20 mm friction course are linked to material thicknesses greater than the 40-50 mm laid in the Ngauranga Gorge site. For a repeat study trialing a section using an increased thickness of material would be advantageous.

ABSTRACT

The two main types of road surface in New Zealand are chipseal and asphaltic concrete. The latter is generally confined to high volume urban roads. For high volume, high speed roads, open-graded porous asphalt, known as friction course, is preferred.

This project, carried out between 1995 and 1997, compares the performance of two sizes (14 mm and 20 mm) of open-graded asphalt laid on a road section when first laid and after periods of wear. The performance, in terms of noise reduction, skid resistance and permeability, was monitored at construction and after 6, 12, 17 and 24 months. An adjacent site of 14 mm friction course, which had been in place for about eight years, was also monitored. Recommendations for improvements to future studies are made.

1. INTRODUCTION

The two main types of road surface in New Zealand are asphaltic concrete and chipseal, with asphaltic concrete being generally confined to higher volume[1] urban roads. For areas where the speed limit is greater than 50 km/h, dense-graded asphaltic concrete is regarded as unsuitable because its poor drainage accentuates the decline in wet skid resistance for higher speeds, and the surface water causes loss of visibility through spray. For these high-volume, high-speed areas, open-graded asphalt, known in New Zealand as friction course, is the preferred surface as, compared to dense-graded asphaltic concrete, it is believed to offer:

- better retention of wet skid resistance with increasing speed,
- improved driver visibility through reduction of water sprays from tyres,
- reduced levels of noise.

Each of these characteristics stems from the drainage properties of the material arising from its porosity. Economic evaluations consider that friction course has a service life of about 8-12 years. With regard to pavement integrity, such as freedom from rutting or roughness, this expected service life is met. However, observations are that the drainage property of the surface appears to be starting to degrade after about two years, with significant deterioration being evident after 4-6 years. This deterioration is manifested in significant increases of tyre spray, especially from heavy vehicles. This early loss of drainage capability is undesirable, as it implies that for a large part of its expected life the pavement may not be delivering the main performance characteristics for which it was selected.

The dominant grade of friction course used in New Zealand has a maximum aggregate size of 14 mm. However, because of the short duration of its good drainage properties, a study of the international literature was made in 1994-95 to determine if there were means of improving its life. The findings of this study (Patrick 1995) were that the deterioration of the drainage properties is primarily through the clogging of the pores with detritus, and this is worse beyond the wheelpaths (because tyre-water pumping in the wheelpaths in wet weather can help to clean the pores). There is also a compaction element in the deterioration, but it is not usually a significant contributor.

The study reported literature that recommended using friction course with a higher level of larger, interconnecting pores, and of a thicker layer than that typically used in New Zealand. This would increase the capacity of the friction course to buffer the short-term, high-level rainfall, with slower release of water to the road shoulders when the rain eased. This thicker structure could be best achieved with friction course made with larger aggregate, for example, friction course with a 20 mm maximum aggregate size. The larger pores would also be less likely to be clogged by dirt.

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[1] approximately 10,000 vehicles average annual daily traffic (AADT)

Some of the findings suggest that use of the 20 mm aggregate could have disadvantages in that the larger aggregate could generate more tyre noise. Conversely, other literature suggests that the well known ability of a porous road surface to provide at least a small reduction in road noise may be enhanced by a thicker layer of porous material.

Pavement noise has other aspects likely to be affected by the choice of paving material. For car tyres, an increase in speed results in an increasing level of noise, and noise increases with increasing texture depth. Truck tyres have different tread patterns, and it has been argued that increases in texture depth need not result in increased noise levels.

It is also known that traffic noise has different tones when the road surface is wet. A strong linkage between permeability and tonal changes on wet roads indicates that noise could be used to monitor permeability.

An opportunity arose in 1995, in the course of normal road maintenance to examine the possibility of achieving some of the benefits of a larger sized friction course. A three-lane section of State Highway 1 in the lower Ngauranga Gorge north of Wellington, New Zealand, was being re-laid in 14 mm friction course to a depth of 25 mm. Within this section to be re-laid, a 30-m length was considered to have inadequate crossfall for good drainage and was to be laid in 20 mm friction course to a depth of 50 mm. The site was not ideal in that it sloped downhill, which would accentuate drainage, while the adjacent rising land would have a small impact on noise measurements.

2. TEST PROGRAMME

The 14 mm material and the 20 mm material were tested for conformity with their mix design using standard laboratory tests for friction course. The two types were compared for their ability to maintain good levels of these surface drainage-related properties by monitoring the water permeability, skid resistance and noise levels at approximately six-month intervals over two years (April 1995 to March 1997).

Immediately adjacent to this re-laid section was a section of previously laid (approximately eight-year-old) 14 mm friction course of similar construction to the newly laid 14 mm friction course. This was included in the monitoring to indicate an end point of the monitored properties.

The monitoring of properties continued over a period of 24 months, with measurement at construction and then at six-monthly intervals. All tests were carried out in the middle lane. The parameters monitored were: on-site permeability; skid resistance; vehicle noise.

2.1 On-site Permeability

Tests were initially carried out on the newly laid 20 mm and 14 mm friction courses only. Measurements of the permeability of the previously laid 'old' friction course were subsequently included as a measure of the likely permeability of the material towards the end of its useful life. Permeabilities were measured in the right- and left-hand wheeltracks of the middle lane, and between the wheeltracks.

Tests were performed by measuring the time taken for 150 ml of free-standing water, constrained within a 150 mm-diameter ring, to drain through the surface. With the inclusion of monitoring of the permeability of the old friction course, an upper time limit of five minutes for the 150 ml of water to drain was adopted. Material with drainage times longer than this could be considered to be blocked material, given that the initial permeabilities of new 14 mm material were between 6-8 seconds.

2.2 Skid Resistance

The friction measuring instrument was a GripTester manufactured by Findlay Irvine Ltd in Scotland. It consists of a lightweight trailer with a measuring wheel which drags at a rate of 14.5% of the rolling speed. Load and drag are measured and recorded at 0.4 m intervals. Calibration of the GripTester was checked before each survey. During the survey, water was applied to the road surface immediately in front of the test wheel at a rate of 14.6, 27.1 and 39.6 litres per minute. This equates to a water film thickness of 0.5 mm on the road for a vehicle speed of 35, 65 and 95 km/h respectively. For each survey, two friction runs were made at each of these speeds.

2.3 Vehicle Noise

Vehicle noise was measured both as drive-by noise and interior noise levels. The interior levels also enabled the examination of the effects of a wet road surface in comparison to a dry surface. Noise measurements were for both car and a truck at three speeds. These speeds were selected from the region where tyre/road noise effects should dominate over drive-train noise (the noise of the engine, gearbox, drive shaft and exhaust). Car speeds were 60, 80 and 90 km/h, and truck speeds 60, 70 and 80 km/h. The difference in maximum speeds was a safety consideration.

2.3.1 Exterior Drive-by Vehicle Noise

Noise is measured in units of decibels (symbol dB). The unit is the logarithm of the relative loudness of the noise compared to the quietest noise that humans can perceive. The noise spectrum is 'A' weighted so that it measures the human ability to detect sound. 'A'-weighted sound levels have the symbol dBA. The frequency of sound is measured in hertz (Hz).

Initially, this was achieved by setting up three sound level meters on the roadside, each adjacent to the surface type being monitored. The signal from the microphone of each meter was recorded onto separate tape recorders, using the post-weighting network AC output of each meter. This allowed the 'A'-weighted signal to be recorded. This was preferable to the 'flat' response because the low frequency noise was reduced to a level that could be effectively recorded. To further reduce the possibility of error introduced by the use of separate tape recorders, later data were recorded on a single multi-track, multi-channel recorder.

There was some variation in the meters used for the several monitoring stages, but with the exception of a Type 2 Quest meter used twice to monitor drive-by noise adjacent to the 'old' friction course, meters were of Type 1 accuracy. A Rion NL-10 Integrating Sound Level Meter was used as the reference meter. For this reason, all sound level meters used were 'normalised' to the output from this instrument at the start of each monitoring period. This was achieved by arranging the three sound level meters in close proximity, adjacent to the 20 mm friction course. Care was taken that the mutual proximity of the meters did not affect the sound recorded. A number of passing vehicles were then simultaneously recorded. Later, 1/3 octave band spectral analysis showed any differences in individual microphone frequency response. These differences were then corrected in relation to the frequency response for the Rion NL-10 sound level meter.

2.3.2 Vehicle Interior Noise

A single sound level meter of Type 1 accuracy was used for the measurement and recording of vehicle interior noise. The 'A'-weighted signal from this instrument was recorded on tape for subsequent 1/3 octave band spectral analysis. Internal noise measurements were made in both dry and wet (rainy) conditions. The microphone was mounted on the front passenger seat, just above and forward of the seat.

3. RESULTS AND DISCUSSION

3.1 Friction Course Mix Tests

The results of the tests on the 14 mm and 20 mm materials are shown in Tables 3.1 and 3.2. Table 3.2 shows that the 20 mm material was outside the specification for bitumen content and aggregate sizing, with the aggregate mix being low in the larger size ranges.

Table 3.1 Specification and values for 14 mm friction course material.

Bitumen content	5.5% w/w	Air voids	18.9%
JMF range	5.0 - 6.0	Specification range	18 - 25
		Block permeability	7.6 s
		Specification range	15 s max

Sieve analysis	**Sieve size (mm)**				
	13.2	9.5	4.75	2.36	0.075
	Cumulative percent passing				
Sample	100	92	22	13	3.1
JMF range	95 - 100	83 - 93	16 - 26	10 - 16	1.1 - 5.1

Table 3.2 Specification and values for 20 mm friction course material.

Bitumen content	5.1% w/w	Air voids	20.0%
JMF range	3.75 - 4.75	Specification range	18 - 25
		Block permeability	2.61 s
		Specification range	15 s max

Sieve analysis	**Sieve size (mm)**				
	719.0	13.2	6.75	3.35	0.075
	Cumulative percent passing				
Sample	100	75	40	17	2.3
JMF range	95 - 100	64 - 74	18 - 28	12 - 18	1 - 5

JMF	job mix formula
w/w	weight by weight
s	second

3.2 Permeability

The results of the permeability tests are shown in Table 3.3 and Figure 3.1. It can be seen that the permeability of both the 14 mm and the 20 mm friction course decreases significantly from the initial values. The findings of Patrick (1995) (where the deterioration of the drainage properties is said to be primarily through the clogging of the pores with detritus, generally being worse outside of the wheelpaths) initially hold true for both the 14 mm and 20 mm friction course materials. However, at around 14 months after the placement of this material, a changeover occurs for both materials, and from this point the permeability outside the wheelpath is greater than for the material within the wheelpath.

The permeability of the 20 mm material is significantly less than for the 14 mm material for about 12 months. Thereafter they are approximately equal. This indicates that the predicted better tolerance to detritus accumulation of the 20 mm material has not eventuated.

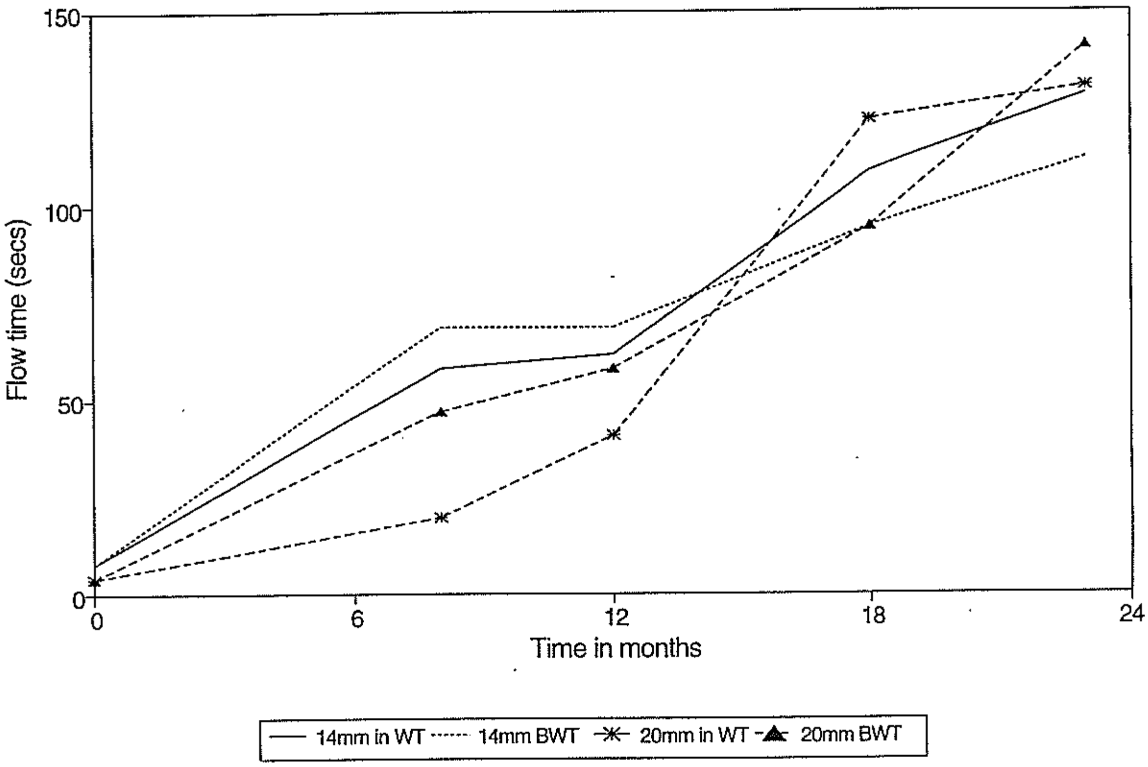
After this time, the 14 mm friction course is more permeable than the 20 mm friction course.

The 'old' 14 mm material indicates the expected long-term value of permeability of both materials, which at the present rate of deterioration could be expected to be approached by the newer surfaces in 2 to 3 more years' time. This flow time is about 300 seconds or greater.

Table 3.3 Permeability of 14 mm and 20 mm friction course and 8-year old 14 mm materials, as measured by flow time.

14 mm	**In wheeltracks (seconds)**	**Between wheeltracks (seconds)**
At construction	8	8
After 8 months	58	69
After 12 months	62	69
After 18 months	109	95
After 24 months	129	112
20 mm		
At construction	4	4
After 8 months	20	47
After 12 months	41	58
After 18 months	122	95
After 24 months	131	141
8-year old 14 mm friction course at end of monitoring period	225 Range 120–300	300 Range 252–300+

Figure 3.1 Permeability of 14 mm, 20 mm and old 14 mm friction course, in wheeltracks (WT) and between wheeltracks (BWT). Old friction course (not shown) has values of 225 seconds (WT) and >300 seconds (BWT).



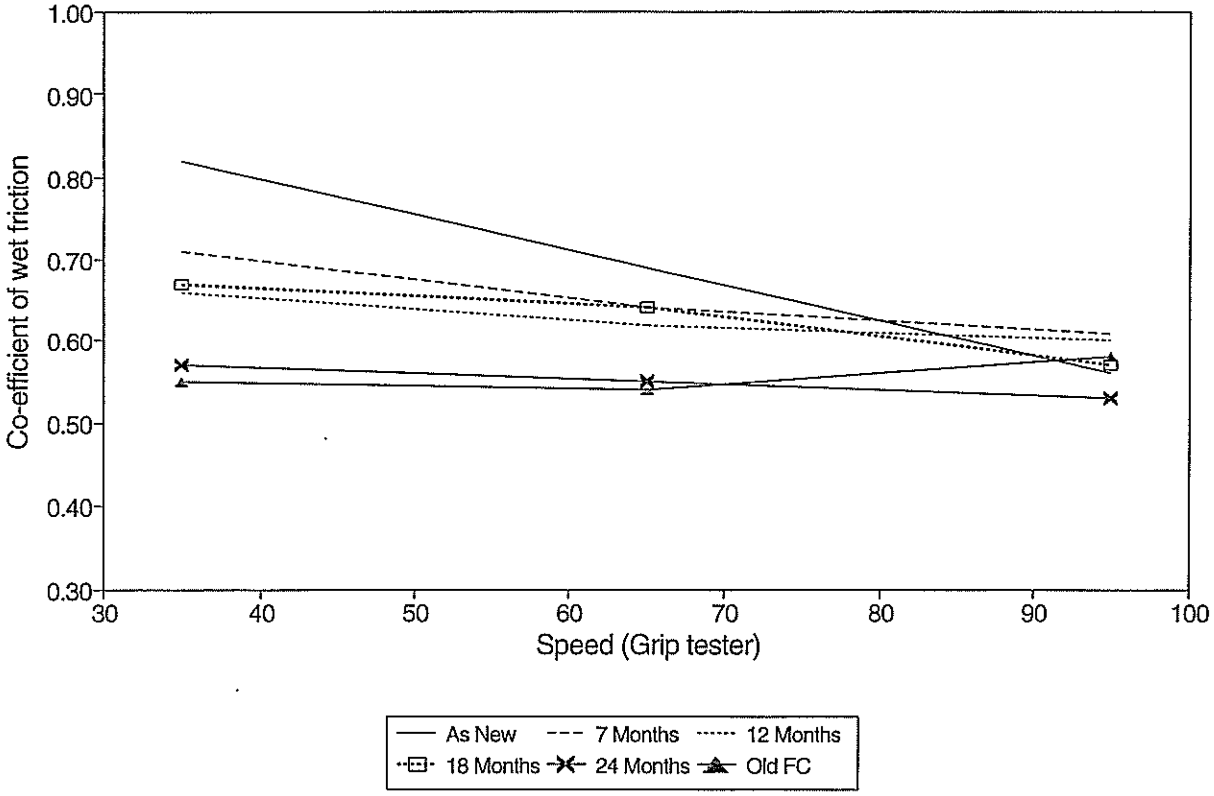
3.3 Skid Resistance

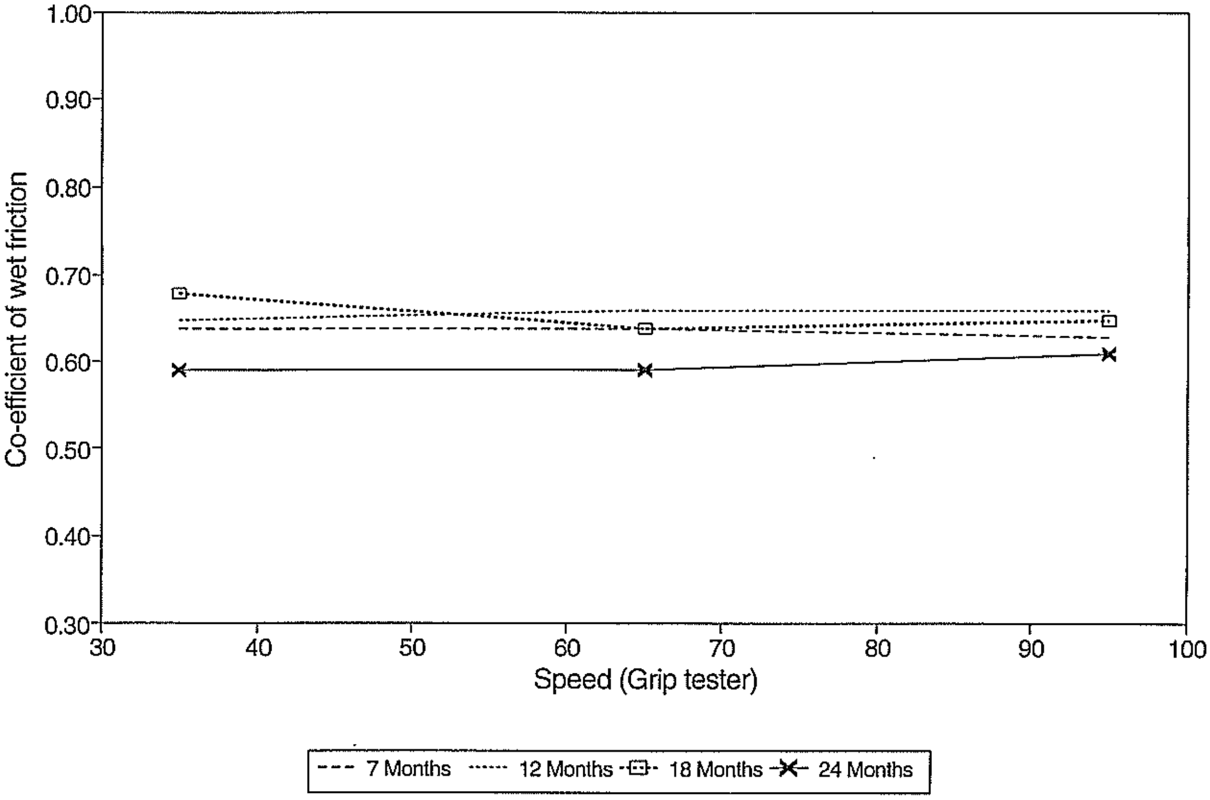
Tables 3.4-3.6 and Figures 3.2a-b show the progression with time of skid resistance and the speed dependency.

The initial results from the more recently constructed sections of 20 mm and 14 mm friction course are consistent with the process of polishing of the stone (which reduces the microtexture), but with the surface maintaining reasonable drainage properties. (Alternatively, the high initial value of the 14 mm mix may result from bitumen/rubber interactions, as the surface was untrafficked prior to the first measurement). However, as the 14 mm friction course surface deteriorates, the speed dependency when new and after six months is reduced significantly, and the speed dependency was worst for the new untrafficked material. The 20 mm friction course does not display a similar speed dependency. However, results were not obtained for untrafficked 20 mm material. By 24 months, deterioration of skid resistance for both the 14 mm and 20 mm friction course surfaces approached that of the older 14 mm friction course (laid about eight years before commencement of this comparison).

Figure 3.2 Skid resistance of the two sizes of friction course and the variation with time from construction, and speed.

(a) 14 mm friction course.





(b) 20 mm friction course.

Table 3.4 Skid resistance of new 14 mm friction course (as coefficient of wet friction).

Vehicle speed (km/h)	Monitoring period				
	Freshly laid	7 months	12 months	18 months	24 months
35	0.82	0.71	0.66	0.67	0.57
65	0.69	0.64	0.62	0.64	0.55
95	0.56	0.61	0.60	0.57	0.53

Table 3.5 Skid resistance of old 14 mm friction course.

Vehicle speed (km/h)	Monitoring period		
	12 months	18 months	24 months
35	0.55	0.60	0.53
65	0.54	0.58	0.53
95	0.58	0.63	0.59

Table 3.6 Skid resistance of 20 mm friction course.

Vehicle speed (km/h)	Monitoring period			
	7 months	12 months	18 months	24 months
35	0.64	0.65	0.68	0.59
65	0.64	0.66	0.64	0.59
95	0.63	0.66	0.65	0.61

3.4 Noise

The noise results are grouped into three subsets:

- Vehicle interior noise levels – dry pavement,
- Vehicle interior noise levels – wet pavement,
- Exterior drive-by vehicle noise.

3.4.1 Vehicle Interior Noise Levels – Dry Pavement

With the exception of the initial car interior measurement, the trend over the monitoring period for each material, including the old friction course, was for either no change or only minor progressive change in noise levels. However, for the car interior noise, the change was not large, being around 1-2 dBA over the monitoring period for each material.

For the truck, a significant increase occurred in overall interior noise levels, and the increase was greater at the lower speeds. For the 60 km/h speed, interior noise levels increased by 4-6 dBA for both materials, while for the 70 and 80 km/h speeds, levels increased by 3-4 dBA for each material. These increases are shown in Tables 3.7 and 3.8, and in graph form for each material in Figures 3.3a-c and 3.4a-c.

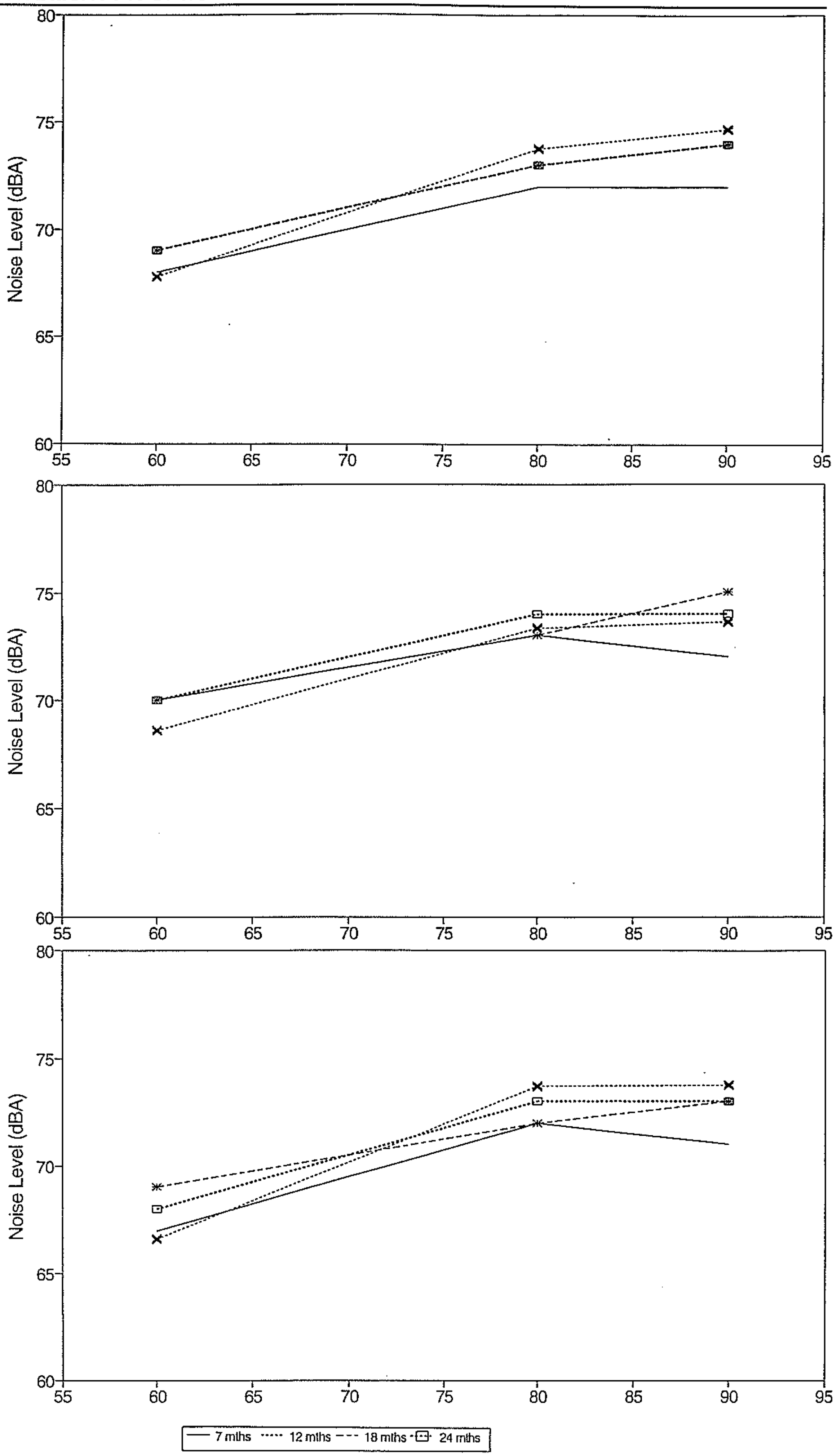


Figure 3.3 Car interior noise levels, 7-24 months after construction.

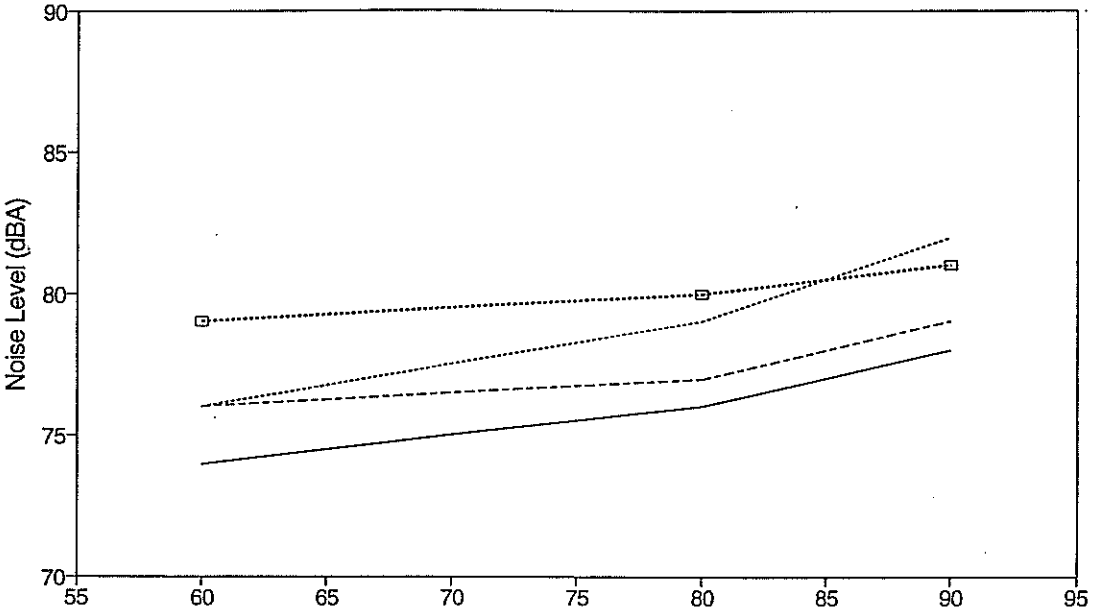
(a) 14 mm friction course.

(b) 20 mm friction course.

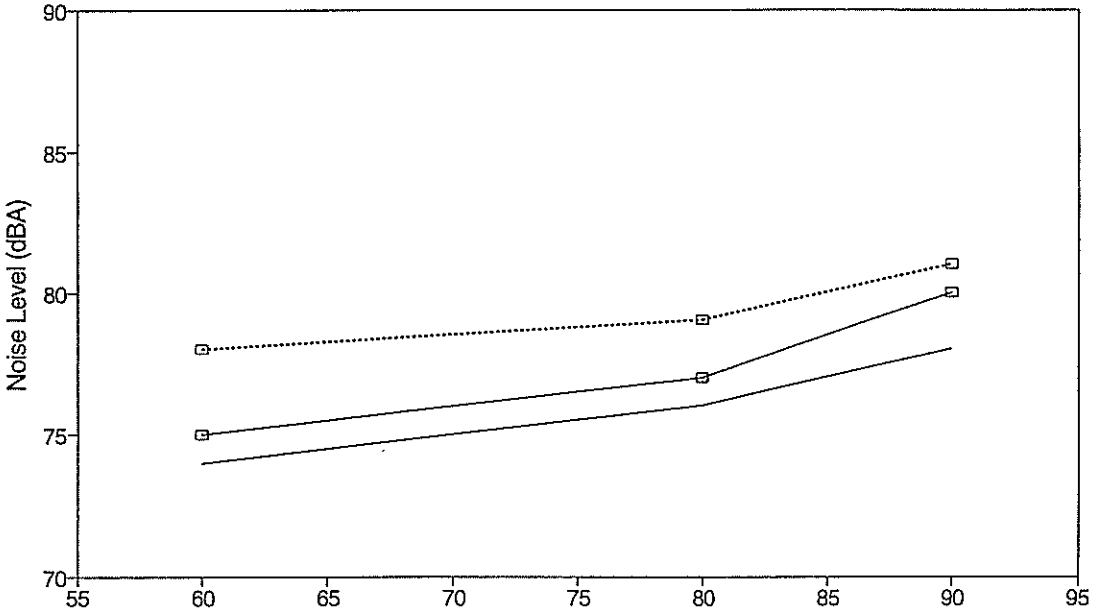
(c) Old 14 mm friction course.

Figure 3.4 Truck interior noise levels, 7-24 months after construction.

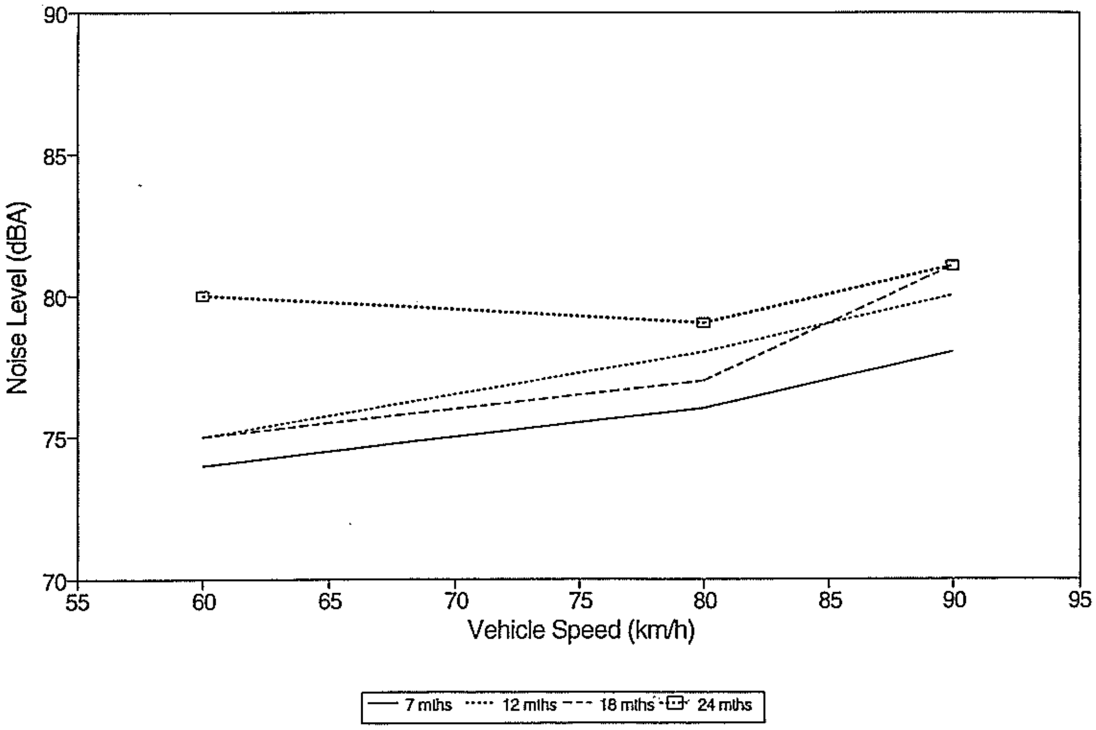
(a) 14 mm friction course.



(b) 20 mm friction course.



(c) Old 14 mm friction course.



At the 12-month monitoring stage, the type of tyre on the car had been changed for tyres of a different tread pattern. A number of tests were carried out using both the original tread pattern and the alternate pattern, and a small consistent difference in noise levels was detected. This measured difference was applied to the measurements made at the 12-month monitoring stage. The 12-month levels reported here have been corrected using this difference. Consequent monitoring at the 18- and 24-month stages was carried out using the original tyres.

Note that the internal noise increased with speed and that this increase was greater for the truck than for the car. This is typical, and was expected. Less expected was the fact that the 20 mm friction course, instead of significantly increasing noise, appears to have had only a minor effect on vehicle interior noise levels. The literature (Patrick 1995) indicated that this was more of an issue than appears to have been the case in this present study. Figure 3.3b indicates a possible trend for the 20 mm surface to be noisier for the car (compared to the 14 mm surface), but this trend appears to be reversed for the truck (Figure 3.4b).

Figures 3.5a-c show 1/3 octave band spectra for the car. The drive-train noise component tends to be to the left-hand side in frequencies up to 100-200 Hz with tyre noise component mainly the remainder on the right-hand side.

Three features are of interest:

- The tyre noise component is similar within each of the three surfaces, differing only in magnitude.

- The drive-train component has a peak 63 Hz for the 80 km/h vehicle speed, which dominates over the tyre noise and is probably the cause of the 80 km/h distortion seen in Figures 3.3a-c. This peak may be related to a car body resonance. It also appears to be present at 50 Hz, but is less dominant at the 60 km/h speed.

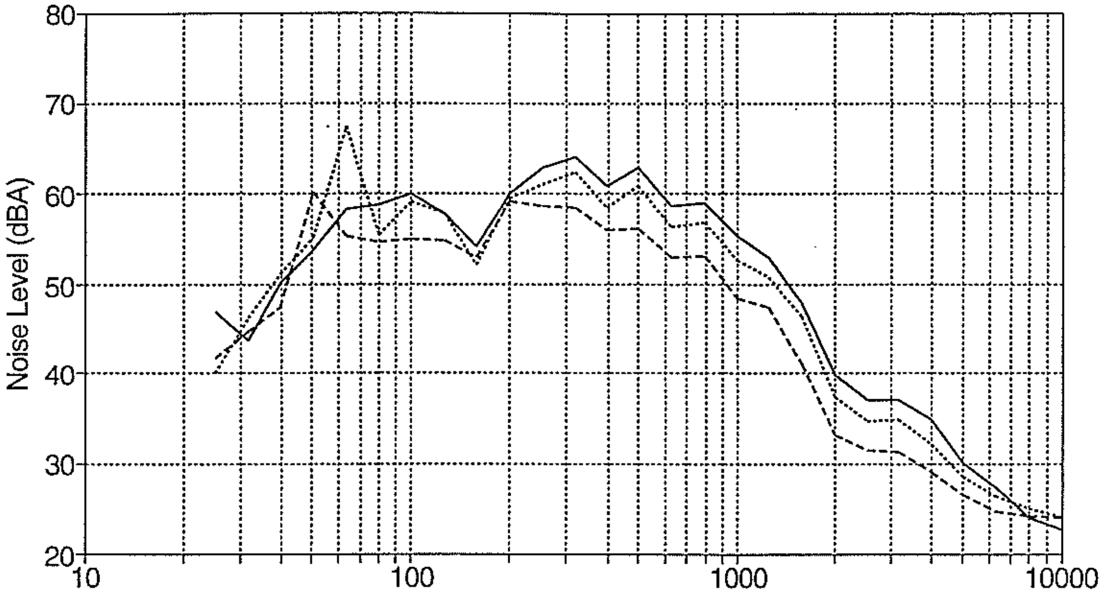
- On the old friction course, the drive-train side of the spectra is of equal or greater magnitude than the tyre component at all speeds.

In Figures 3.6a-b, trends such as car interior noise increasing with time are not clearly defined. As can be seen in these Figures and in Table 3.7a, the general change in overall noise is minor, to the point where some of it may be accounted by possible experimental variation. A slight trend can be seen in Figures 3.6a-b where the contribution to the overall noise by the drive-train (most of the <1000 Hz component) reduces, while the tyre/road noise (the component >1000 Hz) increases by a similar amount.

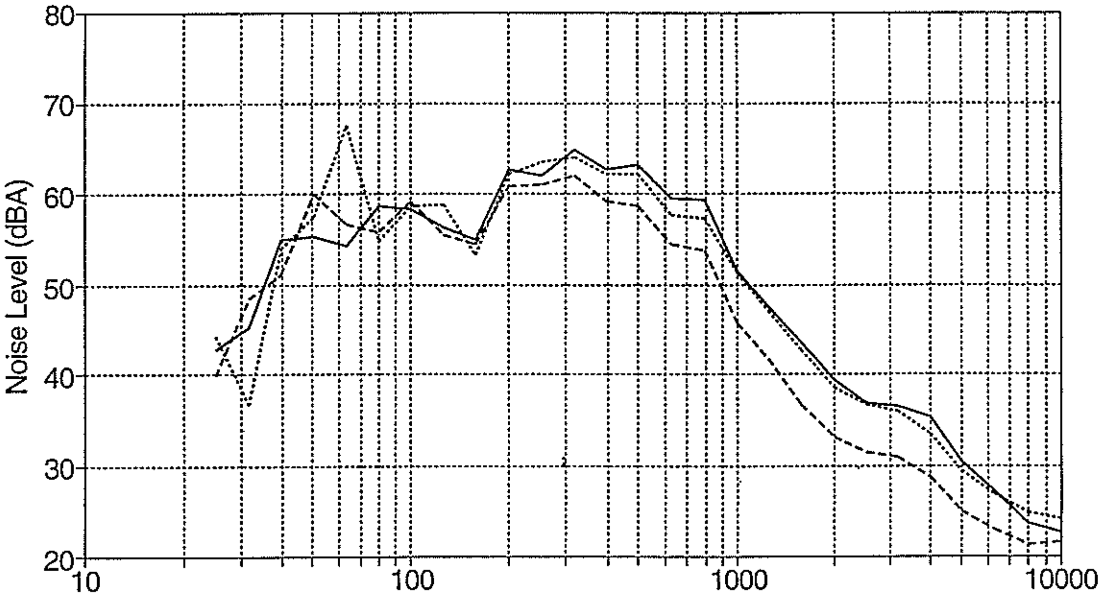
There is no apparent reason for the reduction of 2 dBA over 24 months for the old 14 mm friction course, as shown in Table 3.7a. This should be a stable surface in view of its age. An alternate analysis would be to use the old material as a benchmark to 'normalise' the readings on the other surfaces, so that for each measurement period the measurement relative to the old surface is used to chart deterioration.

Figure 3.5
⅓ octave band spectra for car interior noise, 6 months after construction, at 90, 80 and 60 km/h.

(a) 14 mm friction course.



(b) 20 mm friction course.



(c) Old 14 mm friction course.

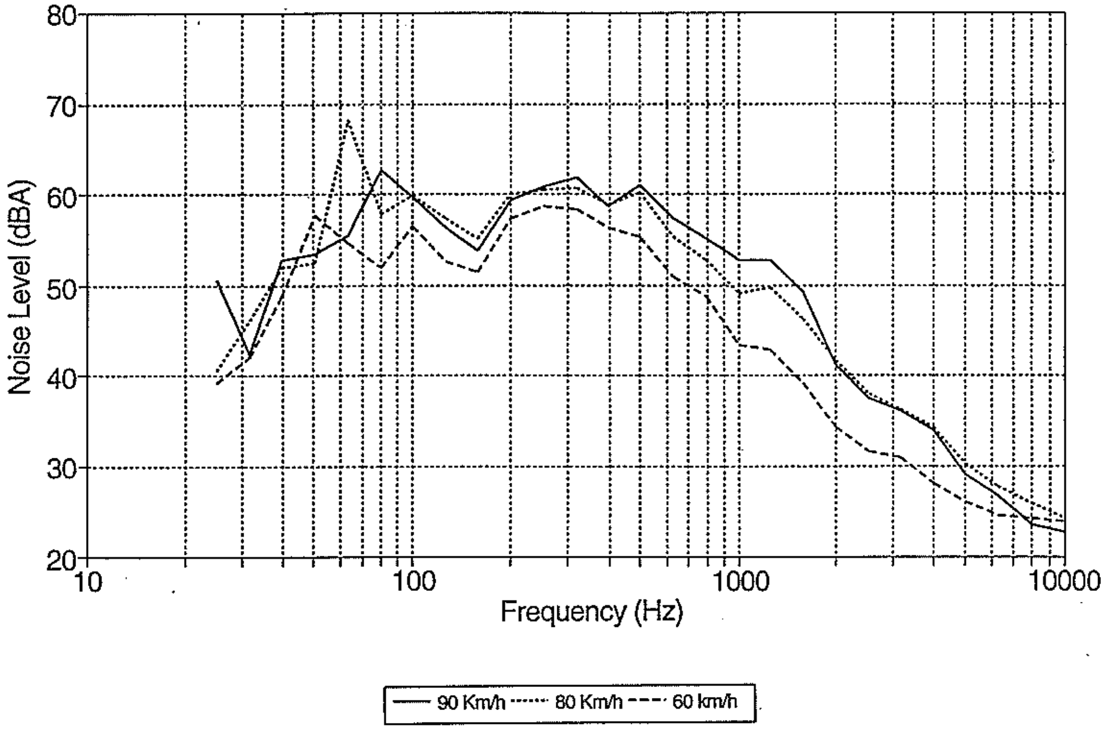
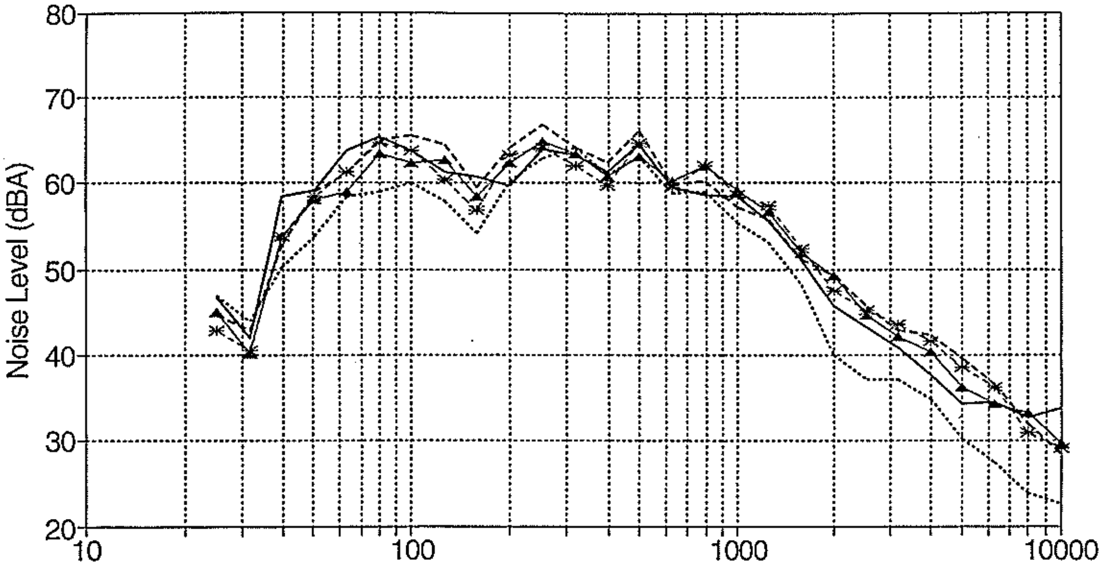


Figure 3.6
⅓ octave band spectra for car interior noise, at 90 km/h, over the monitoring period.

(a) 14 mm friction course.



(b) 20 mm friction course.

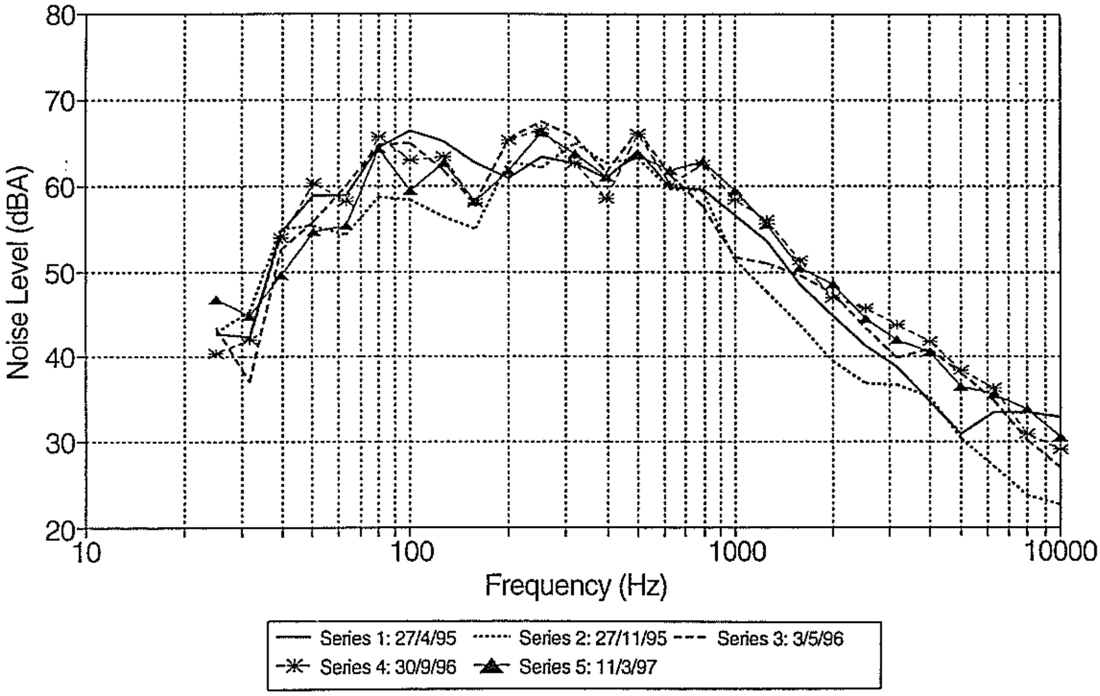
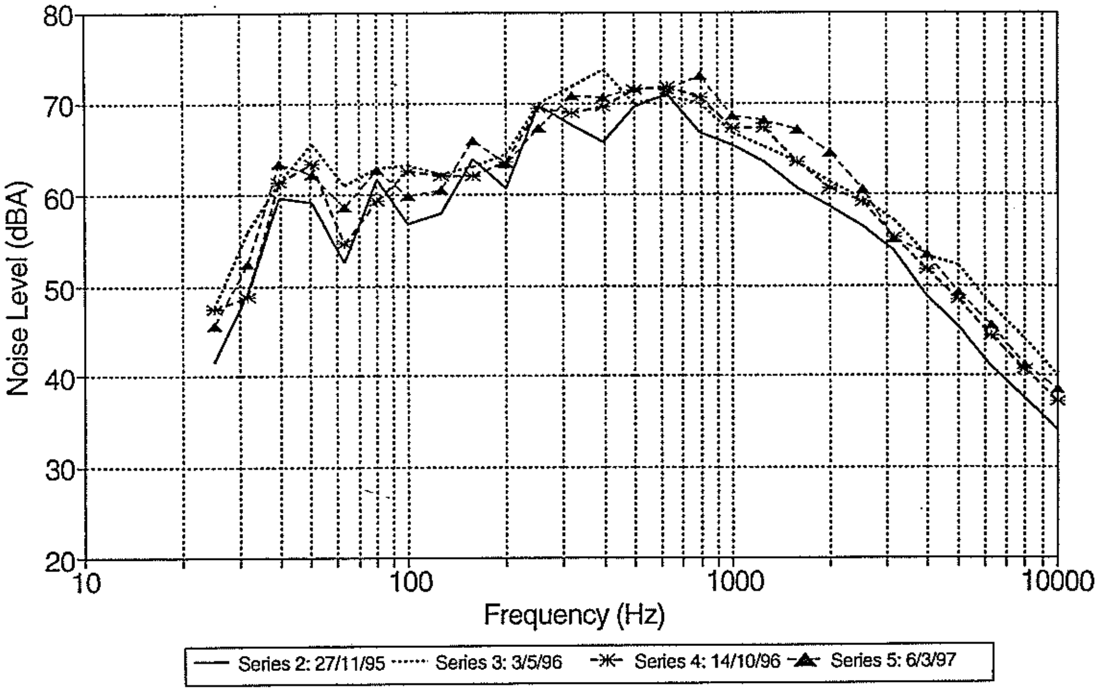


Figure 3.7 ⅓ octave band spectra for truck interior noise, at 80 km/h, from 7-24 months, for 20 mm friction course.



If this is done there is little change for the car interior levels, and the change noted below for the truck measurements becomes much smaller.

For the truck interior noise the trend for noise increase with time is slightly stronger. Figure 3.7 and Table 3.7b show that the tyre/road noise component tends to increase chrono-logically, especially between 1000 and 3000 Hz. At frequencies above this level the trend is less clear.

Table 3.7 Vehicle interior noise levels (dBA) for dry pavement.

(a) Car

Surface type	Speed (km/h)	Car noise levels (dBA) for time (months) since construction					Change in noise (dBA) over 24 months
		0	6	12	18	24	
14 mm	90	74	72	75	74	74	0*
	80	N/A	72	74	73	73	+1
	60	N/A	68	68	69	69	+1
20 mm	90	74	72	74	75	74	0*
	80	N/A	73	73	73	74	+1
	60	N/A	70	69	70	70	0
Old 14 mm	90	75	71	74	73	73	-2*
	80	N/A	72	74	72	73	+1
	60	N/A	67	67	69	68	1

(b) Truck

Surface type	Speed (km/h)	Truck noise levels (dBA) for time (months) since construction				Change in noise (dBA) from 6-24 months
		6	12	18	24	
14 mm	80	79	82	79	81	+3
	70	76	79	77	80	+4
	60	74	76	76	79	+5
20 mm	80	78	80	80	81	+3
	70	76	77	77	79	+3
	60	74	75	75	78	+4
Old 14 mm	80	78	80	81	81	+3
	70	76	80	77	79	+3
	60	74	75	75	80	+6

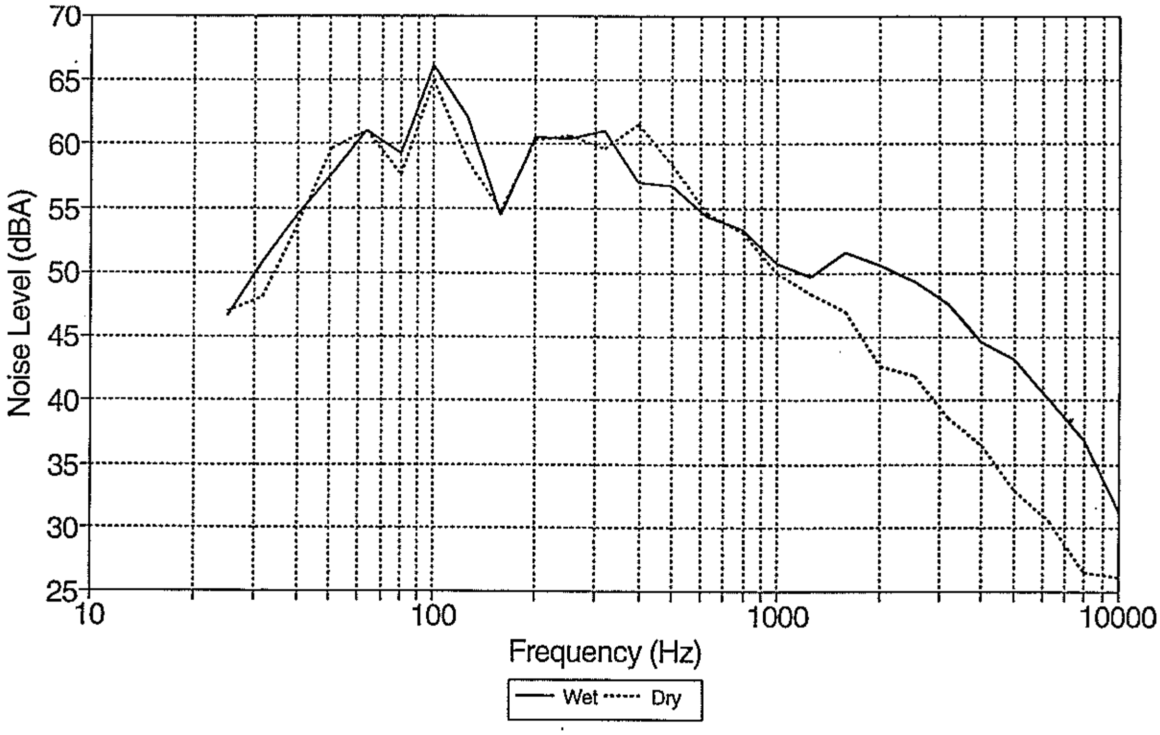
* Extent of change-over period 0-24 months.
N/A measurements not made.

3.4.2 Vehicle Interior Noise Levels – Wet Pavement

Vehicle interior noise levels were also measured during periods of heavy rain. Figure 3.8 demonstrates the effect of a wet pavement surface on vehicle interior noise levels. In this instance, the surface was at another site (in Petone) and was a 10 mm dense-graded asphalt surface in a 50 km/h speed area. The full band noise levels of this surface, wet and dry, are equal, but the spectra are quite different.

With reference to the three previous spectra, the drive-train component (the low frequencies) is quite large and the tyre component (the higher frequencies) is smaller, because of the smaller stimulation of the tyre on this smooth 10 mm surface. This effect is combined with the increased drive-train component from travelling on a level road, compared to the reduced drive-train component resulting from travelling downhill in Ngauranga Gorge. The main area of interest is the region beyond 1000 Hz, where there is a significant rise in the spectra caused by the water on the pavement surface.

Figure 3.8 Spectra of interior vehicle noise on wet and dry dense-graded asphalt showing rise in noise levels for wet pavement in the region 1000 Hz to 10 000 Hz.

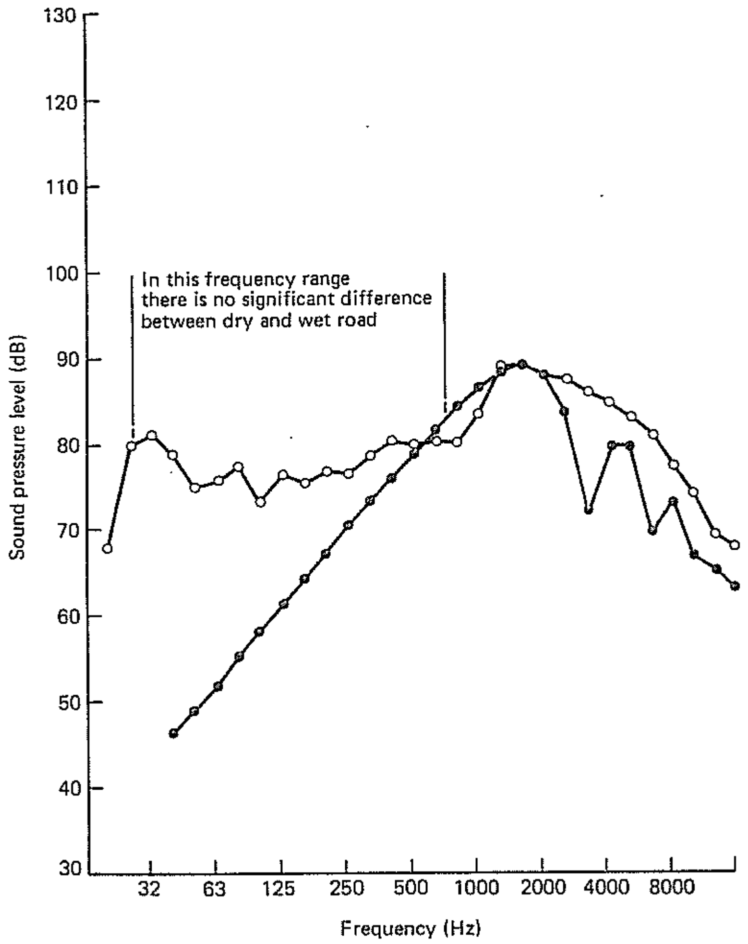


Nelson (1987) has demonstrated (Figure 3.9) that this can be explained in terms of the acceleration of water droplets away from the tyre. Figures 3.10a-c show the interior noise spectra for the car on both the wet and the dry friction course. Each of these Figures shows a rise in the spectra beyond 1000 Hz (the tyre noise component) for the wet road, when compared to the dry road data. The wet road spectra also demonstrate a tyre noise component which steadily increases with time. This is likely to be related to the progressively deteriorating permeability of the friction course material, which will in turn allow a greater amount of free water to be present.

In general, this increase is consistent, but although efforts were made to carry out these studies during rainfall of similar rates, the uncontrolled nature of the rain may have caused the slight anomalies seen in the spectra for the car travelling at 90 km/h, where the trend of increasing noise against time is not as clear. This variability of rainfall may also be the reason for the lack of such a strong trend for the truck interior noise at 80 km/h.

Although the tyre noise components of these spectra for wet friction course are always greater than those for the dry friction-course material, Figures 3.11a-c show that the increase in this component for trucks is not as time-ordered as that for the car. However, this component is greatest at the 24-month stage, similar to that for the car interior noise.

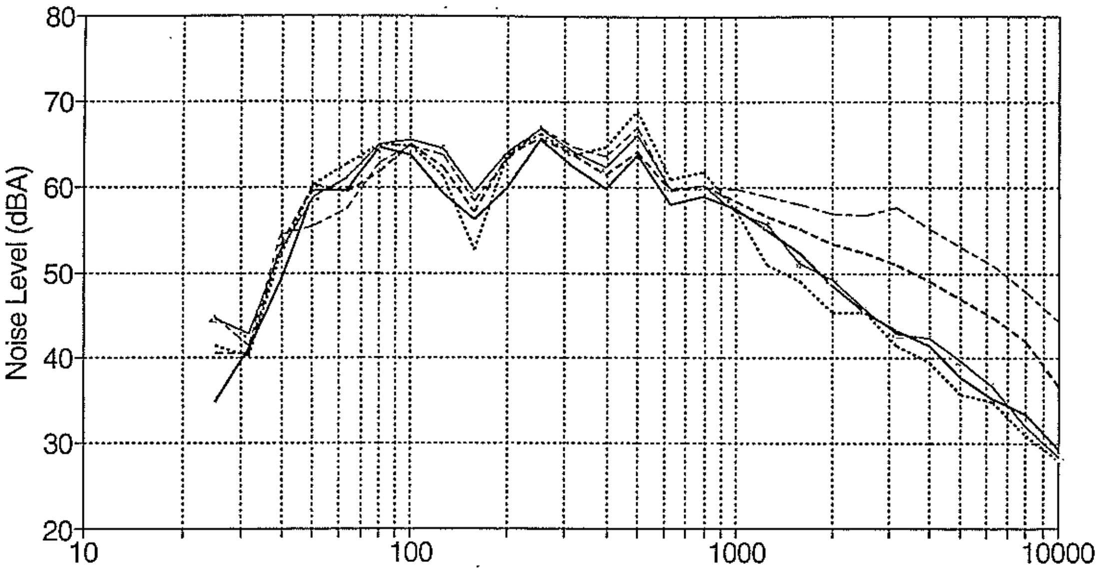
Figure 3.9 Comparison of measured and predicted noise for a car rolling on a wet road surface (from Nelson 1987).



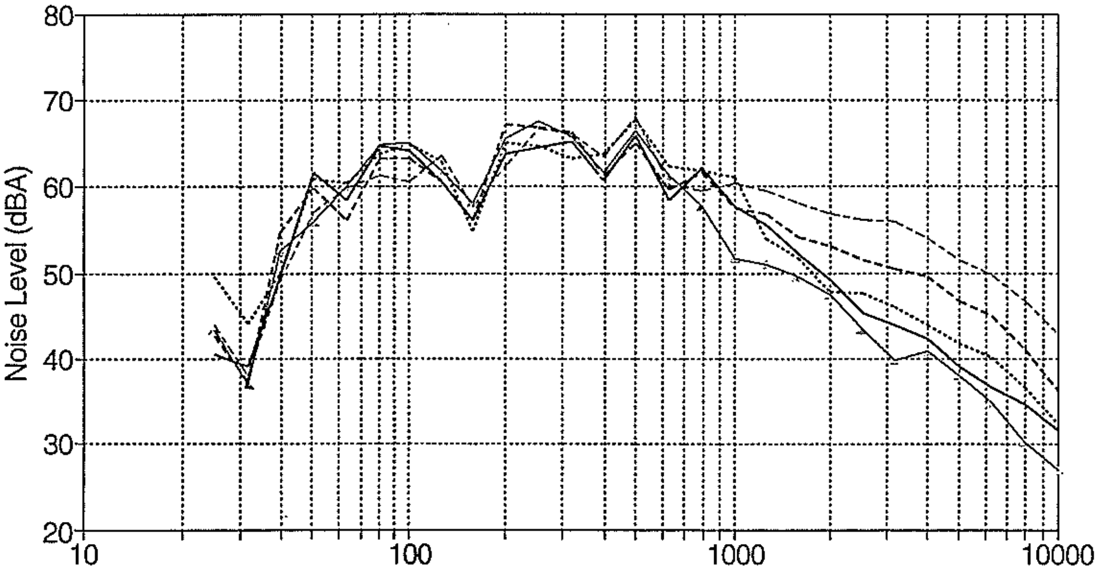
o-o = rolling noise of a car on a wet road
●-● = theoretical values for acceleration noise of water droplets

Figure 3.10 Car interior noise spectra for wet and dry friction course, over 6-24 months, at 90 km/h.

(a) 14 mm friction course.



(b) 20 mm friction course.



(c) Old 14 mm friction course.

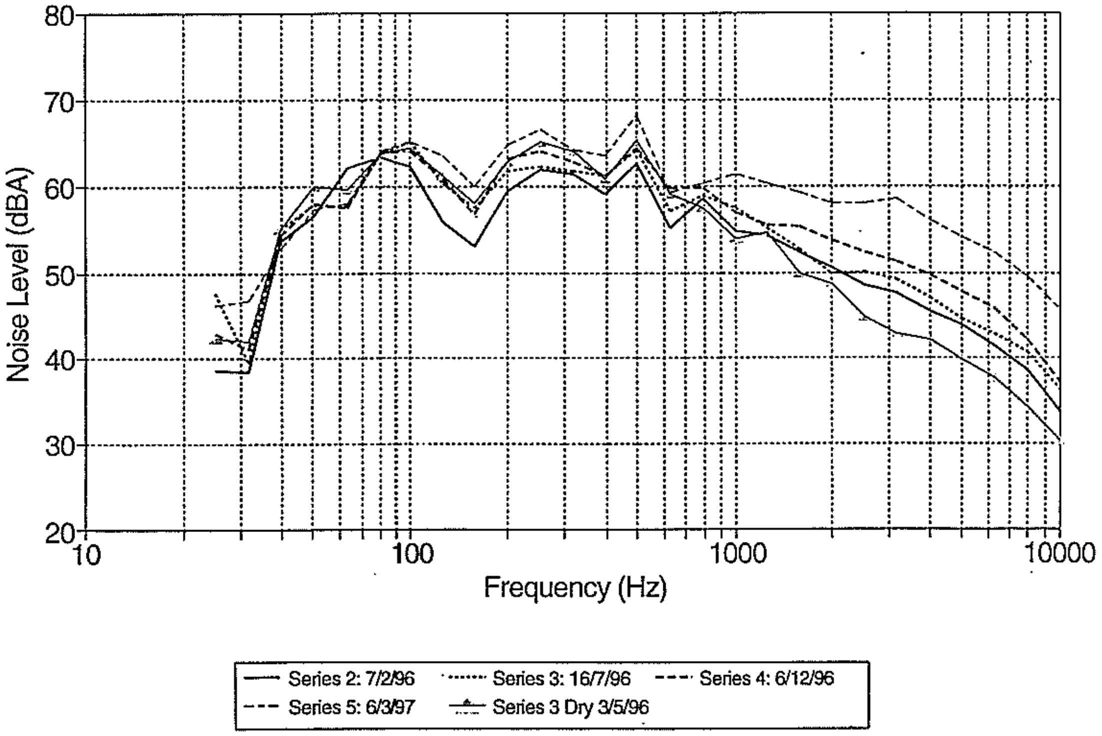
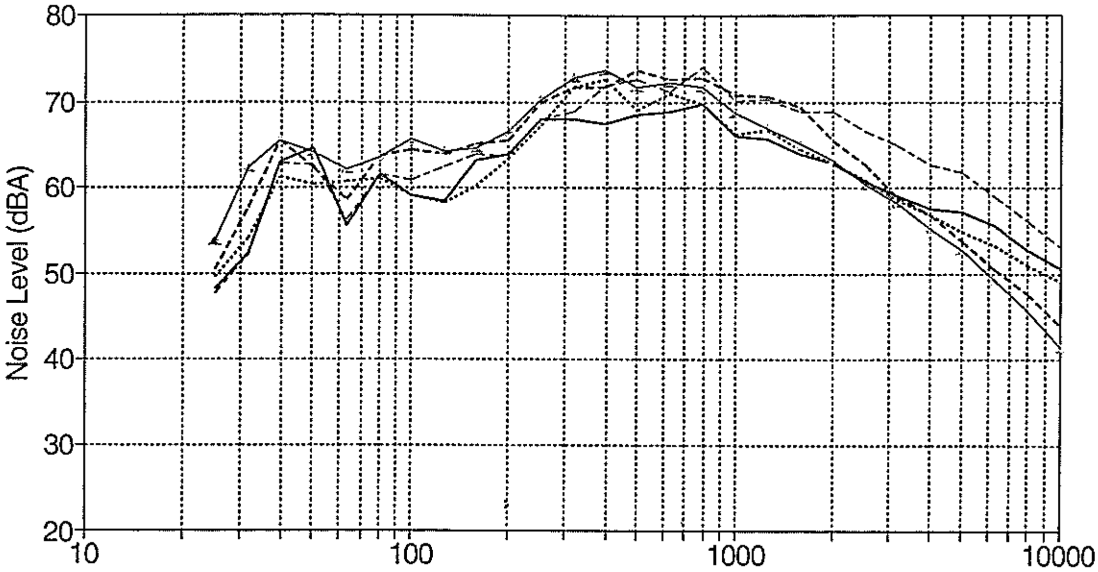
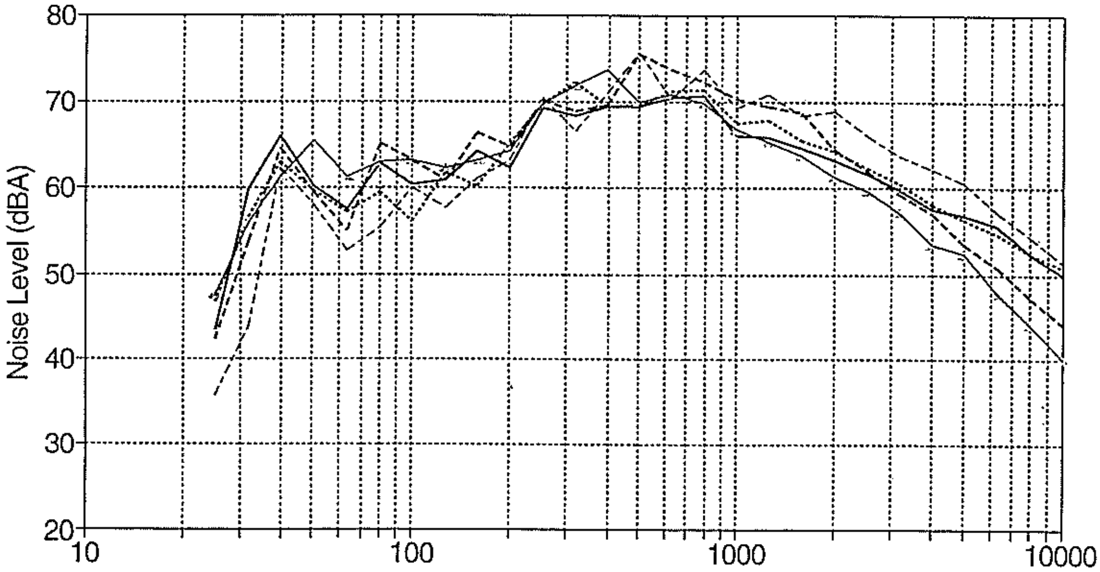


Figure 3.11 Truck interior noise spectra for wet and dry friction course, over 6-24 months after construction, at 80 km/h.

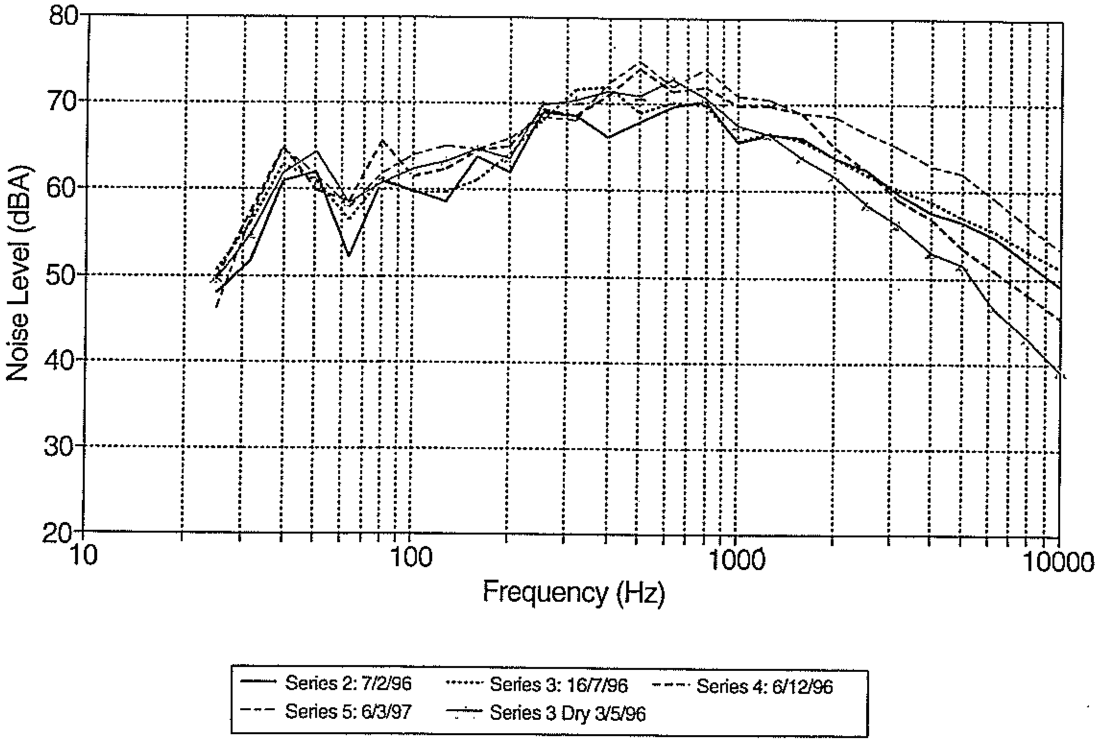
(a) 14 mm friction course.



(b) 20 mm friction course.



(c) Old 14 mm friction course.



The lack of clear trends for the truck interior noise may also to be related to other factors, such as the reduced sensitivity of the truck tyres to different road surfaces, or greater vehicle body and windscreen area transmitting wind noise into the truck cab (which may mask subtle differences).

A further general observation is that the difference in spectra between the dry surface and the initial wet surface is greater for the old friction course than for either the 20 mm or 14 mm material. This difference may be because the pores in the old material were already significantly blocked at the outset of this monitoring period, whereas the initial drainage qualities for the newly placed 20 mm and 14 mm friction courses were such that it initially performed more like the dry material. That is, any surface water quickly drained away, leaving little or no free water to notably affect the noise arising from the tyre/road interaction. Again, although this trend is relatively strong for the car interior noise, the relationship is less strong for the truck interior noise.

The significance of this aspect of the work is that interior noise of a vehicle on wet friction course may be an indicator of its permeability. However, one difficulty is that rainfall is highly variable in its intensity, and driving rain with wind could generate spurious noise.

3.4.3 Exterior Drive-by Vehicle Noise

The exterior drive-by noise levels are shown in Tables 3.8a-b, and in Figure 3.12. The comparatively low 90 km/h 20 mm six-month reading of Table 3.8 appears to be an anomaly. In general, there appears to be very little difference in vehicle noise for the old, 20 mm or 14 mm friction course materials for either the car or the truck. In the case of the car, the 20 mm may be 1 or 2 dBA quieter than either the new or the old 14 mm surfaces, which is a slight reversal of the trend for the interior noise.

Spectral analysis can offer some explanation. For the vehicle interior noise levels, the drive-train component is of almost equal magnitude as the tyre noise component, and vehicle body resources could influence the overall level. These are approximately the same for the 14 mm and 20 mm materials. For the drive-by noise, the tyre noise component is much greater than the drive-train component. Other than these observations, it is difficult to spectrally establish any strong trend of vehicle drive-by noise changing with time for any of the friction course materials monitored.

In real terms, the overall drive-by noise levels did not change by more than 2-3 dBA over the full 24-month monitoring period. However, there were occasional exceptions to this, as demonstrated by the car drive-by noise levels measured at 90 km/h on the 20 mm material at the six-month monitoring stage, and the truck drive-by noise levels measured at 60 km/h on the 14 mm material, also at the six-month monitoring stage.

Figure 3.12 Exterior drive-by noise (dBA) for car at 90 km/h on 14 mm, 20 mm, and old 14 mm surfaces.

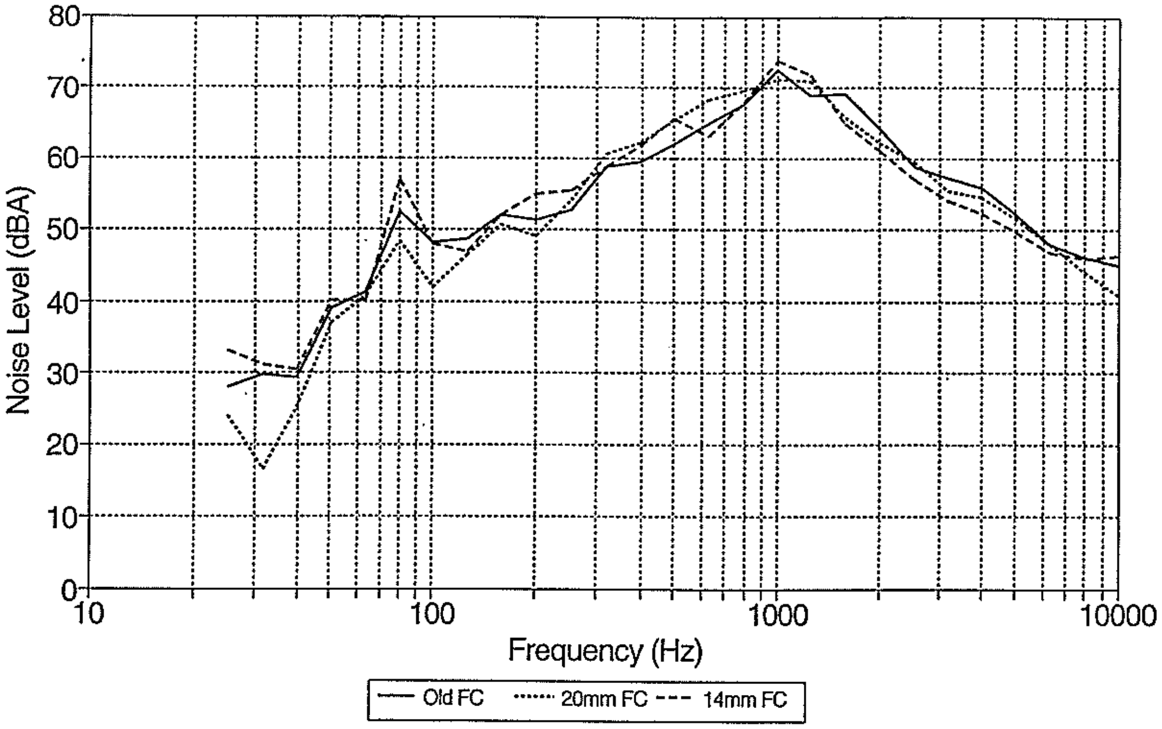


Table 3.8 Exterior drive-by noise levels (dBA) for vehicles.

(a) Car

Surface type	Speed (km/h)	Noise levels (dBA) for time (months) since construction					Change in noise (dBA) over 6-24 months
		0	6	12	18	24	
14 mm	90	78	75	78	79	78	0**
	80		76	77		77	+1
	60		70	73	73	72	+2
20 mm	90	78	71	76	77	77	-1**
	80		76	75	76	75	-1
	60		72	71	73	71	-3
Old 14 mm	90	82		78	78	77	-1*
	80			77	75	74	-3*
	60			74	74	71	-3*

(b) Truck

Surface type	Speed (km/h)	Noise levels (dBA) for time (months) since construction				Change in noise (dBA) over 6-24 months
		6	12	18	24	
14 mm	80	78	79	80	80	+2
	70	79	78	78	78	-1
	60	81	77	77	76	-5
20 mm	80	79	80	80	81	+2
	70	78	78	78	78	0
	60	76	75	78	75	-1
Old 14 mm	80		80	80	81	+1*
	70		79	79	78	-1*
	60		77	79	76	-1*

* denotes change over 12-24 months.

** denotes change over 0-24 months.

4. CONCLUSIONS

- The hoped-for improvement identified by the literature (Patrick 1995), that a larger sized friction course may give a surface which retains its drainage properties possibly 50% longer than the 14 mm aggregate friction course, has not occurred. Wheeltrack permeability of the 20 mm material is significantly better for the first 12 months, but after 24 months the drainage properties for both the 14 mm and the 20 mm friction course are similar. This indicates that the predicted better tolerance to detritus accumulation of the 20 mm material has not eventuated.

- Measurements of the skid resistance on the old 14 mm friction course demonstrate that the long-term indication is for skid resistance to regress to a low value at all speeds. Over the 24-month monitoring period, the skid-resistance values for both the 14 mm and the 20 mm materials have gradually converged, approaching values similar to those obtained from the old 14 mm friction course.

- The initial speed dependence of skid resistance observed for the 14 mm friction course has reduced significantly after 24 months.

- No significant noise increase is apparent in using the 20 mm friction course, but conversely, the acoustic benefit that was expected from a thicker, more porous material has not occurred.

- Surface permeability may possibly to be linked to acoustic properties. This linkage is stronger for vehicle interior noise when measured on wet roads.

5. RECOMMENDATIONS

- A further monitoring stage of permeability and skid resistance in about 24 months of concluding the trial would have helped to confirm the perceived trend towards a short-than-projected life-span for the drainage properties of both the 14 mm and 20 mm friction course materials. It would have provided a useful data point linking these first two years to the eight-year-old friction course. This further stage could not be done as flooding had severely damaged the test site.

- Vehicle interior noise showed some relatively strong trends when measured on wet friction course, and this could perhaps be used to monitor permeability. Development of test equipment to provide controlled water depth, and subsequent vehicle interior noise monitoring, would reduce the possibility of anomalies being introduced into these observations, and confirm the existence of such trends.

- A number of the observations made in this study may be partially attributable to site-specific characteristics, such as atypical drainage related to the slope and crossfalls, or abnormal noise conditions because Ngauranga Gorge tends to act as a wind funnel. Repeat studies, if undertaken, should be on a level site with more controllable parameters.

- For such a repeat study, the friction course material should have improved quality control, during both manufacture and laying, so that the specifications are more closely complied with.

- Overseas studies have indicated that a lot of the advantages (particularly acoustic) of using 20 mm friction course are linked to material thicknesses greater than the 40-50 mm laid in the Ngauranga Gorge site. For a repeat study trialing a section using an increased thickness of material would be advantageous.

6. REFERENCES

Nelson, P.M. 1987. *Transportation Noise Reference Book.* University Press, Cambridge.

Patrick, J.E. 1995. Maintaining the porous nature of friction course. *Transit New Zealand Research Report No. 46.*