AUSTRALIAN DEVELOPMENTS TO REDUCE ROAD TRAFFIC NOISE ON CONCRETE PAVEMENTS

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SUMMARY

In the Australian State of New South Wales, the Roads and Traffic Authority in its Northern Region is constructing trial concrete pavements with variations in surface texture to study the relationships between surface texture, tire noise and skid resistance.

The trials are being conducted with the sponsorship of the Cement and Concrete Association of Australia on new dual carriageway concrete pavement sections of the F3 Freeway which is part of the Federally funded National Highway system. The F3 Freeway connects the principle cities of Sydney and Newcastle.

The aim of the research is to detail production of a predictable and uniform concrete surface texture that will provide minimum tire noise with a defined skid resistance.

INTRODUCTION

This paper reports on research and investigatory work being undertaken by the Australian State Road Authority, Roads and Traffic Authority – New South Wales (RTA) Northern Region, Major Projects Branch.

A primary aim of the investigation is an analysis of the relationship between the surface texture of a concrete pavement, the traffic noise generated and the level of skid resistance which is provided by that surface.

The goal of the research work is to produce a surface texture that optimises the balance between low traffic noise generation and high speed skid resistance for a particular situation.

Various surface textures have been created on new concrete freeway pavements and then analysed for their effectiveness.

From these results further modifications and refinements to additional new surface texture formats are made and the process of analysis is repeated, with the appropriate balance of noise and skid resistance being targeted.

SITE DESCRIPTION

The work is being conducted on the F3 Freeway which is the principal motorway between the cities of Sydney and Newcastle in the State of New South Wales.

The concrete surface textures are being created in the pavements of the dual carriageway sections of the F3 Freeway between Palmers Road and Lenaghans Drive,

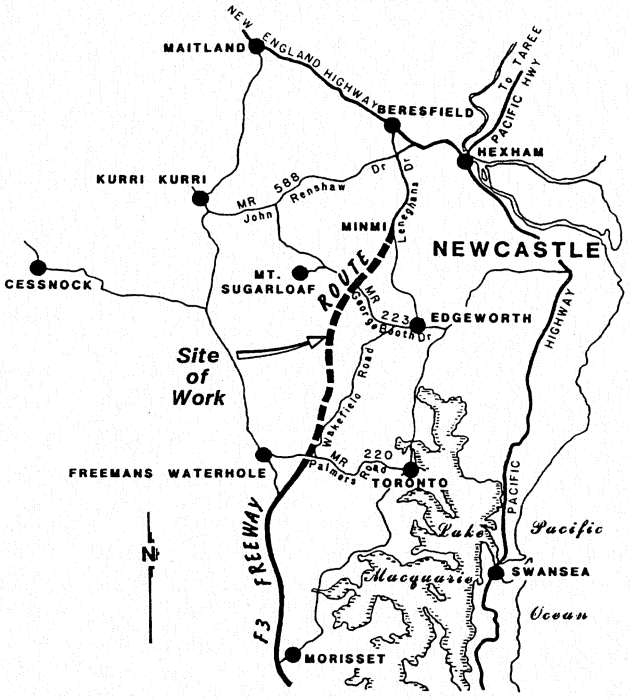


Figure 1 Locality Sketch

covering a 19-km section of this Freeway between 127 and 146 km north of Sydney (see Figure 1). These Freeway sections when operated under traffic normally have a traffic speed limit of 110 km/h.

The pavement construction program is divided into two stages. The completed first stage includes texture variations over a seven kilometre section between Palmers Road to Wakefield located 127 to 134 km north of Sydney.

The second stage comprises the remaining 12-km section of concrete freeway pavement which will be constructed during 1992 and 1993.

A typical freeway cross section of the work for Stage 1 is as described in Figure 2. The travel lane widths have been reduced to 3.5 m and paved median and kerb shoulders reduced to widths of 1.0 m and 2.0 or 3.0 m respectively in the more recently designed second stage.

Site conditions with expansive fill material and mine subsidence required an unjointed continuously reinforced concrete (CRC) pavement rather than plain concrete (PC) pavement with sawn transverse joints which is more common in NSW. The pavement structure consists of a 230-mm, 32-MPa compressive strength CRC base over a 150-mm, 5-MPa compressive strength sub-base.

SURFACE TEXTURE

Background

Concrete surface practice in Australia to date has been primarily directed on the basis of friction, ie to provide a surface that is safe in terms of resistance offered to tire skidding and to ensure that the required friction is maintained throughout the life of the pavement.

Requirements of skid resistance are a function of many variables, one of which is traffic speed. Generally the higher the traffic speed the greater the need for increased skid resistance for emergency stopping although special consideration is also required for tight geometry, steep grades and frequent braking situations. Also dependent on the speed of traffic operation are the particular parameters of the surfacing materials and construction which provide this skid resistance. At low speed, skid resistance is primarily provided by the fine scales of surface texture. However at higher speeds on wet roads, the surface must contain, in addition, sufficient drainage channels for the water to be dispersed before the fine scales of texture can come into play.

It had been held in concrete surface practice that for traffic speeds up to 80 km/h a "Hessian Drag" finish provides acceptable skid resistance (the finish "Hessian Drag" as the name implies is produced by dragging a sheet of hessian over the plastic concrete surface after final screeding).

It has also been general practice that for traffic speeds greater than 80 km/h a finish which provides a greater drainage capacity than Hessian Drag is required. This surface has been provided by Transverse Tining (which as the name implies has a surface which has transverse indentations made in the plastic concrete by tines, after the screeding and floating stages).

Transverse tining provides escape channels for water and lessens the likelihood of aquaplaning at high speed. It also provides macrotexture which deforms the tire rubber and generates hysteretic friction even if all the water is not dispersed[1].

Skid resistance on transverse tined surfaces appears to be greater than on Hessian Drag surfaces and traffic noise and harsh ride on transverse tined surfaces appears to be considerably greater than that of Hessian Drag finishes.

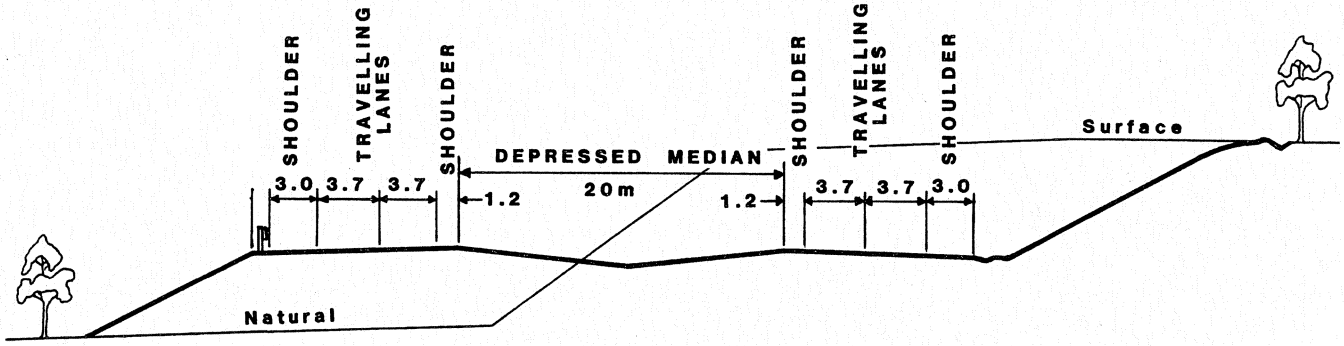


Figure 2 Typical Freeway Cross Section (dimensions in metres, not to scale)

At first glance it appears that there may be a balance between skid resistance and traffic noise generation. The determination, quantification and extent of this interaction forms the basis of this research.

Construction

The PIARC Technical Committee on Surface Characteristics defines the various wave lengths of surface irregularities as follows:

<0.5 mm	microtexture
0.5 – 50 mm	macrotexture
50 – 500 mm	megatexture
0.5 – 50 m	roughness

Surface characteristics of concrete pavements have for the sake of simplicity, so far, been referred to as either being Hessian Drag or Transverse Tine, but there are many different surface textures that emanate by altering or manipulating the causal factors of texture.

Surface texture is dependent upon source construction material such as the difference in the microtexture of the exposed stone due to the difference of geological materials, eg rhyolite versus basalt.

As well, surface texture is dependent upon the morphology of the parent pavement material composition such as the differences produced by varying sand content versus coarse aggregate content and the varying porosities of pavements.

Microtexture skid resistance is obtained in concrete pavements by the sand in the mortar. In RTA pavements at least 40% by mass of aggregates is specified to be quartz sand which is defined as having a nominal size less than 5 mm and consisting of at least 70% by mass of quartz.

While these factors influence surface texture, to reduce the possible number of variables they have been held as constant as possible in this investigation so that the effect of surface physical structure alone can be observed.

By varying the Hessian Drag length and Transverse Tine spacing, width and depth, many different surface textures are produced, and further textures are in turn produced by combinations of these two techniques.

There are also other families of concrete surface finishes for road surfaces other than Hessian Drag or Transverse Tine, eg Longitudinal Tine, Transverse Broom, Exposed Aggregate, Applied Aggregate, or even Open Graded Concrete. While these other techniques will have effects on skid resistance and traffic noise, Hessian Drag and Transverse Tine alone have been selected for further investigation on the basis of ease of construction and expediency of development.

The surface textures constructed in Stage 1 of the Freeway were varied by adjustment of the following variables:

Hessian length
Tine depth
Tine width
Tine spacing.

Hessian Length
The length of the hessian in contact with the plastic concrete was either 0.6 or 1.2 m.

The hessian was secured behind and towed by the slipform concrete paver. The longer the contact length of the hessian with the plastic concrete the greater the depth of the longitudinal striations that were imparted to the surface of the concrete by the drag rolling the fine aggregate.

The hessian that was 0.6 m in length produced a texture that is called Light Hessian Drag, and that 1.2 m long produced Coarse Hessian Drag.

One of the benefits of the technique using the (longitudinal) Hessian Drag is that it acts as a secondary smoothing operation in the longitudinal direction of the pavement. This action tends to increase the smoothness of the surface hence decreasing the roughness. It is believed that decreasing the roughness of a road surface is a contributing factor toward decreasing noise generation. Some lack of surface uniformity is desirable to decrease constant pitch whine caused by the tires of traffic vehicles pumping out air.

On the F3 Freeway with close control of mix uniformity and attention to paving technique, the contractor, Abigroup Ltd, produced a pavement between Palmers Road and Wakefield with roughness readings consistently in the range of 27 to 32 counts per km. The highest count is in the low 40s.

The Austroads Roughness Meter measures the riding quality of the road surface by summing the vertical movement between the axle housing and body of a standard vehicle whilst travelling at a standard speed, which is 80 km/h for non-urban roads, with test intervals at 100 m.

Tine Depth
The depth of penetration of the transverse tine was altered to produce a light or a medium effect. This was controlled by two different methods. The first was by delaying the relative time of tining behind the slipform paver. The longer the time the greater the degree of cement set, the greater the degree of surface resistance, and the less the tines penetrate the surface.

The second method was to increase the length of the spring steel tines from 100 to 225 mm. The additional length of the tines produced a greater curvature in the tines and a greater tine length of arc to the concrete surface, hence a lighter impression in the plastic concrete. It is desirable to have texturing carried out as soon as possible after paving and so allow early application of a curing compound which reduces exposure to plastic shrinkage cracking at times of high evaporation.

Tine Width
Two tine widths were chosen – 2 or 3 mm.

The flexible square ended tines move around large aggregate particles and produce grooves with vertical sides in the paste. Grooves with rounded sides pressed into the surface were produced by a specially manufactured bull float on earlier F3 work. This pressed-in grooved surface is perceptibly noisier than the adjacent tined surface.

Tine Spacing
Two randomised averaged spacings were used being nominally 13 and 26 mm.

The spacings are randomised to avoid the creation of harmonic resonances in travelling vehicles. An example of a randomised spacing, nominally 13 mm and 13.1 mm average is:

10/14/16/11/10/13/15/16/11/10/21/13/10 mm.

Combination of Texture Elements
From the above variables seven different surface textures have been constructed in Stage 1 of the Freeway works. Refined modifications of these will be constructed in the next stage where it is also intended to trial artificial turf drags.

Seven surface texture variations were constructed in the following combinations.

- Light hessian drag only (Surface Texture No. 2)
- Light hessian drag with light transverse depth, tine width 2 mm, tine spacing 13 mm (Surface Texture No. 8)
- Light hessian drag with light transverse depth, tine width 3 mm, tine spacing 13 mm (Surface Texture No. 7)
- Light hessian drag with medium transverse depth, tine width 3 mm, tine spacing 13 mm (Surface Texture No. 9)
- Coarse hessian drag only (Surface Texture No. 1)
- Coarse hessian drag with light transverse depth, tine width 3 mm, tine spacing 13 mm (Surface Texture No. 6)
- Coarse hessian drag with light transverse depth, tine width 3 mm, tine spacing 26 mm (Surface Texture No. 5).

In addition two existing freeway sites were tested for control purposes, viz:

- F3 Freeway, Freemans Waterhole; no hessian drag, transverse texture depth 1.5 to 3.0 mm (medium), tine width 3 mm, tine spacing 13 mm; under traffic for three years (Surface Texture No. 3)
- F3 Freeway, Calga Interchange; open-graded asphalt surface (Surface Texture No. 4).

These texture variations are summarised in Table 1.

Table 1 Surface Descriptions

	CONCRETE								ASPHALT
	Light hessian drag				Coarse hessian drag			No drag	(open graded)
Surface texture no.	2	8	7	9	1	6	5	3	4
Transverse tining									
depth	nil	L	L	M	nil	L	L	M	
width (mm)		2	3	3		3	3	3	
nominal spacing (mm)		13	13	13		13	26	13	

L = Light, M = Medium



Figure 3 Surface Texture No. 2



Figure 4 Surface Texture No. 3

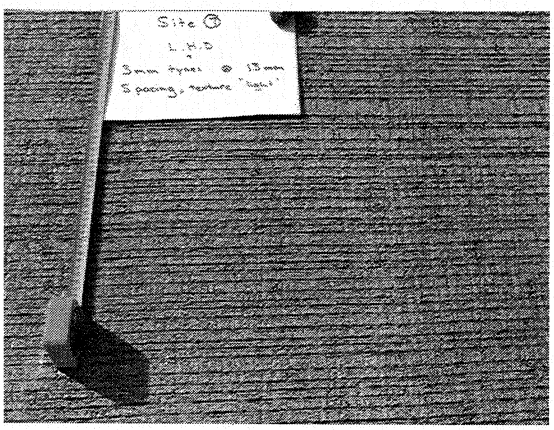


Figure 5 Surface Texture No. 7

Surface Evaluation

The surface textures were evaluated using the following methods:

- SCRIM (Sideways Coefficient Routine Investigation Machine)
- Sand Patch Method (Texture Depth)
- Mini Texture Meter
- Sound Level Meter with Microphone.

The Sideways Coefficient Routine Investigation Machine (SCRIM)

The Sideways Coefficient Routine Investigation Machine is a truck mounted apparatus which measures skid resistance in the sideways mode at speeds up to 100 km/h.

It has two test wheels (free running) toed in at 20° to the longitudinal axis of the test vehicle. The wheels, equipped with smooth pneumatic tires, are brought into contact with the road surface and the sideways force on the wheel is measured with a load cell located in the axle box. By spraying water in front of the test wheels friction is measured on a wet surface.

The Sideways Force Coefficient (SFC) is calculated by dividing the Sideways Force by the Vertical Reaction.

The SCRIM results were recorded at speeds of 50 and 80 km/h and appear in Table 2. Mean Sideways Force Coefficients are the average of two wheels on a single run in either the median or kerb travel lanes over 100- to 340-m lengths except the site for Surface Texture No. 9 where reading pairs only were measured over a 40-m length.

Table 2 Friction – Sideways Force Coefficient (SCRIM)

	CONCRETE								ASPHALT
	Light hessian drag				Coarse hessian drag			No drag	(open graded)
Surface texture no.	2	8	7	9	1	6	5	3	4
Transverse tining									
depth	nil	L	L	M	nil	L	L	M	
width (mm)		2	3	3		3	3	3	
nominal spacing (mm)		13	13	13		13	26	13	
50 km/h									
minimum	0.50	0.62	0.69	0.69	0.64	0.69	0.69	0.69	–
standard deviation	0.050	0.040	0.028	0.012	0.035	0.034	0.022	0.018	–
mean	0.64	0.75	0.77	0.89	0.77	0.84	0.84	0.84	–
80 km/h									
minimum	0.46	0.55	0.69	–	0.64	0.69	0.69	0.69	–
standard deviation	0.059	0.079	0.017	–	0.034	0.020	0.020	0.035	–
mean	0.56	0.68	0.74	–	0.72	0.84	0.77	0.79	–

RTA Circular No. M&R2 *Skid Resistance and Traffic Crashes*[2] nominates SFC values of between 0.35 and 0.50 at a 50 km/h test speed for Freeways. With textured concrete surfaces, a characteristic lowest probable SFC value of 0.65 is nominated on worn surfaces under light traffic (less than 2000 vehicles per day per lane) and 0.55 for heavy traffic. Equivalent figures for untextured concrete are 0.50 and 0.40 respectively.

At Clybucca Flat on the Pacific Highway north of Kempsey, 17 years of pendulum and SCRIM testing results are available. The concrete pavement friction values show little reduction over time and this is attributed to specifications requiring a high quartz content to enhance microtexture which is continually renewed as the pavement wears.

Sand Patch Method

The Sand Patch Method (RTA Test Method T240) which involves spreading sand into surface depressions was used to evaluate the texture depth. The specified texture depth value is 0.30 to 0.65 mm based on the calculated sand volume needed to fill a 1.3- to 2.8-mm tining depth as follows:

$$\frac{\text{3-mm tine width x 1.3- to 2.8-mm tining depth}}{\text{13-mm average spacing}}$$

= 0.30 to 0.65 mm.

The results indicate that the Light Hessian Drag alone raises the texture depth as recorded by the Sand Patch Test above that recorded by even medium depth tining. This is believed to be caused by rolled fine aggregate from the drag producing striations with depth approaching the 0.15- to 0.30-mm size sand used in the Sand Patch Test Method T240.

Mini Texture Meter

The Mini Texture Meter developed by the Transport and Road Research Laboratory, UK is a manually propelled unit combining laser and microprocessor technologies. A laser beam continually scans the pavement surface with the reflected light passing through an optical system to a complex array of diode sensors.

The Mini Texture Meter is considered the more reliable indicator of texture for Hessian Drag surfaces because the size of the sand grains used in the sand patch test is of similar size to the hessian drag striations, leading to extreme difficulty in obtaining reliable values.

Texture Depth Measurements

Texture depth values obtained by the Sand Patch Method and Mini Texture Meter on the Test Sites are given in Table 3.

Table 3 Texture Depth (mm)

	CONCRETE								ASPHALT
	Light hessian drag				Coarse hessian drag			No drag	(open graded)
Surface texture no.	2	8	7	9	1	6	5	3	4
Transverse tining									
depth	nil	L	L	M	nil	L	L	M	
width (mm)		2	3	3		3	3	3	
nominal spacing (mm)		13	13	13		13	26	13	
Sand patch test									
Result 1	0.58	0.52	0.59	1.00	0.94	1.02	1.08	–	–
Result 2	0.57	0.53	0.63	0.95	0.93	1.03	1.03	0.50	–
Result 3	0.50	0.55	0.59	0.79	0.94	1.11	1.04	0.49	–
mean	0.55	0.53	0.60	0.91	0.94	1.05	1.05	0.50	–
Mini texture meter									
mean over 5 m	0.43	0.43	0.45	0.77	0.67	0.72	0.64	0.34	–
mean over 25 m	0.40	0.40	0.41	0.67	0.68	0.73	0.65	0.44	–

A comparison of results from the Sand Patch Test and Mini Texture Meter (MTM) for eight Test Sites is given in Figure 6. This graph shows the MTM results less than the Sand Patch results for all surfaces tested with a much greater variation in Hessian Drag surfaces.

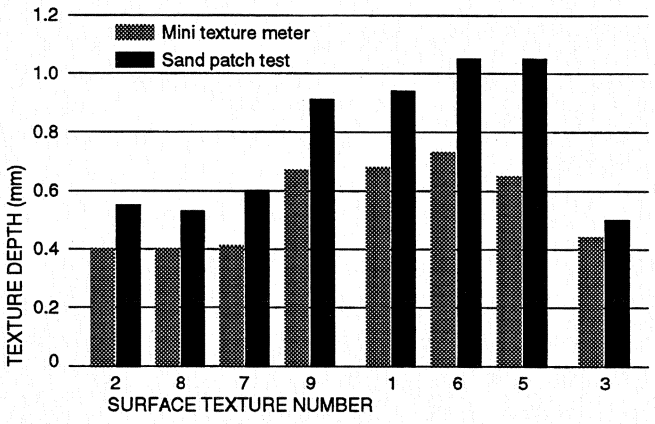


Figure 6 Comparison of Sand Patch Test versus Mini Texture Meter

Sound Level Meter with Microphone
The nine test sites were evaluated for noise generation by Mitchell McCotter and Associates Pty Ltd (Dr Stephen Samuels, Senior Acoustic Consultant) using a sound level meter with a microphone.

This was performed by setting up acoustic monitoring stations at each of the sites and measuring the noise received from specific passing vehicles. The survey did not address noise inside the vehicle as heard by vehicle occupants or detail of the tone distribution.

It is generally accepted that below about 70 km/h for trucks and 50 km/h for cars, engine noise dominates over rolling noise in vehicle noise generation.

The same vehicles were used for all sites and consisted of a car (General Motors Holden Commodore four-door sedan; 3.6-litre V6 engine, conventional exhaust and Goodyear 185/75 HR14 tires) and a truck (Volvo F86; rigid body, twin-steer tip tray; 8.6-litre V8 engine; vertical exhaust; 19-tonne GVM and Dunlop 10.00 x 20 tires).

Both vehicles were driven past the measuring stations at nominal speeds of 50, 65 and 80 km/h with three replicate runs being undertaken at each speed.

The recording microphones were established at a vehicle trajectory distance of 7.5 m and noise levels measured, at five Test Sites by two instruments, and repeated for Surface Texture No. 2.

The noise levels recorded are in Table 4.

Table 4 Measured Average Noise Levels (dB(A))

Surface texture no.	INSTRUMENT 2231						INSTRUMENT 2209					
	50 km/h		65 km/h		80 km/h		50 km/h		65 km/h		80 km/h	
	car	truck	car	truck	car	truck	car	truck	car	truck	car	truck
2	72.7	88.6	77.2	90.0	80.1	92.4	73.5	88.4	77.3	89.9	80.0	92.3
8	73.4	89.6	76.2	88.8	79.6	91.4	–	–	–	–	–	–
7	–	–	–	–	–	–	73.0	89.3	75.7	89.3	79.0	89.9
9	75.2	86.6	78.1	89.2	80.7	90.5	75.1	86.2	78.2	88.4	80.0	89.9
1	–	–	–	–	–	–	74.6	87.3	77.6	89.5	81.1	90.4
6	76.9	86.2	78.4	88.1	82.0	90.9	76.2	86.4	77.6	87.6	81.0	90.9
5	74.7	88.2	77.8	88.4	80.5	90.5	–	–	–	–	–	–
3	75.0	89.7	77.7	90.2	80.4	91.2	74.8	89.2	77.2	89.5	79.3	90.8
4	73.2[a]	87.4[a]	73.9	87.1	77.1	88.7	73.0	86.7	73.5	86.2	75.9	88.4
2 *(repeated)*	74.3	–	77.7	–	79.4	–	74.0	–	77.1	–	78.6	–

[a] *doubtful due to background noise*

At 80 km/h, concrete pavement noise levels span a range of 2.6 dB(A) for the car and 2.4 dB(A) for the truck.

In order to allow easier interpretation of surface texture type, friction and noise, these results are presented again in Table 5.

Table 5 Friction and Noise Properties of Tested Surfaces

	CONCRETE								ASPHALT
	Light hessian drag				Coarse hessian drag				No drag	(open graded)
Surface texture no.	2	8	7	9	1	6	5	3	4	
Transverse tining										
depth	nil	L	L	M	nil	L	L	M		
width (mm)		2	3	3		3	3	3		
nominal spacing (mm)		13	13	13		13	26	13		
Friction – Sideways Force Coefficient (SCRIM)										
50 km/h										
minimum	0.50	0.62	0.69	0.69	0.64	0.69	0.69	0.69	–	
standard deviation	0.050	0.040	0.028	0.012	0.035	0.034	0.022	0.018	–	
mean	0.64	0.75	0.77	0.89	0.77	0.84	0.84	0.84	–	
80 km/h										
minimum	0.46	0.55	0.69	–	0.64	0.69	0.69	0.69	–	
standard deviation	0.059	0.079	0.017	–	0.034	0.020	0.020	0.035	–	
mean	0.56	0.68	0.74	–	0.72	0.84	0.77	0.79	–	
Average Noise Levels (dB(A)) – two instruments										
50 km/h										
car	72.7	73.4	–	75.2	–	76.9	74.7	75.0	73.2	
	73.5	–	73.0	75.1	74.6	76.2	–	74.8	73.0	
truck	88.6	89.6	–	86.6	–	86.2	88.2	89.7	87.4	
	88.4	–	89.3	86.2	87.3	86.4	–	89.2	86.7	
65 km/h										
car	77.2	76.2	–	78.1	–	78.4	77.8	77.7	73.9	
	77.3	–	75.7	78.2	77.6	–	77.2	73.5	–	
truck	90.0	88.8	–	89.2	–	88.1	88.4	90.2	87.1	
	89.9	–	89.3	88.4	89.5	87.6	–	89.5	86.2	
80 km/h										
car	80.1	79.6	–	80.7	–	82.0	80.5	80.4	77.1	
	80.0	–	79.0	80.0	81.1	81.0	–	79.3	75.9	
truck	92.4	91.4	–	90.5	–	90.9	90.5	91.2	88.7	
	92.3	–	89.9	89.9	90.4	90.9	–	90.8	88.4	

From this data Samuels states that there is no clear trend as to which concrete surface produces the lowest noise levels. Overall, however, the Light Hessian Drag with Light Tining (2- or 3-mm tine widths) produces the lowest noise levels.

For the car, the Coarse Hessian Drag surfaces are the loudest but for trucks at high speeds there is little, if any, difference between most of the surfaces.

The quietest surfaces, however, would be perceived as noticeably different from the loudest since the road noise acoustic frequency components, where the noise from the two surface types differ most[3], are in the range where the human auditory response is most sensitive.

Samuels also adjusted data to a reference distance of 4.4m to allow comparison with data in ARRB Research Report ARR 177[4]. In this report a correlation between speed and noise was developed and using this correlation he states:

'Considering first the car data, it is apparent that the range of present values encapsulates those of the two cement concrete pavements of the 1990[4] study. The quietest of the present surfaces (Surface Texture No. 7) is a small but useful 1.4 dB(A) quieter than the previously studied Hessian Dragged Surface. In fact Surface Texture No. 7, car noise levels project to be less than 1dB(A) louder than those of an open graded asphaltic concrete, which places Surface Texture No. 7 at the low end of the range exhibited by all known surface types. Although the relativities vary a little, the same effects are present in the truck noise data. At the upper end of the range, the loudest of both sets of vehicle noise exceed that of a dense graded asphaltic concrete by around 1dB(A). Again this is a small difference.'

ANALYSIS

Results are preliminary from the first third of the proposed study which will involve follow-up trials and retesting after opening of the Freeway. It is intended to continue improvements to obtain a consistent and predictable low noise surface with good long term skid resistance.

The Light Hessian Drag surface when tested at 80 km/h had the lowest Sideways Force Coefficient and was noisier than the Light Transverse Tined surfaces with Light Hessian Drag at both 65 and 80 km/h.

The 2-mm tine width with Light Hessian Drag and Light Transverse Tining had lower friction, lower MTM texture depth and higher noise than the equivalent 3-mm tine width surface.

The Coarse Hessian Drag and Light Transverse Texturing with 26-mm nominal tine spacing did not show any markedly superior performance to the equivalent 13-mm nominal tine spacing in friction, MTM texture depth or noise. It is considered that this variable was masked by the effects of the Coarse Hessian Drag.

Quantitive criteria for friction and texture depth on high speed roads can be met by a Coarse Hessian Drag alone but at the expense of a noisier pavement than a combination of Light Hessian Drag and Light Transverse Tining.

CONCLUSION

The construction and analysis of various concrete pavement surface textures has demonstrated the surface's influence on skid resistance and traffic noise.

The quietest surface texture produced to date in this trial, Light Hessian Drag with Light Transverse Tine Depth and 13-mm nominal Tine Spacing has acceptable skid resistance in terms of Sideways Force Coefficient and texture depth.

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