Guide to state highway road surface noise

Version 1.0, January 2014

The type and condition of a road surface can have a significant effect on the noise levels experienced by residents adjacent to state highways. This guide has been produced to inform roading practitioners, contractors and the public about how road surfaces affect noise levels and what low-noise road surfaces are available in different situations. Information is also provided on maintenance issues and basic engineering considerations.

This guide has been withdrawn, but remains available for information. The reader is advised that some of the information it contains is outdated.

New Zealand road surface noise corrections in this guide were replaced in February 2024 by new corrections set out in the *Guide to assessing road-traffic noise*. The old corrections and method of application set out in this *Guide to state highway road surface noise* have been withdrawn and must no longer be used.

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Guide to state highway road surface noise
v1.0

NZ Transport Agency
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1 Introduction

1.1 Background

01 NZ Transport Agency (2008) *State highway environmental plan.* www.nzta.govt.nz

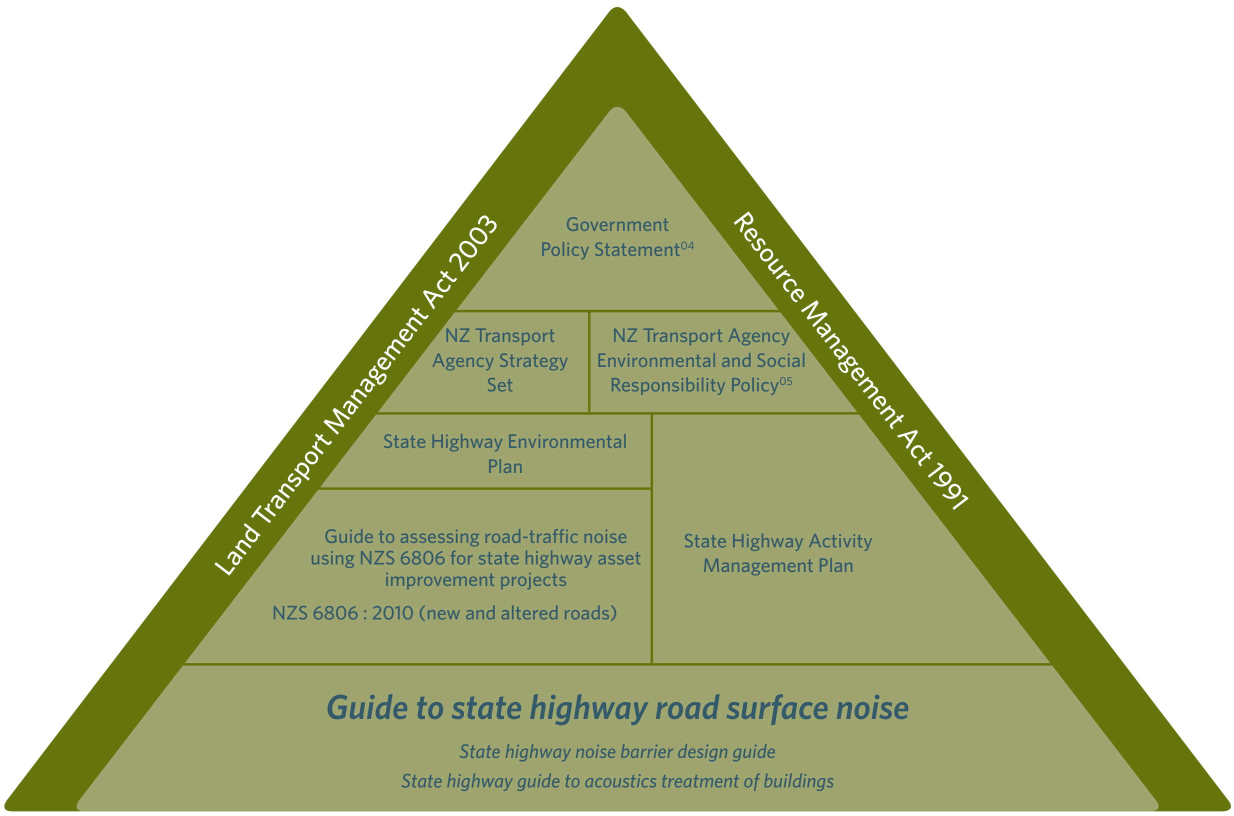
02 Ministry of Transport (2003) Land Transport Management Act. www.transport.govt.nz

03 New Zealand Legislation (1991) Resource Management Act. www.legislation.govt.nz

The NZ Transport Agency aims to be a good neighbour, taking social and environmental responsibility seriously, including the management of noise. This is reflected in external and internal strategy and policy documents that the Transport Agency is required to implement, including the Transport Agency's *State highway environmental plan*[01]. These documents are consistent with the requirements of the Land Transport Management Act 2003[02] and Resource Management Act 1991[03] (refer to figure 1.1).

Road surface noise is an important issue as it is one of the factors that can contribute to some people living or working near state highways experiencing annoyance or potentially sleep disturbance.

FIGURE 1.1 Relationship of this guide to key policy and strategy documents



04 Ministry of Transport *Government policy statement on land transport.* (This is updated every 3 years.) *www.transport.govt.nz*

05 NZ Transport Agency (2012) *Environmental and Social Responsibility Policy. www.nzta.govt.nz*

The Transport Agency's *State highway environmental plan* sets formal objectives regarding noise from the state highway network including:

N1 Reduce exposure to high traffic noise levels from the existing state highway network.

N2 Determine reasonable noise requirements when seeking new or altering existing designations including when designating existing local roads by using RMA procedures.

Noise from road surfaces is an important factor the Transport Agency should consider with respect to these objectives.

1.2 Purpose of this document

Managing the effect of the road surface can be an effective way of reducing road-traffic noise and its impacts, and complements other management methods such as noise barriers.

The purpose of this guide is to provide:

- an understanding of the effect that the road surface has on road-traffic noise
- road surface noise data that is specifically relevant for New Zealand use
- guidance on how the selection and maintenance of the road surface can be effective in managing road-traffic noise

This guide should assist in:

- the application of the Standard NZS 6806:2010[06] to new and altered roads
- applying the Transport Agency's *Environment plan* with respect to noise from existing roads
- managing noise and avoiding complaints about state highway road surface noise.
- the Transport Agency to avoid, remedy, or mitigate SH effects in accordance with the Resource Management Act (RMA) when preparing resource consent or notice of requirement applications.

This guide complements the:

- Transport Agency *State highway noise barrier design guide*[07]
- Transport Agency *State highway guide to acoustic treatment of buildings*[08]
- *Guide to assessing road-traffic noise using NZS 6806 for state highway asset improvement projects*[09].

FIGURE 1.2 Transport Agency noise guides

A number of expert inputs are required to determine the most appropriate noise mitigation solution and therefore this guide is targeted at a wide audience.

For the road engineer this guide provides acoustical information needed in road design and maintenance. For the acoustics professional it provides the required road noise data and also information on the engineering constraints and limitations around road surface choice. For the planner this guide provides information on road surface options that are available to mitigate adverse noise effects.

The guide is also intended to assist the public to have an understanding of one of the significant contributors to road-traffic noise and the factors in its management.

06 Standards New Zealand (2010) NZS 6806:2010 *Acoustics – Road-traffic noise – new and altered roads.* www.standards.co.nz

07 NZ Transport Agency (2010) *State highway noise barrier design guide, version 1.0.* www.acoustics.nzta.govt.nz

08 NZ Transport Agency (2012) *State highway guide to acoustic treatment of buildings*, in preparation. www.acoustics.nzta.govt.nz

09 NZ Transport Agency (2011) *Guide to assessing road-traffic noise using NZS 6806 for state highway asset improvement projects,* version 1.0. www.acoustics.nzta.govt.nz

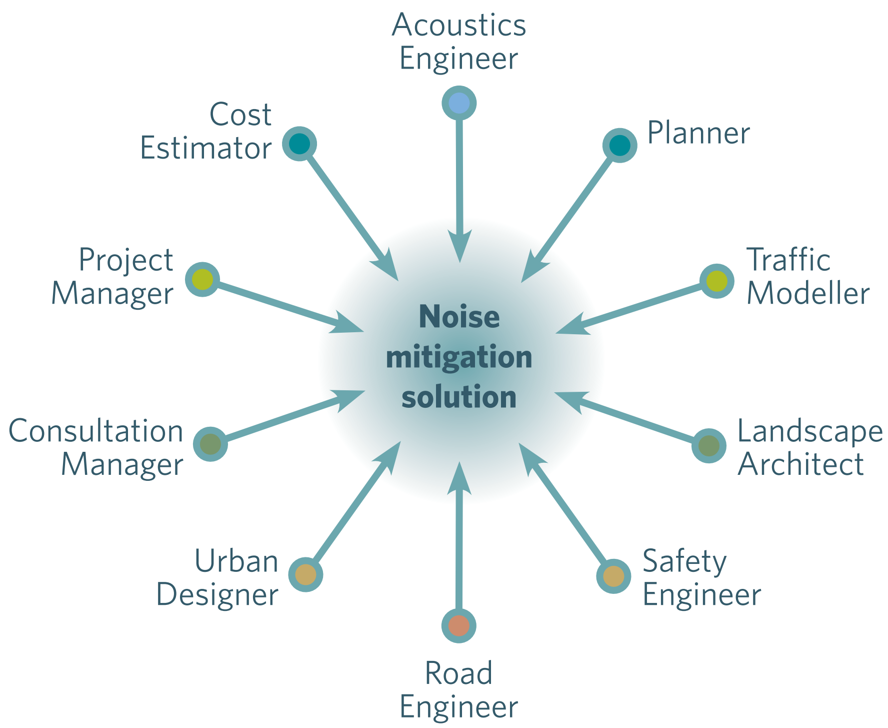
1.3 Responsibilities

Responsibility for road surfaces lies with:

- new or altered road – project engineer
- existing road – asset manager

For a new or altered road project, any noise mitigation solution should be determined through an assessment under NZS 6806:2010, involving the expert inputs shown in figure 1.3. A requirement for a low-noise road surface is one possible outcome arising from this process. The road engineer should identify any engineering constraints during this process so that low-noise road surfaces are only selected where it is practicable to do so.

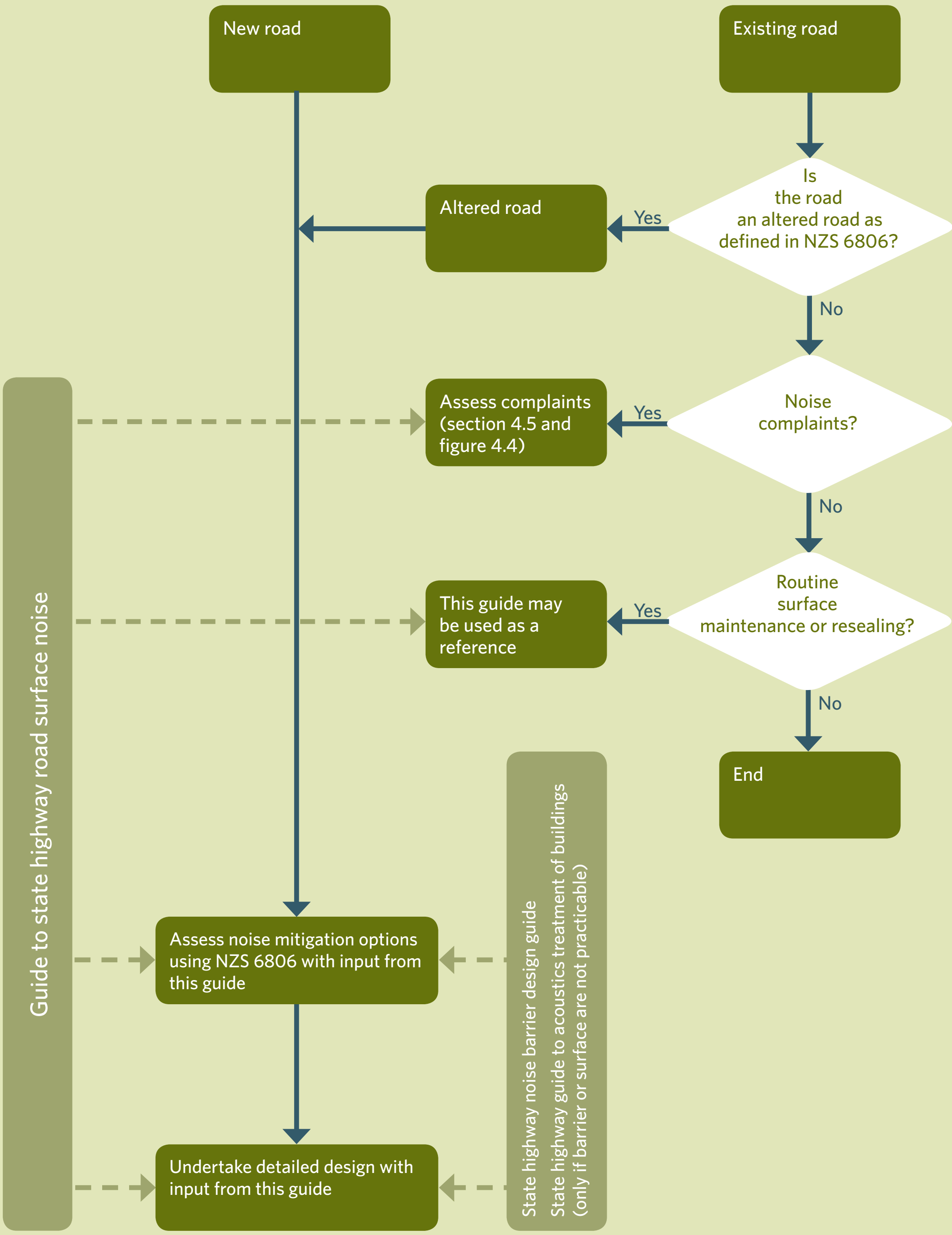
FIGURE 1.3 A range of expert inputs is required to determine the most appropriate noise mitigation solution



For existing roads the Regional Asset Manager is responsible for determining the appropriate road surface for resealing, and also the appropriate remedy where road surfaces may be causing disturbance.

Figure 1.4 illustrates the use of this guide within the road design process.

FIGURE 1.4 Use of this guide within road design process



1.4 Road formation

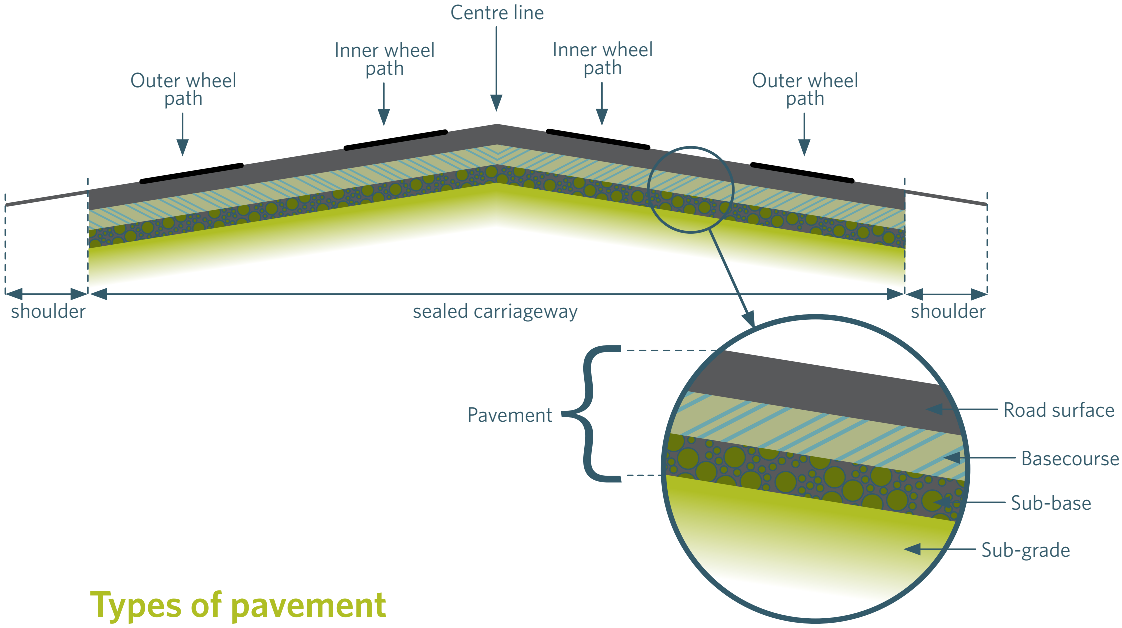
10 NZ Transport Agency. *What highways are made of.* www.acoustics.nzta.govt.nz

A modern road is a complex construction[10] and is made up of four main layers (figure 1.5):

- The road surface or seal.
- The basecourse layer, which is a strong compacted layer to support and distribute the load.
- The sub-base layer which is the first, usually granular, layer constructed on the subgrade.
- The subgrade which is the existing ground on which the other layers will be built.

The upper three layers above the subgrade, known as the 'pavement', provide the structure of the road and distribute the load from the wheel to the subgrade.

FIGURE 1.5 Cross section of typical road construction



Types of pavement

While the emphasis when considering road surface noise is invariably on the surface, for the road engineer the layers below are equally important as it is those layers that give strength to the surface and affect its engineering performance. There are some effects on noise that arise from undulations in the sub-base and basecourse that are then reflected in the surface layer. However, these are not the main focus of this document. The pavement strength and deflection under load are critical factors affecting the available choices of road surface that can be applied. Pavements can be broadly classified as flexible pavements or rigid pavements[11, 12].

11 Austroads (2009) *Guide to pavement tehnology, Part 1: Introduction to pavement technology.* www.austroads.com.au

12 Transit New Zealand (2007) *New Zealand supplement to the Austroads document: Pavement design – a guide to the structural design of road pavement, version 2* www.nzta.govt.nz

FLEXIBLE PAVEMENTS

For the low traffic volumes found across the majority of New Zealand, a low cost, flexible pavement is usually used. This typically consists of unbound granular basecourse and sub-base with a bitumen surface. These flexible pavements can be used with the following surface types: running-course metal (unsealed); chipseal; or a thin asphalt mix, which are all usually less than 40mm thick.

Flexible pavements may also be constructed with bound upper layers of stabilised materials or asphalt, which are generally 110mm or greater in thickness with a sacrificial layer on top. Low-noise road surfaces such as open graded porous asphalt may not be suitable for use with some flexible pavement due to the high deflections (refer to section 3.1).

RIGID PAVEMENTS

Pavements in high traffic and/or stress situations are typically of rigid construction, using high strength concrete over a sub-base or structural asphalt. These pavements, while strong and durable, have relatively high cost. Any surface type can be used on a rigid pavement.

1.5 Road surfaces

The main types of surface used on New Zealand roads are:

- gravel/metalled (unsealed)
- chipseal (also known as spray-seal or surface dressing)
- asphalt mix (also known as bituminous mix).

Concrete surfaces are another distinct type, but are not commonly used in New Zealand (section 2.11). Brief descriptions of these surfaces are given below, with more detail in the pages that follow.

FIGURE 1.6 Gravel road

FIGURE 1.7 Chipseal

FIGURE 1.8 Asphalt road

Gravel roads

Gravel roads do not have a hard surface of stone/chips and bitumen to protect the layers below the surface. They tend to be used on minor roads in rural areas where the traffic volumes are low, and are generally not used on state highways. Due to the rural location of these roads where traffic volumes are low and are sparsely populated, gravel surfaces will not be discussed further in this guide.

Chipseal

Chipseal consists of a layer of aggregate of a specific size embedded into a bitumen binder[13, 14]. Many types of chipseal exist (see page 12) and are usually described according to chip size and design (eg single coat or two-coat).

One type of chipseal is slurry seal comprising of a graded aggregate mixed with an emulsion binder, a filler and water[15]. There are two common types of slurry seal which are standard slurry seal and cape seal.

Asphalt mix

Asphalt mix surfaces are blends of aggregate and bitumen combined and laid whilst hot (see page 13). The common types include:

- asphaltic concrete (AC), also known as dense graded asphalt (DGA)[16, 17]
- open graded porous asphalt (OGPA)[18]
- stone mastic asphalt (SMA)[17]
- macadam.

13 Transit New Zealand (2004) *Specification for sealing chip*, TNZ M/6. *www.nzta.govt.nz*

14 Transit New Zealand (2005) *Chipsealing in New Zealand*, ISBN 0-478-10562-2. *www.nzta.govt.nz*

15 Roading New Zealand (2010) *Specification for slurry surfacings*, RNZ 9806. www.roadingnz.org.nz

16 Transit New Zealand (2005) *Specification for asphaltic concrete*, TNZ M/10. www.nzta.govt.nz

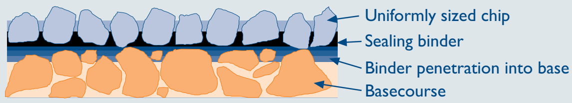
17 NZ Transport Agency (2010) *Draft specification for dense graded, stone mastic paving materials*, Draft M/10. www.nzta.govt.nz

18 Transit New Zealand (2007) *Specification for open graded porous asphalt*, TNZ P/11. www.nzta.govt.nz

Single coat seal

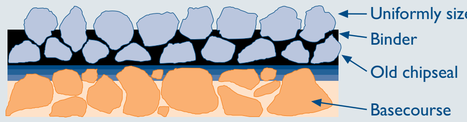
A single coat seal is a sealing binder with a single application of chip. When a road is first made this single coat will be referred to as a 'first coat seal'.

FIGURE 1.9 Single coat seal



Typically roads are resealed every eight to 15 years, so additional single coat seals are often laid over the existing layers.

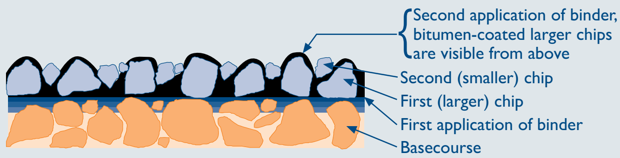
FIGURE 1.10 Reseal



Two-coat seal

A two-coat chipseal has two applications of binder and two applications of chip, the second smaller in size to the first. The smaller chip of the second coat locks and supports the larger chip of the first coat.

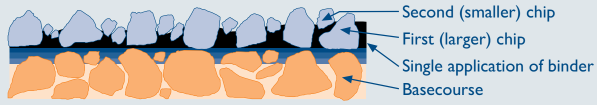
FIGURE 1.11 Two-coat seal



Racked-in seal

A racked-in chipseal consists of one application of binder and two applications of chip.

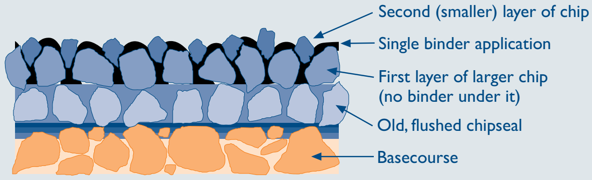
FIGURE 1.12 Racked-in seal



Sandwich seal

A sandwich seal is a variation of a two-coat seal and is used as a re-seal where there is excess 'flushed' bitumen on the original surface.

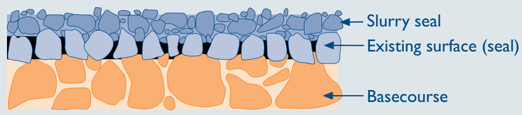
FIGURE 1.13 Sandwich seal



Slurry seal

A specifically designed mix of aggregates plus an emulsified binder.

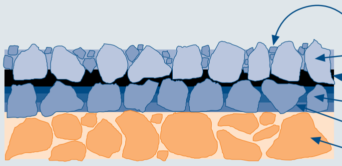
FIGURE 1.14 Slurry seal



Cape seal

A cape seal is a two-coat seal where the first coat is a chipseal and the second coat is a slurry seal, which fills the texture of the chipseal.

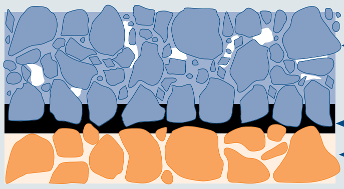
FIGURE 1.15 Cape seal



Asphaltic concrete (AC)

These mixes have a range of aggregate particle sizes and filler (evenly distributed from coarse to fine) and a low design air void content generally of 4%.

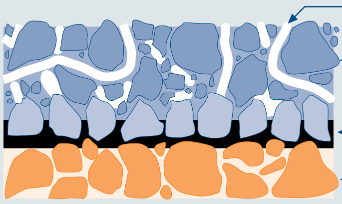
FIGURE 1.16 Asphaltic concrete



Open graded porous asphalt (OGPA)

OGPA has less fine aggregates than AC and more air voids, typically between 15% and 30%.

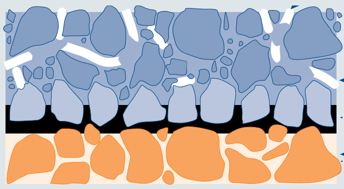
FIGURE 1.17 OGPA



Stone mastic asphalt (SMA)

SMA has a high-course aggregate content and has similarities with OGPA but with fewer air voids (typically 4%).

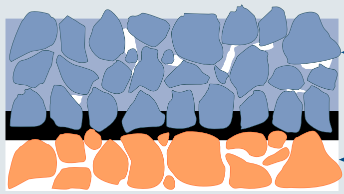
FIGURE 1.18 SMA



Macadam

A surface type currently unspecified in New Zealand. These surfaces are similar to ACs and SMAs.

FIGURE 1.19 Macadam



1.6 Terminology

Surface types are named according to both their overall design and chip size. Prior to 2007, the asphaltic concrete aggregate size was specified as the maximum size. Since then, the chip nominal size has been used. For example, AC-10 is asphaltic concrete containing a 10mm sized chip.

The size of aggregate used in chipseals is not specified by the actual dimension but according to a grading index between two and six, with Grade 2 being the largest. For chipseals constructed of two or more layers of different sized chips, a two figure convention is used. The first figure corresponds to the lower layer, thus Grade 3/5 means that Grade 3 is overlaid with Grade 5.

TABLE 1.1 Road surface terminology

Surface		Aggregate maximum size (mm)	Aggregate nominal size (mm)	% air voids	Polymer modified bitumen	Reference*
Chipseal, single coat		19	-	-	Optional	Grade 2
		16	-	-		Grade 3
		13/14	-	-		Grade 4
		10	-	-		Grade 5
		7	-	-		Grade 6
Chipseal, two-coat		19, 13	-	-	Optional	Grade 2/4
		16, 10	-	-		Grade 3/5
		16, 7	-	-		Grade 3/6
		13, 7	-	-		Grade 4/6
Slurry seal		7	-	-	Optional	Slurry-7
Cape seal		3	-	-	Optional	Cape-3
		5	-	-		Cape-5
		7	-	-		Cape-7
Asphaltic concrete		13/14	10	3-5%	Optional	AC-10
		16	14			AC-14
		20	16			AC-16
OGPA	high strength	14	10	12-16%	Optional	PA-10-HS
	standard	14	10	20-25%	Optional	PA-10
		16	14			PA-14
	high voids	10	7	25-30%	With PMB	PA-7-HV
		14	10			PA-10-HV
		16	14			PA-14-HV
		25	20			PA-20-HV
	twin layer	20 or 25	14/7 or 20/7	20-25%	Optional	PA-TL
Stone mastic asphalt		13/14	10	4%	Optional	SMA-10
		14	11			SMA-11
		20	14			SMA-14
Macadam (bitumin bound macadam)		20	14	-	No PMP	BBM-14

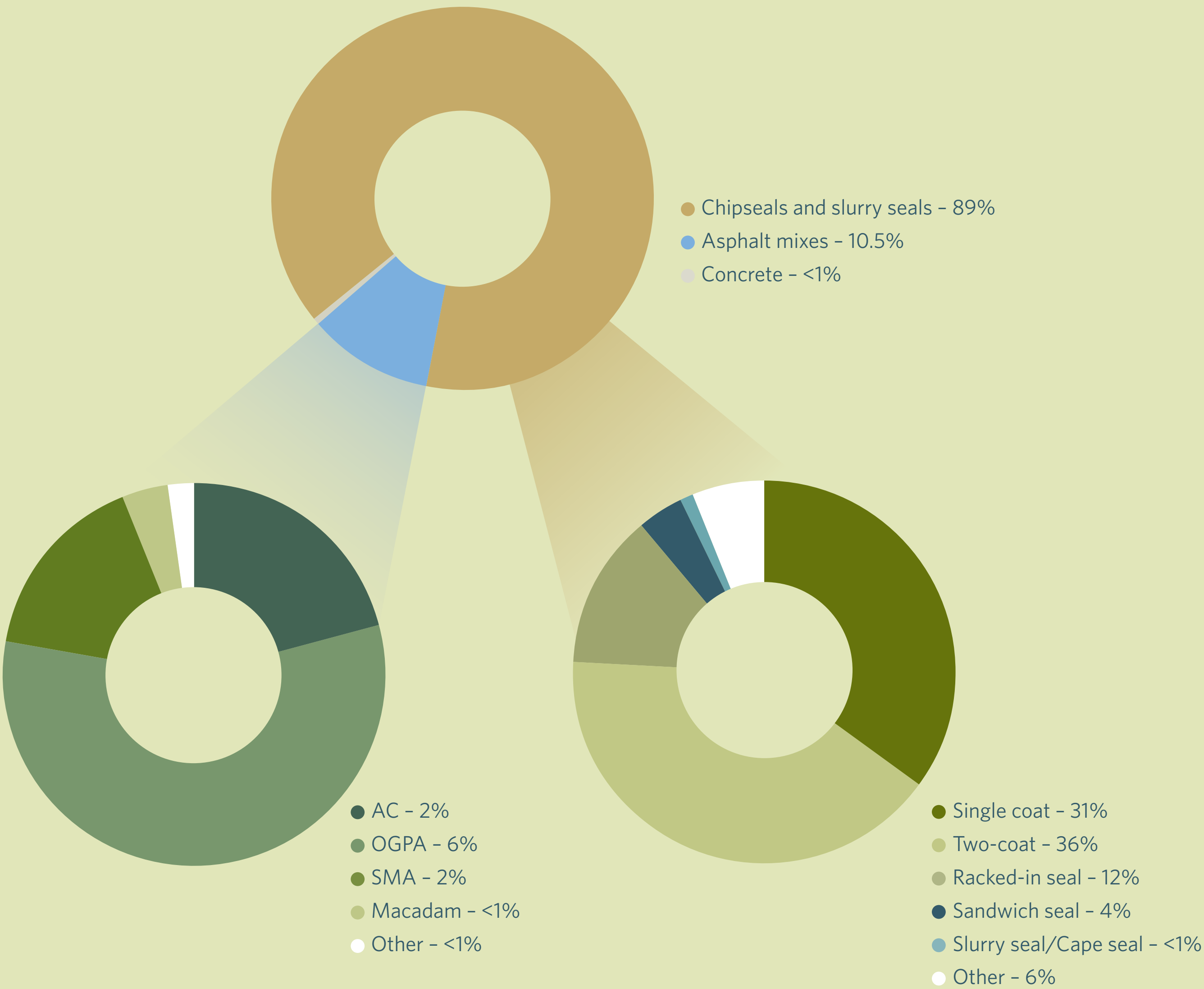
*Refer to section 4.2 for RAMM categorisations of surface types

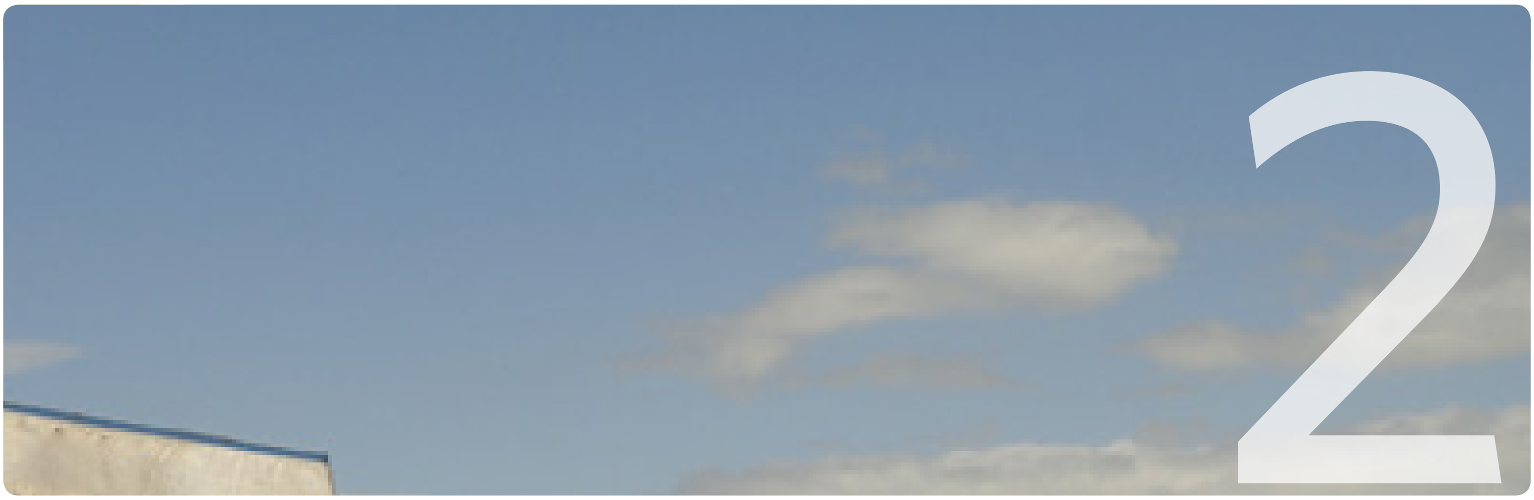
1.7 Surface types

The dominant surface type on the current state highway network[19] is chipseal covering 89% of the total road length of approximately 11,000km. However, there are significant lengths of asphalt mixes (10.5%) which continue to extend as traffic volume and stress increase and environmental issues affect the selection of surface. The proportion of each type of surface in 2010 is shown in figure 1.20.

19 NZ Transport Agency (2010) *Interim State highway asset management plan 2010/2011.* **www.nzta.govt.nz**

FIGURE 1.20 Proportion of surface by length (2010)





2 Road surface noise

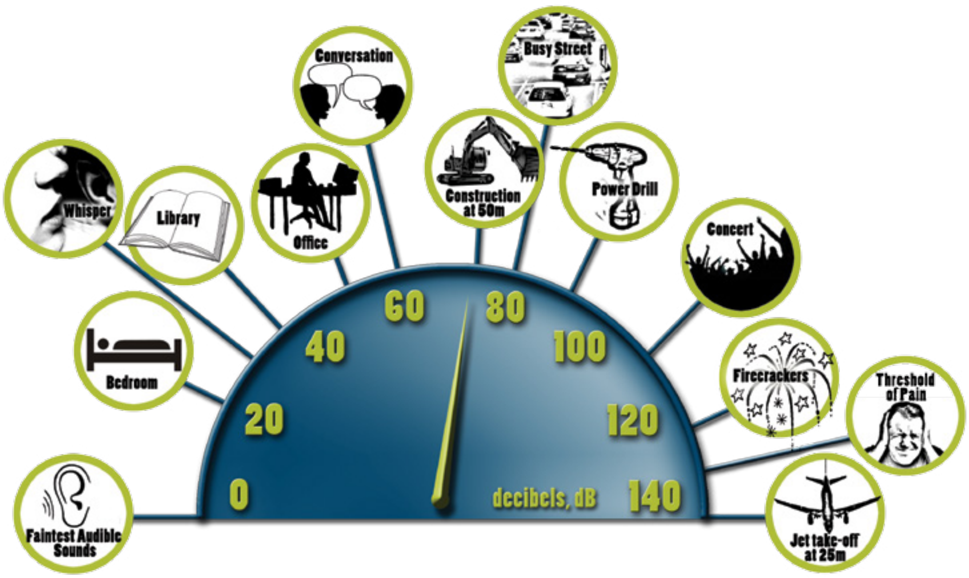
2.1 Fundamentals

20 Wikipedia *Acoustics*. . www.wikipedia.org

The purpose of this section is to outline the basic acoustics principles required to understand the concepts presented in this document. Further information on acoustics can be obtained from Wikipedia[20].

Sound sources cause changes in air pressure which are detected by our ears and can also be measured by a sound level meter. The pressure changes are expressed in decibels, which is written as 'dB'. The equation for this uses a logarithmic (non-linear) scale, in order to condense the wide range of pressure levels into a sensible scale. Being a logarithmic scale, familiar mathematical rules for addition do not apply, eg 55dB + 55dB = 58dB. An increase of 3dB is a doubling of sound energy. However, a 3dB increase is only just perceptible to the human ear. As a rule-of-thumb a 10dB increase corresponds approximately to a doubling of perceived loudness, eg 60dB sounds twice as loud as 50dB. Some typical sound levels are presented in figure 2.1.

FIGURE 2.1 Typical sound levels



The difference between the terms 'sound' and 'noise' is subjective, but generally speaking noise is defined as unwanted sound. In this guide the term 'road noise' is used to describe the sound/noise produced by road-traffic.

Road noise is heard inside and outside of a vehicle, and the two are closely related. However, this guide is only concerned with noise outside of the vehicle.

Road noise ranges from a daily average level of about 50dB for a quiet suburban street to about 75dB for a busy (eg 40,000 vehicles per day) urban arterial. Traffic volume, traffic speed, the number of large freight vehicles and the road surface are all key factors contributing to the noise level. The type of road surface can affect the road noise levels by up to 10dB, although due to constraints on the road surface that can be used at a particular location, typical effects are between 3 and 6dB.

Sound can occur across a whole range of frequencies from low frequency rumbles to high frequency chirps, depending on how fast the air pressure changes are occurring. Where a sound contains air pressure changes at only one distinct frequency, it is described as a 'tone'. Frequency has the units of cycles per second or Hertz (Hz). Like sound levels, the perception of frequency is also non-linear. A change from 1000 Hz to 2000 Hz is perceived in a similar way as a change from 2000 Hz to 4000 Hz.

Measured sound levels include all frequencies, but as our hearing is less sensitive to lower frequencies, the measured levels are adjusted to correspond to human hearing. This adjustment is called 'A weighting' and is identified by the letter A, eg 60dB $L_{Aeq(t)}$. Sound levels with no frequency weighting are identified by the letter Z.

In this guide, road noise levels are presented in two different ways, to illustrate particular points:

- As a single figure number representing the (A-weighted) level, eg 55dB, or
- As a graph showing the unweighted sound level at each frequency, known as a 'spectrum' (figure 2.2).

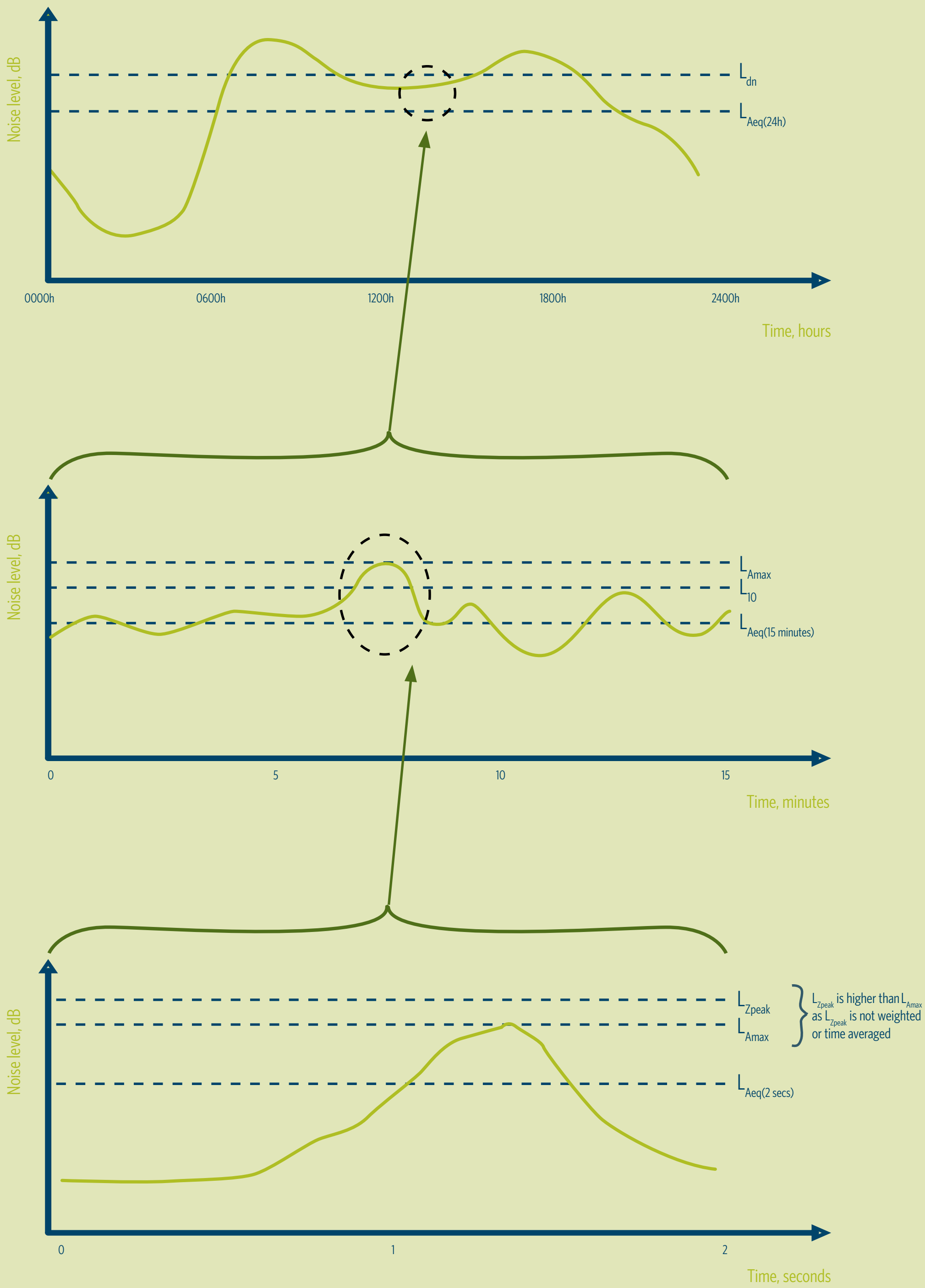
To illustrate the effect of the A-weighting, the dashed line on the graph is the equivalent A-weighted spectrum. The levels at low frequencies are reduced compared to the unweighted spectrum, corresponding to the frequencies at which the human ear is less sensitive.

FIGURE 2.2 | Example road noise spectrum

Road traffic noise levels fluctuate over time: there are short-term changes over one or two seconds as an individual truck passes, variations over a number of minutes due to the changing mixture of cars and trucks, and daily oscillations due to peak and off-peak traffic flows (figure 2.3). A number of different noise measurement parameters are available to use over these time periods. The choice of parameter depends on which feature of the noise is needed. Commonly used parameters are:

- $L_{Aeq(t)}$ – an average A-weighted noise level over the duration t. This is an 'energy' average of the decibel values and results in a higher average level than normal arithmetic value. Depending on the length of time t, the effect of peaks in the noise are reduced (see figure 2.3). For road-traffic noise $L_{Aeq(24h)}$ is used in New Zealand.
- $L_{AS/Fmax}$ – the maximum A-weighted noise level with a one second/slow time constant (indicated by a 'S') or by default a 1/8 second/fast time constant (indicated by the letter 'F').
- L_{Zpeak} – the peak unweighted noise instantaneous noise level.
- L_{A10} – the noise level exceeded for 10% of the time of the measurement duration. This was used for environmental noise assessment in New Zealand but has now been replaced by the $L_{Aeq(t)}$.
- L_{dn} – the day-night average noise level over 24 hours, with levels over the night-time period (22:00 to 07:00) increased by 10dB to reflect the greater potential disturbance during the night. This is used for airport, heliport and port noise in New Zealand.

FIGURE 2.3 | Measurement of fluctuating noise



2.2 Principles

Road-traffic noise

Road-traffic noise is the combination of all sources of noise from a vehicle and includes propulsion, tyre/road, mechanical and aerodynamic noise sources[21, 22]. Propulsion noise is generated by the engine, exhaust, intake, and other power-train components. The tyre/road, noise or road surface noise is that which is generated as the tyre rolls along the pavement. Aerodynamic noise is caused by turbulence around a vehicle as it passes through the air. Supplementary braking systems, such as engine brakes, are also a source of noise on downhill sections of road.

Before considering low-noise road surfaces it must first be established that road surface noise is the issue of concern and not other traffic/vehicle noise sources.

21 Federal Highway Administration (2007) *The little book of quieter pavements*, FHWA-IF-08-004. www.tcpsc.com

22 SILVIA (2006) *Guidance manual for the implementation of low-noise road surfaces*, Forum of European National Highway Research Laboratories report 2006/02. www.trl.co.uk/silvia/

FIGURE 2.4 Road-traffic noise sources

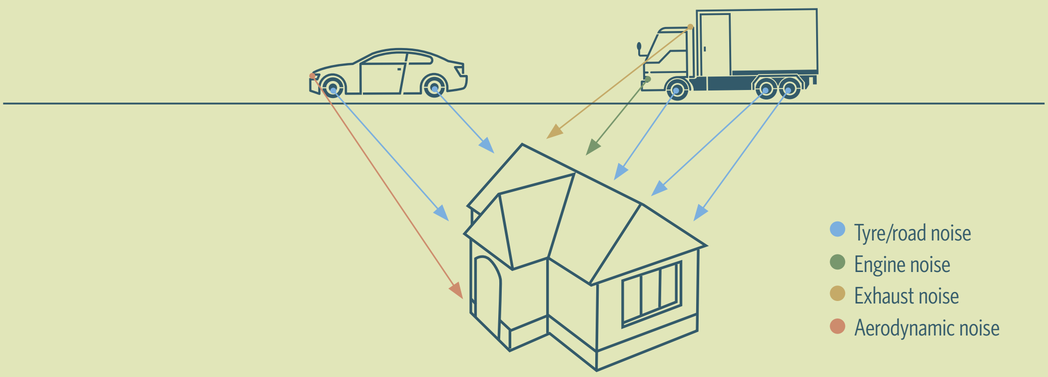
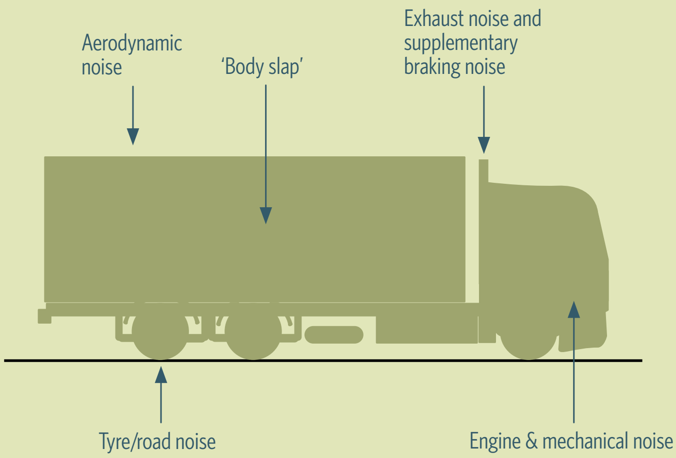


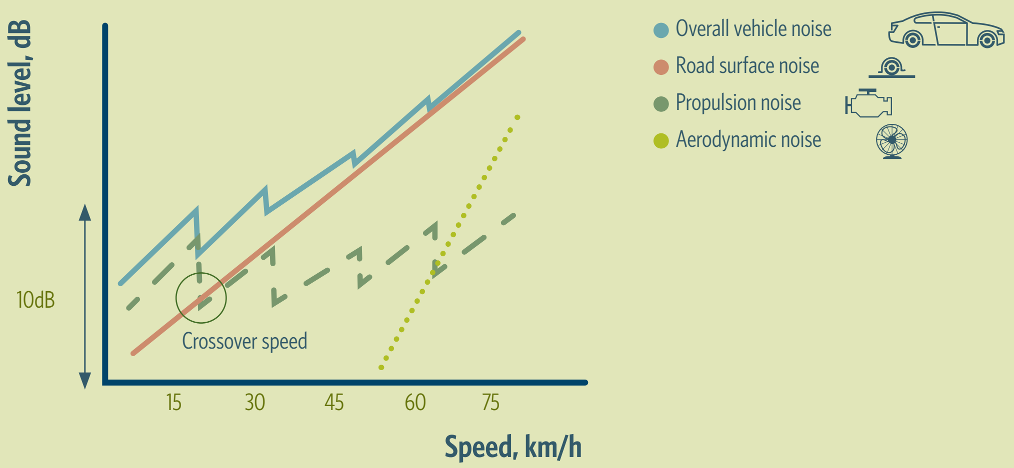
FIGURE 2.5 Noise sources from a truck



Propulsion noise will dominate the total road noise at low speeds (figure 2.6). As speed increases, a crossover speed is reached at which the tyre/road noise becomes an equal source of noise, then at higher speeds it becomes the dominant source. Only at high speeds will aerodynamic sources begin to dominate[23]. As engines have become quieter over time, the crossover speed has decreased, and low-noise road surfaces now have an affect at lower as well as higher speeds. Therefore, in understanding road and tyre/road noise, more reliance should be placed on newer literature.

23 U Sandberg and JA Ejsmont (2002) *Tyre/road noise reference book*, ISBN 91-631-2610-9. www.informex.info

FIGURE 2.6 | Vehicle noise sources



Source: The little book of quieter pavements

Compared to cars, trucks are noisier due to large propulsion systems and more tyres. At highway speeds, a 'typical' truck is up to 10dB noisier than a 'typical' car[24]. This means that one truck generates the same acoustic energy as 10 cars, thus if trucks make up 9% of the traffic, the cars and trucks are contributing equally to the traffic noise. As the engine noise from trucks is generally greater than from cars, the crossover speed for trucks is higher.

24 Opus International Consultants Ltd (2010) *Low noise surfacing performance monitoring*, report no. 521087.03.

Tyre characteristics

Cost and safety are the principal considerations in the manufacture of a tyre, along with durability and handling. Noise is an additional consideration, although the emphasis for manufacturers is usually on the noise inside the vehicle rather than outside. The design of the tyre can influence the noise generated to the same extent as the type of road surface (up to 10dB)[25].

25 FEHRL *Tyre/road noise*, SI2.408210. www.ec.europa.eu

- Air gaps (grooves) help to minimise some noise from being generated, but also amplify other noise.
- Skewed (angled) blocks allow for a more gradual roll in and out of each block, reducing sudden impacts that can lead to a noisier tyre.
- Tyre tread pattern the more aggressive the pattern the louder it will be.
- Tyre compound hard rubber compounds will be louder compared to soft compounds.
- Randomness of the tread block size will minimise tonal frequencies.

Road surface properties

Three surface properties that affect tyre/road noise, in order of decreasing importance, are texture, porosity and stiffness. How these all interact with the tyre to generate noise is complex and care is needed when applying simple rules, such as 'noise increases as texture size increases', because there may be other interactions that disrupt these trends.

Stiffness

The stiffness of the pavement has an influence on the generation mechanisms involving impacts. Typically the pavement is much stiffer than the rubber of the tyre and hence the impact forces are high. Lower impact forces, and therefore lower noise, can be achieved using pavements of reduced stiffness. See section 2.10 for new surfaces being developed.

Texture

Texture can be thought of as the 'bumps and dips' on the pavement surface. There are long bumps and dips that might give your car a rough ride. There are also very short bumps and dips that cannot be seen by the naked eye; for example, the microscopic texture of the surface of the chip (known as micotexture).

Noise heard outside the vehicle is affected most by texture that repeats itself every 10 to 150mm (known as 'macrotexture'). All else being equal, this type of texture should be minimised (flattened). Texture with dimensions of less than about 10mm is usually beneficial, as it provides escape paths for air under the tyre, as well as water, lessening the effect of some of the generation and amplification mechanisms (see pages 24 and 25).

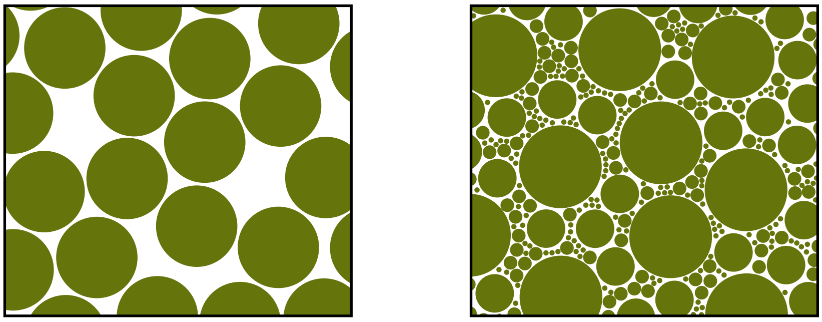
Texture can be described as 'positive' or 'negative' (figure 2.7). Positive texture does not provide a smooth surface for the tyre and therefore increases tread impact excitation in comparison to negative texture. The gaps or voids in a surface with negative texture also assist in reducing noise by absorbing some of the noise and decreasing the effect of the generation and amplification mechanisms. Therefore, increasing the amount of positive texture is usually a bad thing in terms of noise, whereas increasing the amount of negative texture is usually a good thing. Texture can be measured using the mean profile depth or a sand circle test (refer section 4.1).

FIGURE 2.7 Diagrammatic representation of negative texture (left) and positive texture (right)

Porosity

The porosity of a material is the ratio or the volume of air to the total volume. Materials used in most road surfaces have a porosity of less than 5%. When the porosity increases to 20% or more and/or when air can flow through the material, noise reduction can result. This is because porosity increases the ability of a material to absorb sound and thus prevent that sound reflecting back into the air.

FIGURE 2.8 Diagrammatic representation of larger air voids with open graded material (left) and of smaller air voids with well graded material (right)



The texture of the porous surface may also be beneficial, as it is generally a negative texture. However, a decrease in effectiveness can occur when the pores are clogged or wet internally. Generally, drainage through a porous road surface will reduce the distinctive 'swish' sounds from wet roads.

Rubber, polymers, or fibres are sometimes added to asphalt mixes for porous surfaces to increase the durability and the presence of these inclusions can also assist in reducing noise as they can make the surface more flexible, thus reducing excitation mechanisms.

Noise generation mechanisms

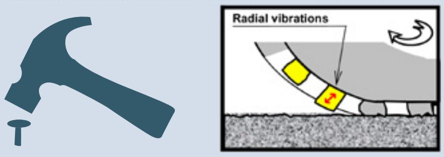
Noise is generated and amplified by a number of mechanisms, which depend on the specific tyre/road combination. The main tyre/road noise mechanisms are described using physical analogies on the following pages.

Images courtesy of *The little book of quieter pavements*[21].

Tread impact or 'the hammer'

As the tyre rolls along the road surface, the tread and the surface impact together many times a second, causing noise. Each impact is analogous to a hammer strike.

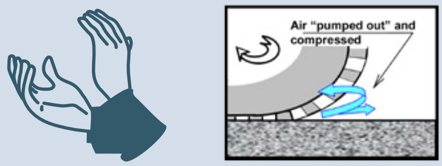
FIGURE 2.9 'The hammer' generation mechanism



Air pumping or 'the clapper'

In between the tyre tread and the road surface are gaps filled with air. As they roll together the air is squeezed out or trapped and compressed. As the tyre loses contact with the surface, the trapped air is forced out rapidly, generating noise. This process is similar to hand clapping, where much of the noise is caused by air being quickly pushed away.

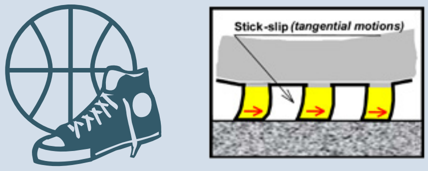
FIGURE 2.10 'The clapper' generation mechanism



Stick-slip or 'the sneaker'

Squeaking sneakers are heard during a basketball game. This type of noise is also produced as a tyre rolls along the road surface. As the rubber treads continually deform and distort underneath the tyre, a stick-slip action occurs. These stick-slips occur rapidly under each tread block, generating high frequency noise.

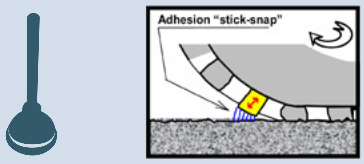
FIGURE 2.11 'The sneaker' generation mechanism



Stick-snap or 'the suction cup'

A suction cup can stick to a smooth surface because of both adhesion and a vacuum that is created when the air in the cup is pushed out. A similar effect can occur between the tread and the road surface. On release of the vacuum, noise is generated.

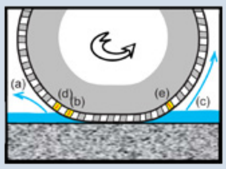
FIGURE 2.12 'The suction cup' generation mechanism



Water swish

The precise noise generation mechanism is not known but it is currently thought to comprise a mixture of (a) displacement of water, (b) compression of water, (c) ejected water hitting the vehicle body, (d) impact of tyre on water, and (e) breaking of adhesion bonds between tyre and water.

FIGURE 2.13 Water swish generation mechanism

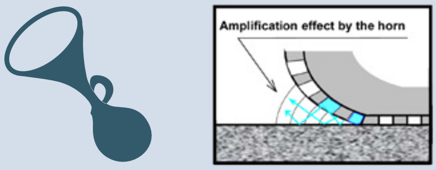


Noise amplification mechanisms

Acoustical horn or 'the horn'

A wedge-shaped segment of air is formed between the tyre and the pavement as the tyre rolls. Within this wedge multiple reflections of noise generated near the throat of the wedge can occur, much like the reflections that occur within a musical horn or megaphone.

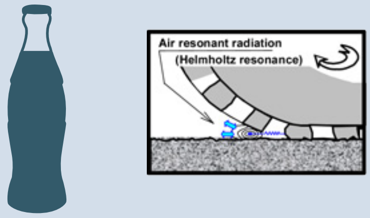
FIGURE 2.14 'The horn' amplification mechanism



Helmholtz resonance or 'the pop bottle'

Blowing across the top of a pop bottle causes a distinct tone. This occurs as the air in the neck of the bottle (acting as a mass) vibrates up and down on the pillow of air inside the bottle (acting as a spring). By itself, blowing creates very little sound. However, blowing across the bottle significantly amplifies the frequency that is distinct to that bottle. A similar geometry can be found close into the wedge where the tyre and pavement meet.

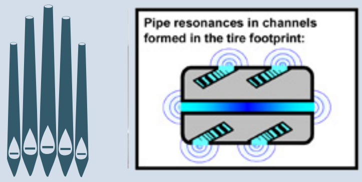
FIGURE 2.15 'The pop bottle' amplification mechanism



Pipe resonance or 'the organ pipe'

When air is blown across an organ pipe, a tone will be amplified that is unique to the length of the pipe and the number of openings. Similar 'pipes' occur in the various grooves on a tyre. Noise that is generated elsewhere can be amplified within these pipes.

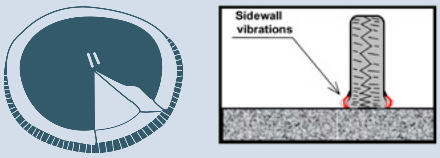
FIGURE 2.16 'The organ pipe' amplification mechanism



Sidewall vibrations or 'the pie plate'

The noise from an electric shaver or vibrating cell phone can be amplified if placed on an upside-down pie plate, as the small vibrations are amplified significantly. Many of the vibrations generated in the tyre will be amplified in this manner by the tyre sidewall.

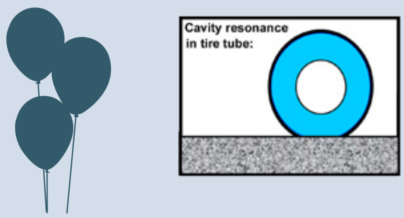
FIGURE 2.17 'The pie plate' amplification mechanism



Cavity resonance or 'the balloon'

When a balloon is hit, a distinctive ringing can be heard. The same occurs with a tyre. This is more readily heard inside the vehicle, as the vehicle itself amplifies the frequencies excited by the impact. Hence this mechanism is less important for the noise heard outside the vehicle than that heard inside.

FIGURE 2.18 'The balloon' amplification mechanism

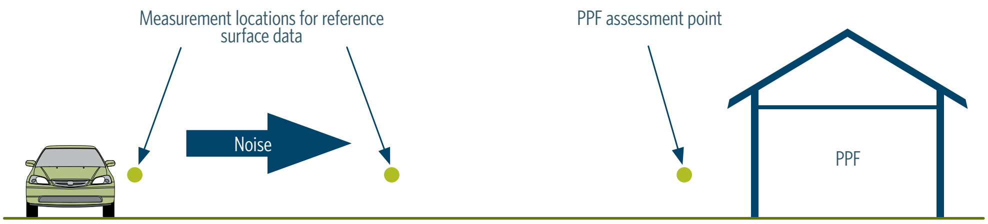


2.3 Monitoring methods

Protected premises and facilities

The key factor when considering low-noise road surfaces is the resulting noise levels at the nearest houses. In NZS 6806:2010 houses near roads are defined as 'protected premises and facilities' (PPFs) together with other buildings such as schools. Noise measurements can be made directly at a PPF for the situation with an existing road surface. However, to calculate what the change in noise level would be if the road surface were altered, comparative data is required for different surfaces. Likewise, when predicting noise from a proposed new road, knowledge of road surface characteristics is needed. To obtain reliable reference data for road surfaces, measurements are made near to the road rather than at the PPF. This data is then used to calculate the noise level at PPFs for a specific scenario.

FIGURE 2.19 Measurement locations



Road surface noise measurements

Although noise data from different surfaces are available from New Zealand and abroad, there are variations in measurement method and in the characteristics of the local vehicles and road constructions. To interpret the data, it is important to understand the measurement methods used.

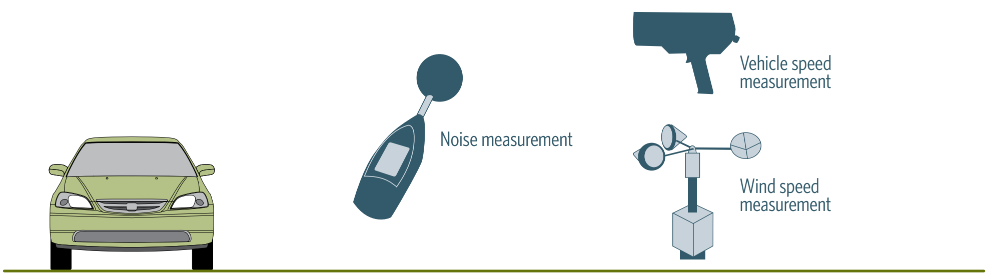
Two types of measurement are usually undertaken:

- Wayside measurements – undertaken beside the road and include the many different vehicles and tyre types, or
- Source noise measurements – undertaken adjacent to a wheel and include long lengths of pavement but only one tyre type at a time.

Wayside noise measurements

Measurements made at the side of the road are the most common way of quantifying road noise. These are usually undertaken at a fixed distance of 7.5m or 15m from the edge of the nearest traffic lane. The noise measurements are often combined with measurements of traffic speeds, weather conditions and classifications of vehicles types (figure 2.20).

FIGURE 2.20 Components of a wayside measurement



There are four common methods of making wayside measurements:

- Statistical pass by (SPB)[26].
- Controlled pass by (CPB).
- Continuous flow traffic time-integrated model (CTIM) or 'time-averaged'.
- Backing board (BB)[27].

In instances where individual vehicles are distinguishable (low to moderate traffic flow), the SPB measures the maximum noise level from many individual vehicles at a distance of 7.5m from the road. From these measurements, a calculation is made of the noise level from an 'average' car, medium truck and heavy truck travelling at a standardised speed. The CPB method is similar, using one or more known test vehicle/tyre combinations.

Using SPB and CPB, road surfaces at different locations can be compared to one another. Some caution must be exercised as there are differences in the 'average' vehicle from site-to-site for SPB and unique interactions between a specific tyre and road surface combination for CPB.

Most of the recent measurements in New Zealand, conducted on behalf of the Transport Agency, have used a modified SPB method. Measurements on SH58 north of Wellington have shown that the minimum number of 20 vehicle pass bys used in this modified SPB method results in sufficient accuracy (compared to 100 pass bys specified in ISO 11819-1). Additionally, the modified SPB method uses the highest $L_{eq,1\ second}$ noise level from a vehicle pass by to quantify the maximum vehicle pass by noise, which is not fully defined in ISO 11819-1.

In the CTIM method, the noise from all vehicles is measured over a fixed time (typically 5 to 30 minutes) as well as the traffic counts and speeds. This process can be repeated and an average noise level calculated.

In most urban situations, there will be noise reflecting surfaces (eg walls) that will affect the measured noise level. To overcome this, the BB method follows the SPB method with the exception that the microphone is mounted on a rectangular board measuring approximately 0.9m by 0.75m and positioned closer to the road (typically 5m). The board increases the reflected noise at the microphone in a fixed way so a correction can be applied.

FIGURE 2.21 Backing board method

Source: SILENCE project[27]

FIGURE 2.22 Close proximity measurement trailer

Source noise measurements

Source noise measurements use one or more microphones positioned close to the tyre/road contact patch (figure 2.22), sometimes within an enclosed trailer to reduce the effect of other noise sources. Two methods are currently used: close proximity (CPX)[28] and on board sound intensity (OBSI), which is used in the United States of America.

As the noise emitted is highly dependent on the type of tyre, CPX measurements are usually repeated with a number of different tyres to produce a 'noise effect' for the surface that is representative of the typical tyres used on the road.

26. International Standards Organisation (1997) ISO 11819-1 Acoustics – *Measurement of the influence of road surfaces on traffic noise – Part 1: Statistical Pass-By method.* www.iso.org

27. European Commission Silence Project (2008) *Noise classification methods for urban road surfaces: 'Backing Board' Method: LCPC Contribution.* www.silence-ip.org

28. International Standards Organisation (1997) ISO/CD 11819-2 *Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 2: Close proximity method, under development.* www.iso.org

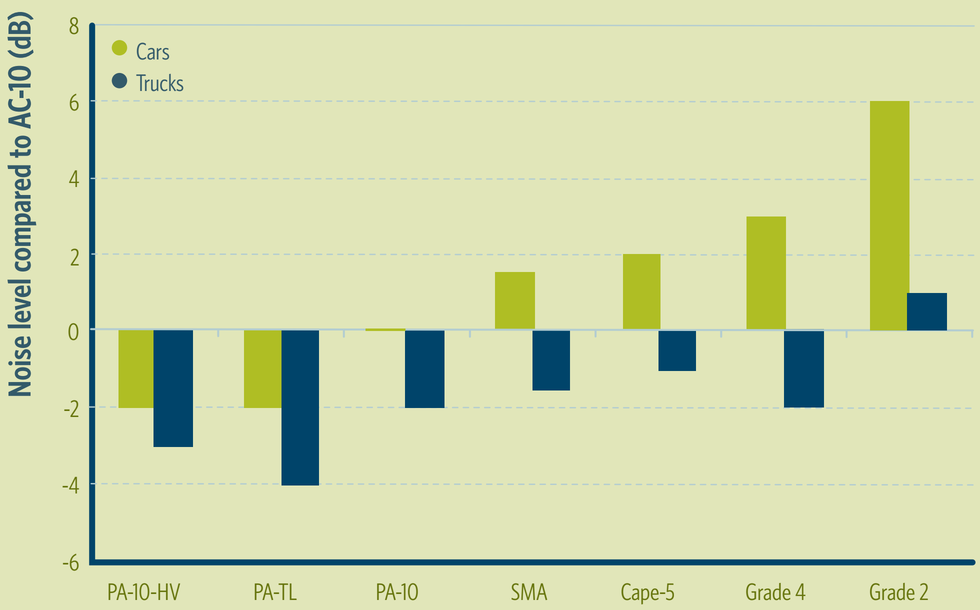
2.4 Low-noise road surfaces

In New Zealand the majority of roads have chipseal surfaces and surfaces quieter than standard chipseal are often referred to as 'low-noise' road surfaces (a 'standard' chipseal surface in an urban environment is a Grade 4 chipseal, as opposed to a Grade 2 in rural areas). The most commonly used low-noise road surface in New Zealand is open graded porous asphalt, but other surfaces such as stone mastic asphalt, asphaltic concrete, slurry seal, cape seal and small chipseal (Grade 5 and 6) can also be referred to as being low-noise. Some surface finishes to concrete roads used overseas have comparable noise data to these low-noise road surfaces (section 2.11). The noise reduction of OGPA can be improved by including a higher percentage of voids or by using a twin layer such as the WhispA® product developed by Fulton Hogan.

OGPA was initially developed to provide paths for water to drain through the road surface, decreasing the amount of spray produced during wet weather and the acoustic performance is a side benefit. In some circumstances, OGPA is now installed purely for the noise benefit.

Figure 2.23 illustrates the typical noise reductions of these low-noise surfaces. These reductions are relative to AC-10, this being the common practice with all road surface data in New Zealand. These surfaces are described in detail in section 1.5 and further information on their noise performance is in section 2.8. Grade 2 chipseal is included for reference but is not a low-noise surface (potential noise effects should be considered before using a Grade 2 chipseal or similar surface).

FIGURE 2.23 **Comparison of noise levels**



Case study – Road surface selection

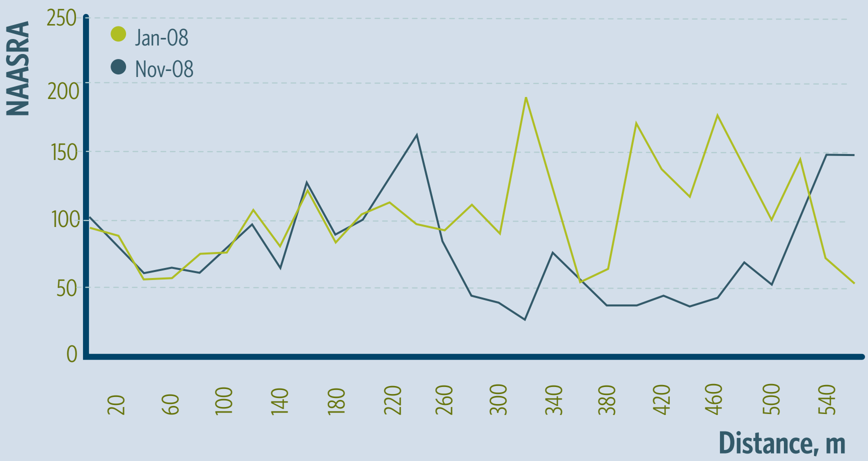
In 2007 a resident living on a hill overlooking SH50 Hyderabad Road, Napier, was experiencing significant disturbance from trucks travelling to and from the Port of Napier. The issues were attributed to the road surface.

This case study highlights the importance of establishing the nature of noise disturbance and not automatically assuming that a low-noise road surface will be an appropriate response to all noise complaints.

FIGURE 2.24 SH50 after 2008 resurfacing (house on hill to left above photograph)

In this instance the disturbance was being caused by truck body noises as trucks passed over bumps in the road. The January 2008 NAASRA measurements (refer section 4.1) in figure 2.25 show several counts between 150 and 200, which corresponds to the poor road surface condition associated with the reported disturbance. Resurfacing with an asphaltic mix might have provided a short-term resolution, but without reconstructing the entire pavement to provide appropriate support an asphaltic mix would be likely to have quickly failed, resulting in bumps and a reoccurrence of the noise disturbance. The benefits of an asphaltic mix in reducing tyre/road noise would have no effect on the truck body noise. In this instance the solution adopted was to undertake pre-seal repairs and resurface with a new chipseal. Figure 2.25 shows the November 2008 NAASRA measurement after laying the new chipseal to have been reduced to around 50 counts. This new chipseal surface resulted in a significant reduction of truck body noise.

FIGURE 2.25 NAASRA counts on SH50 Hyderabad Road, Napier



2.5 Road noise spectra

Different road surfaces

Figures 2.26 and 2.27 show the road noise spectra from six different surfaces for cars travelling at 50km/h[29]. The first figure illustrates that chipseals and slurry seals are noisier than the AC surface at all frequencies less than approximately 2.5kHz. The chipseal surface has a pronounced peak at 1kHz. In the second figure, the spectrum for the OGPA surface is higher than typical due to the poor permeability of the constructed surface at the measurement location and the levels are similar to that of the SMA surface. Usually, the OGPA surface would be quieter. The macadam surface has the highest levels across most of the frequency range.

29 Land Transport New Zealand (2007) *Road surface effects on traffic noise: Stage 3 – selected bituminous mixes*, research report 326.
www.nzta.govt.nz

FIGURE 2.26 Spectra from AC, chipseal and slurry seal surfaces

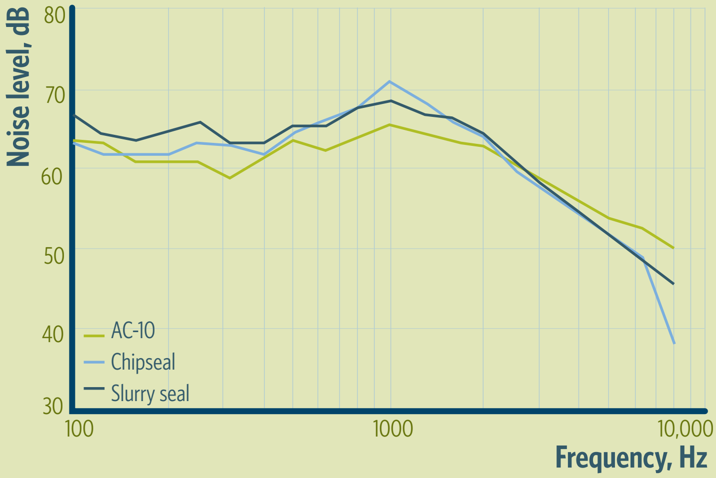
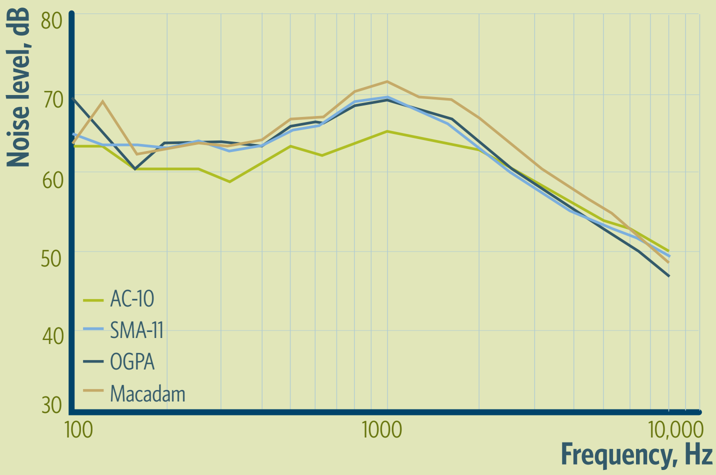


FIGURE 2.27 Spectra from AC, SMA, OGPA and Macadam surfaces



Note: The OPGA surface in this data was poorly constructed and is untypically noisy.

Wet and dry conditions

The characteristics of the noise change when the road surface is wet, particularly on porous surfaces. All the data contained in this guide is for dry roads and hence all predictions based on the information in section 2.8 is on that basis. The water held within the pores of an OGPA surface after a period of rain can take one or two days to dry completely and the road noise changes over this time. On an OGPA surface, the noise 50 hours after rain is between 1.3 and 2.1dB quieter than the noise level four hours after rain[29].

While OGPA provides less noise benefit when wet, those are the conditions when it is providing significant benefit in reducing spray and standing water (section 3.3).

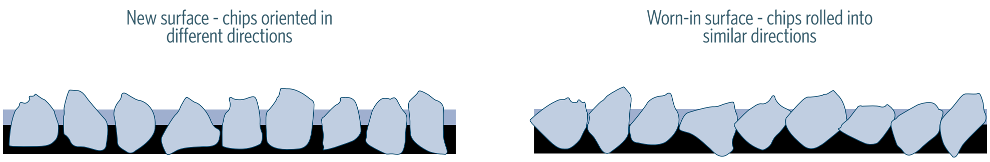
2.6 Performance over time

Chipseals

Chipseals are generally 'worn-in' over the first year of their life. After this time, noise levels do not change significantly as the surface ages further. The noise from light vehicles on a worn chipseal surface has been measured to be up to 1dB less than on a newly laid surface[30]. This is due to the 'rolling over' of the chips and the bitumen rising with time, producing a smoother surface with less texture.

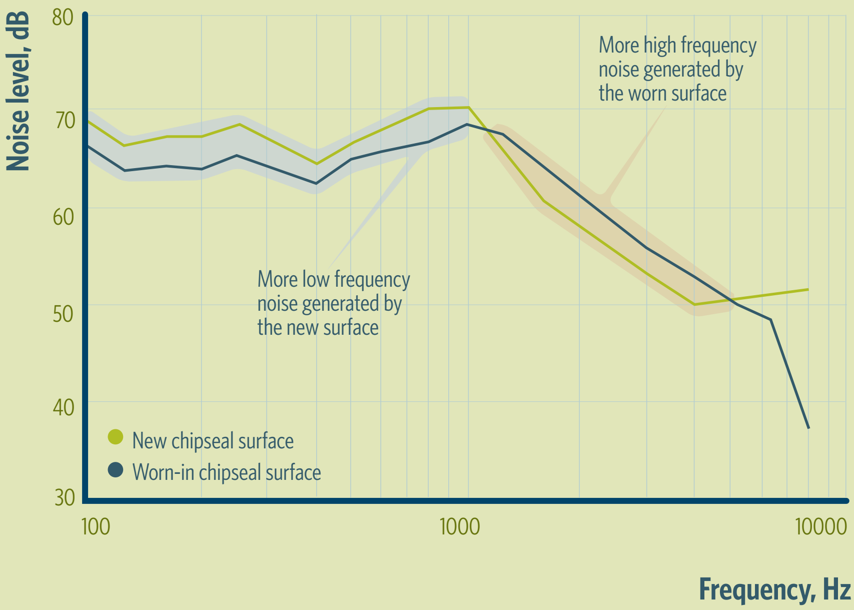
30. Land Transport New Zealand (2006) *Road Traffic Noise - Determining the influence of New Zealand road surfaces on noise levels and community annoyance,* research report 292. **www.nzta.govt.nz**

FIGURE 2.28 | Smoothing of surface due to rolling chips



Despite the small change in the overall noise level, figure 2.29 shows how the individual frequencies of noise generated by tyres on a Grade 3 chipseal change over time. The new surface is noisier at low frequencies, whilst the worn surface is noisier at higher frequencies. This may also be connected to annoyance, as complaints have occurred immediately after a reseal whereas the noise is considered acceptable after the surface has worn. This characteristic is also found in other types of chipseals, although the noise level and frequency changes are less with smaller chip sizes.

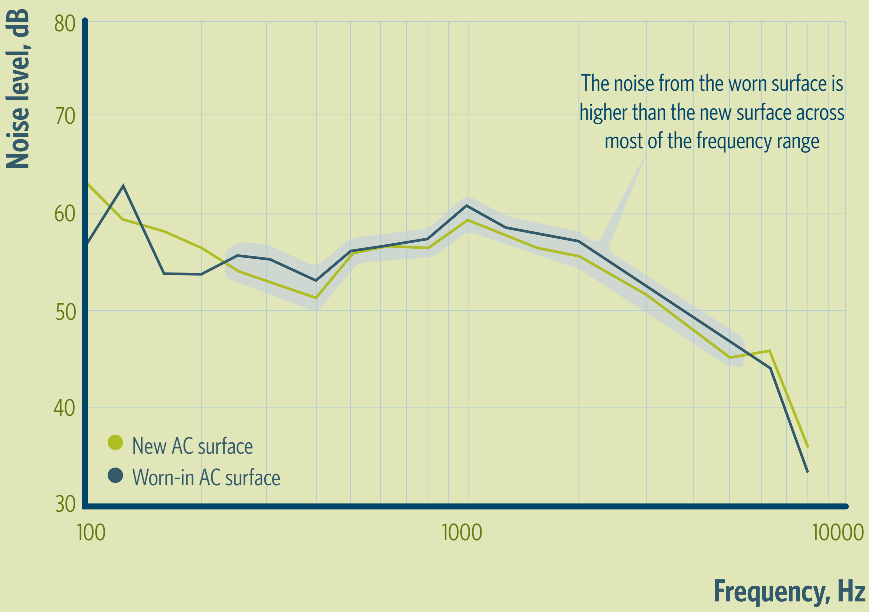
FIGURE 2.29 Difference in noise spectra between new and worn chipseal – light vehicles at 50km/h.



Asphaltic concrete

For AC surfaces noise from light vehicles on a worn surface can be up to 2dB louder than on a new surface. The frequency distribution of the noise is similar for new and worn asphaltic concrete, although the worn surface is slightly noisier at higher frequencies (figure 2.30).

FIGURE 2.30 | Difference in noise spectra between new and worn AC – light vehicles at 50km/h



Open graded porous asphalt

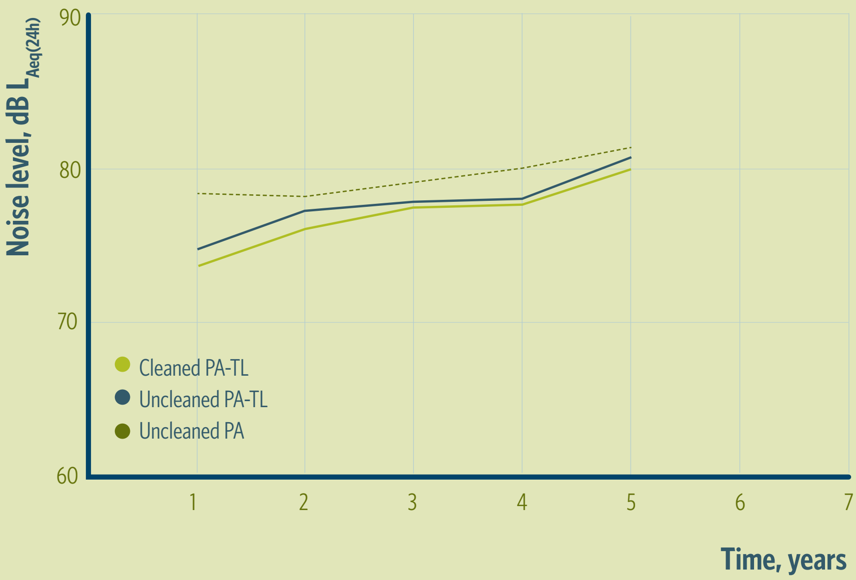
Over time, the pores in an OGPA surface can trap dirt and fine particles, leading to a decrease in the porosity and acoustics performance. This effect has been measured at a number of sites, with the greatest increase obtained being 5dB over a four year period (1.25dB/year). However, on high speed roads (eg 100km/h), the pumping action of passing tyres can clean the surface on the wheel tracks, maintaining the porosity. An OGPA surface can be vacuum cleaned or spray cleaned. However, there is no evidence that this provides a worthwhile benefit on high speed roads, where the pumping action by tyres is sufficient.

FIGURE 2.31 Open graded porous asphalt

Twin layer OGPA

Figure 2.32 shows the effect of yearly vacuum cleaning of the twin layer OGPA surface on SH1 in Auckland (south of the Silverdale Interchange, nominal traffic speed 100km/h)[24]. Only a marginal improvement in noise level occurs from the cleaned surface in this instance, and overall the performance is still significantly degraded over a six year period. These measurements suggest that for porous surfaces on roads with traffic speeds of 100km/h, the pumping action caused by passing wheels provides a level of cleaning in the wheel tracks which cannot be improved upon by additional cleaning. Evidence is not available to show the effects of cleaning porous asphalt for roads with lower vehicle speeds.

FIGURE 2.32 Change in noise level over time for vehicles at 100km/h for cleaned and uncleaned PA-TL



Case study - Twin layer OGPA

As part of a trial of a number of different road surfaces on SH1 near Fairfield, a 400 metre length of 70mm thick twin-layer OGPA was laid in December 2002, comprising of a 30mm top layer over a 40mm layer with higher voids[24]. In addition to regular inspections, the road noise and surface permeability were measured annually.

As expected, the twin-layer OGPA surface was one of the quietest of the surfaces used in the trial, with measured noise levels approximately 6dB less than the noisiest trial section (a macadam surface). Between two and six years after installation, the twin-layer surface increased in noise by approximately 3 dB for cars and between 1 and 3dB for trucks. The permeability of the twin-layer OGPA surface remained consistently high between two and six years after installation.

Cleaning of the surface has not been carried out due to the relatively low increase in noise level and the consistency of the permeability. Recent inspections of the surface have indicated that oxidisation of the top layer and fretting in the wheel tracks have occurred. For these reasons, the top layer will be replaced in 2012 (nearly 10 years after installation).

2.7 Traffic speed

Figure 2.33 shows the measured change in road noise due to an increase in speed, for cars and trucks[29]. The noise level from cars increase by 4.5dB for a speed change of 50 to 70km/h, whereas for the same speed change, the noise level from trucks increase by 2.3dB. Similar increases in noise are seen from 70 to 100km/h.

These measurements have also shown that there is little difference due to surface type in these changes in noise level.

FIGURE 2.33 Increase in road noise level due to a change in vehicle speed

There is little change in the frequency distribution of road noise from light vehicles at different speeds on a Grade 3 chipseal (figure 2.34), Grade 4 chipseal, AC and OGPA surfaces. In general, the effect for heavy vehicles is similar, although there are some anomalies at certain frequencies (figure 2.35).

FIGURE 2.34 Noise spectra for light vehicles at different speeds on a Grade 3 chipseal

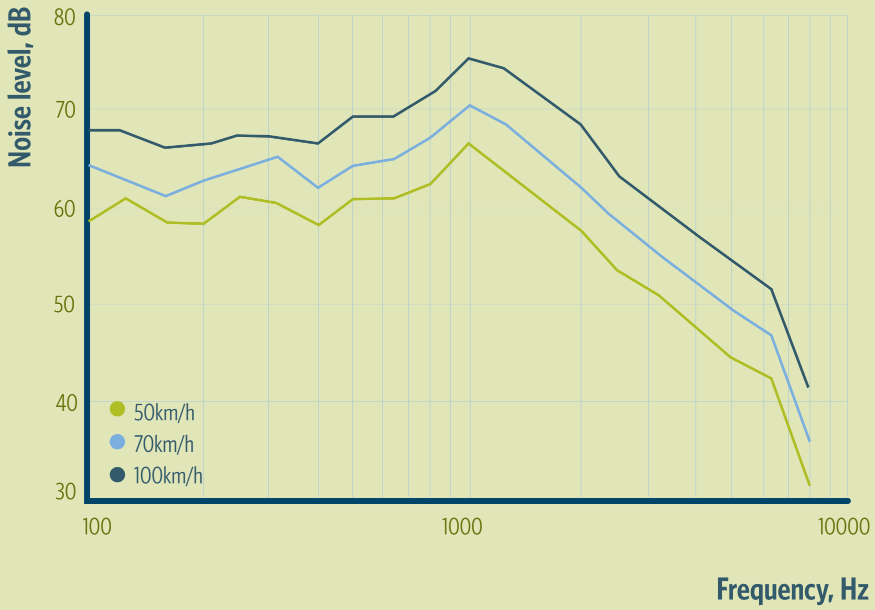
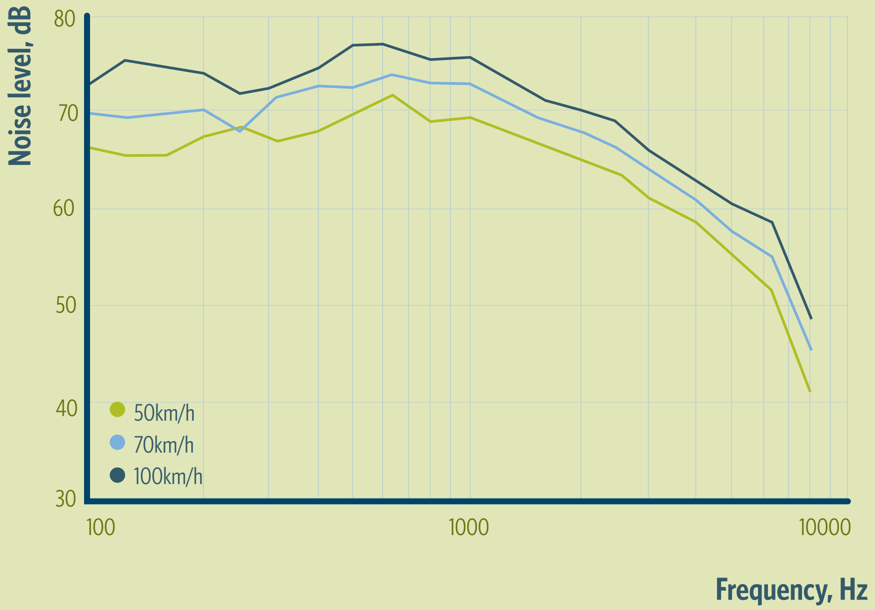


FIGURE 2.35 Noise spectra for trucks at different speeds on a Grade 3 chipseal



2.8 Modelling performance

To assess the noise impacts of a new or altered road typically requires use of computer-based prediction models. Such models calculate the noise levels at neighbouring properties, taking into account traffic speed, ratio of cars and trucks, distance, potential screening by the terrain, ground propagation, air absorption, etc and the road surface.

The calculation of road traffic noise[31] (CRTN) is the most commonly used road noise model in New Zealand. An adjustment is required to the results of the model to account for the type of road surface. The adjustment to a New Zealand asphaltic concrete (AC-10) is -2dB[32]. A further adjustment[29] is then applied to account for the difference between the actual surface and the AC-10 reference surface. These New Zealand adjustments are shown in table 2.1 and are used in place of the those quoted in CRTN. It should be noted that these are the best available adjustments and may be refined as more data becomes available. Further research is required to determine the adjustment for some types of surfaces such as raked-in seals, and to better define adjustments for porous asphalt with different percentages of air voids.

31 Department of Transport, Welsh Office (1988) *Calculation of road traffic noise*, published by HMSO, London. **http://products.ihs.com**

32 Transit New Zealand (1994) *Traffic noise from uninterrupted traffic flows*, research report 28. **www.nzta.govt.nz**

TABLE 2.1 New Zealand road surface adjustments, relative to AC-10 for speeds of 40km/h and above

Surface			Adjustment dB	
Category	Type	Reference	Cars (Rc)	Trucks (Rt)
Chipseals	Single coat	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	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
Slurry seals	Slurry seal	Slurry-7*	+2.0	0
	Cape seal	Cape-7*	+3.0	+1.0
		Cape-5*	+2.0	-1.0
		Cape-3*	0	-1.0
Asphaltic mixes	DGA/AC	AC-10	Reference	Reference
		AC-14	0	0
		AC-16*	0	0
	OGPA	PA-10	0	-2.0
		PA-10-HV	-2.0	-3.0
		PA-TL	-2.0	-4.0
	SMA	SMA-10	+1.5	-1.5
		SMA-11	+1.5	-1.5
		SMA-14*	+1.5	-1.5
	Macadam	BBM-14	+3.0	0

** Results indicative only as data from a small sample*

The adjustments in table 2.1 are given separately for cars (Rc) and trucks (Rt). Based on the equation for correction due to vehicle speed (V) and percentage of heavy vehicles (p) in Chart 4 of CRTN, these are combined to give a total adjustment (R) using the following equation:

$$R = 10 \text{x} \lg \left[\frac{(1 - p/100) \text{ x } 10^{Rc/10} + (p/100 + 5p/V) \text{ x } 10^{Rt/10}}{1 + 5p/V} \right]$$

Table 2.2 shows the total adjustment for a selection of road surfaces. These have been calculated at 70km/h although in practice, the combined surface adjustments are independent of speed. For consistency with CRTN, the vehicle speed has been retained in the equation above even though it has a minor influence. This calculation is included in the road-traffic noise calculator provided on the transport noise website (www.acoustics.nzta.govt.nz).

TABLE 2.2 Combined car and truck surface adjustment

Category	Type	Grade	Percentage of heavy vehicles			
			0	3	10	20
			Combined surface adjustment dB			
Chipseals	Single coat	Grade 4, 5, 6	3.0	2.4	1.3	0.3
		Grade 3	4.0	3.5	2.8	2.2
		Grade 2	6.0	5.4	4.3	3.3
	Two-coat	Grade 3/5, 3/6 & 2/4	6.0	5.4	4.3	3.3
Asphalt mix	AC	AC-10	0.0	0.0	0.0	0.0
	OGPA	PA-10	0.0	-0.3	-0.8	-1.2

Example – Determining surface correction

- Road surface – Grade 3/5 two-coat chipseal
- Percentage of heavy vehicles – 10%

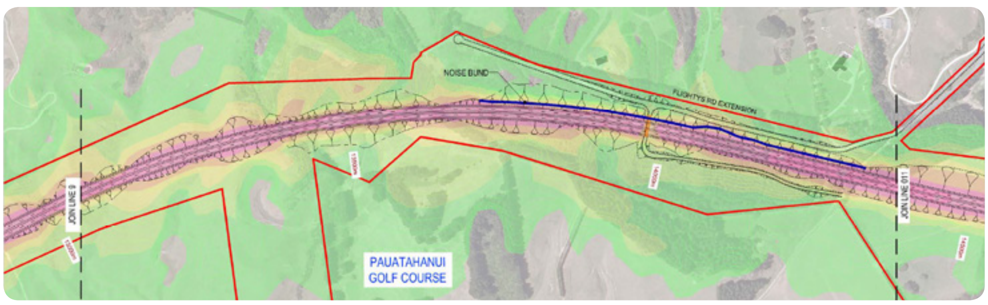
The road-traffic noise level calculated by CRTN needs to be adjusted by -2 dB to account for the New Zealand reference surface (AC-10).

The surface adjustments relative to AC-10 for a Grade 3/5 two-coat chipseal are R_c = +6.0 and R_t= +1.0 dB (see table 2.1).

The combined car (90%) and truck (10%) surface correction is +4.3 dB (see table 2.2)

Hence, the surface adjustment for CRTN is -2.0 + 4.3 = +2.3 dB

FIGURE 2.36 Road-traffic noise model



2.9 Surface features

Complaints

Surface features or defects are a common cause of noise complaints to the Transport Agency. Section 4.5 details considerations when investigating complaints. A key issue for complaints arising from surface features is that where possible the surface should be fixed quickly, as over time people can become increasingly sensitised to the types of noise caused by surface features. Once people have become sensitised to a noise then the same fix may no longer provide relief for them.

Disturbance from road surface features usually relates to mechanical noise such as truck body slap, and does not relate to the tyre/road noise. This mechanical noise is generally characterised by short peaks, which are often not evident when examining the average daily noise levels ($L_{Aeq(24h)}$) used for most road-traffic noise assessment (refer section 2.1).

A low-noise road surface is usually not the solution to noise disturbance from surface features, rather the cause of the features should be addressed, generally to minimise bumps in the road surface.

Patches

To achieve the design life of most road surfaces it is normal and accepted for them to be patched. However, whenever a patch/dig-out is made in a road surface there is an unavoidable bump created due to the size of the aggregate, generally around 10mm height. At best, if special care is taken and with precision working the bump can be reduced to around 5mm height, although this is unusual. Such bumps in road surfaces, even at 5mm height, are likely to cause mechanical noise from heavy vehicles, which can create disturbance.

In the case of a low-noise road surface, any benefits in the reduction of tyre/road noise could be negated by mechanical noise caused by bumps. Therefore, in some noise sensitive locations consideration should be given to potential noise effects before installing patches. This can significantly reduce the design life of a road surface as rather than repairing the surface it may instead need to be completely replaced.

Asphaltic mixes laid on flexible pavements are more likely to crack, and therefore issues with patches will be exacerbated and the design life further reduced.

Utilities

Utility covers (eg manholes) in state highways should be completely avoided. Even if the cover is made perfectly flush with the road surface initially, when the road is resurfaced the cover will be depressed, creating similar vehicle mechanical noise to patches. Covers can also create additional impact noise themselves. Where utility covers cannot be avoided on state highways they should be positioned off the wheel paths.

Case study – Patches

The Breakwater Road section of SH50 in Napier carries a high proportion of trucks which are entering and leaving the port. In 2004 maintenance work changed the surface on a length of this road, creating a joint outside a residential property. While the joint was not unusual, and was constructed to normal tolerances, the increased noise from the trucks running over the new joint (page 41) caused the resident to complain. The small step-change in the road surface height at the joint caused 'body slap' noise to be generated (section 2.2), especially from empty trucks.

FIGURE 2.37 Breakwater Road with initial maintenance work completed

The complaints led to further work being undertaken on the joint, with a significant amount of effort spent in repeated attempts to produce the smoothest possible joint, considerably in advance of standard practice. However the step could not be eliminated completely and the noise levels remained elevated even with a step of only a few millimetres. In fact, cutting out the section with the initial joint to conduct this work resulted in two joints, one either side of the patch, which to some extent worsened the issue. In 2006, the surface and pavement was replaced over a 160m length of road, eliminating the joint at this location and reducing the macro- and mega-texture.

The NAASRA (refer to section 4.1) counts for this segment of road are presented in figure 2.38 taken over 20m lengths in the vicinity of the residential property. The work undertaken to improve the profile of the joint does not show any significant improvement in the NAASRA counts. This is because the joint is a single, discrete feature within the 20m measurement length. The improvement in texture following the road replacement is obvious.

FIGURE 2.38 NAASRA counts

The lessons learned from this case study are:

- Joints can give rise to significant amounts of truck noise.
- If possible, locate joints away from residential properties.
- It is not possible to get a perfectly smooth joint that will not cause additional noise compared to the road surface without a joint.
- Individual defects are not typically visible within road surface texture measurements.

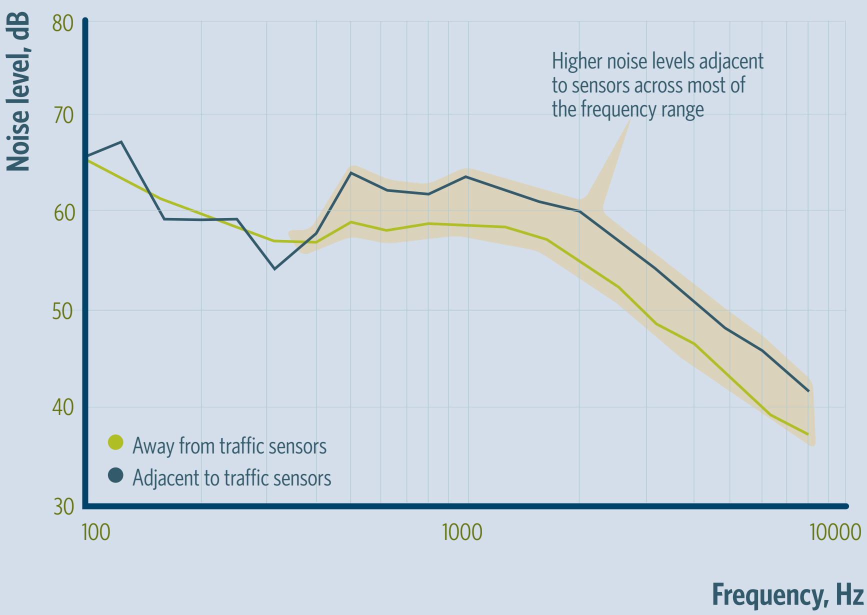
Case study – Traffic light sensor

Traffic sensors were installed in the road surface of SH1 at a newly signalised intersection in Dunedin (2010). The new sensors caused increased noise in the vicinity.

FIGURE 2.39 Traffic sensors in roadway

Inspection of the sensors found that the joints in the road surface around their perimeters were slightly raised and were creating a 'phup' sound each time a vehicle tyre passed over. The sound was more pronounced for cars than for trucks and vehicles with larger tyres. With freely flowing traffic, the traffic noise levels immediately adjacent to the traffic sensors was measured to be 4 dB higher than a nearby location without sensors (figure 2.40). This increased noise level and the character of the 'phup' could have caused complaints if there had been residents living adjacent to the sensors.

FIGURE 2.40 Traffic sensors in roadway



Similar sensors at an adjacent intersection were not slightly raised and did not generate increased noise, indicating that this issue relates primarily to the installation method or quality of installation of the sensors. Care should be taken to avoid any raised joints on road surfaces.

Joints and ramps

In a similar manner to patches, joints in road surfaces can cause mechanical noise from vehicles, which can result in disturbance to neighbouring residents. All road surfaces are at least the thickness of the aggregate (eg 10mm), which makes creating a perfect joint difficult.

The key factor is to position joints between different road surface types as far from houses as practical. In many cases this may require extending say a SMA surface on a high stress junction, roundabout or bend, slightly further along the road so that the joint is away from houses.

It is important that significant steps in road surfaces in urban areas or near to houses are avoided. In these circumstances, if the joint cannot be moved or a section of the old surface milled out and replaced, then a ramp from one surface type to the other should be formed. A ramp should be around 1m long and formed by a surface with a smaller chip size, or a feathering of asphaltic concrete. Ramps should be a similar texture to the road surface, so an asphaltic concrete ramp should not be used for a chipseal surface. For example, as shown in figure 2.41, a ramp to a Grade 3 chipseal surface could be formed by a Grade 5 chipseal.

FIGURE 2.41 Cross section of chipseal ramp

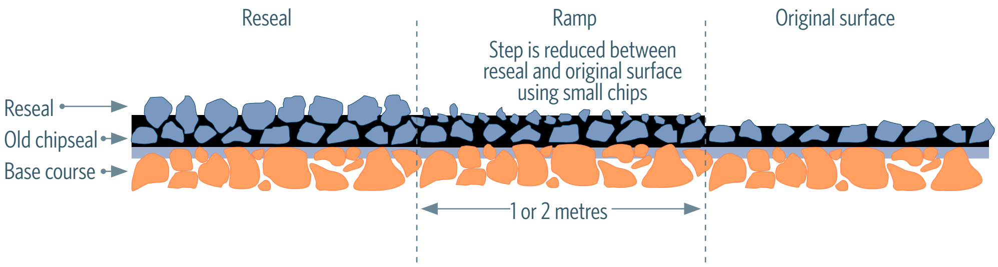
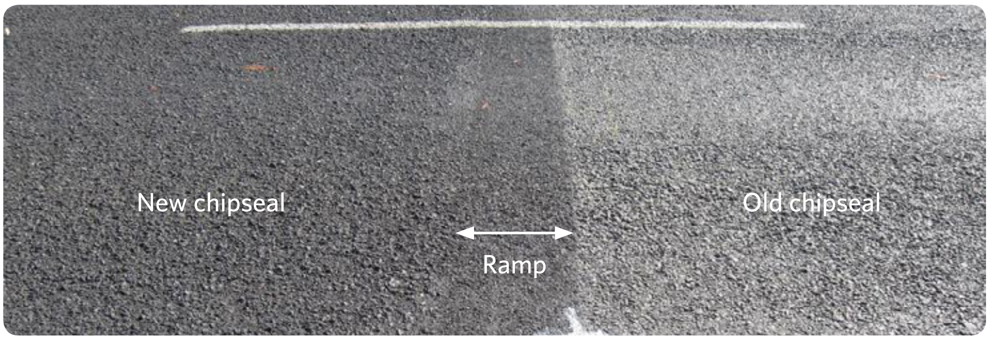
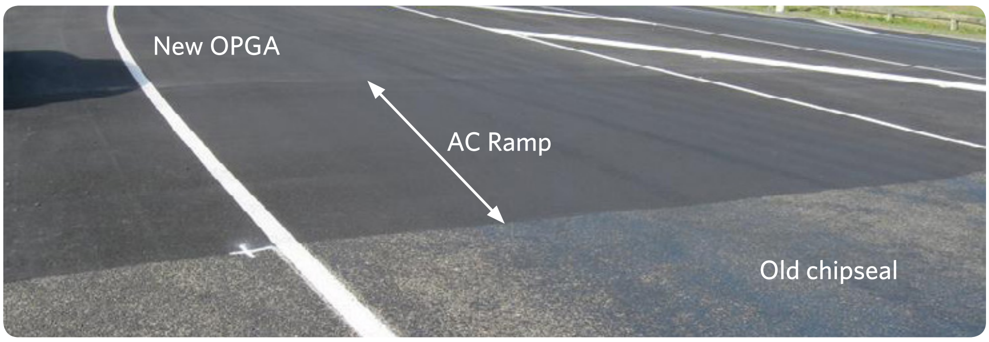


FIGURE 2.42 A chipseal ramp in Napier



Where the surface changes from chipseal to OGPA, there is an unavoidable step of up to 40mm. In these cases, a ramp is usually constructed from asphaltic concrete (AC-10). The length of the ramp is typically 2m to provide a smooth transition but depends on the road geometry, road shape at the joint and vehicle speeds (figure 2.43).

FIGURE 2.43 Chipseal to OGPA ramp



Paving

Good practice in paving can have a significant effect on noise levels. As with patches and joints, any benefit of a low-noise road surface can be negated by surface features introduced by poor paving technique.

Cold joints when paving create a discontinuity, which can result in mechanical noise from vehicles. These joints are unavoidable, but the locations should be planned and kept away from residents as far as practicable.

An issue can also arise during road construction if trucks unloading asphalt mix bump into the paver. The trucks reverse up to the paver but must stop short and not make contact. If the truck bumps into the paver then it can cause the screed plate forming the road surface at the other end of the paver to momentarily drop by a few millimetres. This causes a small depression in the finished road surface which can be sufficient to cause mechanical noise from trucks.

For example, depressions in the road surface caused by trucks bumping into the paver can be felt in the OGPA surface when driving along the Hawke's Bay Expressway in Napier between Prebensen Drive and Taradale Road (2012).

Case study - Audio tactile profile

The guidelines for noise from audio tactile profiled (ATP) line markings are being developed[33] and the current advice is:

> '… ATP line markings should not be laid closer than 200 metres from residences or other noise sensitive properties, although this may be reduced to 100 metres where lines are unlikely to be frequently trafficked.'

As part of a safety improvement scheme on SH1 in Southland, (ATP) line marking was applied wherever the minimum road width requirements were met. This included a straight section of the highway through Longbush, east of Invercargill. Contrary to the specifications for these strips, the ATP was applied at a location which was less than 20m from a residential property.

The additional noise generated by the ATP was audible within the property and caused the residents to complain to the Transport Agency. As a result, the line marking was removed from the immediate vicinity of the property as per the advice of the specification.

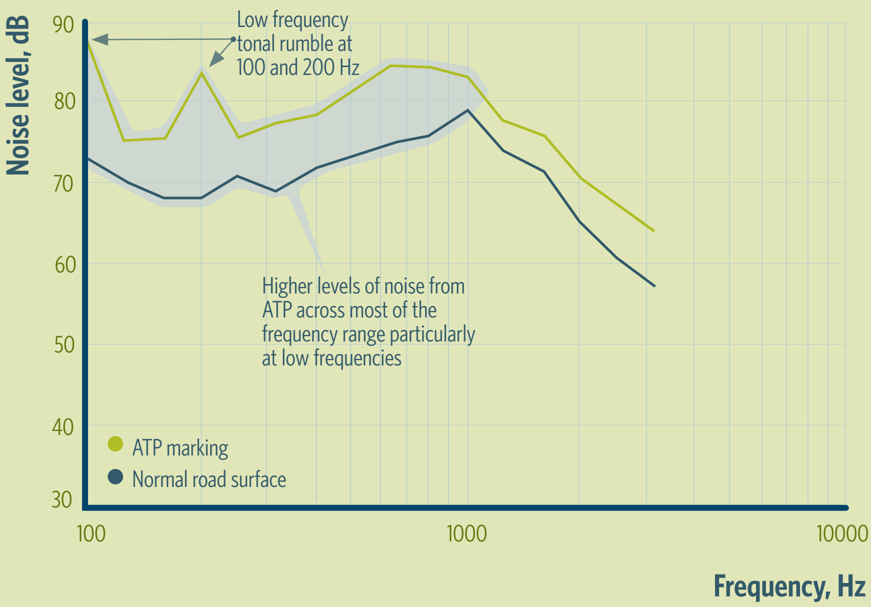
Road markings

Audio tactile profiles (ATPs), otherwise known as a rumble strips, are designed to generate noise inside a vehicle as a warning to the driver (figure 2.44). However, they also cause significant noise outside the vehicle. The noise produced by vehicles travelling on an ATP[33] is dependant on vehicle type, speed, rib height and spacing between ribs. Typically the road noise is increased by 6 dB and has a distinctive low frequency tonal character (rumble), illustrated by two peaks in the noise spectrum (figure 2.45).

33 NZ Transport Agency (2010) *Miscellaneous pavement markings,* Manual of traffic signs and markings, part 2, section 4. www.nzta.govt.nz

FIGURE 2.44 Audio tactile profiled road marking

FIGURE 2.45 Frequency content of noise on ATP marking compared to on normal road surface



Due to its level and character, the noise from ATP line markings often causes disturbance to residents living in dwellings located close to the road, and the noise can be heard a significant distance from the road in rural settings at night. The present guidelines[33] suggest that ATP line markings should not be laid closer than 200m from residences or other noise sensitive properties, although this may be reduced to 100m where lines are unlikely to be frequently trafficked.

If ATP line markings are laid on a low-noise road surface, the reduction in annoyance due to the surface may be offset by increased annoyance due to vehicles tracking over the ATP. Therefore, attention needs to be given to the location of the ATP line markings with respect to dwellings in order for the benefits of the low-noise surface to be realised.

2.10 Research

34 Danish Road Institute/DVS (2009) *Super quiet traffic - International search for pavement providing 10 dB noise reduction*, report 178. www.rijkswaterstaat.nl

35 Transport Research Laboratory (2010) *A review of current research on road surface noise reduction techniques*, report PPR443. *www.trl.co.uk*

The low-noise road surfaces used in New Zealand are mainly OGPA and high voids OGPA. Research into improving the durability of these surfaces is being undertaken by the Transport Agency (see case study below).

Internationally, research work is being undertaken to develop quieter surfaces, involving asphalts with greater porosity; surfaces with very fine textures; plus elastic and poro-elastic surfaces[34, 35].

- A thin-layer porous asphalt consisting of aggregates up to 4mm, a rubberised bitumen binder and air voids content of 25% results in a significant reduction in road-noise compared to standard OGPA for car speeds of 115km/h and 15% trucks.
- Poro-elastic rubber surfaces (PERS), comprising aggregates up to 5mm; large proportions of rubber, eg 50% rubber crumb; and a polyurethane binder results in a similar reduction.

Work continues to ensure that the surfaces also meet the safety, durability, and affordability requirements. It is expected that it will be many years until any surface type of this nature has been sufficiently developed to be used in normal road construction.

FIGURE 2.46 **Laying of PERS**

Case study – Long life OGPA

36 NZ Transport Agency (2012) *Ultra long life low noise porous asphalt.*

Under an international collaborative research programme, the Transport Agency carried out laboratory studies and field trials of 20% and 30% void epoxy-modified OGPAs (EMOGPA) to investigate the durability compared with standard OPGA[36]. EMOGPAs use the same aggregate mixes as conventional OGPA but the bitumen component is replaced with a bituminous binder incorporating an epoxy resin and curing agent. Results from the laboratory tests indicated that lifetimes of up 144 years were achievable for the EMOGPA surface, with an increase in cost of 2.3 times that of conventional OGPA.

As part of the field trial, a 60 metre length of 20% void EMOGPA surface was laid in 2007 on SH1 at Belfast in Christchurch, along with a standard PA-14 20% void OGPA surface as a control. No significant modification to plant or operating procedures was required to lay the EMOGPA surface. At this location, 16,000 vehicles per day pass over the site, with 6% heavy commercial vehicles. Measurements after four years showed that in terms of durability and noise, the EMOGPA surface is performing comparably against the control.

2.11 Concrete road surfaces

Currently, there are few state highways with concrete road surfaces in New Zealand. Texturing of concrete surfaces is required to provide adequate skid resistance.

Texturing methods include:

- transverse grooves/tining
- longitudinal grooves/tining
- brushed concrete
- burlap drag
- diamond grinding/grooving, and
- exposed aggregate concrete

Care should be taken in using texturing methods, such as brushed or burlap drag, as these can produce inadequate texture.

Traditional texturing methods such as transverse grooves (grooves across the road) have a regular pattern with grooves in the order of every 50mm. As tyres hit each groove at the same time interval this generates an unpleasant tonal noise. Transverse grooves were used as they provide good water drainage but due to the relatively high noise levels are the probable reason for the noisy reputation of concrete road surfaces. Randomising the spacing of the transverse grooves can reduce the tonal effect but may not reduce the overall noise level.

Longitudinal grooves, burlap drag, diamond grinding (which smoothes the overall surface but also cuts in longitudinal grooves) and exposed aggregate concrete (which is a non-directional random texture) have been shown to provide noise levels equivalent to or quieter than AC or SMA surfaces. The noise level achieved is strongly influenced by the quality of the installation. Current developments in concrete road surfaces include trials of porous concrete surfaces in Europe. All surfaces require adequate texture for skid resistance to be checked.

In addition to noise effects from concrete road surfaces, traditionally concrete roads have had joints which can generate noise. These can cause an impulsive 'clap' noise when traversed by the tyre, generating up to 5 dB additional noise, although this can be minimised to 1 dB by good detailing of the joints. This effect does not exist for continuous concrete roads without joints.

FIGURE 2.47 | Continuous concrete road construction using a slipformer

Image courtesy of CCANZ

FIGURE 2.48 Transverse grooves (coin size approximately 25mm)

FIGURE 2.49 Longitudinal grooves

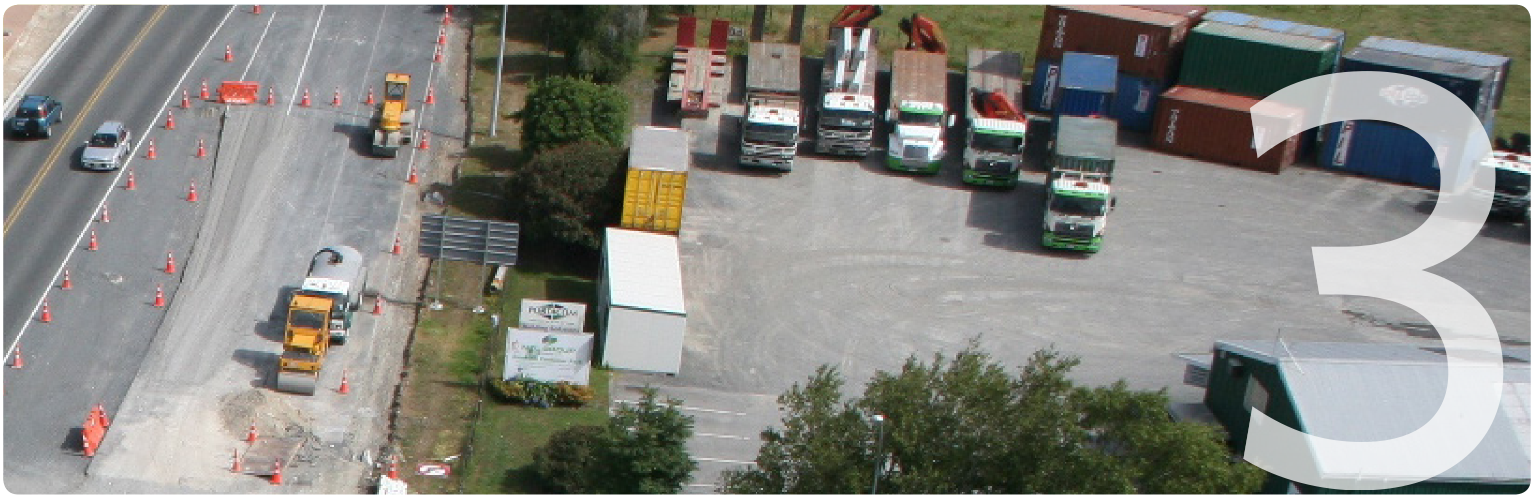
FIGURE 2.50 Artificial turf drag

FIGURE 2.51 **Burlap drag**

FIGURE 2.52 **Diamond grinding**

FIGURE 2.53 **Exposed aggregate**


60
60



3 Road engineering

3.1 Pavement

The primary criteria for a road surface and pavement are safety, durability and cost. The selection of a road surface for noise purposes should not conflict with these criteria. This section is intended to provide an understanding of the non-acoustical factors in surface choice.

Stresses

The road surface is supported by the other layers of the pavement and the subgrade. Not all surface types can be used with any pavement, as different surfaces require different amounts of support. In areas where vehicles turn or brake, the stress on the surface increases and a higher strength surface is required.

The basic philosophy of pavement structural design is to choose, for the different layers, materials that have sufficient strength to carry the traffic loading. These materials are used to limit both compressive stress on the subgrade, and tensile-compressive stresses at the bottom of any bound layer (eg bitumen-bound materials and concrete).

Deflection

As traffic passes over the pavement the surface deflects. The amount of deflection is determined by the pavement structure and the strength of the subgrade. If there is sufficient deflection, cracking of any bound material can occur.

Chipseal is significantly more flexible than an asphalt mix and therefore can withstand higher deflections before cracking. If a low-noise asphalt mix surface is required, the road engineer needs to design an appropriate pavement structure to prevent excessive deflections and cracking. This may require a fundamentally different pavement design than if chipseal were used, eg a 100mm structural layer of asphaltic concrete and a corresponding increase in cost (section 3.11).

With the exception of structural asphalt pavements, new roads with a flexible pavement that are required to have a low-noise asphalt mix surface, a chipseal surface should be laid first and left for up to 12 months prior to laying the asphalt mix surface. This allows the road to settle with any initial deformation and to ensure that the chipseal is sufficiently waterproof, thereby reducing the risk of premature failure of the final asphalt mix surface. Allowance for this 12-month period with a chipseal surface should be made in any designation conditions relating to noise mitigation, and the associated noise effects should be considered in the assessment for statutory approvals.

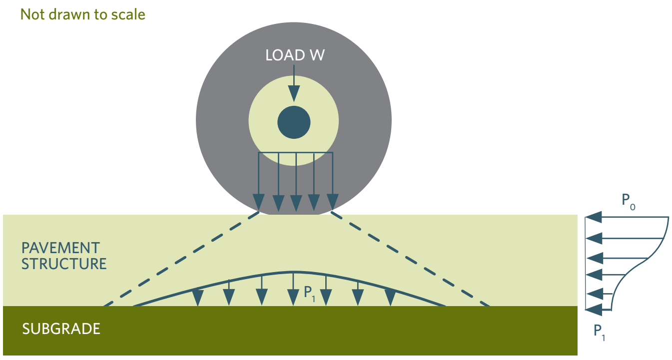
Whenever it is proposed to lay an asphaltic mix surface over an existing chipseal a pavement design check is essential[37]. This may include a measurement of the deflection of the road surface under a standard wheel load and tyre pressure is measured over a range of distances centred on the wheel. The geometry of the resulting 'bowl-shaped' displacements is used to calculate the maximum deflection and the curvature. In New Zealand, a falling weight deflectometer (figure 3.1) or Benkelman beam are used to measure deflection.

37 NZ Transport Agency (2012) *Asphalt surfacing treatment selection guidelines*, SP/M/035. **www.nzta.govt.nz**

FIGURE 3.1 Falling weight deflectometer

Compressive stresses are vertical stresses exerted under a wheel load. They are spread and dissipated by the pavement and the subgrade. High compressive stresses can cause deformations in the pavement in the form of roughness and rutting (see section 4.1).

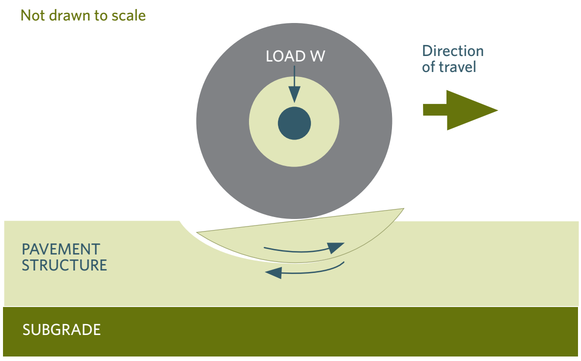
FIGURE 3.2 **Compressive stress exerted under a wheel load**



Shear stresses are generated during braking and acceleration.

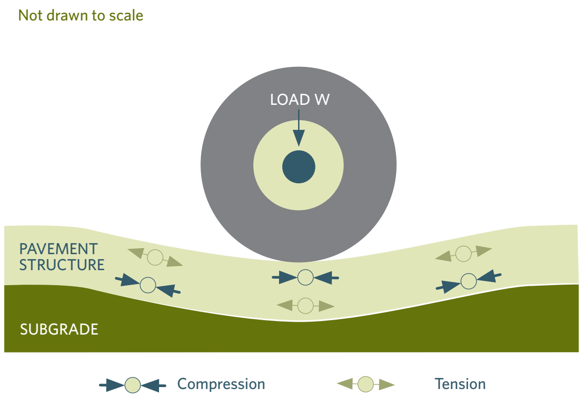
Deformations caused by these stresses form bumps on the surface of the road.

FIGURE 3.3 **Shear stresses exerted by a braking wheel**



Tensile stresses are generated by deflection of the pavement by the wheel load. These stresses can only be generated in bound materials, and are not considered in the design of granular materials or the subgrade. Surface cracking can result from high tensile stresses.

FIGURE 3.4 **Tensile stresses exerted by a load in a bitumen-bound layer**



3.2 High stress environments

Pavement surfaces generally fail on corners, intersections and steep gradients where high stresses are caused by braking or turning traffic[14]. Stress levels are classified from 1 (low) to 6 (high). A classification of 1 implies low stress, eg on a flat and straight section of road. On corners the classifications are dependent on speed and gradient (table 3.1). The number of low-speed trucks also affects this classification, as they create higher turning stresses then cars, which can damage the chipseal.

TABLE 3.1 Stress level classification on corners

Gradient (%)	Advisory speed (km/h)			
	Less than 30	30 to 50	50 to 70	More than 70
Less than 5	4	3	2	1
5 to 10	5	4	3	2
More than 10	6	5	4	3

Braking and slow-speed turning areas are also high stress areas and include:

- roundabouts
- intersections
- commercial driveways (in industrial areas)
- railway crossings
- pedestrian crossings.

The same classification system is used as for corners but based on the truck volume per lane per day (table 3.2). As for cornering, the number of low-speed trucks also affects this classification.

TABLE 3.2 Stress level classification for braking and turning areas

Number of trucks per lane per day	Roundabout	Intersection	Commercial driveway	Railway crossing	Pedestrian crossing
Less than 20	5	3	5	2	2
20 to 50	6	5	6	3	4
More than 50	6	6	6	4	4

3.3 Safety

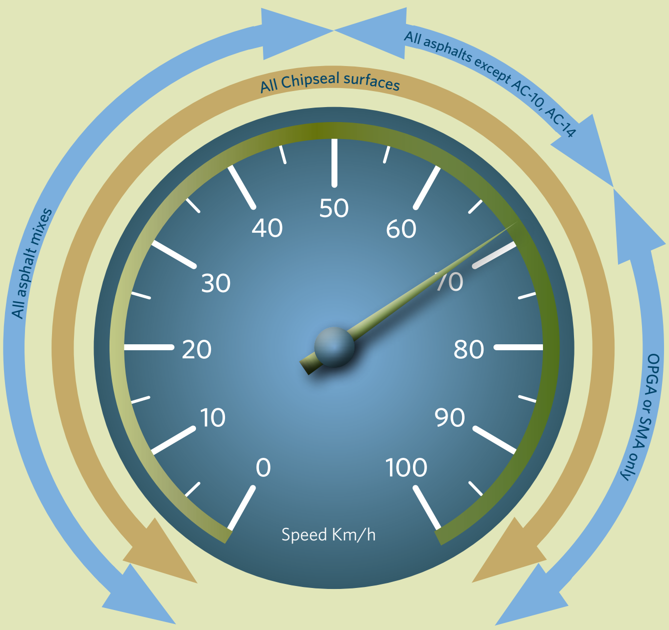
Skid resistance

Adequate skid resistance is obtained by using an appropriate aggregate that is resistant to polishing and has sufficient texture so that water can be expelled from under vehicle tyres. The minimum texture required depends on the traffic speed; at higher traffic speeds more texture is required to maintain skid resistance and resist aquaplaning. Skid resistance requirements are given in Transport Agency T/10[38]. Figure 3.5 illustrates the situations where different road surfaces can be used.

The surface texture influences the skid resistance, primarily due to the undulations of the tyre/road contact area (macrotexture) and the chip surface (microtexture). SCRIM® measurements (section 4.1) determine these quantities to show whether the surface has sufficient texture to

38 NZ Transport Agency (2012) *Specification for State highway skid resistance management*, T/10. www.nzta.govt.nz

FIGURE 3.5 Suitable surfaces for skid resistance at different speeds



Spray

Due to the nature of porous road surfaces, they typically drain rainwater more effectively than asphalt surfaces and thus have reduced levels of surface water. This leads to less spray generated by a moving vehicle and therefore increases visibility, lessoning the risk of collisions.

Additionally, the reduced surface water decreases the risk of aquaplaning.

Glare

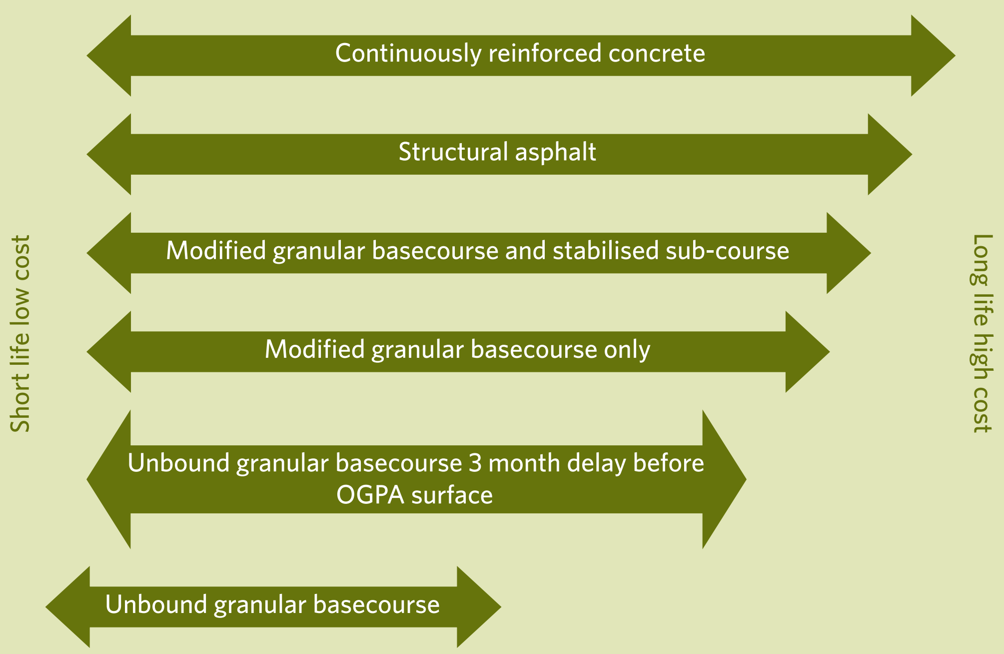
Less surface water on porous road surfaces also means that glare from reflected lights on wet pavements is reduced. This is a factor both during the day and night and improves the visibility of pavement markings.

3.4 Pavement selection

Many factors need to be considered in the selection of a pavement, including stress levels (section 3.2), costs (sections 3.11 and 3.12) and texture requirements (section 4.1). Comprehensive advice on this process is provided in the New Zealand supplement to the Austroads pavement design guide[12]. One of the factors in pavement selection can be the noise during maintenance, especially for locations where future resurfacing works would be at night near to residences. Longer-lasting pavements should be considered in those instances to reduce the frequency of maintenance.

In instances where noise from future maintenance is likely to be an issue the pavement engineer should liaise with an acoustics specialist when determining the optimum pavement structure and each location should be considered on a case-by-case basis. As a general guide, figure 3.6 illustrates length of life for a selection of pavement structures.

FIGURE 3.6 Relative pavement structure life



Specific advice about maintenance noise at night is presented in section 5.6 of the Transport Agency *State highway construction and maintenance noise and vibration guide*[39]. That guide and the guidance here supersedes the previous advice on maintenance noise as a factor in pavement selection contained in the New Zealand supplement to the Austroads pavement design guide.

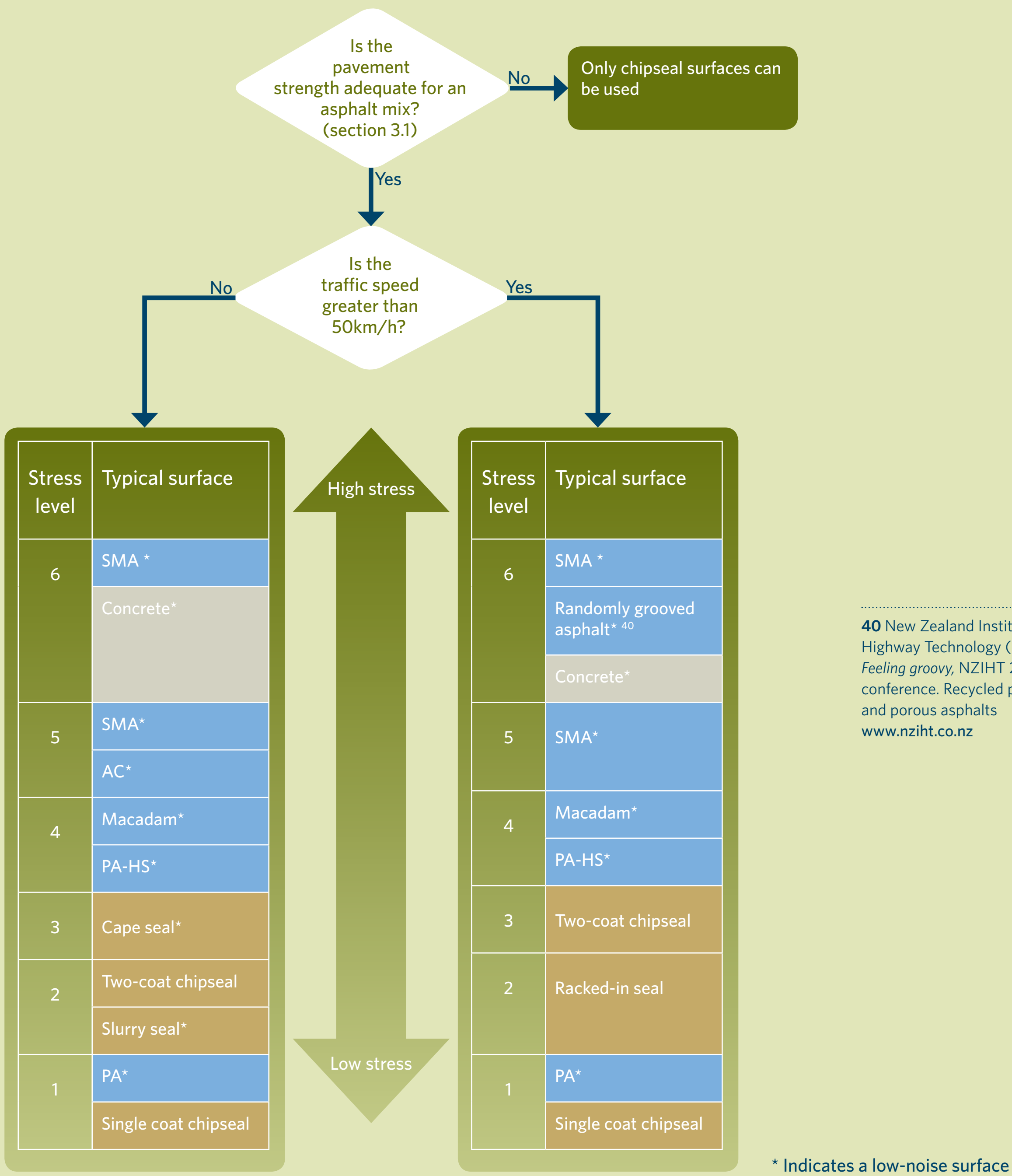
When considering noise from maintenance, reference should be made to designation/resource consent conditions or general district plan provisions (where there is no designation in place), which sometimes include noise criteria. As a precursor to this issue, care should be taken when drafting designation conditions for Notices of Requirement to ensure that noise limits are not imposed which cannot be achieved by unavoidable resurfacing at night. Advice on noise criteria and designation conditions can be found in section 2 of the construction and maintenance noise and vibration guide. If impractical conditions already exist for a designation then the Transport Agency Environment and Urban Design team should be consulted (environment@nzta.govt.nz).

39 NZ Transport Agency (2013) *State highway construction and maintenance noise and vibration guide.* Version 1.0. www.acoustics.nzta.govt.nz

3.5 Surface selection

The selection of road surface and the underlying pavement depends on many factors, including costs (section 3.11). The following flowchart gives an outline of the selection process for a road surface.

FIGURE 3.7 Outline of the selection process for a road surface.

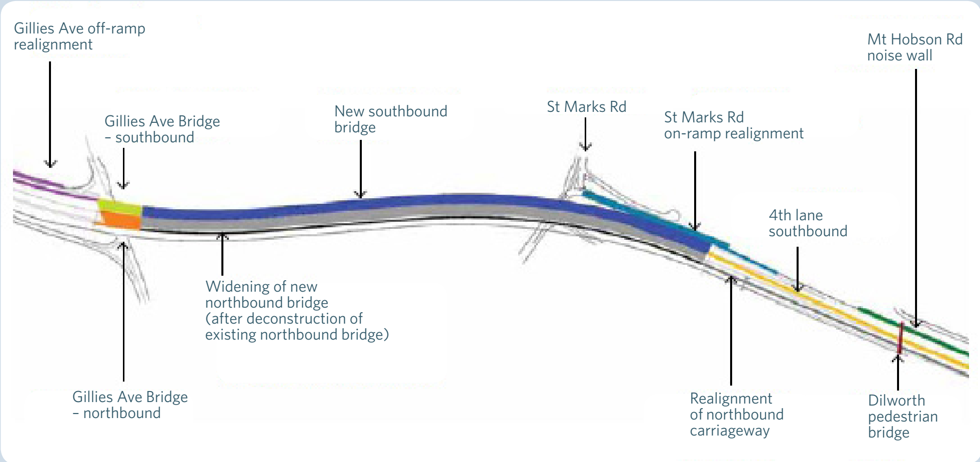


40 New Zealand Institute of Highway Technology (2006) *Feeling groovy*, NZIHT 2006 conference. Recycled pavements and porous asphalts **www.nziht.co.nz**

Case study - Expansion joints

The Newmarket Connection project, Auckland (2008-2012) was a four-stage replacement of the Newmarket Viaduct (motorway flyover), with a wider, stronger, more sustainable new structure. Delivery of the project was by the NGA Newmarket Alliance, comprising the Transport Agency, Fulton Hogan, Leighton Contractors, VSL NZ, Beca, URS, Tonkin & Taylor and Boffa Miskell.

FIGURE 3.8 | Project schematic



As discussed in section 3.6, joints in the road surface often cause mechanical noise from vehicles but are generally required for structures to due thermal expansion and contraction. During the design of the replacement Newmarket viaduct, the mechanical bearings between the viaduct structure and the piers were arranged to force the viaduct to move around the 'S' curve during expansion/contraction, without generating excessive forces in the bearings or piers. Such an arrangement of bearings enabled the viaduct structure to be continuous without the need of intermediate expansion joints.

Hence the number of expansion joints in the new viaduct was reduced. The benefits of this design are:

- Reduced road surface/vehicle noise for nearby residences
- Improved noise and ride for the road user
- Improved appearance
- Reduction in the maintenance required on the joints
- Reduction in the number (half) of bearings required at each pier.

FIGURE 3.9 | Newmarket viaduct bridge bearing

3.6 Structures

The main noise issue with structures is joints. As discussed in section 2.9, joints in the surface often cause mechanical noise from vehicles. Whereas joints between different surface types on a road at-grade can usually be moved away from noise sensitive areas, the location of bridge joints is typically fixed unless there is the opportunity during the design of a new structure to optimise the location and number (see case study opposite).

A study in 2013 reviewed bridge joint noise and included measurements of noise and vibration on a car travelling over state highway bridge joints in Auckland, Wellington and Tauranga[41]. Significant variations were found in noise and vibration generated from the same joint types in different locations, more so than differences between joint types. This indicates that joint installation and maintenance is a key factor in noise and vibration generation. From this research it was concluded that in noise sensitive areas:

- Where possible structures should be designed so that the road surface can be continuous,
- Where expansion joints are required steel finger joints appear to have consistent and inherently good (low) noise and vibration performance,
- If modular joints are required they should include noise reducing surface plates,
- Particular attention should be paid to achieving good installation and maintenance quality, which should be a requirement in the contract documents,
- The cavity under the joint should be assessed and if required a barrier should be installed under the joint to close the cavity and acoustic absorption should be installed within the cavity.

41 URS and Opus (2013) *State highway bridge expansion joint noise. Report reference 42185280/R004/C.* www.acoustics.nzta.govt.nz

3.7 Stormwater

Stormwater from roads increases the quantity of water runoff compared to the 'greenfield' situation and can convey contaminants into adjacent watercourses. The Transport Agency has obligations under the RMA to drain, collect and treat stormwater and thus provides design standards for state highways[42]. Cleaning of road surfaces by water blasting can also prouce contaminated run-off (refer to section 4.3)

Water incident upon a road surface will either run-off over the surface to the shoulder or infiltrate into the pavement, with the amount of infiltration depending on the porosity of the surface type (section 2.2). A water proof layer prevents the water from penetrating the basecourse and the infiltrated water drains through the surface to the shoulders. To prevent pooling of water on the surface, the design of the pavement should allow a faster rate of drainage than expected rainfall.

For a limited period of time, typically three to five years, OGPA surfaces have the ability to trap pollutants contained in the infiltrated water. This reduces the amount of water that can infiltrate the surface and also reduce its acoustics performance (section 2.5). When this occurs the stormwater performance, in terms of treating the contaminants in the run-off water, also becomes impaired.

42 NZ Transport Agency (2010) *Stormwater treatment standard for state highway infrastructure.* www.nzta.govt.nz

FIGURE 3.10 | Stormwater drain

3.8 Greenhouse gases

The selection of surface type affects road user emissions in terms of greenhouse gases (GHG):

- A pavement in good condition typically causes fewer GHG emissions from road users than one in poor condition, due to the additional energy losses caused by higher surface roughness/texture. This appears to have a more significant effect on overall GHG emissions than the actual pavement type[43].
- Rough patches in the road surface that cause traffic to slow and then accelerate will affect fuel consumption and therefore keeping up with maintenance is important to ensure that the road surface does not negatively affect road user emissions. Road user emissions are typically far greater than those from maintenance activities[44].
- Additionally, roads constructed from concrete appear to be responsible for more construction GHG emissions than bitumen roads, but are thought to require less maintenance resulting in an overall balance between the two materials (excluding vehicle emissions). To study these, and other contributing factors, over the whole of life of a road project, a workbook has been developed by New Zealand and Australian roading authorities to standardise the assessment of GHG[45]. This project has led to the development of a calculator known as 'Carbon Gauge'® to quantify GHG emissions associated with the construction, maintenance and operation (in terms of street lights and traffic lights, vehicle emissions are assessed by other means and added manually). Further advice is available from the Environment and Urban Design Team (environment@nzta.got.nz). A review has also been conducted of GHG emissions specifically associated with asphaltic mixes[46].

In summary, GHG emissions are not currently a significant factor in the selection of road surfaces, but highlight the importance of maintaining roads in good condition.

As for noise generation, energy consumption/fuel efficiency is affected by the interaction of both the road surface and the tyres. Research has shown low rolling resistance tyres can benefit fuel efficiency[47].

43 Joint EAPA/Eurobitume Task Group Fuel Efficiency (2004) *Environmental impacts and fuel efficiency of road pavements.* www.eapa.org

44 US Federal Highway Administration (2001) *Perspectives on fuel consumption and air contaminant emission rates by highway vehicles*, FHWA-RD-01-100. www.tfhrc.gov

45 Transport Authorities Greenhouse Group (2011) *Greenhouse gas assessment workbook for road projects.* www.mainroads.wa.gov.au

46 Austroads (2012) *Carbon and asphalt: a review of environmental factors including emissions calculators.* www.onlinepublications.austroads.co.au

47 Opus International Consultants Ltd (2012) *A comparison of low rolling resistance tyres on New Zealand roads.* www.eeca.govt.nz

3.9 Legal

Section 1.1 sets out the legal framework under which the noise from road surfaces should be considered. There may be noise requirements under the Resource Management Act (RMA) both during construction/maintenance and operation.

Surfacing works may be required to comply with either specific or standard construction noise criteria set in the designation conditions or resource consent for the road. Relevant designation conditions can be identified by Transport Agency staff (generally planners and environmental specialists) using CSVue (www.csvue.com). If there are no noise limits in the designation conditions, the RMA still requires the works to adopt the best practicable option to avoid unreasonable noise. Further information is provided in the Transport Agency *State highway construction and maintenance noise and vibration guide*[38].

Operational road-traffic noise is usually assessed using NZS 6806 at the time a road corridor is designated. In some cases it is determined that a low-noise road surface is required for all or part of that section of road, and a requirement for a certain road surface is included in the designation conditions. Therefore, in any situations where it is proposed to remove a low-noise surface the conditions should first be checked on CSVue. If there is a designation condition requiring a specific surface type then it may be possible to use an equivalent surface, but advice should be sought from the Environment and Urban Design Team (environment@nzta.govt.nz).

3.10 Vibration

Building damage caused by traffic operating on roads does not typically occur, but potential vibration effects in buildings immediately adjacent to roads do include human perception and annoyance. In addition to 'feelable' vibration, a 'rumble' noise may be heard due to the reradiated noise (or ground borne noise) of the building structure. This is usually more prominent when the path of the direct/ airborne noise is blocked, eg by a barrier or when the road is in a tunnel. It is often difficult for a listener to distinguish this effect from felt vibration. Rattling of building components, such as windows, is more commonly caused by the sound from heavy vehicles travelling through the air, rather than from vibration travelling through the ground.

The type of road surface typically does not have an effect on the level of vibration emitted from an operational road. A more significant factor in the generation of vibration is the megatexture (section 4.1), defects and other surface features (section 2.9). Following the Canterbury earthquakes (2010-2011) many roads in Christchurch exhibited uneven megatexture resulting in increased vibration effects. In areas where unusual local ground conditions do cause vibration effects, the issues can be complex and often there are not practical mitigation measures available. In such instances advice should be sought from the Environment and Urban Design Team (environment@nzta.govt.nz).

Case study - Vibration from surface joints

Following complaints from residents on McKenzie Street (SH2), Taneatua, of vibration from passing trucks the Transport Agency commissioned vibration measurements (2011).

In this instance, more comprehensive measurements were made than required solely for investigating the specific complaints. Measurements were made at six locations along McKenzie Street and at each of these locations four tri-axial accelerometers were used. At five of the locations, the four accelerometers were in a parallel line 5m from the road edge at 10m intervals. At the sixth location, the accelerometers were in a line perpendicular to the road at 5, 10, 15 and 20m from the road edge to investigate the change in level with distance.

A test truck and trailer was used to drive past each of the measurement locations, two passbys in each direction. Measurements were also made of other passing heavy vehicles. The data was analysed in terms of the peak particle velocity (ppv) and the maximum component ppv for all the measurements 5m from the road are shown below.

FIGURE 3.11 | Measured vibration levels at 5m from the road edge

There is variation in vibration levels at all locations. A joint in the road surface adjacent to location 4 was the cause of the increased vibration levels seen at this position. The vibration levels near this joint would be expected to result in disturbance for any residents living adjacent to the road. This case study reiterates the need to keep surface joints away from houses (refer page 39) where practicable, and to use ramps to smooth the transition between different surfaces (refer page 41).

3.11 Design and construction costs

Typically a road engineer will decide on the surface type based on cost effectiveness to achieve the safety and durability requirements. This will normally be a chipseal unless there are high traffic stresses or there is a policy or environmental reason to use an asphalt mix.

The design and construction costs of different surface types depend on a number of factors, including material quantity and transport distances to site. Table 3.3 gives an approximate ranking of costs for urban and rural environments, relative to a Grade 4 and Grade 2 chipseal respectively.

In high-stress areas, polymer modified bitumen (PMB) is often used. Where PMB is used, two should be added to the values in table 3.3. For example, a PA-10 with PMB in a rural environment will be approximately 6.5 times more expensive than a Grade 3/5 chipseal.

If a pavement requires strengthening to prevent excessive deflections which can cause premature cracking of asphalt surfaces, 20 should be added to the values in table 3.3 if such strengthening is accomplished using a 100mm structural layer of asphaltic concrete.

TABLE 3.3 Relative design and construction costs

Surface type	Reference	Relative cost	
		Urban	Rural
Chipseals	Grade 6	0.6	0.5
	Grade 5	1	0.9
	Grade 4	1	0.7
	Grade 3	n/a	0.9
	Grade 2	n/a	1
	Grade 4/6	1.1	0.8
	Grade 3/5	1.3	1
	Grade 2/4	1.6	1.2
Asphalt	AC-10	4.5	n/a
	AC-14	5.5	4
	AC-20	6.5	5
OPGA	PA-10	6	4.5
	PA-10-HS	6	4.5
SMA	SMA-10	8	6
	SMA-14	10	7.5

Data from personal communication with John Patrick.

Example - Surface costs

For a straight urban road carrying 15,000 vehicles per day:

- Typical surface type would be Grade 4 chipseal at a cost of $4/m² (2010).
- If a low-noise surface was required, an option would be an AC-10 surface at a cost of $4/m² x 4.5 = $18/m².
- Alternatively an OGPA surface could be used at a cost of $4/m² x 6 = $24/m².
- If the OGPA surface requires a 100mm structural layer of asphaltic concrete to strengthen the pavement, the cost would be $4/m² x 26 = $104/m².

This example illustrates that the use of an OGPA surface can be expensive especially if the existing underlying pavement structure is not of sufficient strength.

3.12 Whole-of-life costs

Whole-of-life costs can be split into Transport Agency costs and road user costs.

The Transport Agency costs associated with the choice of surface is a function of the life span of the surface and other parameters used in a cost-benefit analysis. To be economically justifiable, a high cost surface needs to last longer.

The expected life spans of road surfaces are given in table 3.4[48]. The expected life span of AC-10 in high traffic areas is 10–12 years compared to 4–6 years for a Grade 4 chipseal. Although the asphalt life is double that of the chipseal, the cost from table 3.3 is 4.5 times greater. This significant extra cost makes the chipseal the preferred economic option.

48 NZ Transport Agency/ New Zealand Institute of Highway Technology (2010) *Maintaining New Zealand's Chipseal Performance in the 21st Century*, 2010 Conference 'Building and Maintaining Highways for the Future' www.nziht.co.nz

TABLE 3.4 | Expected life span in years of road surfaces

Surface type		Number of vehicles per day						
		<100	100–500	500–2,000	2,000–4,000	4,000–10,000	10,000–20,000	>20,000
Chipseal	Grade 6	8	5	4	3	2	1	1
	Grade 5	8	7	5	5	4	3	2
	Grade 4	12	10	8	7	6	5	4
	Grade 3	14	12	10	9	8	7	6
	Grade 2	16	14	12	11	10	9	8
	Grade 4/6	14	12	10	9	8	6	4
	Grade 3/5	16	14	12	11	10	8	6
	Grade 2/4	18	16	14	13	12	10	9
Slurry seal		8	7	6	5	4	3	2
Asphaltic mix	AC-10	16	15	13	13	12	11	10
	OGPA	12	11	9	9	8	7	6
	SMA	15	14	11	11	10	8	7

Whole-of-life costs, containing the Transport Agency and road user costs, include the following:

- Construction costs.
- Construction vehicle delay costs.
- Pavement maintenance costs.
- Vehicle operating costs.
- Environmental costs.
- Temporary traffic management.

Guidance on the appropriate costs are given in the Transport Agency *Economic evaluation manual* (EEM)[49] and NZS 6806. The monetised benefit of reducing road noise, per decibel, is valued at 1.2% of the market value of the national median house price.

49 NZ Transport Agency (2010) *Economic evaluation manual*, volume 1. www.nzta.govt.nz

In an urban situation, the whole-of-life costs generally do not support the use of an asphalt mix until the traffic volumes are greater than 8,000 vpd, assuming the pavement has sufficient strength. In many cases, the old surface will need removal prior to laying the asphalt, raising the justification limit to 15,000 vpd. On the state highway system in New Zealand, less than 5% of the total length has traffic volumes greater than 8,000 vpd. The use of asphalt surfaces, including OGPA , is usually a policy or environmental based decision rather than cost.

4 Operation and maintenance

4.1 Texture

50 International Standards Organisation ISO 13473 Parts 1 to 5 *Characterization of pavement texture by use of surface profiles.* www.iso.org

The surface texture, or roughness, is an important parameter in the design and maintenance of a road. For example, the texture determines the skid resistance (section 3.3). Textures of various dimensions occur on a road[50] (table 4.1).

TABLE 4.1 | Nomenclature, dimensions and descriptions of road textures

Texture name	Approximate dimension of texture	Description
Megatexture	50 to 500mm (tyre width)	Usually the result of unwanted defects, eg potholes or corrugations.
Macrotexture	0.5 to 50mm (tyre/road contact area)	Determined by the proportion of aggregate and binder or surface finishing technique. Affects water drainage.
Microtexture	<0.5mm (chip surface)	Texture of the surface of the chips. Too small to be observed by the naked eye.

The Transport Agency has systems to monitor and maintain road surfaces. In the Transport Agency *Statement of intent*, road surface condition, including texture, is a key performance indicator which is desired to be stable or improving. This is addressed in the *State highway asset management plan* and given effect to by network management and maintenance contracts. This process is also informed by the annual state highway national pavement condition report[51].

51 NZ Transport Agency (2009) *State highway national pavement condition report.* www.nzta.govt.nz

The Transport Agency aims to provide road surfaces that are safe and comfortable for users. It sets targets for skid resistance, surface texture and road roughness for its roads according to their function and configuration. Mean profile depths are typically in the order of 1mm, with higher values for chipseals compared to asphalt mixes. Minimum requirements are in Table 3 of Transport Agency T/10[38].

The way road roughness affects vehicles depends on the speed of travel: the higher the speed, the greater the impact. The Transport Agency aims to provide the smoothest roads where there is greatest traffic volumes travelling at high speed. It also aims to identify and correct isolated areas of roughness that are out of keeping of the general road quality on a route.

The Transport Agency aims to provide higher skid resistance surfaces in the areas where there is greatest need, for example, where vehicles are braking at the approach to intersections, or slowing and turning as they transition from straights into tight bends. It also aims to provide surfaces with sufficient texture to allow rainwater to flow off the road surface to the drainage channels at the side of the road without greatly affecting the contact of tyres with the road surface, so reducing the chances of 'aquaplaning'.

The road conditions are measured each year, and the subsequent road maintenance programmes prioritised to treat the highest priority skid resistance, texture and roughness defects.

From the 1970s onwards, mega- and macro-texture was assessed by measuring the vertical movement of the rear axle of a standard station wagon as it travelled at a standard speed. A cumulative vertical movement of 15.2mm corresponded to 1 NAASRA count and the number of counts recorded per distance interval (between 20 and 200m) were multiplied up to the number of counts per lane per kilometre travelled. NAASRA is short for 'National Association of Australian State Road Authorities', the predecessor of Austroads and the developer of the assessment method. Standards on the quality of the road surface were set in terms of the number of NAASRA counts. A NAASRA count of greater than 150 typically indicates a road of quality that is likely to generate complaints by road users.

Improvements in surveying technology have led to high-speed data collection of texture data, in addition to other surface condition measures, such as skid resistance, mean profile depth, rutting, gradient, crossfall and curvature. Currently the SCRIM® (sideway-force coefficient routine investigation machine, figure 4.1) truck annually collects these data. This vehicle can operate at speeds of up to 80km/h.

The macro- and micro-texture is assessed in terms of skid resistance using the SCRIM® value. This metric relates the force generated by the resistance to sliding to the wet skid resistance of the road surface. The results are reported for 10m sections of road.

As well as using NAASRA counts, mega- and macro-texture texture is also assessed using the mean profile depth. Three vehicle-mounted lasers are typically used to measure the surface profile in the wheel paths and in between. The vehicle motion relative to the road is removed using data from vehicle-mounted accelerometers to provide a stable inertial profile. The mean profile depth is calculated from the three corrected profiles according to ISO 13473-1:1997[50].

The transverse profile of the road surface is measured using 20 lasers over a width of 3.3m. From these data, the rut depth in each wheelpath is calculated every 20m using a simulated 2m straight edge.

FIGURE 4.1 SCRIM® truck

Sand circle tests

In addition, when considering resurfacing, texture of the existing surface can be measured using the sand circle test[52]. A known quantity of sand is spread into a circle so that the surface depressions are filled. The diameter of the circle relates to the average texture depth.

52 Transit New Zealand (1981) *Standard test procedure for measurement of texture by the sand circle method*, TNZ T/3. www.nzta.govt.nz

4.2 RAMM

53 NZ Transport Agency (2009) *State highway database operations manual*, SM050. www.nzta.govt.nz

54 NZ Transport Agency (2004) *State highway location referencing management system (LRMS) manual*, SM051. www.nzta.govt.nz

The Transport Agency uses a database to store information about the state highway network. This database is known as RAMM (road assessment and maintenance management) and contains descriptions of the road network, the road condition and any defects[53].

RAMM provides detailed information about the road surface, with more classifications than have been used in this guide (table 1.1). A cross-reference for the surface descriptions is provided in table 4.2.

RP/RS

The Transport Agency uses a linear referencing system for the state highway network called the location referencing management system (LRMS)[54]. The 'route position' (RP) is defined as a unique point along the highway from a preceding known point called a 'reference station' (RS). Reference stations (RS) are 'bench marks' along a highway and generally occur at approximately 16km intervals; at state highway junctions and at regional boundaries. They also occur at the start of ramps; at the end of highways and at large roundabouts. For convenience there are also intermediate reference posts between the RSs called established route positions (ERP). An example of a route position is:

01N-0262/11.50

Where:

- 01N identifies State Highway 1, North Island
  (The SH reference is always three characters. In the case of SH 1 that runs the length of the country, the last character denotes the island ('N'orth or 'S'outh). For all other highways, zeros are used to pad the reference to three characters, eg SH6 would be 006; SH20A as 20A and SH6B as 06B.)
- 0262 corresponds to RS number 262.
  (The RS reference is always four characters.)
- 11.50 is the distance past the RS in kilometres.
  (The distance past the RS should be recorded to two decimal places.)

A graphical tool that covers all the state highways in New Zealand is available at lrms.aucklandmotorways.com which can be used to find the location reference of a position.

FIGURE 4.2 Location referencing management system

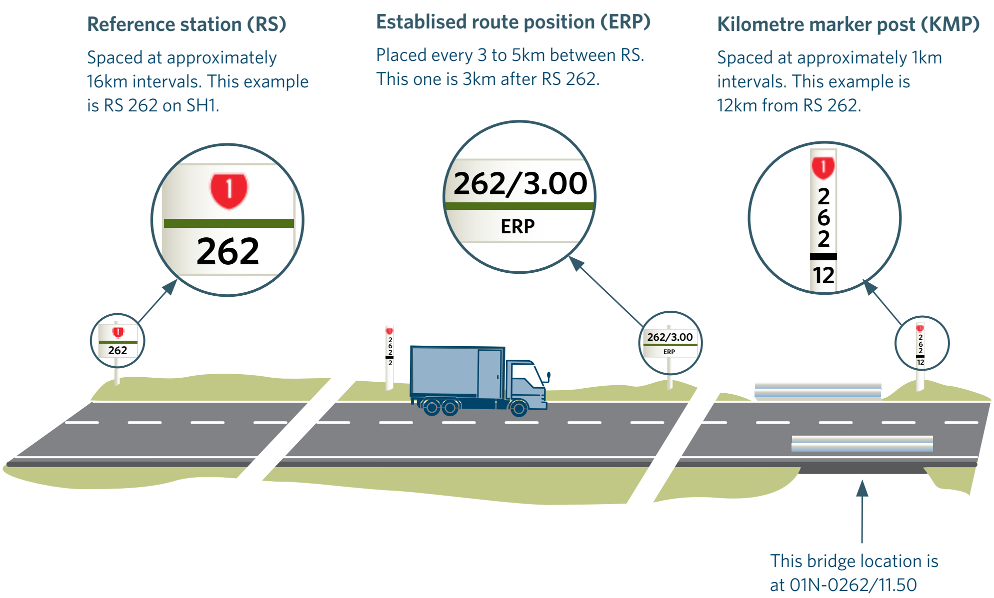


TABLE 4.2 Surface type cross reference

Category	RAMM code	Description	Reference used in this guide
Chipseal	1CHIP	Single coat seal	Grade 2-6
	2CHIP	Two coat seal	Grade 2/4-4/6
	RACK	Racked in seal	
	VFILL	Void fill seal	
	TEXT	Texturising seal	
	RCHIP	Red chip seal (McCullum)	
	PSKID	Premium skid surface PSV >70	
	PSEAL	Prime and seal	
	LOCK	Locking coat seal	
	BOLID	BOLIDT polyurethane mix	
	B/S	Bicouche/sandwich	
Asphalt mix	SLRY	Slurry seal	Slurry-7
	CAPE	Cape seal	Cape-3/5/7
	AC	Asphaltic concrete	AC-10/14/16
	OGPA	Open graded porous asphalt	PA-7/10/14/20
	OGEM	Open graded emulsion mix	
	SMA	Stone mastic asphalt	SMA-10/11/14
	BBM	Bitumen bound macadam	BBM-14
Concrete	CONC	Concrete	
Metal	METAL	Metal running course	
Other	OTHER	Other material type	
	INBLK	Interlocking concrete blocks	

4.3 Cleaning

The noise performance of porous surfaces reduces over time (section 2.6) due to clogging of the voids by dirt and oily materials. Additionally, when the road is wet, the clogging reduces water drainage. This has a detrimental effect on spray and skid resistance, with the latter compounded by the oily material that is brought to the surface by the water.

Depending on the level of traffic, the expected life span of an OGPA surface is between six and 12 years (section 3.12) but clogging can occur after two or three years[55].

Captive water blasting at 3000psi has been shown during trials to effectively clean the surface without damage to the structure. In the trials, surfaces older than two years had significant reductions in permeability after cleaning. However, the levels achieved by cleaning on these aged surfaces, remained higher than those obtained on surfaces aged two years or less.

The waste water generated by the water blasting contains high levels of copper, nickel, lead and zinc, as well as an oily sludge and therefore recovery and treatment of the water is required before disposal. Refer to section 3.7 and the Transport Agency's standard operating procedure for such substances[56].

In a trial with a twin layer OGPA surface, noise measurements indicated that the pumping action caused by passing wheels provides a level of cleaning that additional vacuum cleaning does not significantly improve upon in terms of resultant noise levels. Whilst unproven, it is thought that at lower speeds, the pumping action may provide a lessor effect and cleaning might be beneficial.

55 Pavement Treatments Ltd (2005) *Lane OGPA cleaning trial.* www.nzta.govt.nz

56 NZ Transport Agency (2012) *Standard operating procedure response to spills arising from transport incidents on the state highway network,* in preparation.

FIGURE 4.3 Road surface cleaning truck

4.4 Re-surfacing

Re-surfacing can alter road-traffic noise levels, particularly if the surface type is changed. Therefore, when an existing road is re-surfaced the noise implications should be considered. Section 2.8 details the relative noise levels for different surface types.

Same surface type

Generally, re-surfacing with the same road surface type (including the chip size) will result in similar road-traffic noise. Further consideration is not required for routine re-surfacing with the same surface type.

For re-surfacing with the same type of chipseal, there is an initial increase in noise level of typically 1dB due to the orientation of the new chips, together with a change in character (section 2.6). This effect can be evident for up to approximately one year, although the impact of the temporary change on neighbouring residents will usually be low.

Quieter surface type

As discussed in section 4.5, a new quieter surface type should only be used on the basis of noise levels, if funding is approved for a business case that justifies the quieter surface.

In some cases there may be a range of factors, other than noise levels, which justify the use of a quieter surface type during re-surfacing. In those cases the re-surfacing and any resulting reduction in road-traffic noise levels occur independently of noise considerations.

Noisier surface type

Re-surfacing with a significantly noisier surface may have a large impact on residents, the extent of which depends not only on the change in noise level but also the pre-replacement noise level.

For locations with high existing noise levels (>70dB $L_{Aeq(24h)}$), such as where houses are immediately adjacent to a busy state highway, residents can be sensitive to relatively subtle changes in noise caused by re-surfacing. For example, with high existing noise levels[30] :

- A 1dB increase in noise will result in a 5% rise in population that is exposed to levels above those defined as 'acutely affected'.
- An increase of between 1 and 3.5dB will result in a 10% rise.
- An increase of more than 3.5dB will result in a 15% rise.

Where the existing noise levels are lower (<60 dB $L_{Aeq(24h)}$), the same re-surfacing changes are less likely to provoke the same scale of response. For example, an increase of more than 3.5dB will result in only a 5% rise in 'acutely affected' population.

4.5 Complaints

Complaints about road noise due to road surfaces might occur for the following reasons:

- After the construction of a new road.
- Following maintenance work, such as a reseal.
- Where a surface defect exists.
- Where residents are seeking a low-noise surface rather than an existing chipseal surface.

All these complaints should be addressed in the first instance by the regional highway manager as advised by the Transport Agency guidelines[57] and dealt with as such.

57 NZ Transport Agency (2012) *HNO Environmental and social responsibility manual - Guideline for handling environmental complaints.* www.nzta.govt.nz

New roads

For a new road, any requirement for a low-noise surface should have been determined in accordance with NZS 6806.

- If there are complaints, it should first be confirmed that the surface laid is in accordance with the NZS 6806 assessment.
- Following that, it should be confirmed that the surface conforms to specification.
- If the issue remains unresolved after these steps, advice should be sought from the Environment and Urban Design Team (environment@nzta.govt.nz) to confirm that the NZS 6806 assessment was appropriate.

Maintenance

Following maintenance work, such as a reseal, the characteristics of the road surface noise change (section 2.6).

- If complaints are still occurring after the surface has worn, confirm that the surface was laid to specification.
- If the issue remains unresolved, deal with as per existing roads below.

Defects

For complaints relating to a defect, eg a pot hole or uneven joint between surfaces:

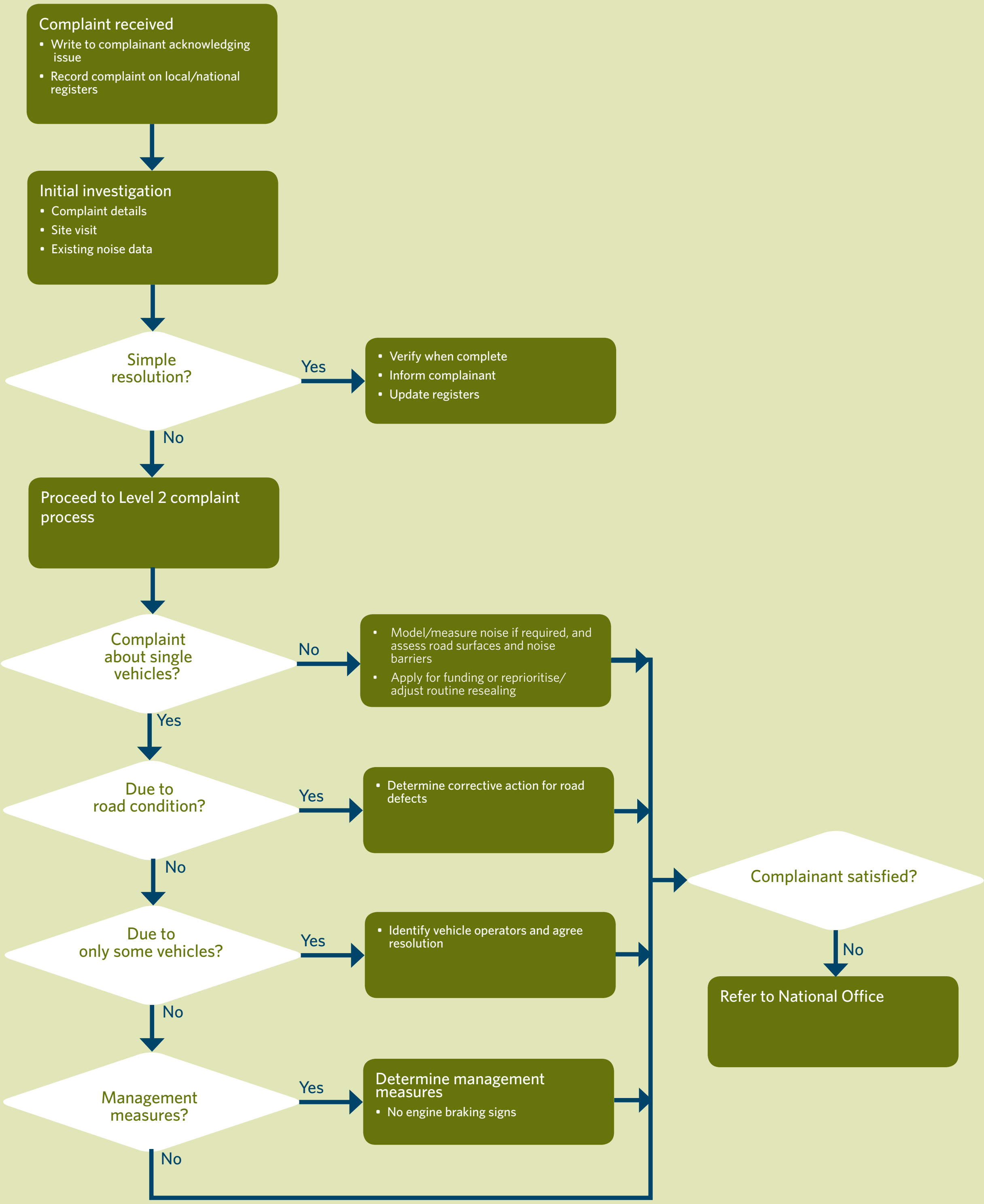
- Confirm if there is a defect and that it is causing significant noise. If a defect is a cause of the noise complaint, fix the defect.
- If the issue remains unresolved, deal with as per existing roads below.

Existing roads

Where neighbours seek an improvement to an existing road surface which does not have significant defects this should be addressed in a methodical way on a regional basis. If the road is scheduled for a reseal then the benefits of a low-noise surface as part of that process could be considered. Otherwise, a business case should be prepared and submitted to either the three-yearly state highway activity management planning process or the yearly state highway annual planning process. Contact the Environment and Urban Design Team for information about prioritising specific locations (environment@nzta.govt.nz).

An example complaint process for noise from existing roads is shown in figure 4.4.

FIGURE 4.4 Complaint process



Glossary & References

Glossary

ALTERED ROAD	An existing road that is subject to alterations of the horizontal or vertical alignment and meets criteria defined in section 1.5 of NZS 6806, including certain sound level thresholds.
ANNUAL AVERAGE DAILY TRAFFIC (AADT)	The vehicle count for an entire year in both directions past a point on the road, divided by the number of days in the year.
ASPHALT MIXES	Asphalt mix surfaces are blends of aggregate and bitumen usually combined and laid whilst hot
ASPHALTIC CONCRETE (AC)	These mixes have a range of aggregate particle sizes and filler (evenly distributed from course to fine) and a low design air void content generally 3% to 7%.
BASECOURSE LAYER	A strong compacted layer below the road surface which supports and distributes the wheel load.
CAPE SEAL	A cape seal is a two-coat seal where the first coat is a chipseal and the second coat is a slurry seal, which fills the texture of the chipseal.
CHIP	Aggregate stone used in road surfacing and construction.
CHIPSEALS	A road surface consisting of a layer or layers of aggregate of a specific size embedded into a bitumen binder. Many types of chipseal exist and are usually described according to chip size and design (eg single coat or two-coat). A 'standard' chipseal surface in an urban environment is a Grade 4 chipseal, as opposed to a Grade 2 in rural areas.
CONDITIONS	Conditions placed on a resource consent (pursuant to section 108 of the RMA) or conditions of a designation (pursuant to subsection 171(2)(c) of the RMA).
DECIBEL (dB)	A unit of measurement on a logarithmic scale which describes the magnitude of sound pressure with respect to a reference value (20 µPa)
DEFLECTION	The movement of the pavement under loading applied to the pavement through the vehicle wheels.
DESIGN LIFE	The period during which the performance of a pavement is expected to remain acceptable.
EXISTING ROAD	A formed legal road existing at the time when road-traffic noise from a new or altered road is assessed using NZS 6806.
FREE-FIELD (NOISE)	Description of a location which is at least 3.5 metres from any significant sound reflecting surface other than the ground.
GRAVEL ROADS	Gravel roads (otherwise known as metalled or unsealed roads) do not have a hard smooth surface of bitumen or tar to protest the layers below the surface. They tend to be used on minor roads in rural areas where the traffic volumes are low.
HERTZ	Unit of frequency, used for sound and vibration.
L_{A10}	The noise level exceeded for 10% of the time of the measurement duration. This is was used for environmental noise assessment in New Zealand but has now been replaced by the $L_{Aeq(t)}$.
$L_{Aeq(24h)}$	Time-average sound level over a 24 hour period, measured in dB.
$L_{AS/Fmax}$	The maximum A-weighted noise level with a one second/slow time constant (indicated by a 'S') or by default a 1/8 second/fast time constant (indicated by the letter 'F').
L_{dn}	The day-night average noise level over 24 hours, with levels over the night-time period (2200 h to 0700 h) increased by 10 dB to reflect the greater potential disturbance during the night. This is used for airport, heliport and port noise in New Zealand.
LOW-NOISE SURFACE	Surfaces quieter than standard chipseals are often referred to as 'low-noise' road surfaces.

MACADAM	Macadam is an asphalt with a high coarse aggregate content, normally with a 14mm sized aggregate mix.
MACROTEXTURE	A surface characteristic related to potential channels for water drainage between the vehicle tyre and road surface, which has a wavelength range of 0.5mm to 50mm.
MEGATEXTURE	A surface characteristic related to pavement defects and 'waviness' having wavelength components from 50mm to 500mm.
MICROTEXTURE	A surface characteristic having wavelength components less than 0.5mm, formed by the irregularities on the surface particles exposed at surface level. It is measured with SCRIM methodology in New Zealand.
NAASRA	A measure of the surface roughness of a road, defined as the cumulative vertical movement of 15.2mm of the rear axle of a standard station wagon as it travelled at a fixed speed. NAAZRA is short for 'National Association of Australian State Road Authorities', the predecessor of Austroads and the developer of this assessment method.
NEW ROAD	Any road which is not an altered road and is to be constructed where no previously formed legal road existed.
NOISE	Noise may be considered as sound that serves little or no purpose for the exposed persons and is commonly described as 'unwanted sound'. If a person's attention is unwillingly attracted to the noise it can become distracting and annoying, and if this persists it will provoke a negative reaction. However, low or controlled levels of noise are not necessarily unreasonable.
NZS	New Zealand Standard
NZ TRANSPORT AGENCY	The crown agency responsible for, amongst other functions, the management and maintenance of the state highway network.
OPEN GRADED POROUS ASPHALT (OGPA)	OGPA has relatively high air voids, generally in the range 15% to 30%, and relies largely on the mechanical interlock of aggregates particles for stability.
PAVEMENT	The three layers above the subgrade of a road formation (ie the road surface, basecourse and sub-base).
POROSITY	The porosity of a material is the ratio or the volume of air to the total volume. Materials used in most road surfaces have a porosity of less than 5%. When the porosity increases to 20% or more and/or when air or water can flow through the material, noise reduction can result.
RACKED-IN SEAL	A racked-in chipseal consists of one application of binder and two applications of chip.
RAMM	Road Assessment and Maintenance Management System: A computer based system to manage the inventory of the maintenance and rehabilitation of pavements and other road features.
ROAD SURFACE	The top layer of a road construction on which the wheels of vehicles roll.
ROAD SURFACE NOISE	The road surface noise or tyre/road noise is that which is generated as the tyre rolls along the pavement.
SANDWICH SEAL	A sandwich seal is a variation of a two-coat seal and is used as a re-seal where there is excess 'flushed' bitumen on the original surface.
SINGLE COAT SEAL	A single coat seal is a type of chipseal, consisting of a sealing binder with a single application of chip.
SCRIM®	Sideway-force coefficient routine investigation machine. A vehicle used to routinely measure the surface skid resistance of in-service roads whilst travelling at normal road speeds.

SKID RESISTANCE	The coefficient of friction between the road surface and a vehicle tyre, normally measured on a wet road surface.
SLURRY SEAL	A road surface consisting of specifically designed mix of aggregates plus an emulsified binder.
SOUND	Sound (pressure) levels are an objective measure of changes in pressure levels that may be heard by humans. Unwanted sound can be considered as noise.
SPECTRUM	A graph of sound level versus frequency.
STIFFNESS	A measure of the deflection of the pavement under a load. The stiffness of the pavement has an influence on the generation mechanisms involving impacts
STONE MASTIC ASPHALT (SMA)	SMA has a similar aggregate skeleton to OGPA but with some of the voids filled with bitumen and fine aggregate.
STRESSES	The forces generated in the pavement due to the load, turning and braking forces of a wheel.
SUB-BASE LAYER	A granular layer between the basecourse and the subgrade.
SUBGRADE	The existing ground on which the other layers of a road formation are built.
TEXTURE	The profile of the road surface affects the interaction between the tyre and the pavement. The large-scale profile determines the ride experienced in the vehicle, for example bumps and dips. Shorter scale features determine the amount of noise generated by the tyre and pavement, for example the surface roughness of the chips.
TWO-COAT SEAL	A two-coat chipseal has two applications of binder and two applications of chip, the second smaller in size to the first. The smaller chip of the second coat locks and supports the larger chip of the first coat.
VPD	Vehicles per day.

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Further information

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