Maintaining the effectiveness of audio tactile profiled roadmarkings for their full life cycle

May 2017

T Lester, V Dravitzki and J Burton
Opus International Consultants, Opus Research

NZ Transport Agency research report 615
Contracted research organisation – Opus International Consultants Ltd

ISBN 978-1-98-851225-9 (electronic)
ISSN 1173-3764 (electronic)

NZ Transport Agency
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
research@nzta.govt.nz
www.nzta.govt.nz

Lester, T, V Dravitzki and J Burton (2017) Maintaining the effectiveness of audio tactile profiled roadmarkings for their full life cycle. *NZ Transport Agency research report 615*. 59pp.

Opus International Consultants Ltd was contracted by the NZ Transport Agency in 2016 to carry out this research.

Keywords: audio tactile profiled (ATP) markings/roadmarkings, chipseal, inverted-profile line markings, maintenance, noticeability, raised-profile markings, reseal, rumble strips, visibility

An important note for the reader

The NZ Transport Agency is a Crown entity established under the Land Transport Management Act 2003. The objective of the Agency is to undertake its functions in a way that contributes to an affordable, integrated, safe, responsive and sustainable land transport system. Each year, the NZ Transport Agency funds innovative and relevant research that contributes to this objective.

The views expressed in research reports are the outcomes of the independent research, and should not be regarded as being the opinion or responsibility of the NZ Transport Agency. The material contained in the reports should not be construed in any way as policy adopted by the NZ Transport Agency or indeed any agency of the NZ Government. The reports may, however, be used by NZ Government agencies as a reference in the development of policy.

While research reports are believed to be correct at the time of their preparation, the NZ Transport Agency and agents involved in their preparation and publication do not accept any liability for use of the research. People using the research, whether directly or indirectly, should apply and rely on their own skill and judgement. They should not rely on the contents of the research reports in isolation from other sources of advice and information. If necessary, they should seek appropriate legal or other expert advice.

Acknowledgements

The project team acknowledges the support and expertise of the Opus Information Centre; Urban Camenzind; Igor Kvatch; Russell Kean; Anthony Paterson; Robert Henderson; John Bowers; Rodney Nicholas; the steering group of Fergus Tate, Joanna Towler, and Alister Harlow; and peer reviewers Sam Charlton and Dave Bates.

Abbreviations and acronyms

ATP	audio tactile profiled (roadmarkings)
DBH	Department of Building and Housing (New Zealand). Its functions are now incorporated within the Ministry of Business, Innovation and Employment.
MoT	Ministry of Transport
MOTSAM	*Manual of traffic signs and markings*
RRPM	reflectorised raised pavement marker
TNZ	Transit NZ

Contents

Executive summary

New Zealand has adopted the raised rib form of audio tactile profiled (ATP) roadmarkings. The ribs are typically formed of thermoplastic or two-part reactive cold-hardening material (referred to in the sector as 'cold plastic') and the ATP roadmarkings are generally used longitudinally as edgelines or centrelines.

The effective life of ATP roadmarkings is estimated as 6 to 8+ years. Theoretically, the effective life of ATP roadmarkings is comparable to the effective life of the road surface on which they are laid. However, to date many ATP roadmarkings have been introduced onto road surfaces that are already midway through their lives. In addition, road surface failures do sometimes occur prematurely. Therefore situations arise where ATP roadmarkings have effective life remaining at a time when the road surface's effective life is expired and reseal of the road surface is scheduled.

This report describes a project commissioned by the NZ Transport Agency in 2013. At that time in New Zealand there was no formal advice on techniques for the retention of ATP roadmarking through reseal cycles; though two techniques were being practised at a local level:

- 'In-lane reseal' where the road surface of the trafficked lane adjacent to ATP roadmarkings is resealed but the non-trafficked shoulder and the ATP roadmarking itself are left without being resealed.
- 'Seal over' the ATP roadmarking, with the intention of allowing its audio/tactile effects to be retained through the reseal layer.

While there is literature on many aspects of ATP roadmarkings, there is little literature available on ATP roadmarking maintenance and/or retention substantively relevant to the New Zealand context. Local industry practitioners were contacted for their practices and experiences.

ATP roadmarkings are defined by their visual and audio/tactile effects when traversed. These essential effects depend on different properties of the ATP roadmarkings. The visual effects primarily depend on contrast with the road surface, typically white or yellow on a mid-to-dark grey surface, and presentation of glass beads or other optics for retroreflectivity. The audio/tactile effects depend on the frequency and prominence of the raised ribs of the ATP roadmarking relative to the adjacent road surface. Maintenance of ATP roadmarkings needs to address the visual, audio and tactile effects.

Visibility of roadmarkings is expected all the time, during daylight and night conditions, and during dry or wet conditions, though not all marking types achieve this. Visibility during night conditions is provided by different mechanisms or properties compared with visibility during daylight, so visibility during night should not be inferred from performance in daylight, nor vice versa.

ATP roadmarking maintenance should include monitoring of visual effects during daylight and night conditions, including wet conditions where practicable. Objective measurements of the properties providing the visual effects of ATP roadmarkings are desirable, but if unavailable then subjective monitoring of visual performance can be an effective alternate approach and is preferable to no visibility monitoring.

Techniques for refreshing ATP roadmarking visibility may be cleaning of the existing ATP roadmarking or recoating the ATP roadmarking with an application of paint (or other regular-build roadmarking material) including beads or other optics.

The audio effects of examples of ATP roadmarkings with in-lane reseal or seal over were measured. With 'good practice', the audio/tactile effects of the ATP roadmarking are unaffected by the in-lane reseal. With resealing over ATP roadmarkings, some of the pre-reseal audio/tactile effects can be successfully retained.

However, the success is variable and may be difficult to predict, depending on both the pre-reseal condition of the raised ribs and the size of chips used during the resealing.

Of the two practices, in-lane reseal appears more practicable because there is more certainty that the residual audio/tactile life will be unimpaired. If road surface reseal is intended where ATP roadmarkings are still working effectively, it is recommended that in-lane reseal be considered as the preferred method.

This project inspected the noticeability of the effects of ATP roadmarkings. The methodology used a car instrumented with a sound level meter and sound recording device, driven first over a plain road surface to capture the baseline sound. Then, thin strips were spaced out and adhered to the road surface, to simulate ATP roadmarking ribs, and the car was driven over the ‘ribs’ to capture the sound with one layer of strips. Strips were incrementally adhered to the preceding layer of strips to build up the height of the ribs. Between each additional layer of strips, the car was driven over the ribs to capture the sound. The captured baseline and incremental sound were used as inputs to a driving-task simulator.

A driving-load simulator was set up with a concentration task on a screen for the participant to complete. This task simulated the mental load of driving. The participant heard through headphones the baseline sound of the car on the plain road surface, then at intervals, the sound of the car being driven over the ribs was played. The participant was instructed to respond to that sound as soon as they noticed it (if they noticed it). The driving-load simulator ran through a sequence, playing the baseline sound and the range of sounds from different rib heights. An algorithm recorded as the participant responded, or did not respond, to the sound from the ribs, building a ‘threshold’ between the rib height (or number of layers of strips) which the participant noticed and responded to and the rib height (or number of layers of strips) that was unnoticed.

The ‘driving-load simulator’ was also used to investigate if the rib-height noticeability was different with 250 mm rib spacing from 500 mm rib spacing.

From an earlier project there were quite strong indications that a 4 mm height was the minimum height for ATP markings to provide sufficient audio tactile effects. However, this current project used a smoother road surface than the earlier project, as well as a different test speed. In this current project about 80% of participants detected the 1.8 mm thickness and 98% detected the next thickness of 2.8 mm.

It is still unclear therefore what stimulus threshold levels are necessary for ATP roadmarking audio/tactile stimuli to be noticed by drivers and there is scope for further investigation of the experimental method and mechanisms operating. The in-car noise when traversing the ATP markings is made up of one or both tyres on one side traversing the marking and two on the other side on the road surface so the road surface/tyre noise effects may be implicated within the overall effectiveness of the ATP marking.

However, for the experimental conditions tested here, at the rib heights required by current New Zealand ATP roadmarking specifications (between 4 mm and 9 mm) there was no significant difference in audio/tactile noticeability between 250 mm rib spacing and 500 mm rib spacing.

The inception of this research project demonstrates that ATP roadmarkings are now recognised as having service lives much longer than anticipated and are starting to be treated as assets. However, the research project found that ATP roadmarkings were generally not managed to the same extent as other assets.

Suggested management for ATP roadmarkings includes best practice monitoring of regular measurement of visual effects, possibly using a mobile retroreflectometer, and regular measurement of audio tactile effects, possibly with a sound level meter mounted in the vehicle. Alternatively, the research project has discussed a subjective rating system and this could be developed for monitoring, as a complement to objective measurements or until there is a fully developed method for relevant objective measurements.

Future research should develop criteria and methods for objective measurements of the ATP marking as the primary goal or a method for subjective rating of the ATP marking as the secondary goal. Either approach, objective or subjective, needs to account for audio, tactile and visual effects of ATP roadmarkings.

Abstract

This research considered maintenance of the audio, tactile and visual effects of ATP roadmarkings including for situations where the road surface was to be resealed while the ATP roadmarkings had remaining effective life. The ATP roadmarkings studied are formed with raised ribs of thermoplastic or two-part reactive cold-hardening material laid on a chipseal road surface.

Measurements and observation indicate the audio and tactile effects of the ATP roadmarkings are long-lasting and effectiveness can be retained with resealing ‘in lane’ adjacent to the ATP roadmarkings. Visual effects of ATP roadmarkings need to be considered and maintained separate from the audio and tactile effects. Overall, ATP roadmarkings should be considered an asset and their performance monitored accordingly. The report proposes an approach to monitoring using a subjective rating system.

1 Introduction

New Zealand has adopted the raised-rib form of audio tactile profiled (ATP) roadmarkings. The ribs are typically formed of thermoplastic or two-part reactive cold-hardening material (referred to in the roadmarking sector as ‘cold plastic’) and the ATP roadmarkings are generally used longitudinally as edgelines or centrelines. The most common road surface on the New Zealand network is chipseal and many of New Zealand’s ATP roadmarkings are on this road surface; though some ATP roadmarkings are on asphaltic surfaces primarily on open-graded porous asphalt on motorways and expressways.

Estimates of the effective life of chipseal road surfaces are 8 to 10 years and for asphaltic surfaces about 10 to 15 years. These estimates may seem imprecise but the effective life is affected by many factors. Estimates of the effective life of ATP roadmarkings in New Zealand are also equivocal as their use in New Zealand is relatively recent overall and even within that time improved materials and novel application layouts have developed. The effective life of ATP roadmarkings was estimated to be about 4+ years in the 1990s and now (2016) estimated effective life of ATP roadmarkings is usually taken as 6 to 8+ years. There are situations of failure occurring early, ribs cracking or de-bonding from the road surface, or trafficked ribs being pressed down into the road surface; but these situations are now better understood and are considered atypical.

Theoretically the effective life of ATP roadmarkings is comparable to the effective life of the road surface on which they are laid. To date many ATP roadmarkings have been applied on road surfaces already midway through their lives and in addition, there have been instances of premature failure of the road surfacing. Therefore situations may arise where ATP roadmarkings have effective life remaining at a time when the road surface’s effective life is expired and reseal is scheduled.

This report describes a project commissioned by the NZ Transport Agency in 2013. At that time in New Zealand there was no formal advice on techniques for the retention of ATP roadmarking effects through reseal cycles; though two techniques were being practised at a local level:

- ‘In-lane reseal’ where the road surface of the trafficked lane adjacent to ATP roadmarkings is resealed but the non-trafficked shoulder and the ATP roadmarking itself is left without being sealed over.
- ‘Sealing over’ the ATP roadmarking, with the intention of allowing its audio/tactile effects to be retained through the reseal layer.

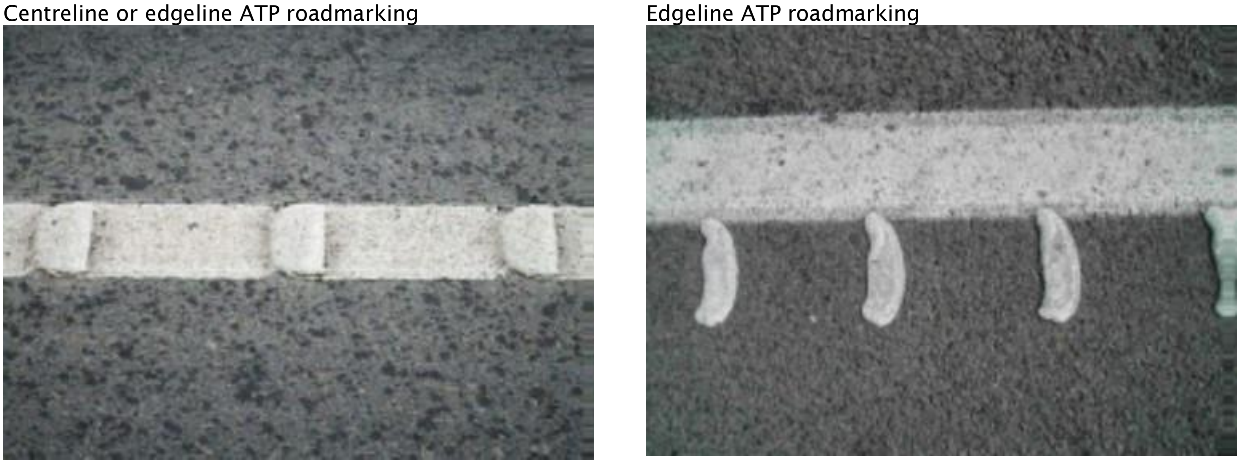
The report is structured as follows:

- Chapter 2: Existing knowledge of retention of ATP roadmarking effects through reseal cycles, via literature and industry practitioners
- Chapter 3: Visual effects of ATP roadmarkings, new and ageing without any resealing
- Chapter 4: Audio and tactile effects of on-road examples of ATP roadmarkings with use of objective measurements and a subjective rating system
- Chapter 5: Simulation experiment to investigate audio and tactile threshold levels for ATP roadmarkings of 250 mm rib spacing compared with 500 mm rib spacing.
- Chapter 6: Conclusions and recommendations resulting from the research.

1.1 Explanation of terms

Unless otherwise stated, in this report 'ATP roadmarking' refers to a roadmarking with regular raised segments which when traversed provide audible and vibratory/tactile feedback to the road user. In New Zealand, for ATP roadmarking centrelines the ribs are placed on the line, and for ATP roadmarking edgelines the ribs may be placed on the line or on the shoulder immediately adjacent to the line. As defined earlier, in New Zealand the ribs may be formed with thermoplastic or a two-part reactive cold-hardening material (referred to in the sector as cold plastic or cold-applied plastic). The line under the raised ribs or adjacent to the raised ribs may be regular-build paint or a higher-build material matching the material of the ribs.

Figure 1.1 Two examples of typical New Zealand ATP roadmarkings



Centreline or edgeline ATP roadmarking

Edgeline ATP roadmarking

There is another roadmarking type, usually formed from thermoplastic, consisting of a low profile with closely spaced grooves or channels marked into the roadmarking material. These are sometimes referred to as profiled roadmarkings or by proprietary names such as Rainline. These roadmarkings may have an audio effect but extremely limited (or no) tactile effect (usually a high-pitched whine) and are not considered ATP roadmarkings. Also distinct are 'structured roadmarkings', built up by a formation of patterns, profiles, random texture or 'splatters' of roadmarking material. These may be known in the roadmarking sector as structured cold plastic or Polydot markings.

Throughout the project and in this report, where resealing and retention of ATP roadmarkings is considered, a chipseal road surface is assumed. Reseal using a chipseal road surface involves a thin overlay. It does not involve reconstruction of the pavement and typically does not involve removal of any of the existing road surface. Reseal using an asphaltic road surface involves a much thicker application, approximately 30 mm deep, which would obliterate any effect of ribs beneath the reseal layer. Asphalt reseals typically involve milling to remove the existing asphalt, with any markings also removed in the process.

2 Existing knowledge

Academic and industry sources were searched for existing literature and sector guidance relating to retention or maintenance of the effective life of ATP roadmarkings. In reviewing this information some features of ATP roadmarkings in New Zealand are important to note.

- The raised-rib form of ATP roadmarkings used in New Zealand is also predominant in Australia and used in the UK. However, other countries such as the USA more typically create ATP roadmarkings with an indented profile by milling or pressing ribs into the road surface then applying a line with a paint or other roadmarking material across/through the ribs.
- The most common road surface on the New Zealand state highway network is chipseal and many of New Zealand's ATP roadmarkings are on this road surface. Therefore it was given most focus in this research project. This situation is similar to parts of Australia. For some countries outside New Zealand and Australia, chipseal is not a common road surface or is not the road surface upon which ATP roadmarkings are applied or studied.
- As stated in the introduction, retention of ATP roadmarking effects through reseal involving an asphaltic road surface is considered not practicable due to the layer depth of an asphaltic road surface.

While literature from other countries holds value it can need interpretation. Therefore the following discussion is in two sections: section 2.1 for local literature from New Zealand and Australia and section 2.2 for other sources. Section 2.3 presents knowledge from direct contact with New Zealand industry members.

2.1 Local literature: New Zealand and Australia

Kiesel (2007) establishes some of the context for this project, considering how the audio and tactile performance of ATP roadmarkings is affected after various maintenance treatments. The study was performed in Victoria, Australia. The ATP roadmarkings were raised ribs formed of thermoplastic, very similar to typical New Zealand practice.

A set of test sites was identified with existing ATP roadmarkings being 'sealed over' with a range of road surface types, including chipseals. The test method involved a station wagon being driven over ATP roadmarkings and the driver subjectively noting in-cabin sound level changes and vibration levels. The driver rated the effect of the ATP roadmarkings as 'reasonable' if having an effect similar to new ATP roadmarkings, 'medium' if having a reduced effect, or 'poor' if having little or no audio and tactile effect.

Kiesel (2007) finds where ATP roadmarkings are sealed over with a chipseal road surface, the effect of the existing ATP roadmarking can be retained as reasonable if the reseal uses a small chip size, say 7mm[1], and retention of the existing ATP roadmarking effect diminishes if the reseal uses larger chip sizes.

The New Zealand Roadmarkers Federation (NZRF 2011) has a *Line removal guide* with a section on removal of ATP roadmarkings prior to reseal. The purpose of the guide is oriented to practical advice.

NZRF (2011) recommends removal of ATP roadmarkings prior to reseal as sealing over existing ATP roadmarkings may affect road surface drainage or create extra stresses in the reseal layer related to the now underlying ATP roadmarking. There is also concern if an ATP roadmarking is reinstated over the position of an existing or now underlying ATP roadmarking, there may be a 'confusion of profiles' as 'it is likely to be very difficult to match exactly the marking spacing'.

---

[1] 7 mm chip size approximately corresponds to New Zealand's grade 4 chip

Other literature also refers to matching the placement of new ribs exactly on top of existing ribs. Edgar et al (2008) show an example of ribs of a new ATP roadmarking installed between ribs of an existing one, resulting in an ATP roadmarking with inconsistent rib spacing and rib heights 'which fails to meet specification'. This is concluded as unacceptable but it is not clear if this conclusion is made relative only to specification compliance or considers the actual performance of the resultant ATP roadmarking. Kiesel (2007) recommends that reinstated ribs are placed exactly on top of the now underlying ribs to avoid creating additional intermediate ribs. Conversely, as stated in the *Manual of traffic signs and marking* (MOTSAM) (NZ Transport Agency 2010b), if reinstated ribs are on top of the now underlying ribs, attention may be needed to ensure the total rib height does not exceed the maximum allowable rib height of 9mm.

The NZ Transport Agency (2010a) *Guidelines for using audio tactile profiled (ATP) roadmarkings* has a section on 'Removal, reinstatement and reseals'. Where ATP roadmarkings in good condition coincide with reseal using a fine grade chip 'the ATP should be resealed over and a continuous line should be marked either immediately next to or over the existing ribs'. If the continuous line is marked next to the existing ribs, then the ribs would visually appear the same as the surrounding road surface which is said to pose a hazard to cyclists and motorcyclists as they may not visually detect the ribs prior to riding on them. 'If a coarse grade chip is to be used over fresh ATP ribs and residual ATP response is non-existent or very faint, then reinstatement of ATP roadmarking can proceed as usual, otherwise the ribs must be mechanically removed prior to the reseal'. This recommendation appears contradictory. If there is residual ATP response found after reseal, at that stage it is no longer possible to remove the ATP roadmarking prior to the reseal.

2.2 Literature from other countries

The literature review found no substantive relevant literature on ATP roadmarking maintenance and/or retention from countries outside New Zealand and Australia.

Where maintenance associated with ATP roadmarkings is discussed, it appears more with regard to the milling or pressing to form the indented-pavement type of ATP roadmarking potentially adversely affecting the effective life of the road surface (see Price 1996; Watson et al 2008.) This is largely not relevant to New Zealand where the application of the raised ribs should not affect the effective life of the road surface.[2]

The US Federal Highway Administration offers some advice on reinstating ATP roadmarkings after a reseal, indicating that a chipseal reseal 'on top of an existing rumble strip has been shown to retain the basic shape of the rumble although losing some cross-section'. Where this is undesirable, through roading agency preference or if the road layout is to be altered so that ATP roadmarkings will not be reinstated in the same positions, then the existing ATP roadmarkings may be removed/infilled prior to the reseal. Otherwise it seems simply resealing over the ATP roadmarkings then reinstating the ATP roadmarkings is adequate and common (FHWA 2011).

Montana Department of Transportation (MDT) uses indented-pavement ATP roadmarkings and states:

> *Depth of rumble strip – A 5/8" [15.9 mm] rumble strip depth is typically used. The depth of a rumble strip can be reduced to minimum of 3/8" [9.5 mm] to provide a 'quieter' pattern near residential areas. The 3/8" depth will not provide adequate noise/vibration after a chipseal has been placed, so the rumble strip would have to be re-milled after every chip seal.* (MDT 2012)

---

[2] The introduction mentioned occasional situations of ribs that are frequently trafficked being punched down into the road surface. The effect of this action on the effective life of the road surface, particularly its permeability local to the affected ribs, was not studied within this project.

2.3 Practices and experiences

Overall, there was insubstantial relevant literature but further information was required to guide the research project. As mentioned in the introduction, at the time of this project two ATP roadmarking retention techniques were emerging in New Zealand, particularly in the Waikato and Bay of Plenty regions. We were able to hold a workshop with the two practitioners identified as having the most knowledge and greatest level of involvement, and from this compiled the following information. It does not necessarily reflect practice recommendations; it only reports observations and experiences from current practices.

2.3.1 In-lane reseal

Presuming the condition of the shoulder is satisfactory, where a site requiring resealing has ATP roadmarkings, the current process for in-lane reseal is generally as follows:

1. Drive on the ATP roadmarkings and decide subjectively if the ATP roadmarkings generate sufficient audio/tactile effects.
2. If the audio/tactile effects are judged ‘easily noticeable’ reseal the traffic lane but not the shoulder and not the ATP roadmarking ribs. Where only edgelines have ATP roadmarkings, the in-lane reseal covers (nominally) from edgeline to edgeline. Where the edgelines and centreline have ATP roadmarkings and all are deemed to have remaining effective life, the in-lane reseal covers edgeline to centreline and centreline to opposite edgeline; leaving the centreline and shoulders without being resealed.

   Thus, the in-lane reseal is from approximately ribs to ribs, allowing for some tolerance (50 to 100 mm) to ensure the reseal does not impinge on the ribs. This requirement can be practicably achieved with cut-off nozzles on the ends of the bitumen sprayer (for example, *TNZ P/4 Notes for resealing*, TNZ 1989).[3]
3. As per a standard full-width reseal, re-mark the continuous edgeline. Experience has been that visibility (retroreflectivity) of ATP roadmarkings is stable and reasonable for several years, say four or five, but then deterioration to a low or unacceptable level may occur rapidly. (U Camenzind, pers comm 24 July 2014)

   If the site has a non-profiled centreline that has been sealed over, reinstate the centreline with a normal roadmarking, as per a standard full-width reseal. If the site has a profiled centreline, the in-lane reseal will not impinge on these ribs and reinstatement is with a normal roadmarking over the ribs.

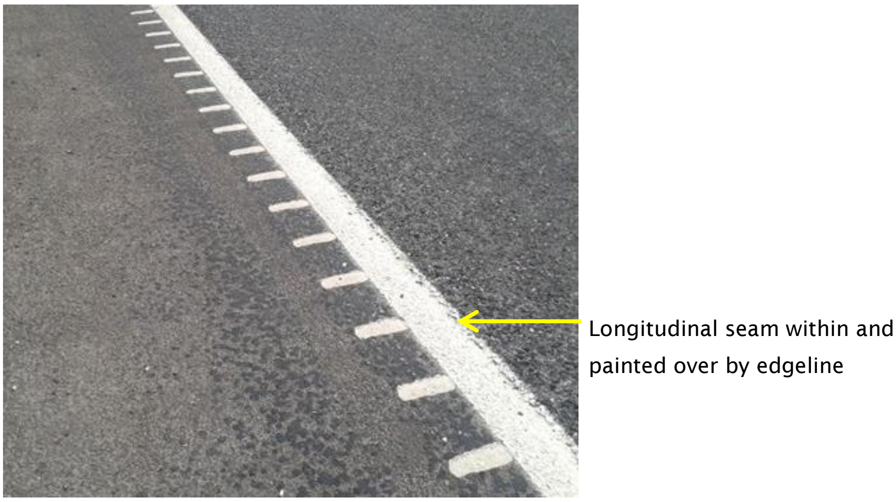
Some caution was expressed about in-lane reseal creating a longitudinal lip with safety concerns for bicyclists and motorcyclists and/or drainage problems at the longitudinal seam. Concerns (not necessarily experiences) were also expressed about excess (unchipped) bitumen at the seam creating an area for ponding or an area of low slip resistance.

Existing examples of such longitudinal seal joints were inspected. Figure 2.1 shows an example of in-lane reseal ‘good practice’ where the longitudinal seam is within the (non-profiled) edgeline. Figure 2.1 demonstrates how in-lane reseal is particularly compatible with edgelines where ribs are on the shoulder-side of the continuous non-profiled line. This easily allows 50 to 100 mm separation between the edge of the in-lane reseal and the ribs, which Kiesel (2007) recommends as good practice.

---

[3] Industry practitioners noted that the road width constituting a reseal can vary between some contracts. It needs to be ascertained if an in-lane reseal satisfies the contractual definitions but that is an operational issue not pertinent to this research project.

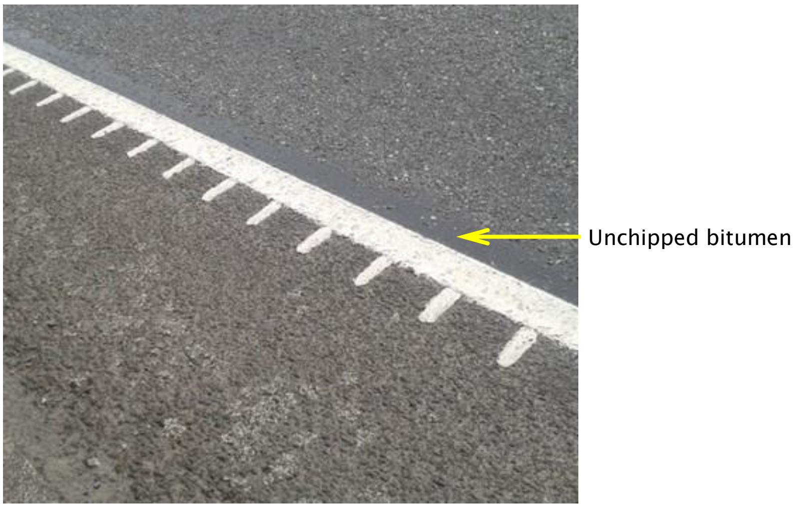
Figure 2.1 Example of in-lane reseal with the edge of the reseal within the normal/flat edgeline



In figure 2.1 the visual effects of the ribs are the same as pre-reseal. There is an option to re-mark not just the non-profiled line but widen that re-marking to include the raised ribs. This could renew visual effects of the ribs and create a wider edgeline, which in itself has benefits (Gates and Hawkins 2002; Carlson and Wagner 2012).

Figure 2.2 shows another example of in-lane reseal. The longitudinal seam of the in-lane reseal is approximately parallel to the edgeline, which is considered good, but this seam is marked by a line of bitumen with no chips on it. This is attributed to the execution of the in-lane reseal operation. The unchipped line of bitumen may have reduced skid resistance with potential effects, particularly for cyclists. The unchipped line of bitumen is also visually obvious in some conditions and could affect drivers' lane positioning and effectively narrow the traffic lane. The good practice example in figure 2.1 is considered to have no visual impact on the lane width.

Figure 2.2 Example of an in-lane reseal with a line of excess 'unchipped' bitumen



From the existing examples observed, the longitudinal seam does not seem to create a strong lip. This may be in part because the nature of chipseal is that the reseal edge depends on the scatter of chip and interaction with the underlying chipseal layer. There was no experience of drainage problems at the longitudinal seam, even at sites with multiple in-lane reseals. Figure 2.3 shows a photo of an in-lane reseal during heavy rain. Although there is appearance of some slight ponding/accumulation of water along the seam, it does not seem to create a major adverse effect or risk. The ponding/accumulation is not universally visible at sites of in-lane reseals but the location of the photo was specifically chosen to illustrate the effect.

Figure 2.3 Example of an in-lane reseal seen in heavy rain and with lighting conditions highlighting water ponding/accumulation [4]

Any concerns expressed by industry about the longitudinal seams from in-lane reseal seem to be risks that are manageable through good practices. Slight ponding/accumulation of water along an ATP roadmarking has been observed entirely independent of any in-lane reseal and is acknowledged within the *Manual of traffic signs and markings* (NZ Transport Agency 2010b) which states drainage gaps should be provided in ATP roadmarkings, spaced at about 10 m centres and each gap about 100 mm to 150 mm long.

2.3.2 Sealing over the ATP roadmarkings

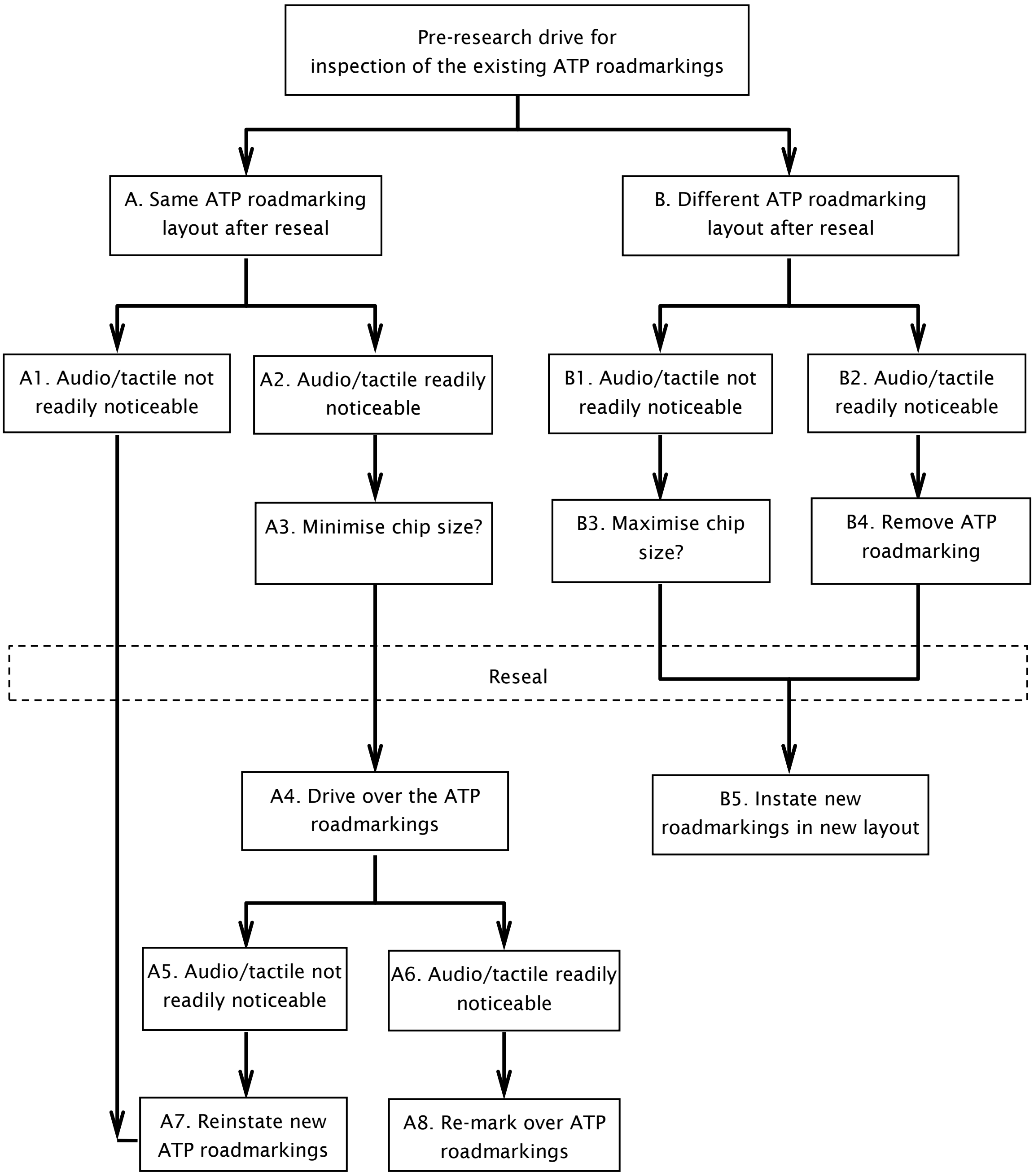
The alternate retention technique is resealing the full carriageway width, from road edge to road edge, including over the ATP roadmarkings. The general process follows the flowchart shown in figure 2.4. Note, this is not necessarily a recommendation, only a summary of the process currently in practice.[5]

---

[4] This site has ATP roadmarkings only on the centreline. No in-lane reseal sites with ATP roadmarkings on both the edgeline and centreline were available to photograph during heavy rain.

[5] It is not indicated in figure 2.4 but all governing contractual requirements shall be met, including but not limited to post-reseal application of a non-profiled paint-type (at minimum) generally within 24 to 48 hours of reseal.

Figure 2.4 Suggested 'seal over' practice for determining retention/reinstatement of ATP roadmarkings



The first step in the process is to drive over the existing ATP roadmarkings at the site for reseal, and decide subjectively if the ATP roadmarkings generate sufficient audio/tactile effects. (A subjective rating system is discussed in section 2.3.3.)

For situation A, where the ATP roadmarkings are to remain in the same layout post-reseal:

- If (A1) the audio/tactile effects of the existing ATP roadmarkings are not readily noticeable, seal over the existing ATP roadmarkings then (A7) reinstate new ATP roadmarkings.
- If (A2) the audio/tactile effects of the existing ATP roadmarkings are readily noticeable, if possible, (A3) consider using a smaller chip as this may facilitate retention of the audio/tactile effects through the reseal.

Post-reseal, (A4) drive over the now sealed ATP roadmarkings and decide subjectively if the ATP roadmarkings generate sufficient audio/tactile effects:

- If (A5) the audio/tactile effects of the sealed-over ATP roadmarkings are not readily noticeable, (A7) reinstate new ATP roadmarkings.
- If (A6) the audio/tactile effects remain readily noticeable, then to refresh the visual effects of the ATP roadmarking (A8) re-mark with a normal (or profile-optional) roadmarking on top of the ribs/bumps.
- The *Line removal guide* (NZRF 2011) considers 'the difficulty of marking paint or other marking materials to acceptable tolerances over the now obscured ATP line'. However, more care or a slower speed during application of the roadmarking could assist accurate placement and reseal tags[6] could also be used.

Situation B, where there is to be a different roadmarkings layout post-reseal is relatively rare. However, if a new roadmarkings layout is intended, it is important that any audio/tactile effects of the pre-reseal ATP roadmarking do not remain post-reseal.

- From the pre-reseal inspection drive, if (B1) the audio/tactile effects of the existing ATP roadmarkings are not readily noticeable, consider using a larger chip (B3) as this may be better at masking the audio/tactile effects through the reseal.
- If (B2) the audio/tactile effects of the existing ATP roadmarkings are readily noticeable, consider (B4) removal of these ATP roadmarkings prior to the reseal as it is likely that the post-reseal audio/tactile effects of the now-underlying ATP roadmarking will remain in part.

Post-reseal, (B5) instate new roadmarkings (normal or ATP, as required) for the new layout.

2.3.3 Subjective rating system

Section 2.3.2 mentions a system for the subjective rating of ATP roadmarking effects. The system was developed by industry and has been used in practice[7].

The rating system uses a regular car and at least two assessors in the car, without significant eyesight or hearing impairment (using corrective lenses or devices if necessary). The assessors drive over the subject site at least twice (but more if required to obtain agreement between their ratings). Each drive includes periods of:

- driving with the vehicle completely within the traffic lane, as per regular travel, making no contact with the ATP roadmarking
- steering smoothly but to make brief or 'glancing' contact with the ATP roadmarking as if accidentally or inadvertently drifting while driving
- steering to make sustained (0.5 to 1.0 second) contact with the ATP roadmarking.

The assessors assign ratings according to the extent to which they notice:

- the audio effects relative to travel on the adjacent road, scored from 0 to 4
- the tactile effects relative to travel on the adjacent road, scored from 0 to 4

---

[6] Tags that are placed prior to resealing to show the pre-reseal locations of the roadmarkings. The tags are L-shaped with a 90° bend, placed so that post-reseal a portion of the tag protrudes vertically through the reseal.

[7] Appropriate health and safety management is required but not included here.

- the visibility of the ATP roadmarking, scored from 0 to 2.[8]

The total score from the subjective rating system is summed:

- If the summed score is less than 5, the ATP roadmarking effects are deemed deficient and new ATP roadmarking should be instated.
- If the summed score is 5 or greater, the ATP roadmarking is considered effective and can be retained.

---

[8] The practice reported was that visibility was only inspected in dry conditions during the day.

3 Visual effects of ATP roadmarkings

ATP roadmarkings need to be driven over to provide their special audio/tactile effects but should provide visual effects all the time: during daylight and night conditions, and during dry or wet conditions.

The visibility of roadmarkings needs to be considered for night conditions and during daylight conditions. Visibility during night conditions is provided by different mechanisms or properties compared with visibility during daylight. Visibility performance of roadmarkings at night should not be inferred from visibility performance in daylight, nor vice versa.

3.1 Visibility during night conditions: retroreflectivity

Visibility during night conditions is defined by retroreflectivity and standard measurement uses a retroreflectometer. In brief, the standardised retroreflectometers simulate the emission of light equivalent to the angle of a car's headlights onto a roadmarking 30 m ahead of the headlights and then measure how much of that light is reflected back at the equivalent angle which would reach the car driver's eyes. The amount of light reflected back is called the reflected luminance, R_L, or retroreflectivity, and is measured in units of millicandela per square metre per lux, mcd m^{-2} lux^{-1}. Retroreflectivity of a roadmarking is typically provided by glass beads or other optics semi-embedded in the surface of the roadmarking.

Some retroreflectometers are static instruments that sit flat upon or immediately beside the area of roadmarking to be measured. The contact between the base of the static retroreflectometer and the measurement surface is critical to achieving the correct measurement angle. With some static retroreflectometers it can be difficult to accommodate the profile of ATP roadmarkings for obtaining valid measurements. With a static retroreflectometer, careful 'stepping' along the ATP roadmarking profile and multiple readings are required to obtain representation of the effective retroreflectivity of the ATP roadmarking.

There are also dynamic retroreflectometers. These are externally mounted on vehicles, typically 100 mm to 150 mm above the road surface, so can easily accommodate the profile of ATP roadmarkings. Dynamic retroreflectometers can take measurements at a set sampling rate with the vehicle travelling at up to open road speeds, so can readily take multiple measurements to represent the longitudinal effect of ATP roadmarkings as they present to drivers.

For measuring retroreflectivity in dry conditions, dynamic retroreflectometers appear to offer advantages over static retroreflectometers, notwithstanding the availability of the equipment.

Considering visibility in wet conditions is also important. Typically retroreflectivity of a roadmarking in dry conditions is degraded in wet conditions. There are two primary reasons.

1 Accumulation of water can form a continuous layer on top of the glass beads or other optics in the roadmarking material so much of the incident light that would ordinarily be retroreflected is instead reflected off the water surface.

2 The beads or other optics in the roadmarking material have a particular refractive index or retroreflectivity efficiency in air. When wet, the refractive index of the beads in combination with the refractive index of water alters the angles at which light is reflected for a different retroreflectivity efficiency. (Diamandouros 2013).

For visibility or retroreflectivity measurements, 'wet' can be after recent cessation of wetting or rain which may be termed 'wet-recovery', or wet can be *during* wetting or rain which may be termed 'continual wetting'.

Most static retroreflectometers can be readily used for wet-recovery retroreflectivity measurements. The area to be measured can be wetted, a set time allowed for drainage of the water, then the static retroreflectometer positioned for the intended measurement. Static retroreflectometers that cover the roadmarking during its measurement (internal beam instruments) cannot be used for measuring in continual wetting conditions. External beam static retroreflectometers can be used for measuring with particular care in continual wetting conditions, or other equipment can be employed to manage the wetting while protecting the retroreflectometer itself from the water. (for example, Pike et al 2007).

Dynamic retroreflectometers are also sensitive to water and spray. Wet recovery retroreflectivity measurements have been managed using a water truck driving a small distance ahead of the following dynamic retroreflectometer. The water truck carefully wets the subject roadmarking and minimal area each side of the roadmarking. After a set time allowed for drainage of the water, the dynamic retroreflectometer is driven to take the measurements, taking care that the vehicle tyres do not splash water onto the lenses of the retroreflectometer (eg Lindly and Wijesundera 2003). Dynamic retroreflectometer measurements with continual wetting are limited, but some have been attempted with a slight modification of the method used for wet recovery measurements (eg Diamandouros 2013).

Compared with non-profiled roadmarkings, ATP roadmarkings are understood to have better visibility in wet night conditions because the raised elements of the profile facilitate shedding of water and/or parts of the raised elements can stand clear of an accumulated water film. Maintenance of ATP roadmarkings should include consideration of this performance attribute of ATP roadmarkings. Appendix A describes attempts to measure retroreflectivity from ATP roadmarkings and other roadmarkings with a dynamic retroreflectometer and a simulated continual wetting condition. There is ongoing work in this area, including development of testing methods and understanding of each of wet recovery and continual wetting conditions. Schnell et al (2003) report results of the visibility and retroreflectivity of roadmarkings in dry, wet recovery and continual wetting conditions[9]. The results indicate the wet recovery test performance may not wholly predict continual wetting performance, or vice versa, suggesting the tests are not interchangeable and there is some recognition that visibility mechanism may be different for each of these conditions.

Carlson et al (2007) also tested the effects of continual wetting, using a range of wetting rates up to 500 mm/h. The general trend shown by the tested roadmarkings was a large reduction in retroreflectivity as wetting rates increased up to about 100 mm/h; for wetting rates above 100 mm/h, there was only a slight further retroreflectivity reduction. To place these wetting rates in context, the New Zealand Building Code includes rainfall intensity maps for New Zealand. For a rainfall intensity with an annual probability of exceedance of 10%, the amount of rainfall lasting 10 minutes is up to about 100 mm for most areas of New Zealand with the highest 10-minute rainfall of 225 mm shown near Milford Sound (DBH 1992).

Retroreflectivity measurements are related to the distance at which roadmarkings are visible or can be noticed. To test 'visibility distances' in continual wetting conditions, typically a test track situation is used with wetting equipment designed to simulate rain. Test roadmarkings at different distances in wet-recovery and/or continual wetting conditions are presented to test subjects who report if they can see the roadmarkings (for example, Gibbons and Hankey 2007). Alternatively, within the test track situation or

---

[9] Using ASTM 1710 for dry, ASTM 2177 for wet-recovery and ASTM 2176 for continual wetting (simulated rain)

where light sources can be controlled, visibility distances may be inferred via measurement with a luminance camera or photometer (eg Burns et al 2006).

As part of this project ATP roadmarkings were observed during informal drive-through inspections undertaken during night conditions and during dry, wet and continual wetting (falling rain) conditions. The roads for these drive-through inspections were in the Wellington/Wairarapa region on State Highway 1 between Paraparaumu and Ngauranga Gorge and State Highway 2 between Clareville and Ngauranga. The roads included sections with and without street lighting; sections of chipseal road surface and sections with asphaltic road surfaces. Some of the drive-through inspections could be conducted with headlights on full beam but generally the headlights were dipped.

The ATP roadmarkings observed were on edgelines and centrelines, expected to have infrequent traversing. The ATP roadmarkings were generally of the form with raised ribs on the underlying line, with a few exceptions of the form with raised ribs adjacent to the line. Other non-ATP roadmarkings were conventional paint type and some limited use of structured roadmarkings. Other delineation items were also present. ‘Off-road’ items such as edge marker posts and chevrons were not included in the observations but ‘on-road’ reflectorised raised pavement markers (RRPMs) were included.

The ATP roadmarkings ranged in age from about six years old to less than one year old. In dry night conditions, the ATP roadmarkings less than one year old appeared clean and bright; but it was not possible to immediately compare these newer ATP roadmarkings with non-ATP roadmarkings of a similar age. Other ATP roadmarkings were visible to the end of the illumination from the headlights, typically 80 m to 100 m when the headlights were dipped or readily visible beyond 100 m and possibly up to 150 m when the headlights were on full beam. The RRPMs were visible for a greater distance than the ATP roadmarkings but the ATP roadmarkings gave sufficient near and middle-distance visibility on their own. Where ATP roadmarkings were more than four years old, sometimes visibility was only 40 m to 50 m ahead when the headlights were dipped, but the RRPMs were notably ‘brighter’ and visible for a greater distance ahead of the vehicle.

The visibility of the RRPMs changed little in wet and continual wetting night conditions from their visibility in dry night conditions. In some sections ATP roadmarkings and conventional paint-type roadmarkings were observed in close proximity, though sometimes the roadmarkings were of different ages. In wet conditions on chipseal, the visibility of similarly aged ATP roadmarkings and conventional paint-type roadmarkings was approximately the same, though the ATP roadmarkings may have had a slightly longer visibility distance. In wet conditions on asphaltic road surfaces, the ATP roadmarkings were more consistently visible than the conventional paint-type roadmarkings, with water film sometimes interfering with the visibility. In continual wetting conditions, the visibility of the ATP roadmarkings changed little from visibility in wet conditions on either chipseal or asphaltic road surfaces. For conventional paint-type roadmarkings in continual wetting conditions, on chipseal the visibility was little changed from the visibility in wet conditions but on asphaltic road surfaces the visibility appeared diminished compared with wet conditions.

MOTSAM (NZ Transport Agency 2010b) recommends ATP roadmarking ribs be placed ‘protruding at least 25 mm but preferably 50 mm beyond’ the non-profiled lines ‘so as to be clearly visible to users of two-wheeled vehicles’. Similarly, Edgar et al (2008) report on consultation about ATP roadmarkings with cyclists who advised they can safely negotiate ATP roadmarking ribs ‘provided they can see them’.

Visibility of ATP roadmarkings under diffuse lighting (as in daylight conditions or street lighting) is delivered through contrast between the white (or yellow) material of the roadmarking and the dark grey of the road surface. The colour can be assessed against standard discolouration scales or the ‘brightness of colour’ can be measured by its diffuse luminance, Q_d. *TNZ P/12 Notes for the specification for pavement* *marking* (TNZ 1998) reports observations that many ‘long life markings show considerable discolouration from tyre blackening which gives a dirty daytime appearance’. Cleaning with some scrubbing or low-pressure water-blasting of the ATP roadmarkings could refresh the daytime appearance (NZ Transport Agency 2010a).

Alternatively or additionally, daytime appearance of an aged ATP roadmarking could be refreshed by an application of paint (or other regular-build roadmarking material). Edgar et al (2008) report from consultation with industry practitioners that ‘painting over existing ribs and applying retroreflective treatment has been used effectively to reinstate reflective performance’. Other experience is this has been done with no issues of material incompatibility or lack of adherence noted (R Nicholas and J Bowers 17 December 2014, pers comm). No measurements or particular inspections of placement/retention of beads or other optics appear to have been undertaken.

As discussed above, particularly for night and wet conditions, visual advantages are attributed to the raised elements of ATP roadmarkings. During daylight visits to ATP roadmarkings, it was observed that sometimes when driving towards the sun as it moved lower in the sky, visibility of the ATP roadmarkings appeared to fade due to the angle of the sunlight striking the raised ribs and creating shadows on the parts of those ribs facing towards the driver. Edgar et al (2008) report consultations with ATP roadmarking suppliers who advised that under headlights the raised ribs might create shadowing on the non-profiled parts of the ATP roadmarking ‘behind’ the ribs. Any visibility effect of ‘shadowing’ on parts of the ATP roadmarking is not quantified. It is not necessarily an issue as long as the ATP roadmarking is visually effective overall.

Kiesel (2007) states ‘new installations of [ATP roadmarkings] do not need to have the edge line painted; the reflectivity provided by the thermoplastic bars and glass beads is very high’. This is not unequivocally demonstrated nor universally agreed. On straight sections of road, it may be that a line of ribs can visually appear continuous for drivers travelling at speed; however, when drivers look ahead at corners (horizontal curvature) or are travelling more slowly, the spaces between ribs may be observed, though the effect is unknown. Considering ATP roadmarkings used as edgelines, MOTSAM section 2.03 says edgelines have to be continuous but does say ‘continuous is deemed to include an application of material resembling paint that gives the impression of a line when viewed by a driver’ (NZ Transport Agency 2007).

Until recently, ATP roadmarkings were mostly installed in New Zealand where only infrequent traversing was expected. Application now includes broken (3x7) lines between adjacent motorway lanes, where traversing of the ATP roadmarkings is far more common and expected as part of standard driving. Edgar et al (2008) question whether such application of ATP roadmarkings is desirable because of the potential for ‘loss of clarity of their intended function’. It was agreed this should be subject to further research, but not within this project where the focus has been on maintenance. However, frequent traversing of ATP roadmarking is relevant to its maintenance. This situation exists on the Auckland motorway and experience is that some ATP roadmarkings are becoming ‘grey’ with trafficking and are difficult to see with low sun angles. Also there have been anecdotal reports of accelerated wear or shattering of the glass beads or other optics embedded in the ATP roadmarking material. This performance may be found characteristic or it may be case specific through, for example, a particular circumstance of bead/optic properties and/or hardness of the rib material. Application of ATP roadmarkings in situations where frequent traversing is expected should be monitored and the wear profile not assumed to be the same as in situations where ATP roadmarkings are traversed infrequently.

3.2 Findings and recommendations

The visual effects of ATP roadmarkings are largely separate from the audio and/or tactile effects of ATP roadmarkings.

Within New Zealand specifications for roadmarkings, there is currently no requirement or method set for measuring visibility or retroreflectivity in continual wetting conditions, which is accepted given the apparent difficulties of conducting measurements at these times. However, it should not necessarily be inferred that there is no expectation of visual effects in continual wetting conditions, even if this is considered largely aspirational at present.

For maintenance of the visual effects of ATP roadmarkings it is recommended that visibility be monitored during both daylight and night conditions, including wet conditions where practicable. Instrumented and objective measurements of the visual effects of ATP roadmarkings are desirable but if unavailable then subjective monitoring could be valuable and preferable to no visibility monitoring.

For guidance on subjective monitoring of visibility, the current NZ Transport Agency specification for ATP roadmarkings includes a method for assessing forward distance visibility (TNZ 2006). An informative appendix to the Australian Standard for performance assessment of pavement markings provides procedures for drive-through assessment of roadmarking visibility and defines 'visible' as meaning roadmarkings 'are easily seen and can be instantly recognizable as such' (Standards Australia 2007).

Techniques for refreshing ATP roadmarking visibility may be cleaning of the existing ATP roadmarking or recoating the ATP roadmarking with an application of paint (or other regular-build roadmarking material) including beads or other optics.

It appears the raised ribs of ATP roadmarkings can offer visibility features but also non-profiled roadmarkings may offer different visibility features. For edgelines where the road layout permits, the ATP roadmarking form with raised ribs alongside the non-profiled continuous line is recommended as it also provides benefits as an effectively wider edgeline.

4 Audio (and tactile) effects of ATP roadmarkings

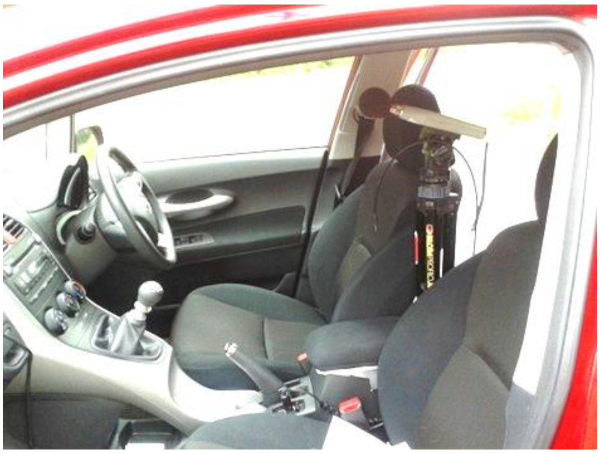
This section recognises both the audio and tactile effects of ATP roadmarkings but the focus is on audio effects. Appendix B discusses some measurements of the tactile effects of ATP roadmarkings and explains why audio effects were adopted as the focus.

Measurement of the audio effects of on-road ATP roadmarkings was undertaken in December 2013 and February/March 2015. Vehicles are designed for occupant comfort including damping of sounds and vibrations entering the cabin. The damping focuses on particular frequencies, so audio/tactile effects measured outside the vehicle cabin might be quite different from those inside the vehicle cabin. Therefore in our research, measurements were made in-vehicle for representing the effects as experienced by the driver.

Ideally a single vehicle or same vehicle model would have been used for all these measurements. However, this was not practicable due to the time and locations over which measurements were to be made.[10] However, Berge (1997) reports measurements of interior and exterior sound levels during travel on different types of ATP roadmarkings, making measurements with different vehicle types including four passenger cars. 'Within the limited range of passenger cars tested, we can conclude that driving on profiled strips gives about the same increase in interior sound levels for a small car [1996 Hyundai Accent 1.3i] as well as a luxury sedan [1996 Mercedes-Benz C180]'. Therefore the effect of different vehicle types is considered acceptable with regard to the experimental method for this section. Also the results obtained for in-situ measurements appear congruent, justifying this approach. (A different vehicle was used for the measurements in chapter 5 and these display some different characteristics. This is discussed in chapter 5.)

Audio effects were measured through a Rion NL-32 sound level meter secured between the driver's and the front passenger's seats with the microphone located near to and at approximately the height of the driver's left ear, as shown in figure 4.1.

Figure 4.1 Sound level meter mounted between the front seats



During measurements, the sound level meter outputs were logged by a multi-channel Logbook 360 data acquisition system to record and enable spectral analysis of the sound measurements. The full log from

---

[10] The vehicle used for the December 2013 measurements was a 2011 Toyota Corolla hatch (1.8 litres). This vehicle was selected as typical of many vehicles in the New Zealand car fleet. For the March 2015 measurements, a 2008 model Holden Commodore sedan (3.6 litres) and for the April 2015 measurements, a 2014 model Holden Commodore sedan (3.6 litres) were used. These vehicles were all petrol fuelled.

each individual measurement was approximately 6 to 10 seconds long. During measurements, observations were made if, for example, the vehicle speed strayed from the intended 95 km/h (as displayed by the speedometer) or if vehicle-positioning on the ATP roadmarking was considered by the driver or passenger to be inconsistent.[11] These observations and inspection of the full log from each individual measurement identified any measurements to discard due to, for example, slow vehicle travel or suspected poor vehicle positioning. From each total logged measurement accepted, a representative one-second sample was selected for analysis (travelling at 95 km/h, a one-second sample equates to approximately 26 m of travel).

To find locations for measurements, industry practitioners were contacted for examples of where a retention technique had been used or where this type of work was scheduled. This provided examples of in-lane reseal and sealed over ATP roadmarkings.[12]

4.1 In-lane reseal

Figure 4.2 shows a photograph of the road surface and ATP roadmarking at an example in-lane reseal site.[13] The road surface in the traffic lane was a grade 4 first coat completed in February 2007 with two grade 5 void fills completed in March 2007 and December 2009. The edgeline was a continuous painted line with raised ribs on the outside/shoulder adjacent to the flat/normal line and installation of the ATP roadmarking ribs was dated June 2009. Measurements were taken in December 2013.

Figure 4.2 ATP roadmarking post-in-lane reseal

A set of five measurements was taken with the vehicle travelling as normal, with all four wheels on the traffic lane. Another set of five measurements was taken with the vehicle travelling with the two passenger-side wheels on the ATP roadmarking edgeline. During contact with industry practitioners (see section 2.3), there was a query whether the road surface on the shoulder roughened over time so the effects of the ATP roadmarking were less distinct from that road surface. Therefore, on the outside of the ATP roadmarkings, a set of measurements was taken with the passenger-side wheels travelling on the shoulder and the driver-side wheels on the traffic lane (straddling the edgeline).

---

[11] Appendix C contains further comment on the method of driving and measurements.

[12] Overall very few examples were identified. The majority of those identified were measured. Other examples were not measured because of geographical location, safety or other practicability considerations.

[13] 033-0017/2.86-5.89

Figure 4.3 shows spectral analysis of one-second samples from each of five accepted measurements taken during travel on the road surface (in the traffic lane) and the average calculated from the five measurements. The figure indicates the variation between measurements and the effect of averaging multiple measurements.

Figure 4.3 Spectral analysis of in-vehicle samples from vehicle travel on the road surface

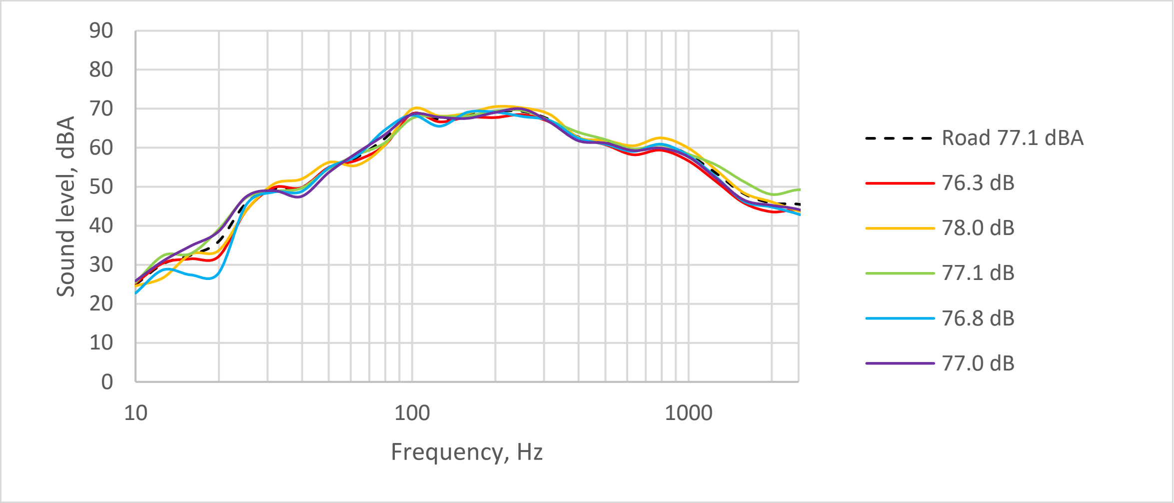
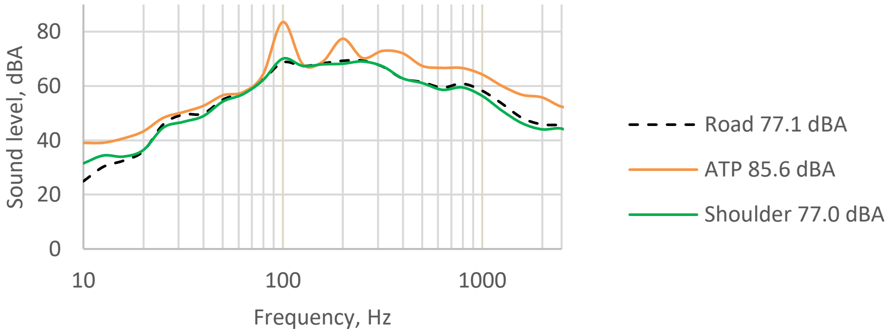


Figure 4.4 shows the average one-second spectral analyses from measurements on the road surface in the traffic lane, the ATP roadmarking and the road surface on the shoulder.

- There is no significant difference between the road surface in the traffic lane (black line) and the road surface on the shoulder (blue line) shown by the figure, and this matches the subjective assessments of audio (and tactile) effects made by the driver and passenger in the vehicle during the measurements. In addition, no obvious visual difference was observed between the road surface in the traffic lane and the road surface on the shoulder.
- In terms of magnitude, the total sound level measured from the ATP roadmarking was 85.6 dBA and from the road surface in the traffic lane was 77.1 dBA. This sound level difference was subjectively easily distinguishable for the driver and passenger in the vehicle during the measurements.
- Figure 4.4 also shows significant tonal peaks present in the sound measured from the ATP roadmarking that were not present in the sound measured from the road surface. This tonal difference was distinct for the driver and passenger in the vehicle. The most significant tonal difference was found at 100 Hz. This is as expected given the travel speed (≈95 km/h = ≈26 m/s) and 250 mm rib-spacing (= 4 ribs/m).

Figure 4.4 Spectral analysis of in-vehicle samples from vehicle travel on the road surface, ATP roadmarking and road shoulder



Figures 4.3 and 4.4 are representative of the measurements and observations from all the in-lane reseal sites visited. All the existing examples of in-lane reseal were from a region where ATP roadmarking edgelines have the ribs immediately adjacent to the continuous non-profiled roadmarking line (rather than on top of or incorporated into the continuous line).

With good practice and the ATP roadmarking edgeline form of ribs adjacent to and outside the non-profiled continuous line, there appears to be insignificant interaction between the in-lane reseal and the ribs, thus it is concluded that the audio and tactile effects of the ATP roadmarking will be unaffected by the in-lane reseal but continue to age as they would if there had been no in-lane reseal.

4.2 Sealing over the ATP roadmarkings

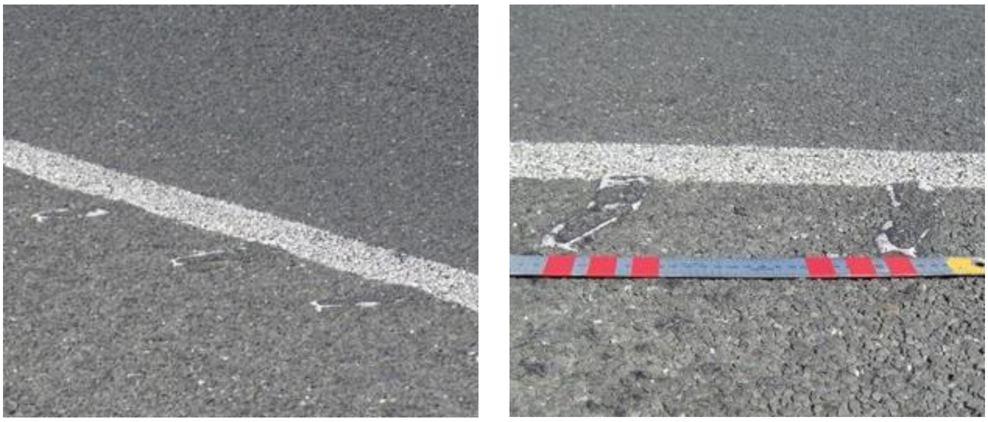
Measurements of sealed over examples were undertaken in March/April 2015.

4.2.1 Example 1

Sealed over example 1[14] used a grade 6 void fill reseal across the full carriageway width. The reseal had been completed in November 2013, about 2.5 years prior to the measurements. Grade 6 refers to the smallest chip size typically used in New Zealand and chips are sized up to about 7 mm average least dimension.[15].

Figure 4.5 shows the road surface and ATP roadmarking at this measurement site post-reseal. The photographs are representative of the appearance of the edgeline in both the northbound and southbound direction. Prior to the reseal, in both the northbound and southbound direction, the edgelines were ATP roadmarkings with raised ribs on the outside/shoulder adjacent to the flat/normal continuous edgeline. The date of application of the ATP roadmarkings is not known but it would have been prior to February 2012 so at the time of these measurements the ATP roadmarkings were more than three years old. Figure 4.5 shows the flat/normal continuous edgeline has been re-painted post-reseal, in accordance with standard practice for a reseal. The ribs have not been painted post-reseal, thus, post-reseal it is the flat/normal continuous line that provides visual performance of the edgeline. However, figure 4.5 illustrates how over time the bitumen of the seal over may wear to reveal the original white of the existing rib.

Figure 4.5 ATP roadmarkings post-reseal with grade 6 chip (example 1)



---

[14] 002-0000/10.40-13.90

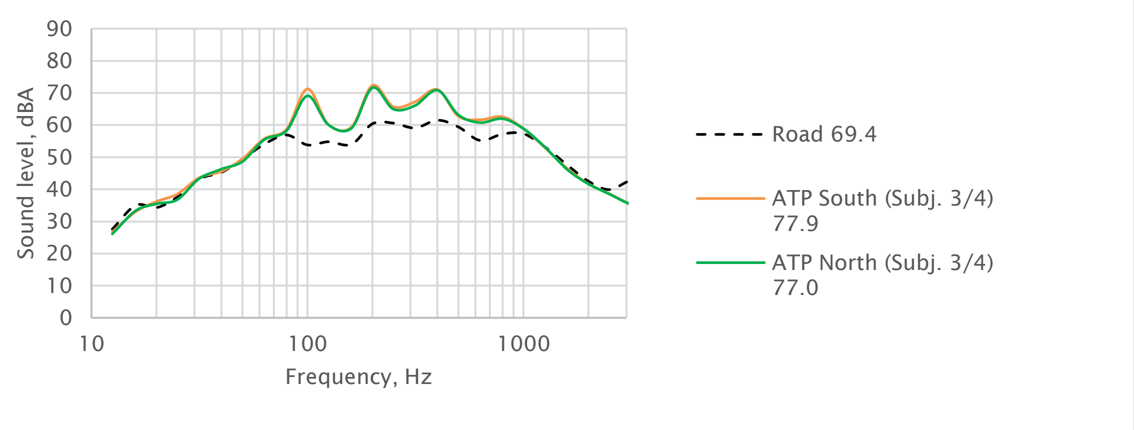
[15] Other documents such as *NZTA M/6: 2011 Specification for sealing chip* (NZ Transport Agency 2011) describe the chip grading system used in New Zealand. Chip grading numbers increase as chip size decreases. Grade 2 chip has an average size of about 9.5 to 12 mm and grade 3 chip has an average size of about 7.5 to 10 mm. Grade 5 chip sizes are within the range of 5 to 9.5 mm and grade 6 chip sizes are within the range of about 3 to 6.7 mm.

A set of five measurements was taken with the vehicle travelling as normal, with all four wheels on the traffic lane. Some measurements were taken travelling northbound and some southbound. The driver and passenger subjectively assessed the sound was consistent between both directions, and this was later confirmed through inspection of the measurement data. Measurements were then taken with the vehicle travelling with the two passenger-side wheels on the ribs of the ATP roadmarking edgeline. Five measurements were taken travelling northbound and five southbound.

Figure 4.6 shows the average one-second spectral analyses from measurements on the road surface in the traffic lane, the ribs of the ATP roadmarkings adjacent to the edgeline for the southbound direction, and the ribs of the ATP roadmarkings adjacent to the edgeline for the northbound direction.

- In terms of magnitude, the total sound level measured from the ATP roadmarkings was 77.9 dBA and 77.0 dBA, and from the road surface in the traffic lane 69.4 dBA. The tonal peaks at 100 Hz were approximately 17 dBA and 15 dBA respectively above the road-only noise level for this frequency band. The difference in sound level and tone was easily distinguishable for the driver and passenger in the vehicle during the measurements.

Figure 4.6 Spectral analysis of in-vehicle samples from vehicle travel on the road surface and ATP roadmarkings (example 1)



Section 2.3.3 describes a system for subjective rating of the effects of ATP roadmarkings. This had been applied about one year prior to the time of these measurements. In the subjective rating system, the audio effects of both the ATP roadmarkings of the southbound edgeline and the ATP roadmarkings of the northbound edgeline were rated as 3 from a maximum 4-point scale. The total subjective rating for the audio, tactile and visual effects of each ATP roadmarking was 6.5 from a maximum 10-point scale and would be judged as effective according to that system's criteria.

4.2.2 Example 2

The first sealed over example used the smallest typical chip size, grade 6. This second example[16] used a slightly larger chip size: a grade 5 void fill reseal, completed in December 2012 about 2.5 years prior to these measurements.

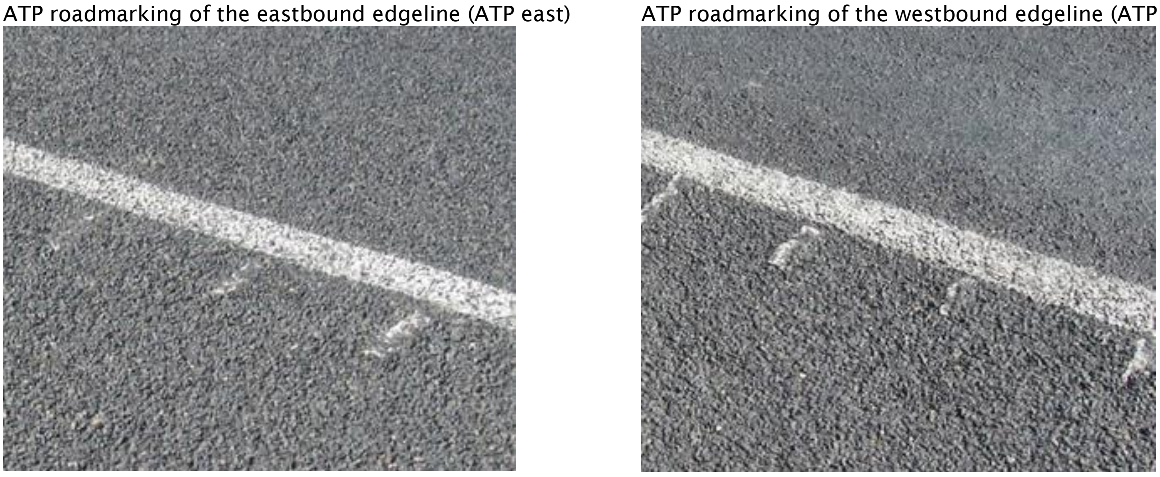
Figure 4.7 shows the road surface and ATP roadmarking at this measurement site post-reseal. The photograph on the left is the edgeline for the eastbound direction and the photograph on the right is the edgeline for the westbound direction. As shown by the photographs, the ribs on the eastbound direction were slightly less prominent than those on the westbound direction.

---

[16] 025-0000/9.66-10.45

Figure 4.8 shows the average one-second spectral analyses from measurements on the road surface in the traffic lane, the ATP roadmarkings of the eastbound and westbound edgelines.

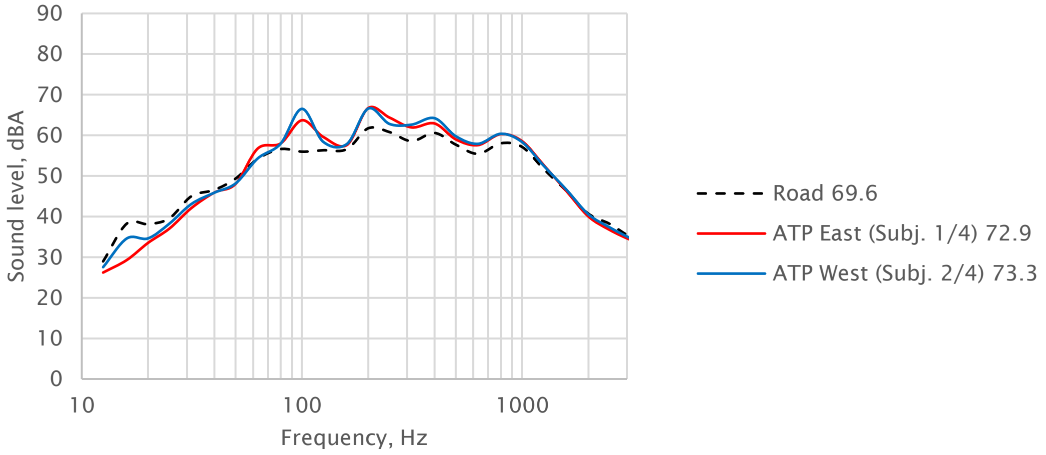
Figure 4.7 ATP roadmarkings post-reseal with grade 5 chip (example 2)



ATP roadmarking of the eastbound edgeline (ATP east)

ATP roadmarking of the westbound edgeline (ATP west)

Figure 4.8 Spectral analysis of in-vehicle samples from vehicle travel on the road surface and ATP roadmarkings (example 2)



From figure 4.8 it is observed:

- The total sound level measured from the ATP roadmarking of the eastbound edgeline (ATP east) was 72.9 dBA, found to be 3.3 dBA higher than the total sound level measured from the road surface in the traffic lane and the tonal difference at 100 Hz compared with the road surface was only 8 dBA. The audio effects of this ATP roadmarking had been subjectively rated as 1/4 about one year prior to these measurements. The total subjective rating for the audio, tactile and visual effects of the ATP east was 3/10 and would be judged as not effective according to that subjective rating system's criteria.
- The total sound level measured from the ATP roadmarking of the westbound edgeline (ATP west) was 73.3 dBA, found to be 3.7 dBA higher than the total sound level measured from the road surface in the traffic lane and the tonal difference at 100 Hz compared with the road surface was about 11 dBA. The audio effects of this ATP roadmarking had been subjectively rated 2/4 about one year prior to these measurements. The total subjective rating for the audio, tactile and visual effects of the ATP west was 5.5/10, slightly greater than the system's threshold rating for effectiveness of 5/10.

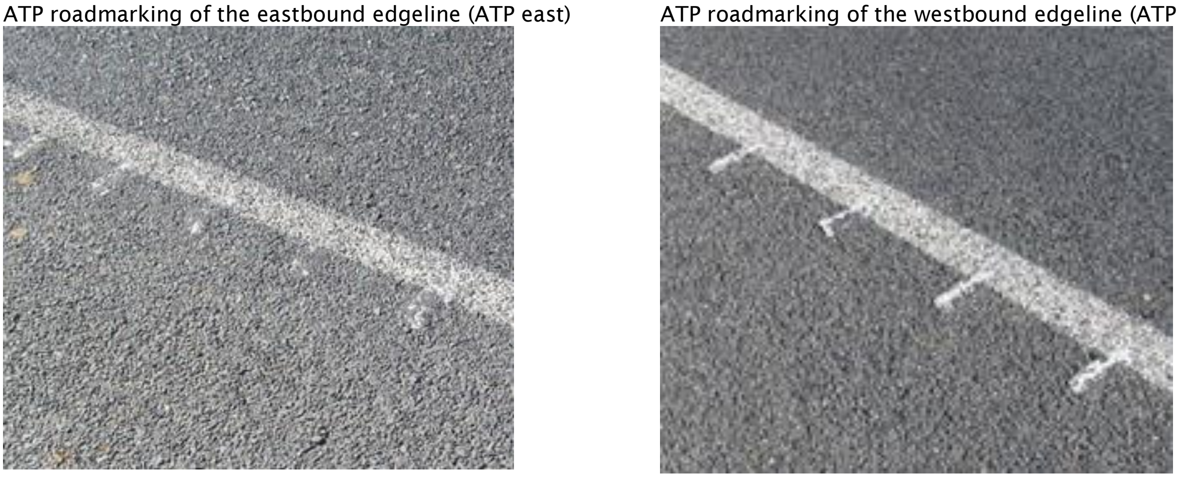
4.2.3 Example 3

To check the repeatability of the subjective rating system, another example was measured.[17] This example 3 was selected as it used a grade 5 void reseal, the same as example 2.

The date of installation of the ATP roadmarkings is not exactly known but was prior to March 2012. Figure 4.9 shows the road surface and ATP roadmarkings at this measurement site post-reseal. The photograph on the left is the ATP east and the photograph on the right is the ATP west. Notwithstanding variations in the photographing and lighting, the photographs indicate how the interaction of ribs and chips on the eastbound direction appeared slightly different compared with the westbound direction. The reseal was performed in November 2012, about 2.5 years prior to these measurements. Either during resealing or in the period since resealing, the chips have moved away from some ‘top edges’ of the ATP roadmarking ribs. There is also no bitumen on some of these top edges.

Figure 4.10 shows the average one-second spectral analyses from measurements on the road surface in the traffic lane, the ATP east and the ATP west.

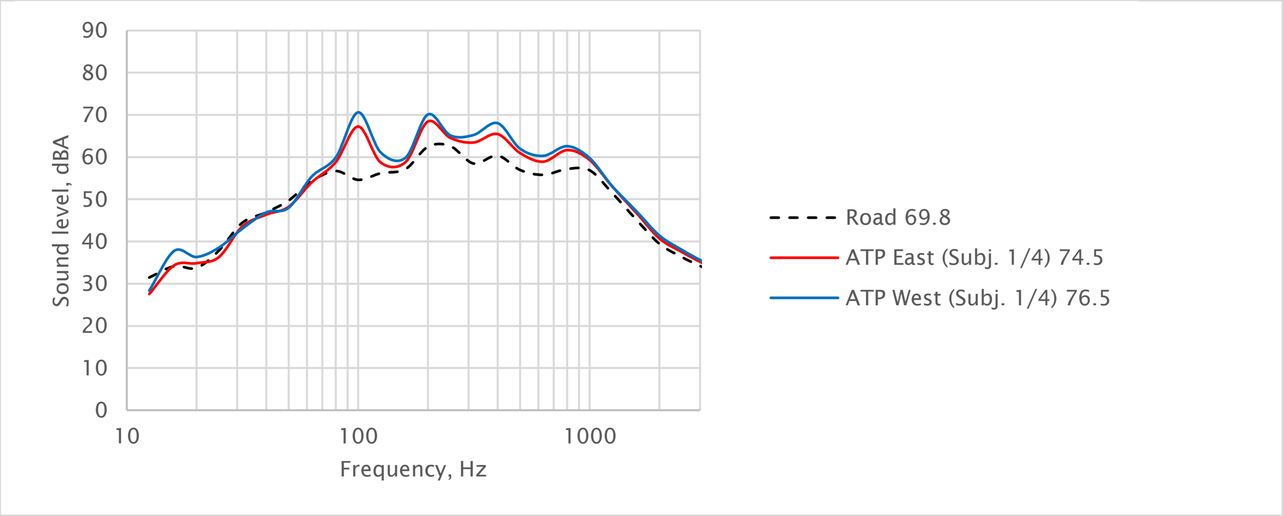
Figure 4.9 ATP roadmarkings post-reseal with grade 5 chip (example 3)



ATP roadmarking of the eastbound edgeline (ATP east)

ATP roadmarking of the westbound edgeline (ATP west)

Figure 4.10 Spectral analysis of in-vehicle samples from vehicle travel on road and ATP roadmarkings (example 3)



---

[17] 025-0012/7.82-8.27

From figure 4.10 it is observed:

- The total sound level measured from the ATP roadmarking of the eastbound edgeline (ATP east) was 74.5 dBA, 4.7 dBA higher than the total sound level measured from the road surface in the traffic lane. The tonal difference compared with the road only at 100 Hz was 12 dBA.
- The total sound level measured from the ATP roadmarking of the westbound edgeline (ATP west) was 76.5 dBA, 6.7 dBA higher than the total sound level measured from the road surface in the traffic lane. The tonal difference compared with the road only at 100 Hz was 16 dBA.
- About one year prior to these measurements, the audio effects of both ATP roadmarkings had been subjectively rated as 1/4. It is noted the subjective rating for each is equal although there is 2 dBA difference measured between the total sound levels of each. The tonal peaks are also quite pronounced. For each ATP roadmarking, the total subjective rating for the audio, tactile and visual effects was 3.5/10 and would be judged as not effective according to that system's threshold for effectiveness.

4.2.4 Example 4 (seal over good condition ATP roadmarkings)

A fourth example of sealed over ATP roadmarkings was identified and measured. Example 4 was in a different region from the preceding three examples and a different vehicle was used.

Figure 4.11 shows the road surface and ATP roadmarkings post-reseal.[18] The ATP roadmarkings were laid only in December 2014 and were in a good condition prior to resealing with a grade 3 chip in February 2015 (about two months prior to these measurements).

Figure 4.11 (Good condition) ATP roadmarkings post-reseal with grade 3 chip (example 4)

Figure 4.12 shows the average one-second spectral analyses from measurements on the road surface in the traffic lane and the sealed over ATP roadmarking. On this site, prior to the sealing over the ATP roadmarkings, there were some previous ATP roadmarkings that had not been sealed over. Measurements were also taken from the good condition ATP roadmarkings and the average one-second spectral analysis of those measurements is also shown in figure 4.12.

---

[18] 0002-0905/7.80-9.98

Figure 4.12 Spectral analysis of in-vehicle samples from vehicle travel on road and ATP roadmarkings (example 4)

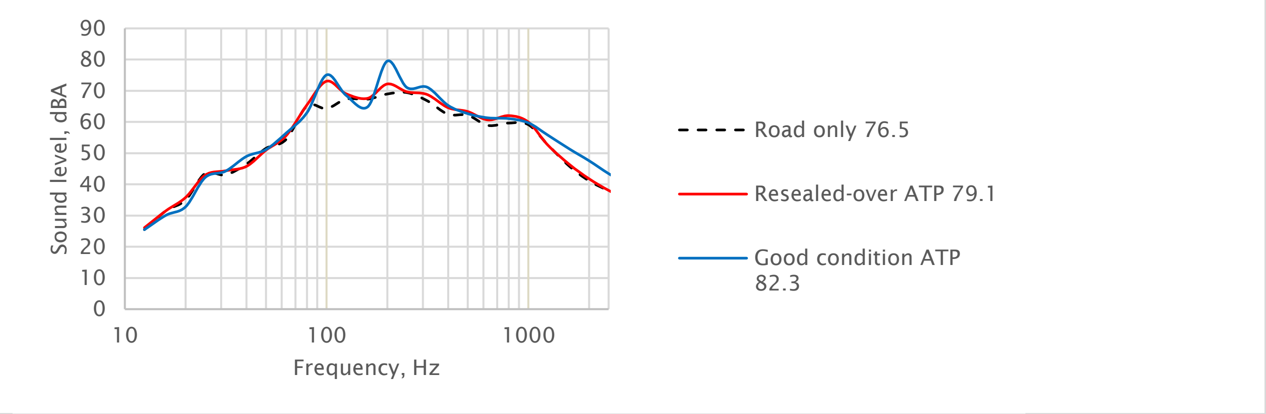


Figure 4.12 shows:

- The total sound level measured from the sealed over ATP roadmarking was 79.1 dBA, which was about 2.6 dBA higher than the sound level measured from the adjacent road surface. The tonal difference at 100 Hz compared with the road was 10 dBA. The sound level difference was subjectively considered difficult to detect consistently by the driver and passenger in the vehicle during the measurements. The driver and passenger did not concur on their perceptions of audible tonal difference when travelling on the ATP roadmarking.
- The total sound level measured from the good condition ATP roadmarking, which was unaffected by the reseal, was 82.3 dBA. This was about 5.8 dBA higher than the sound level measured from the adjacent road surface and the tonal difference at 100 Hz compared with the road was 10 dBA (note there was a very pronounced additional tonal peak at 200 Hz, 12 dBA higher than for the road, that was not present for the sealed over marking, and this sound level and tonal difference was subjectively easily distinguishable for the driver and passenger in the vehicle during the measurements).

Though the example 4 ATP roadmarkings were in good condition prior to being sealed over, the larger chip size used in the reseal appears to have ‘muted’ or obscured retention of the audio effects of the now-underlying ATP roadmarking.

It is acknowledged the measurements of example 4 were conducted using a different vehicle from that used for the preceding examples 1–3, and a third different vehicle was used for the measurements of the in-lane reseal examples (section 4.1).

Considering figure 4.12, the subjective experience of the relative clarity of audio effects from the good condition ATP roadmarking compared with the audio effects of the sealed over ATP roadmarking suggests the subjective experience of ATP roadmarking audio effects may be dependent on a complex combination of total sound level and tonal peaks and harmonics. This is important if attempting to predict ATP roadmarking audio effects post seal over.

4.3 Worn ATP roadmarkings

4.3.1 Example 5 (very poor condition ATP roadmarkings)

For further testing of the subjective rating system, another example of ATP roadmarkings was measured.[19] These ATP roadmarkings were identified as being in very poor condition. Using the subjective ratings system about one year prior to these measurements, audio effects had been rated as 1/4 and the total combined rating was 1.5/10. During these measurements, the driver and passenger found audio and tactile effects of the ATP roadmarkings very difficult to discern.

The ATP roadmarkings were installed prior to 2008 but other than this the exact installation date is not known. The road surface was a grade 3/5 two-coat chipseal laid in November 2012.

Figure 4.13 shows a representative sample of the road surface and the ATP roadmarkings, with arrows indicating the position of the ATP roadmarking ribs. This location had been identified for reseal and the site visit and measurements were undertaken prior to the reseal.

Figure 4.13 (Poor condition) ATP roadmarkings (example 5)

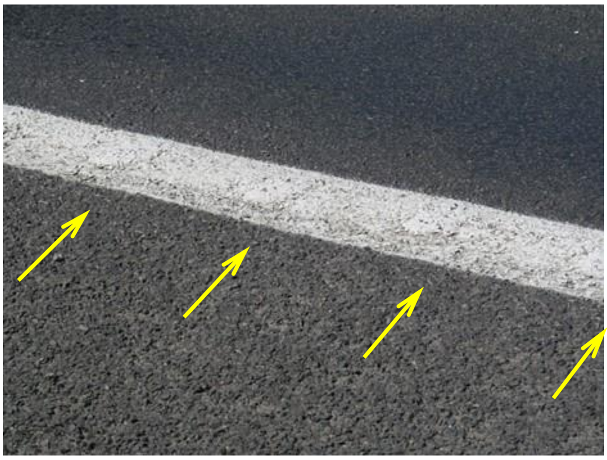
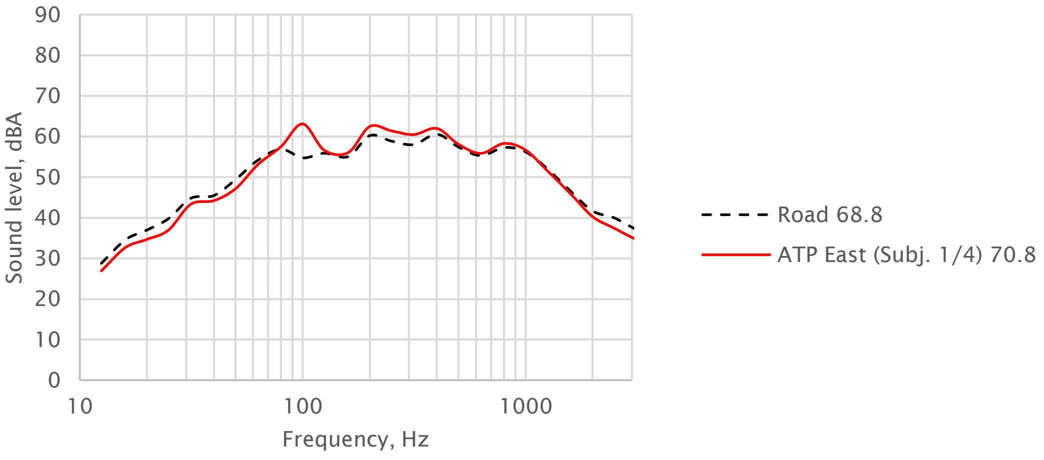


Figure 4.14 Spectral analysis of in-vehicle samples from vehicle travel on the road surface and (poor condition) ATP roadmarkings (example 5)



---

[19] 0002-0073/14.80 to 15.30

Figure 4.14 shows the average one-second spectral analyses from measurements on the road surface in the traffic lane and from the ribs of the ATP roadmarkings.

- The total sound level measured from the ATP roadmarkings was 70.8 dBA and from the road surface in the traffic lane it was 68.8 dBA.
- Figure 4.14 shows the greatest diversion between the spectral analyses of the ATP roadmarking and the road occurs within the frequency band centred on 100 Hz and is 8.3 dBA. This is noted as the only particular diversion between the spectral analyses (compared with other spectral analyses shown in this section where the ATP roadmarking spectral analysis generally has at least two distinctive tonal peaks diverting from the spectral analysis of the road surfaces).

The driver and passenger found the audio effects of the ATP roadmarking almost indistinguishable from the audio effects of the road surface, either with regard to total sound level or tonal change.

4.3.2 Example 6 (snowploughed ATP roadmarkings)

For further information on potential maintenance issues for ATP roadmarkings, measurements were undertaken on some ATP roadmarkings that had been damaged by snowploughing.[20] As indicated by figure 4.15, many of the individual ATP roadmarking ribs had lost some portion of their width but few ribs had been completely removed by the snowploughing.

Figure 4.15 ATP roadmarkings damaged by snowploughing (example 6)

---

[20] 002-0931/7.14-7.91

Figure 4.16 Spectral analyses of in-vehicle samples from vehicle travel on the road surface and ATP roadmarkings damaged by snowploughing (example 6)

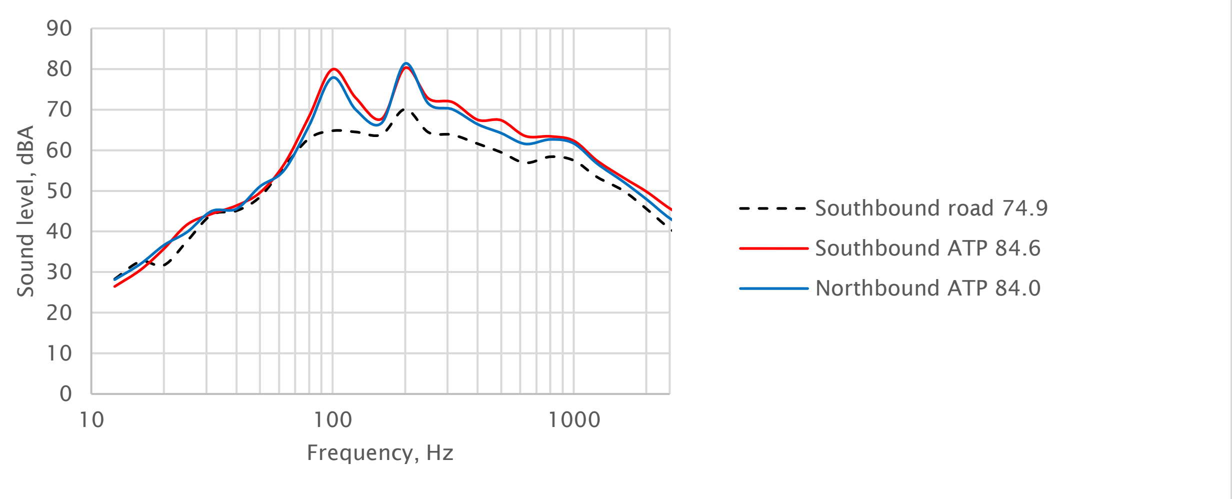


Figure 4.16 shows the average one-second spectral analyses from measurements on the road surface in the traffic lane, the ATP roadmarking of the southbound edgeline and the ATP roadmarking of the northbound edgeline. The road surface was a grade 3/5 two-coat chipseal laid in March 2008 and the total sound level measured from the road surface in the traffic lane was 74.9 dBA. This sound level is higher than measured from other road surfaces shown in this section and aligns with observations by the driver and passenger that the road sounded and felt 'rough'. The total sound level measured from the ATP roadmarkings was 84.6 dBA and 84.0 dBA. Despite the apparent loss of rib width, total sound levels measured from the ATP roadmarkings were 9.7 dBA and 9.0 dBA greater than the total sound level measured from the road surface in the traffic lane. Figure 4.16 clearly shows tonal peaks present in the sound measured from the ATP roadmarkings that do not feature in the sound measured from the road surface. These were about 12 dBA and 15 dBA greater than for the road surface at 100 Hz, and 10 dBA greater at 200 Hz. The driver and passenger also observed the audio effects of the ATP roadmarkings were obvious. The measurements and observations indicate the reduced rib width was sufficient to stimulate the vehicle's suspension to generate audio/tactile effects.

4.4 Comment on consistency of the subjective ratings of audio effects

Table 4.1 summarises some features of the spectral analyses from the preceding examples of ATP roadmarkings where a subjective rating of audio effects was also available. The sound levels in table 4.1 are expressed as differences relative to the adjacent road surface, for the total sound level and for selected third-octave frequency bands where tonal peaks are typically observed from ATP roadmarkings. The ATP roadmarkings are ordered according to total measured sound level difference, from largest to smallest.

Table 4.1 Summary of features of spectral analyses with subjective rating of audio effects

		Sound level difference dBA relative to adjacent road				Subjective audio rating[a]
		Total	100 Hz band	200 Hz band	400 Hz band	
Example 1, figure 4.6	ATP south	8.5	17.4	11.9	9.5	3/4
Example 1, figure 4.6	ATP north	7.6	15.3	11.2	9.3	3/4
Example 3, figure 4.10	ATP west	6.6	16.0	7.6	7.7	1/4
Example 3, figure 4.10	ATP east	4.7	12.6	6.0	5.1	1/4
Example 2, figure 4.8	ATP west	3.7	10.5	4.9	3.6	2/4
Example 2, figure 4.8	ATP east	3.3	7.7	5.0	2.3	1/4
Example 5, figure 4.14	ATP east	2.0	8.3	2.3	1.4	1/4

[a] Subjective audio rating as judged about one year prior to measurements

It is acknowledged that any analysis of table 4.1 attempting to relate measured sound levels with subjective audio ratings is imperfect. One factor is the variable time delay between the judgement of the subjective audio ratings and undertaking the sound level measurements.

Table 4.1 indicates generally there is some correlation between the subjective audio ratings and the measured sound level differences for both the total sound levels and also the frequency bands which typically demonstrate ATP roadmarking tonal peaks with 250 mm rib-spacing and 95 km/h travel speed.

Judgement of subjective audio ratings appears not entirely consistent. For example, table 4.1 shows the total measured sound level difference for example 2 ATP west is 3.7 dBA and the audio effects of this example are subjectively rated 2/4; whereas there are two other examples shown with larger total measured sound level differences but lower audio subjective ratings (1/4). These examples are from different sites, which may be a factor influencing consistency of the subjective ratings.

The other ATP roadmarking from the same example 2 site is ATP east and its total measured sound level difference is 3.3 dBA, which from general acoustics rules should be perceived as indistinguishable from the 3.7 dBA sound level difference from ATP west. However, audio effects of these two ATP roadmarkings were subjectively rated as different.

From table 4.1, the 100 Hz band represents the primary tone and the 200 Hz and 400 Hz bands represent the second and third harmonics. The sound level difference between the ATP roadmarking and the road within the 100 Hz band is mainly two to three times greater than the difference for the total sound level. Dravitzki et al (2012) discuss the tonal aspects of ATP roadmarking audio effects and the likely contribution of these to awareness of the ATP roadmarkings. This discussion was only in the context of the single primary tone. The current work adds to the discussion indicating the audio experience of the ATP roadmarking is probably a more complex interplay of the primary tone and the harmonics/secondary tones. Highly audible ATP roadmarkings have pronounced primary and often pronounced secondary tones whereas the poorly audible roadmarkings have a moderate primary tone but only slight secondary tones.

Another consideration is that the subjective rating 4-point scale is too coarse and/or not sufficiently consistent for this type of analysis. However, this does not imply that a system for subjective rating of audio effects (and other effects also) is irrelevant. A subjective rating system seems very useful if applied primarily to identify ATP roadmarkings which are clearly very noticeable (with no attempt to discern levels below clearly noticeable).

5 Subjective audio/tactile stimulus detection

It is known that in-vehicle sound levels when ATP roadmarkings are traversed generally become higher when the rib height increases and lower when the rib spacing decreases. Miles and Finley (2007) explain that 'sound is generated when a portion of the kinetic energy from tires is converted as tires displace from the normal road surface when contacting rumble strips. As the displacement increases in magnitude and frequency, more energy is converted, which results in more sound'. Miles and Finley also investigate rib-spacing and find 'as the spacing increases sound will decrease because the frequency of the tire displacement will decrease'. They observe that a combination of rib height and rib spacing may prevent a vehicle tyre descending fully between traversed raised ribs. 'The spacing must be far enough to allow the maximum tire displacement, but any increase beyond the distance required to allow for maximum tire displacement will decrease sound'.

For New Zealand state highways, MOTSAM (NZ Transport Agency 2010b) gives rules for ATP roadmarkings in section 4.08, updated in February 2010. For approved ATP roadmarking designs, MOTSAM refers to the specifications TNZ M/24 and NZTA P/30 and their notes.[21]

1 TNZ M/24 refers to 'the profile-design as shown in MOTSAM'. The current MOTSAM section 4.08 does not contain any profile designs but the version of MOTSAM current at the time M24 was published (TNZ 2006) states ATP roadmarkings should conform to a rib height of 7 mm and rib-spacing of 250 mm (MOTSAM, TNZ 1999).

2 TNZ M/24 limits the maximum rib height to 9 mm. The TNZ M/24 notes contain details of ATP roadmarking profile-designs that have been given type approval. The three profile designs in the TNZ M24 notes have nominal rib heights of 4, 7 and 10 mm; and each have rib-spacing of 500 mm (TNZ 2006; 2007).

3 NZTA P/30 states the minimum rib height shall be greater than 4 mm. In the NZTA P/30 notes it is stated the rib spacing 'should be 250 mm' but 'may be increased to 500 mm centres on high-speed roads where experience has shown this to be effective' (NZ Transport Agency 2009).

The rib spacing observed as most common in current New Zealand applications of ATP roadmarkings is 250 mm. It is not known if the predominance of 250 mm has emerged through active or natural selection or because of perceived or measured benefits of this ribspacing. Obviously 250 mm rib spacing uses twice the rib material per lineal metre as 500 mm rib spacing uses, and therefore has increased costs.[22] To justify the increased cost, the 250 mm rib-spacing should provide some incremental benefit above 500 mm rib spacing, potentially through increased audio/tactile awareness

This project inspected subjective detection of ATP roadmarkings with 250 mm rib spacing versus the detection of 500 mm rib spacing using a methodology based on that developed in Dravitzki et al (2012). The methodology uses the theory that there is a threshold sound/vibration level above which the audio/tactile effects of an ATP roadmarking would be noticed by a driver, and below which the effects would not be noticed. There are two states, 'not noticed' and 'noticed', so once the threshold level has been reached and the audio/tactile effects noticed, greater levels of audio/tactile effects are still classed as 'noticed'.

---

[21] Transit New Zealand (TNZ) is one of the predecessor organisations to the NZ Transport Agency. Specifications developed under TNZ are now owned by the NZ Transport Agency but retain their original 'TNZ' naming.

[22] A detailed comparison of the time, traffic control and material costs for 250 mm and 500 mm rib spacing is not part of this project.

Dravitzki et al (2012) use ATP roadmarkings with 500 mm rib spacing and travel over the ATP roadmarkings at 70 km/h. This current project used vehicle travel of 95 km/h, just below the posted open road speed limit of 100 km/h and investigated if the stimulus detection was different with 250 mm rib-spacing compared with 500 mm rib spacing.

For this project, a car instrumented with a sound level meter and sound recording device was driven over a plain road surface to capture the baseline sound. Thin strips were then spaced out and adhered to the road surface to simulate ATP roadmarking ribs, and the car was driven over the ribs to capture the sound with one layer of strips. Strips were incrementally adhered to the preceding layer of strips to build up the height of the ribs. Between each additional layer of strips, the car was driven over the ribs to capture the sound. The captured baseline and incremental sounds were used as inputs to a driving-load simulator.

As in the Dravitzki et al (2012) study, a simulator approach was used rather than real-world driving because the simulator approach better controls variables and it was easier to manage with regard to health and safety. The driving-load simulator placed visual and cognitive loads on participants similar to those experienced while driving but with many variables of real-world driving removed or controlled. A full simulation of driving (vehicle and road environment etc) was beyond project resources.

The driving-load simulator had a participant sitting as if driving a car. On a screen in front of the participant was a concentration-type task for the participant to complete. This task simulated the mental load and concentration requirements of driving. While the participant was completing the task, they heard the baseline sound from the car on the plain road surface through headphones. At intervals, the sound from the car being driven over the ribs was played. The participant was instructed to respond to that sound by pushing a foot-pedal as soon as they noticed the sound (if they noticed the sound). The simulator ran through a sequence, playing the baseline sound and the range of sounds from different rib heights. The participant’s response, or lack of response, to the sound from the ribs was logged and subsequently analysed, building a threshold between the rib heights (or number of layers of strips) to which the participant responded and the rib heights that went unnoticed. The participant’s performance on the driving-load task was also recorded so it could be checked for consistency and for side effects arising from the sound stimulus.

5.1 Data collection for audio inputs to the simulator

Audio inputs to the simulator were also obtained in a simulation type situation. An appropriate range of audio inputs could not be obtained from real-world ATP roadmarkings because there are insufficient examples of these with in-lane reseal or sealed over markings and real-world ATP roadmarking dimensions are highly variable (Dravitzki et al 2007).

Data was collected on a private roadway with straight sections where open-road speeds could be safely achieved. Measurements were conducted on two test sections, one surfaced with an asphaltic concrete and the other surfaced with a small-grade chip seal. The test sections were subjectively judged as equivalent in terms of sound and vibration. (Subsequent comparison of sound measurements confirmed the subjective sound judgement.)

The vehicle used for the data collection was a diesel Ford Focus Trend Wagon with cruise control set to give true vehicle speed of 95 km/h during measurements. The vehicle was instrumented with a sound level meter positioned mid-cabin and a data logger.

Simulated ATP roadmarkings were made using strips of polycarbonate. The strips of polycarbonate were pre-cut to simulate an ATP roadmarking rib 50 mm long (measured in the direction parallel to vehicle travel) and 200 mm wide (measured in the direction perpendicular to vehicle travel). This is the rib length typical of current New Zealand ATP roadmarkings. The rib width (perpendicular to the direction of travel) is wider than typical New Zealand ATP roadmarkings but was selected to facilitate good tyre contact during the data collection. The polycarbonate strip was 1 mm thick.

The first sound measurements were taken while the vehicle was driven on the two test sections without any ribs.

On one test section, a line with marks at 250 mm spacing was made. On the other test section, a line with marks at 500 mm spacing was made. On each mark a strip of polycarbonate was adhered to the road surface using double-sided foam-backed tape, as shown in figure 5.1. With the double-sided foam-backed tape, the effective rib height of the first layer was, on average, about 1.8 mm. Each line of ribs was made with a total length of 40 m to provide sufficient length (plus extra) for sound measurements to capture at least one full second (at 95 km/h) of good vehicle contact with the ribs.

Figure 5.1 Line of polycarbonate strips at 250 mm spacing

Sound measurements were taken while the vehicle was driven on the ribs at 250 mm spacing and then on the ribs at 500 mm spacing. Vehicle contact with the ribs was monitored subjectively by the driver and passenger in the vehicle. If the quality of vehicle contact during a sound measurement was questioned, that sound measurement was discarded and another sound measurement taken until five sound measurements were collected for each rib spacing.

Along both the line with 250 mm rib-spacing and the line with 500 mm rib spacing, to each single layer of polycarbonate strip adhered to the road surface, another single layer of polycarbonate strip was adhered using double-sided tape (without foam backing), as shown in figure 5.2. The effective rib height with the first two layers of polycarbonate strips was, on average, about 2.8 mm. Sound measurements were taken until five sound measurements were collected for each rib spacing.

Figure 5.2 Layering of polycarbonate strips

Along both the line with 250 mm rib spacing and the line with 500 mm rib spacing, another single layer of polycarbonate strip was adhered to each rib using double-sided tape. The effective rib height with three layers of polycarbonate strips was, on average, about 4.0 mm. Five sound measurements were collected for each rib spacing.

This was repeated to make four layers of polycarbonate with an average rib height of 5.2 mm, then repeated to make five layers of polycarbonate with an average rib height of 6.5 mm, and finally repeated to make six layers of polycarbonate with an average rib height of 7.8 mm.

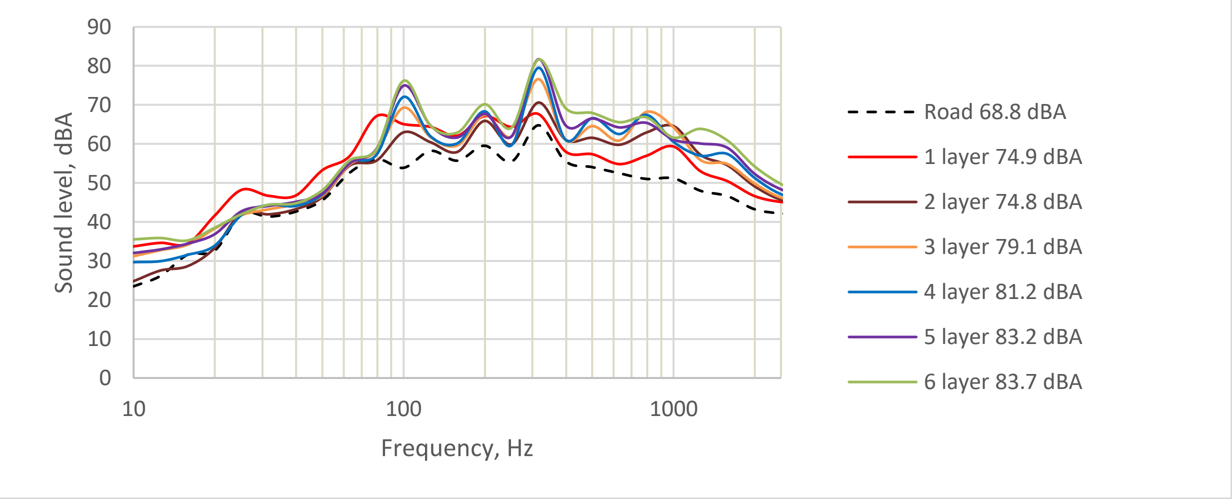
The sets of sound measurements were averaged and combined to prepare the following two graphs. Figure 5.3 shows the results of sound measurements with 250 mm rib spacing for all the rib heights from one to six layers of polycarbonate and also the results of sound measurements from only the road without any ribs. Figure 5.4 shows the equivalent for 500 mm rib spacing.

It is important to note the sound recorded inside the vehicle was modified by the sound damping system which had been designed by the vehicle manufacturer to reduce road noise received in-vehicle. This sound damping typically affects 300 Hz to around 1,000 Hz by about 20 dBA and this range and scale of sound damping differs for different vehicles (Dravitzki et al 2012)[23]

The results follow expectations and other literature. Figures 5.3 and 5.4 show increasing total sound level with increasing rib height. With vehicle-travel of 95 km/h (26 m/s) the vehicle traverses about 106 ribs/s with 250 mm rib spacing or 53 ribs/s with 500 mm rib spacing. Tonal peaks aligning with these frequencies are visible in the respective graphs of figures 5.3 and 5.4.

Comparing figures 5.3 and 5.4, the measurements from equal rib heights show the sound level decreases between the 250 mm rib-spacing and the 500 mm rib spacing, showing the sound level decreases as the number of traversed ribs/s decreases.

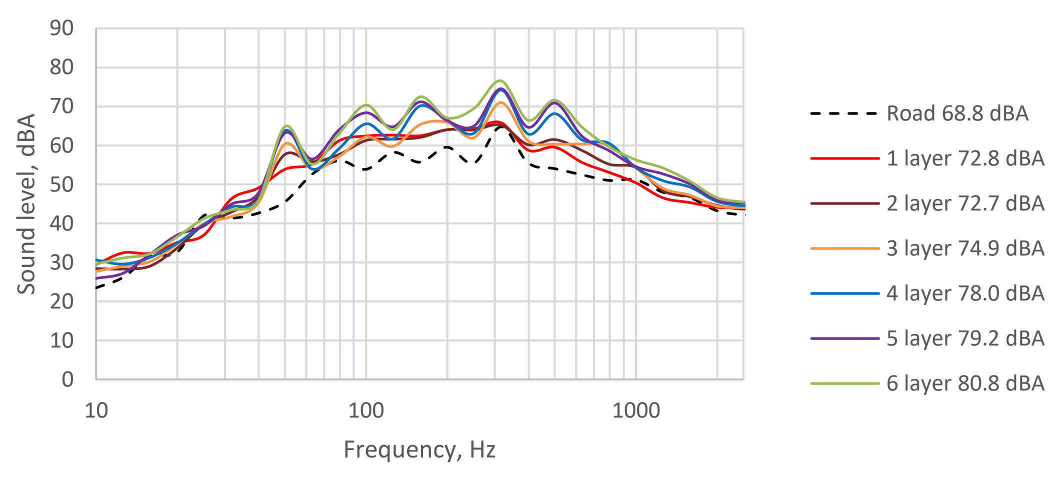
Figure 5.3 Results of in-vehicle sound measurements with 250 mm rib spacing



---

[23] The sound damping of the vehicle used for measurements discussed in this section appears notably different from the sound damping of the vehicles used for measurements presented in the previous section. It is also noted, without investigation, that the vehicle used for this section had a diesel engine whereas the vehicles used for the previous section had petrol engines, although the other simulator study (Dravitzki et al 2012) had used a Hyundai I30 wagon with a diesel engine.

Figure 5.4 **Results of in-vehicle sound measurements with 500 mm rib-spacing**



5.2 Driving-load simulator study

The driving-load simulator consisted of a car driver's seat and steering wheel positioned in front of a 42-inch monitor. Participants used the driving-load simulator as if driving a car and responded to the simulator via two buttons mounted on the steering wheel and a foot pedal.

Audio effects were provided to participants through Sennheiser HD280 Pro headphones. Sound samples from the in-vehicle sound measurements data collection were used as inputs. The headphones and sound samples were calibrated to ensure the characteristics of the sound samples matched the characteristics of the sound received by the participants.

Tactile effects were provided to participants through a Denon stereo system sub-woofer (facing upwards) contained under the car driver's seat.

On the monitor, participants were presented with a task known as the Stroop task (Stroop 1935). The task was used to replicate the visual and cognitive demands of driving. In the Stroop task, participants were presented the name of a colour printed in one of three colours along with two choices for their response. Table 5.1 shows some example prompts and choices. Participants were instructed to respond to the colour of the printed word (not the printed word itself) by choosing the correct one of the two choices via the buttons on the steering wheel.

Table 5.1 **Stroop task examples**

Description	**Prompt on monitor**	**Choices to participant**		**Correct answer (colour of print)**
Congruent: Colour of print matches the word Choices include the word	GREEN	Green	Red	Green
	BLUE	Red	Blue	Blue
Incongruent: Colour of print does not match the word Choices include the word	GREEN	Green	Red	Red
	GREEN	Blue	Green	Blue
Neutral: Colour of print does not match the word Choices do not include the word	GREEN	Red	Blue	Red
	GREEN	Red	Blue	Blue

Each participant was trained in completing the Stroop task. The participant was presented with a minimum of 20 iterations and was required to perform with a minimum 90% accuracy before they could progress to the next task.

Each participant was trained in identifying the audio/tactile effects of the ATP roadmarkings. The audio/tactile effects of the baseline condition of a vehicle on the road (without any ribs) were provided to the participant. Then for a short interval the audio/tactile effects of a high-quality ATP roadmarking that met current specifications were provided to the participant before returning to the baseline condition. Participants were instructed to tap the foot pedal when they noticed audio/tactile effects of the ATP roadmarking. The participant was provided with a minimum of 20 presentations of ATP roadmarking audio/tactile effects and was required to perform with a minimum 90% accuracy before they could progress to the next task.

The main testing then commenced. The participant was continuously presented and engaged in the Stroop task. If performance on the Stroop task diminished, participants were given prompts to maintain their performance to an acceptable level.

One set of audio/tactile effects representing one of the rib spacings (either 250 or 500 mm) was first presented.

An algorithm[24] was run as the participant was provided with short intervals of audio/tactile effects of the ribs between intervals of the baseline (road-only) condition.

- If the participant did not notice three consecutive presentations of the audio/tactile effects of the ribs at their maximum rib height (six layers of polycarbonate), then the algorithm ceased the testing.
- If the participant successfully noticed three consecutive presentations of the audio/tactile effects of the ribs, the algorithm moved to using audio/tactile effects for ribs with one fewer layers of polycarbonate; incrementally decreasing the rib height to a minimum of one layer of polycarbonate.
- If the participant did not notice a presentation of the audio/tactile effects of the ribs, the algorithm moved to using audio/tactile effects for ribs with one more layer of polycarbonate, incrementally increasing the rib-height to a maximum of six layers of polycarbonate. This movement to increase the rib height was described as a ‘reversal’.
- If the algorithm moved to using audio/tactile effects of the ribs at their minimum height (one layer of polycarbonate) and the participant successfully noticed three consecutive presentations of the audio/tactile effects of these ribs, then the algorithm ceased the testing.
- If the algorithm was not ceased through reaching the maximum or minimum rib height, then the testing continued until the participant had been through 16 reversals.

The threshold rib height was determined by the condition at which the participant reliably identified the presence of the ATP roadmarking without significantly dropping in their performance on the Stroop task. This is based on the method (referred to as the staircase procedure) of Dixon and Mood (1948).

The main testing was then repeated with the same algorithm but using the set of audio/tactile effects representing the other rib spacing (either 250 or 500 mm).

---

[24] In setting up the algorithm for this project, an error was found in the algorithm for the Dravitzki et al (2012) study. Instead of three presentations of the same rib height, the algorithm gave two presentations of the same rib height and one presentation of the next lower/higher rib height. The extent of influence of this error on the earlier findings is not known but it possibly overstated the threshold rib height.

All steps performed by the algorithm and all participant responses and response-timings were logged and compiled into a dataset.

For this project, 31 participants were recruited for the driving-load simulator study. The participants were obtained via a sample of drivers who were members of the Automobile Association of New Zealand. The sample was stratified by gender and age to represent the population of New Zealand car licence holders (MoT 2013).

From the driving-load simulator study, four sets of responses were found to be incomplete or non sequitur so valid calculations could not be performed on those responses. These responses were removed from the dataset (with no effect on the intended stratification of the sample). The resultant sample of 27 participants (Group A) ranged in age from 17 to 75+, as summarised in table 5.2. (Table 5.2 also profiles Group B and Group C which are defined below.) Three Group A participants rated their hearing ability as below average and/or self-reported some form of hearing disorder. The remaining participants rated their hearing ability average or above and self-reported no hearing disorders. (Due to the sample size, effects of these features have not been investigated, though no such effects were obvious through inspection of each individual participant's response set.)

Table 5.2 Age-profile for participant groups

Age band	Group A	Group B	Group C
Less than 17	0		
17 to 24 years	2		
25 to 34 years	5	3	3
35 to 44 years	8		
45 to 54 years	4	2	2
55 to 64 years	5		
65 to 74 years	4		
75+ years	2		
Total	27	5	5

Table 5.3 summarises key parameters calculated from the 27 valid Group A responses.

Table 5.3 Summary of Group A participants' results

	Group A, n = 27			
	250 mm rib-spacing first		500 mm rib-spacing second	
	Mean	Std. dev.	Mean	Std. dev.
Threshold layers (#)	1.17	0.40	1.16	0.34
Reaction time to ATP (s)	0.72	0.13	0.73	0.12
Reaction time to Stroop (s)	1.26	0.40	1.22	0.32
Overall Stroop correct (#)	161	75	155	54.7
Overall Stroop incorrect (#)	11	10	9	9

During analysis of the Group A responses it was found an error had been made and, rather than half the sample being presented 250 mm rib spacing first and half the sample being presented 500 mm rib spacing first, all Group A participants were presented with the testing algorithm giving the 250 mm rib spacing first followed by the 500 mm rib spacing. There were concerns that being presented second, ‘fatigue’ might have influenced responses to the 500 mm rib-spacing. To inspect for effect, five additional participants were recruited, Group B. By necessity rather than design, this sample was obtained by convenience.

Group B participated in the testing with the algorithm presenting the 500 mm rib-spacing audio/tactile effects first followed by the 250 mm rib-spacing audio/tactile effects. The key parameters calculated from the Group B sample are shown in table 5.4. For comparison, table 5.4 also contains key parameters calculated from Group C which is a subset of the initial sample Group A. The individual participants for Group C were randomly selected but within a design to match the age profile of Group B. Table 5.2 shows the age profile of Group B and Group C.[25]

Table 5.4 Summary of Group B and Group C participants’ results

	Group B, n = 5				**Group C, n = 5**			
	250 mm rib-spacing second		**500 mm rib-spacing first**		**250 mm rib-spacing first**		**500 mm rib-spacing second**	
	Mean	**Std. dev.**	**Mean**	**Std. dev.**	**Mean**	**Std. dev.**	**Mean**	**Std. dev.**
Threshold layers (#)	1.01	0.02	1.03	0.04	1.03	0.04	1.03	0.04
Reaction time to ATP (s)	0.72	0.10	0.73	0.09	0.66	0.10	0.67	0.10
Reaction time to Stroop (s)	1.15	0.42	1.18	0.37	1.23	0.16	1.14	0.17
Overall Stroop correct (#)	142	47	130	27	142	68	123	30
Overall Stroop incorrect (#)	4	4	7	7	6	3	6	7

Table 5.4 shows Group B and Group C displayed a similar pattern of results and similar values within those results. There are no significant differences for these two groups related to order of presentation of the 250 mm rib-spacing audio/tactile effects and the 500 mm rib-spacing audio/tactile effects. Therefore it was considered reasonable to continue with analysis and interpretation of the table 5.3 results from Group A. (Group B results were not amalgamated with Group A results as this would affect the intended distribution of participants’ ages.)

5.3 Comments

With regard to participants’ performance on the Stroop test, Table 5.3 shows there are no significant differences between responses with 250 mm rib spacing and responses with 500 mm rib spacing. There is also no significant difference between the mean threshold numbers of layers; but it is notable that the mean is very close to just one layer.

Figure 5.5 is drawn from the Group A results and shows the distribution of threshold number of layers from Group A participants. Acknowledging granularity attributed to the small sample size (n = 27), still from figure 5.5 it is difficult to discern any distribution in the results and may suggest the first layer was ‘too obvious’. (There were only six layers used. The x-axis is extended to 7 to assist comparison with figures 5.6 and **5.7**.)

As noted earlier in this section, the methodology used here is based on that developed in Dravitzki et al (2012) which expresses the threshold in terms of rib height (mm). Accordingly, the results shown in

---

[25] Males and females were included in the five participants in each of Group B and Group C.

figure 5.5 have been converted to rib-heights. Figure 5.6 shows the distribution of threshold rib height from Group A participants. It is essentially based on the same inputs as figure 5.5 only altering the spread of the independent variable (x-axis) and so it is not surprising that this figure similarly suggests the first rib height was 'too obvious'. (The lowest rib height was 1.8 mm and the highest rib height was 7.8 mm but the x-axis is chosen to assist comparison with the other figures in this section.)

Figure 5.5 Threshold number of layers (from Group A)

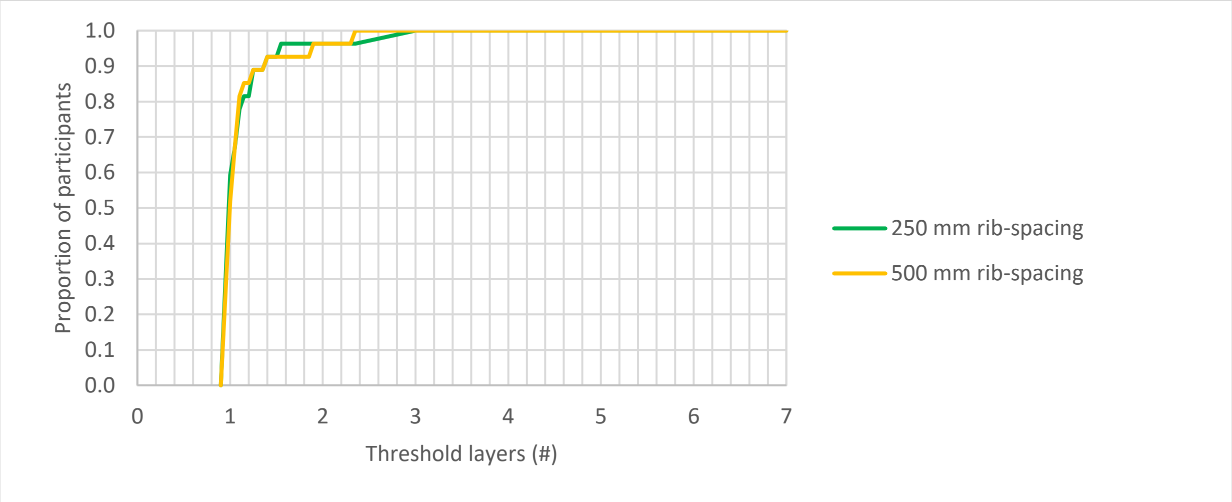
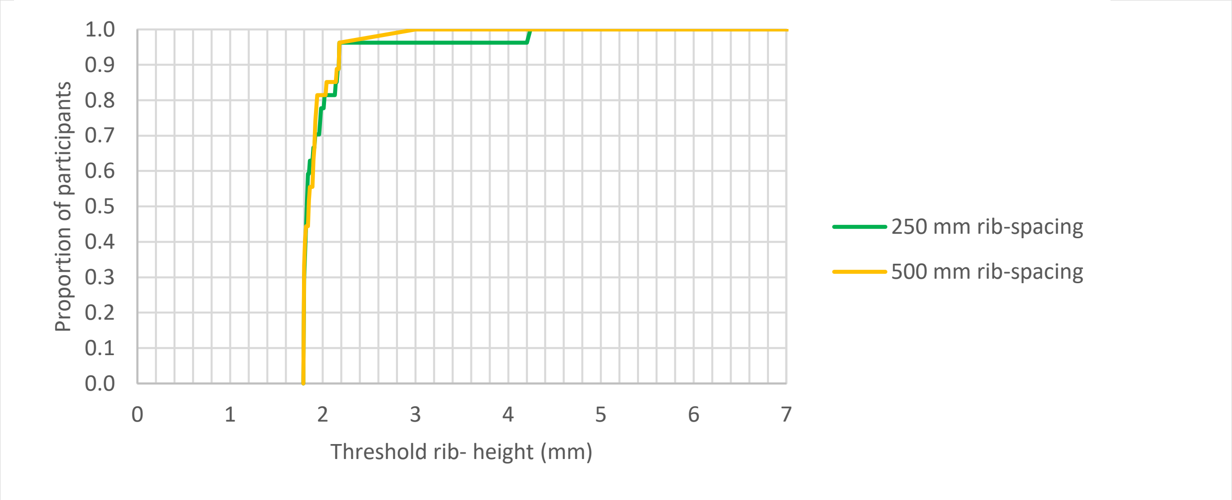


Figure 5.6 Threshold rib height (from Group A)



From analysis of the threshold layers and rib heights, it appears there is little difference between response to the 250 mm rib-spacing audio/tactile effects and the 500 mm rib-spacing audio/tactile effects. However, the sound levels and spectral analyses should also be considered.

Figures 5.3 and 5.4 show the spectral analyses of the audio inputs to the simulator and the total sound levels obtained from each layer (one to six layers)) for each rib-spacing (250 mm and 500 mm). It is observed that:

- With 250 mm rib spacing, the total sound level with one layer is 74.9 dBA and with two layers is 74.8 dBA. The two different rib heights generate essentially the same total sound level. This is also noted with 500 mm rib spacing, where the total sound level with one layer is 72.8 dBA and with two layers is 72.7 dBA.

- With one layer at 250 mm rib spacing the total sound level is 74.9 dBA and with three layers at 500 mm rib spacing the total sound level is also 74.9 dBA. There is another pairing, where with three layers at 250 mm rib spacing the total sound level is 79.1 dBA and with five layers at 500 mm rib spacing the total sound level is 79.2 dBA.

The mechanisms causing these observations were not explored in this research project. However, they are used to suggest that if participants were responding to the total sound level, there should be some response-overlap at these points.

Participant response might not be solely related to the total sound level relative to the road surface but possibly sound level differences at particular tones.

Dravitzki et al (2012) describes a threshold response mechanism for ATP roadmarkings, where 'a certain level of effect is needed for the ATP roadmarking to be noticeable; after this, increases in sound or vibration do not increase the noticeability of the ATP roadmarking'. The results obtained here suggest the audio inputs to the driving-task simulator of the first rib height achieved the noticeability threshold for many participants. Further, analysis of individual participant's responses shows no significant difference in time to respond to any of the ATP roadmarking stimuli, so once the stimulus is noticed then the time to respond is independent of the scale of the stimulus.

Alternate thinner polycarbonate strips could have been used in the physical simulation of ATP roadmarkings to obtain a lower first rib height and finer stepping of rib heights. Alternatively, measurements and recordings from ATP roadmarkings could be synthesised to achieve finer control of steps for input to the driving-load simulator.

It may still be unclear what stimulus threshold levels are necessary for ATP roadmarking audio/tactile effects to be noticed by drivers and there is scope for further investigation of the experimental method and mechanisms operating. However, with particular regard to figure 5.6, for the experimental conditions tested here, there is no significant difference in audio/tactile awareness between 250 mm and 500 mm rib spacing at the rib heights required by current New Zealand ATP roadmarking specifications (between 4 mm and 9 mm).

Some factors possibly influencing rib-spacing selection have been considered:

- Effectiveness of a 500 mm rib-spacing may be more vulnerable to loss of individual ribs. However, indications are that rib loss should be rare with current practices and it is viewed as an issue controlled through contractual arrangements.
- ATP roadmarkings are typically contacted and considered most effective for drifting or inattentive lane departure for which many references ascribe a shallow angle of departure, commonly 3°.[26] With a travel speed of 100 km/h and departure angle of 3°, tyre contact across a 100 mm wide edgeline is about 0.2 seconds (assuming a 200 mm tyre width) or 5.7 m. In this scenario, the selection of either 250 mm or 500 mm rib spacing would have minor influence on noticeability of the audio/tactile effects compared with the degree of influence of the duration of contact.
- Watts (1977) investigates audio effects of transverse application of roadmarkings when traversed, but findings may be still relevant to longitudinal application of ATP roadmarkings. Watts reports using a driving simulator with subjects to determine for two increments of sound stimulus above background sound, the required duration of stimulus to elicit detection by the subject. Watts finds for 90% detection rate by subjects:

---

[26] This 'drift' is a different mode and angle of lane departure than that commonly used/appropriate for design of clear zones and shoulder barriers, for example Jamieson et al (2013).

  - If the stimulus sound level is 2 dB higher than background sound level, then 0.70 seconds of stimulus is required.
  - If the stimulus sound level is 4 dB higher than background sound level, then 0.29 seconds of stimulus is required.

  Figures throughout this report and previous related research (such as Dravitzki et al 2007 and Dravitzki et al 2012) indicate total sound levels from traversing ATP roadmarkings are very often 4 dBA or more higher than the total sound levels from the road surface, and for particular frequency bands, sound levels are commonly around 10 dBA higher than the road surface sound level in the same frequency band.

- There may also be a visual impact of 250 mm rib spacing versus 500 mm rib-spacing. Chapter 3 concludes that measurement of ATP roadmarkings visual effects is appreciated as important but is currently limited. No substantive literature specific to rib spacing and visual effects was found.

6 Conclusions and recommendations

ATP roadmarkings are defined by their audio/tactile effects when traversed and their visual effects. These essential effects depend on different properties of the ATP roadmarkings. The audio/tactile effects depend on the frequency and prominence of the raised ribs of the ATP roadmarking relative to the adjacent road surface. The visual effects primarily depend on contrast with the road surface and presentation of glass beads or other optics for retroreflectivity.

Visual effects of ATP roadmarkings are largely independent of their audio/tactile effects, so they must be considered separately.

It appears the visual performance can deteriorate well before the audio/tactile performance. Techniques for refreshing ATP roadmarking visibility may be cleaning of the existing ATP roadmarking or recoating the ATP roadmarking with an application of paint (or other regular-build roadmarking material) including beads or other optics, though full measurements have not been undertaken. Increased measurement of ATP roadmarking visual effects including after re-marking and further investigation for better understanding of visual effects in wet conditions is recommended.

In terms of acceptable dimensions for rib height and rib width, the raised ribs of ATP roadmarkings are demonstrating lives of 6 to 8+ years. Within this period, the road itself may need resealing. Taking a precautionary approach, early practice was to remove any ATP roadmarkings prior to resealing. However, this disposes of any remaining value of the ATP roadmarkings and removal in itself is another cost. More recently, practices for resealing without removal of ATP roadmarkings have emerged and this project investigated these.

One main practice is to reseal the full carriageway including over any existing ATP roadmarkings. ATP roadmarkings can be sealed over and some of the pre-reseal audio/tactile effects successfully retained. However, the success is variable and may be difficult to predict, depending on both the pre-reseal condition of the raised ribs and the size of chips used in the resealing.

Another main practice is in-lane reseal where the reseal is laid over the traffic lane but stopped adjacent to the raised ribs of the ATP roadmarking. With ‘good practice’, the audio/tactile effects of the ATP roadmarking are unaffected by the in-lane reseal.

Of the two practices, in-lane reseal appears more practicable because there is more certainty the residual audio/tactile life will be unimpaired.

If road surface reseal is intended where ATP roadmarkings have effective audio/tactile effects, it is recommended in-lane reseal be considered.

The in-lane reseal should be checked as acceptable with contractual arrangements and executed in accordance with good practice.

In-lane reseal is particularly compatible with ATP roadmarking edgelines where the raised ribs are placed on the shoulder immediately adjacent to a continuous line. The edge of the in-lane reseal can be placed within the width of the continuous line, parallel but not contacting the raised ribs. Post-reseal, the continuous line is re-marked, with the option of also re-marking the raised ribs which could renew visual effects particular to their vertical profile and provide the benefits of a wider edgeline.

The inception of this project demonstrates that ATP roadmarkings are recognised as assets; however, ATP roadmarkings are generally not managed to the extent that other assets are.

For 'best practice', ATP roadmarkings should be included in the Road Asset and Maintenance Management database, and given documentation and condition monitoring just as other assets such as signs or road surfaces are given.

For ATP roadmarkings, 'best practice' monitoring could include regular measurement of visual effects, possibly using a dynamic retroreflectometer, and regular measurement of audio/tactile effects, possibly with a sound level meter mounted in-vehicle. Alternatively, the report has discussed a subjective rating system and this could be developed to complement objective measurements or applied to the current situation where there is not yet a fully developed method for objective measurements.

Future research should develop criteria and methods for objective measurements as well as a method for subjective rating. Either approach, objective or subjective, needs to account for audio, tactile and visual effects of ATP roadmarkings.

Recommendations from this research are:

- Audio/tactile effects should be assessed relative to the adjacent road surface.
- Visual effects should be assessed in daylight and night conditions, in dry and wet conditions, and in continual wetting conditions if practicable.
- Assessments should be made periodically, repeating the same method each time and should be well documented. Indicative recommendations are monitoring of visual effects at least once a year and monitoring of audio/tactile effects at least once every two years, with additional monitoring if a reseal is proposed.

For objective assessments, sound level measurements (and vibration measurements) should record the total level and the spectral analysis.

For subjective assessments, at least two people should be used, with their age and any vision or hearing impairments/aids noted.

Whether considering audio, tactile or visual effects, to be considered 'effective' the assessors should agree effects are *easily discerned and recognisable*, or otherwise considered not effective.

To assist consistency between assessments and also national uniformity of assessment, a video could be developed to provide training on how the subjective assessments should be performed and clear judgements made.

The research project tested noticeability of ATP roadmarking audio/tactile effects with 250 mm rib spacing compared with 500 mm rib spacing. This work combined objective and subjective approaches. It highlighted that interpretation of the subjective implications of total sound levels and spectral analyses of those total sound levels are complex. There is further complexity added when considering how the engineering and damping of different vehicles affects the in-vehicle experience of ATP roadmarking effects. There is scope for further investigation of the experimental method and operating mechanisms. However, for the experimental conditions used in this project, it was found that at the rib heights required by current New Zealand ATP roadmarking specifications (between 4 mm and 9 mm) there was no significant difference in noticing audio/tactile effects at 250 mm rib spacing compared with 500 mm rib spacing.

7 References

Bucko, T and A Khorashadi (2001) *Evaluation of milled-in rumble strips, rolled-in rumble strips and audible edge stripe*. USA: California Department of Transportation. 117pp.

Burns, D, N Hodson, D Haunschild and D May (2006) Pavement marking photometric performance and visibility under dry, wet, and rain conditions: pilot field study. *Transportation research report 1973*: 113–119.

Carlson, P, J Miles, A Pike and E Park (2007) *Evaluation of wet-weather and contrast pavement marking applications: final report. Report 0-5008-2*. USA: Texas Transportation Institute, Texas A&M University. 158pp.

Carlson, P and J Wagner (2012) *An evaluation of the effectiveness of wider edge line pavement markings.* Accessed March 2015. tti.tamu.edu/documents/TTI-2012-1.pdf. USA: Texas Transportation Institute and American Glass Bead Manufacturers Association.

Department of Building and Housing (DBH) (1992) *Compliance document for New Zealand Building Code clause E1: surface water*. New Zealand: DBH. 48pp.

Diamandouros, N (2013) *Rainvision deliverable 1.1: state of the art*. Accessed March 2015. www.rainvision.eu/images/RAINVISION_ERF_SoA_final.pdf. Belgium: European Road Federation.

Dixon, W and A Mood (1948) A method for obtaining and analyzing sensitivity data. *Journal of the American Statistical Association 43*, no.241: 109–126.

Dravitzki, V, C Wood, J Laing and S Potter (2003) Guidelines for performance of New Zealand markings. *Central Laboratories report 03-527605.* Accessed March 2015. www.nzta.govt.nz/assets/resources/guidelines-for-performance-of-nz-road-markings/docs/guidelines-for-performance-of-nz-road-markings.pdf.

Dravitzki, V, D Walton, T Lester and R Jackett (2007) Measuring the effects of audio tactile profiled roadmarkings. *NZRF/RIAA Conference*, Bay of Islands, 22–24 August 2007. Accessed January 2014. www.nzrf.co.nz/techdocs/conferencepapers2007/Effects-ATPR-Dravitzki.pdf.

Dravitzki, V, J Thomas and K Mora (2012). Improved effectiveness and innovation for audio tactile profiled roadmarkings. *NZ Transport Agency research report 478.* 38pp.

Edgar, J, H Mackie and P Baas (2008) The usability and safety of audio tactile profiled road markings. *NZ Transport Agency research report 365*. 68pp.

Federal Highway Administration (FHWA) (2011) *Frequently asked questions on rumble strips.* Accessed January 2014. safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/faqs.cfm. USA: US Department of Transportation, FHWA.

Federal Highway Administration (FHWA) (2014) *Maintenance concerns: keeping the rumble in the strips*. Accessed January 2014. fhwa.dot.gov/roadway_dept/pavement/rumble_strips/concerns_main.cfm. USA: US Department of Transportation, FHWA.

Gates, T and H Hawkins (2002*)* The use of wider longitudinal pavement markings. *Research report 0024-1*. USA: Texas Transportation Institute. 66pp.

Gibbons, R and J Hankey (2007) Wet night visibility of pavement markings, dynamic experiment. *Transportation Research Record: Journal of the Transportation Research Board 2015*: 73–80.

Jamieson, N, G Waibl and R Davies (2013) Use of roadside barriers versus clear zones*. NZ Transport Agency research report 517.* 92pp

Keisel, K (2007) Management of audio tactile edge line markings. *VicRoads Research and Development report: project no. 952.* Australia: VicRoads. 29pp.

Lindly, J and R Wijesundera (2003). Evaluation of profiled pavement markings. *UTCA report 01465.* USA: University Transportation Center for Alabama. 103pp.

Ministry of Transport (MoT) (2013) *Motor vehicle crashes in New Zealand 2013*. New Zealand: MoT. 180pp.

Montana Department of Transportation (MDT) (2011) *Evaluation of edge line rumble strips (informal)*. USA: MDT Research Programs. Accessed January 2014. www.mdt.mt.gov/other/research/external/docs/epsl/edge_line_rumble/final_report_may11.pdf.

Montana Department of Transportation (MDT) (2012) *Rumble strip guidance* (memo dated 26 November 2012). USA: MDT. Accessed January 2014. www.mdt.mt.gov/other/roaddesign/external/design_memos/2012-11-30_RUMBLE_STRIP-3.PDF

Montana Department of Transportation (MDT) (2013) *Evaluation of hot-laid thermoplastic pavement markings: preparations prior to a seal coat application.* USA: MDT Research Programs. Accessed January 2014. www.mdt.mt.gov/other/research/external/docs/epsl/thermo/FINAL_REPORT_APR13.pdf.

Mulkern, M and E Hildebrand (2013) Development of crash modification factors for left side rumble strips. *23rd Canadian Multidisciplinary Road Safety Conference.* Canada: Montreal, Quebec, 26–29 May 2013.

NZ Roadmarkers Federation (NZRF) (2011). *NZRF line removal guide*. 2nd revision. Accessed December 2014. www.nzrf.co.nz/techdocs/Line-Removal-Guide.pdf.

NZ Transport Agency (2007) *Manual of traffic signs and markings (MOTSAM) part 2: Markings, section 2.03 edge lines* (updated August 2007). Accessed July 2015. www.nzta.govt.nz/assets/resources/motsam/part-2/docs/motsam-2-section-2.pdf accessed July 2015.

NZ Transport Agency (2009) *NZTA P/30: 2009 Specification for high performance roadmarking.* 16pp.

NZ Transport Agency (2010a) *Guidelines for using audio tactile profiled (ATP) roadmarkings*. Accessed December 2013. www.nzta.govt.nz/resources/audio-tactile-profiled-roadmarkings-guidelines/docs/atp-guidelines.pdf.

NZ Transport Agency (2010b) *Manual of traffic signs and markings (MOTSAM) part 2: Markings, section 4.08 audio tactile profiled line marking* (updated February 2010). Accessed July 2015. www.nzta.govt.nz/assets/resources/motsam/part-2/docs/motsam-2-section-4.pdf.

NZ Transport Agency (2011) *NZTA M/6: 2011 Specification for sealing chip.* 4pp.

Pike, A, G Hawkins and P Carlson (2007) Evaluating the retroreflectivity of pavement marking materials under continuous wetting conditions. *Transportation Research Record: Journal of the Transportation Research Board 2015:* 81–90.

Price, D (1996) Evaluation of rumble treatments on asphalt shoulders. *Report CDOT-DTD-96-12.* USA: Colorado Department of Transportation. 33pp.

Schnell, T, F Aktan and Y-C Lee (2003) Nighttime visibility and retroreflectance of pavement markings in dry, wet and rainy conditions. *Transportation Research Record: Journal of the Transportation Research Board 1824.* 144–155.

Standards Australia (2007) *AS 4049.5-2007 Paints and related materials – pavement marking materials, part 5: Performance assessment of pavement markings*. Australia: Standards Australia. 25pp.

Stroop, J (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology 18*: 643–662.

Transit NZ (TNZ) (1989) *TNZ P/4 notes: 1989 notes for resealing.* New Zealand: TNZ. 15pp.

Transit NZ (TNZ) (1998) *TNZ P/12 notes: 1998 notes for the specification for pavement marking*. New Zealand: TNZ. 18pp.

Transit NZ (TNZ) (1999) *Manual of traffic signs and markings (MOTSAM) part 2: Markings, section 4.08 profiled line marking* (updated October 1999). New Zealand: TNZ. (4) pp45–49.

Transit NZ (TNZ) (2006) *TNZ M/24: July 2006 Specification for audio tactile profiled roadmarkings*. New Zealand: TNZ. 21pp.

Transit NZ (TNZ) (2007). *TNZ M/24 Notes: 2007 Notes on audio tactile profiled roadmarkings.* New Zealand: TNZ. 2pp.

Watson, M, R Olson, J Pantelis, E Johnson and T Wood (2008) *Long term maintenance effects on HMA pavements caused by rumble strips and available preventative treatment methods (2008-50).* USA: Minnesota Department of Transportation Research Services. 23pp.

Appendix A: Trial of measuring retroreflectivity during continual wetting

A trial was undertaken to investigate the practicability of measurements with a mobile retroreflectometer and continual wetting conditions.

The mobile retroreflectometer available for the trial consisted of a car with a Zehntner ZRD 6020 dynamic retroreflectometer mounted on the outside of the car approximately mid-way along the bottom of the rear door. The dynamic retroreflectometer can be mounted on the driver's side of the car if measuring centrelines for example, or, as shown in figure A.1, mounted on the passenger's side of the car for measuring edgelines, as was done in the trial.

Figure A.1 Mobile retroreflectometer

The dynamic retroreflectometer makes its measurements 6 m ahead of itself, which is about 3 m ahead of the front of the car. The operator set the dynamic retroreflectometer for measuring an area approximately 1 m wide straddling the roadmarking and 1 m along the roadmarking length. Retroreflectivity readings can be performed at a rate of 600 Hz and under typical operating conditions, an averaged value is calculated on the basis of 50 m or 100 m sections. For the trial, an averaged value was calculated for each 1 m of edgeline length.

The method was:

1 Measurements in the dry condition were made by the operator driving the mobile retroreflectometer in the regular manner, though at a very slow speed, with a dry road surface.

2 Measurements in the continual wetting condition were made by the operator driving the mobile retroreflectometer while two assistants sprayed water from watering cans over the roadmarking while moving in synchronicity with the forward movement of the mobile retroreflectometer to maintain the measurement area being coincident with the area of wetting. (The operator of the mobile retroreflectometer could observe an image of the measurement area in real time through a monitor in the vehicle cabin and so could adjust the car position to also assist in maintaining synchronisation between the measurement area and the area of wetting.)

3 Measurements in the wet condition were made by the operator driving the mobile retroreflectometer in the regular manner within approximately one minute of the continual wetting condition

measurements. The edgeline was wet but had some time to ‘recover’ compared with the continual wetting condition.

A local length of roadway was identified where sections of edgelines suitable for measuring included ATP roadmarkings, non-profiled paint-type roadmarkings, and structured or ‘splatter-type’ structured roadmarkings. Samples of the three roadmarking types are shown in the figure A.2. Note these are not ‘ideal’ examples but photographs representative of the edgelines measured.

Figure A.2 Samples of the three roadmarking types measured

ATP roadmarking (Raised ribs on structured line)

Non-profiled roadmarking

Structured roadmarking

The specifications for the mobile retroreflectometer state it measures retroreflectivity values (R_L) in the range 0 to 4,000 mcd m^{-2} lux^{-1}. However, the operator’s experience was that the mobile retroreflectometer required some threshold contrast between the roadmarking and the road surface and in practice the mobile retroreflectometer recorded readings only above about 30 to 35 mcd m^{-2} lux^{-1}. From previous measurements of retroreflectivity using a static retroreflectometer, typical retroreflectivity values were about 10 mcd m^{-2} lux^{-1} in dry conditions and 10 to 20 mcd m^{-2} lux^{-1} in wet conditions.

The mobile retroreflectometer is specialised equipment and was hired for just one day for the trial. Traffic control requirements allowed only limited time for measurements at each location and locations had to be nominated ahead of time of the trial. Therefore, it was not possible to pilot the method nor spontaneously alter measurement locations during the trial.

As part of preparing for the trial, the locations were visited prior to the day of the mobile retroreflectometer measurements. That visit was without traffic control and so it was not possible to closely inspect the three roadmarking types but ‘drive-by’ observations conducted in daylight indicated the roadmarkings were readily visible. The drive-by observations were supported by observations while on-site with the mobile retroreflectometer, as indicated by figure A.3. In 2011, the operator of the mobile retroreflectometer had measured the dry retroreflectivity at the measurement sites used for this project and at that time all three roadmarking types had retroreflectivity of 300 mcd m^{-2} lux^{-1} or greater. Expectations were the roadmarkings would be satisfactory for measurement with the mobile retroreflectometer.

Figure A.3 Long view of an ATP roadmarking measurement site

Table A.1 shows the results obtained with the mobile retroreflectometer. For each of the three conditions of dry, wet, and continual wetting the table shows the average of the retroreflectivity values obtained and the rate of reading success determined as the percentage of metres measured for which viable average retroreflectivity values were registered by the mobile retroreflectometer.

Table A.1 Retroreflectivity measurements from three roadmarking types in three conditions

		ATP roadmarking	Non-profiled paint-type roadmarking	Structured roadmarking
Dry condition	Retroreflectivity, mcd/m²/lux	72	120	63
	Rate of reading success, %	100	99	99
Wet condition	Retroreflectivity, mcd/m²/lux	49	-	47
	Rate of reading success, %	83	-	39
Continual wetting condition	Retroreflectivity, mcd/m²/lux	54	-	54
	Rate of reading success, %	19	-	32

1 For all three roadmarking types in the dry condition, average retroreflectivity values were obtained from the mobile retroreflectometer at a rate of almost 100%, representing one value per metre of edgeline length as expected. The dry retroreflectivity expected of New Zealand white roadmarkings is generally 100 mcd m^{-2} lux^{-1}. The dry retroreflectivities of the ATP roadmarking and structured roadmarking are poor and well below expected.

2 In the wet condition, no retroreflectivity readings were obtained from the non-profiled paint-type roadmarking indicating the retroreflectivity was consistently below the 30 to 35 mcd m^{-2} lux^{-1} threshold outlined by the operator of the mobile retroreflectometer. For the retroreflectivity readings obtained from the ATP roadmarking and structured roadmarking, the average retroreflectivity values were about the same, but for interpretation this needs to be paired with the rate of reading success being significantly higher for the ATP roadmarking.

3 In the continual wetting condition, no retroreflectivity readings were obtained from the non-profiled paint-type roadmarkings. For the retroreflectivity readings obtained from the ATP roadmarking and the structured roadmarking, the average retroreflectivity values were the same. The rate of reading

success was fairly low for both these roadmarking types but was higher for the structured roadmarking than for the ATP roadmarking.

Overall the results of the retroreflectivity measurements in the dry condition were disappointingly low and the incomplete result set shown in table A.1 limits the conclusions that can be made.

With regard to the ATP roadmarkings as the focus of this project; these are roadmarkings reputed to have 'long life' and the dry condition results indicate there is a pronounced reduction in retroreflectivity over time.

Speculating as to the relative performance in the three measurement conditions, it is noted the average dry condition retroreflectivity of the non-profiled paint-type roadmarking was greater than the average dry condition retroreflectivity of the other two roadmarking types yet no retroreflectivity readings were obtained for the non-profiled paint-type roadmarking in the wet or continual wetting conditions, whereas readings were obtained from the other two roadmarking types. This is in line with expectations that the raised/high-build elements of the ATP roadmarkings and structured roadmarkings are fundamental to assisting shedding of water.

The continual wetting condition method used was not tested with roadmarkings of high retroreflectivity to demonstrate that the wetting method itself was not interfering with the mobile retroreflectometer. However, a few readings were obtained. Development of the wetting method for the continual wetting condition focused on ensuring the wetting covered the measurement area of the mobile retroreflectometer. However, by mistake, calculation of the wetting rate was neglected until after the on-site measurements. The wetting rate was about 380 mm/h and this wetting rate is acknowledged as extreme and far in excess of wetting rates that may be expected from heavy rainfall events. It could be proposed that the apparently-extreme wetting rate recognises the continual wetting condition method does not allow for any effect of rain falling in the approximately 6 m distance between the retroreflectometer and the roadmarking (and return for a total of about 12 m). Further, the retroreflectometer is set up for representation of a 30 m geometry, that is the situation of vehicle headlights onto a roadmarking 30 m ahead then the light returning about 30 m to the vehicle-driver's eyes, which during falling rain would be light travelling and rain scattering the light beam through a total of about 60 m. But still the wetting rate used was probably too heavy. Wetting rates and properties of rain have been the focus of much other work, including as discussed in chapter 3. Some work considers fundamentals such as raindrop size and uniformity or distribution, and speed and direction of falling; indicating how complex realistic simulation of falling rain may be. Achieving a reasonable wetting rate evenly over the measurement area would require a fine dispersion of water and achieving this in outdoor conditions (including wind) would need specific investigation outside the resources or scope of this research project.

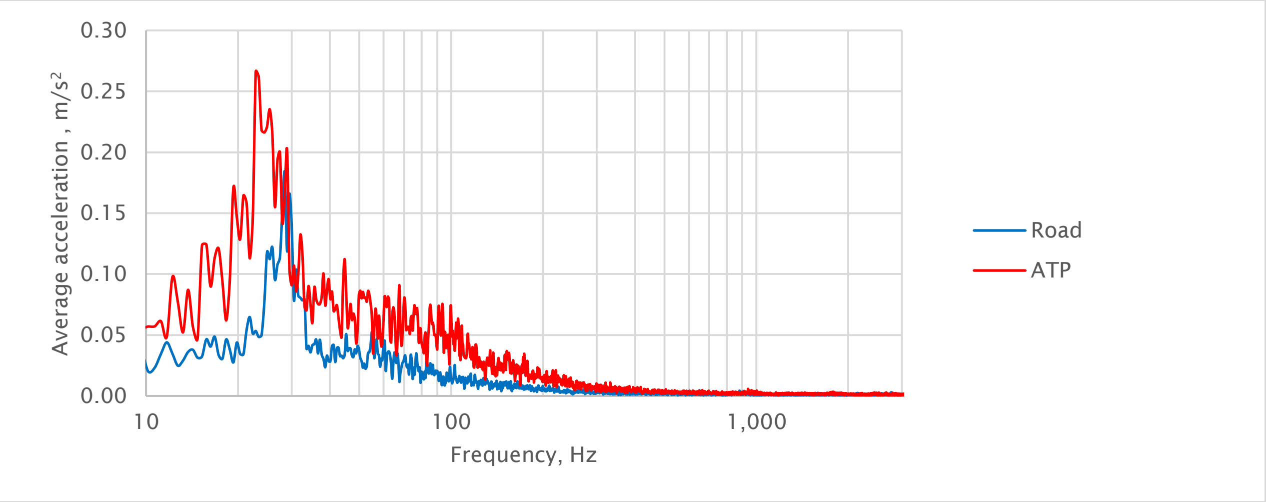
Appendix B: Measurement of tactile effects

During the December 2013 measurements of audio effects, tactile effects were also measured. They were logged, selected and analysed as the audio effects were (as described in chapter 4). Tactile effects were measured with a triaxial accelerometer mounted on the passenger-side dashboard, as shown in figure B.1. It is acknowledged this may be a compromised representation of the driver's experience of tactile effects. The driver has multiple points of contact with the vehicle (including the driver's seat, pedals, footwell and steering wheel) through which tactile effects may be transmitted, albeit with damping. The single accelerometer has only one point of contact and at a point not shared with the driver. This project was to measure tactile effects of ATP roadmarkings in a similar way as Dravitzki et al (2007), who measured tactile effects of ATP roadmarkings with the accelerometer mounted on the central moulding around the drive shaft near the passenger's footwell. Dravitzki et al (2007) adopted this position after trialling other mounting positions on the steering wheel and steering column. The passenger's footwell position is favoured as responsiveness to tactile effects is similar to the other positions trialled but has less impedance or potential interference to the driver. It was intended for this research project to also mount the accelerometer near the passenger's footwell. However, mouldings and materials of the hired vehicle's interior inhibited mounting of the accelerometer other than as shown in figure B.1.

Figure B.1 **Accelerometer mounted on the dashboard**

During the December 2013 measurements, acceleration rates were measured in three dimensions. The vertical acceleration rates are taken as giving the clearest indication of tactile effects. Figure B.2 shows spectral analysis of the vertical acceleration obtained during travel on the ATP roadmarking and obtained during travel on the adjacent road surface. These results are from just one site found representative of the results obtained from other measurement sites.

Figure B.2 Spectral analysis of one second in-vehicle samples from vehicle travel on the road surface and ATP roadmarking



The frequency distributions of responses shown in figure B.1 are affected by the individual vehicle's damping and resonating characteristics through the path of transmission to the accelerometer mounting position. The magnitude of total vertical acceleration is clearly larger while the vehicle is travelling on the ATP roadmarking compared with the vehicle travelling on the adjacent road surface. This matches the subjective response to the driver and passenger in the vehicle during measurements.

After comparing measurements of tactile effects and measurements of audio effects, it was considered reasonable to measure just audio effects. This matched Dravitzki et al (2007) who found 'excellent correlation between the sound and vibration measurements, indicating that sound and vibration levels change together' and suggest 'this may have implications for simplifying the audio tactile profiled roadmarking performance testing procedure, where measurement of only one of vibration or sound is necessary to estimate the overall performance of the roadmarking'.

Currently the equipment suggested for measurement of audio effects, being a sound level meter, appears more readily widely available than the equipment suggested for measurement of tactile effects, being an accelerometer. Also experiences of this research project indicated in-vehicle mounting and response of the sound level meter appeared more consistent between different vehicles compared with in-vehicle mounting and response of the accelerometer. The experience of the driver and passenger involved in the measurements to date was that their subjective assessment of audio effects was more sensitive to variations in magnitude and frequency than their subjective assessment of tactile effects, though this could be specific to the vehicles and individuals involved.

Bucko and Khorashadi (2001) report in-vehicle sound and vibration measurements made during a vehicle traversing a range of ATP roadmarkings paired with subjective ratings of sound and vibration from test drivers traversing the range of ATP roadmarkings. 'The test drivers concluded that the sound produced from the strips had a greater effect in alerting a driver than the vibration produced by the same rumble strip' and 'the test drivers concluded that the vibration felt through the steering wheel was negligible in alerting the vehicle driver compared to the sound level produced while driving over the rumble strips'.

From the December 2013 measurements, it was concluded sufficient for further measurements of ATP roadmarkings proposed within the project to use sound level measurements as a proxy for both audio and tactile effects. Dravitzki et al (2007) similarly suggest 'measurement of only one of vibration or sound is necessary to estimate the overall [audio and tactile] performance of the roadmarking'.

Appendix C: Method of driving and measurements

During the measurements reported in chapter 1, while the driver was holding the vehicle to travel along the ATP roadmarking, the driver and passenger subjectively noted variations in the strength of audio and/or tactile effects. It was sometimes unclear if this was due to inconsistent contact with the ATP roadmarking or due to variations in the ATP roadmarking itself. The method for analysis of the measurement samples then averages results from one second of the total logged measurement period, thereby removing effect (or evidence) of any longitudinal variation. However, as ATP roadmarking audio/tactile effects will be judged on a largely relative basis, longitudinal variation could be a significant consideration. Subjective ratings or impressions of the longitudinal variation could be obtained, or objective measurements could be used. Figure C.1 shows a continuous record of sound level readings during measurements of resealing over example 4 (section 4.2.4). Prior to driving on the reseal over ATP roadmarkings, within the same continuous record, a set of ATP roadmarkings in good condition was driven over. Audio of these good condition ATP roadmarkings was recorded between approximately reading 40 and reading 150. Between reading 150 and 250 is a length of transition, then readings from the length with reseal over ATP roadmarkings follow for the remainder of the record.

Figure C.1 Continuous record of sound level readings during measurements of reseal-over example 4 (section 4.2.4)

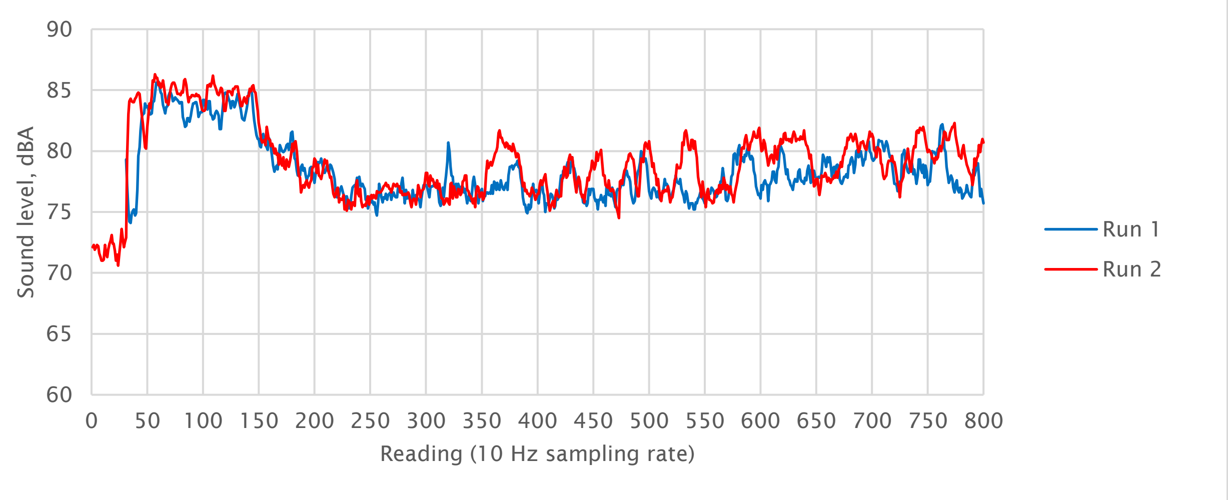


Figure C.1 indicates the driver can make fairly consistent and repeatable contact with the ATP roadmarking when it is in good condition. A good condition ATP roadmarking provides clear and immediate feedback to the driver to reinforce when good contact is being made.

Where the ATP roadmarking audio/tactile effects are less clear, it can be difficult for the driver to discern whether feedback is low because the ATP roadmarking effects themselves are low, or if feedback is low because the vehicle is making poor contact with the ATP roadmarking. However, this may be conclusive in itself with regard to subjective ratings, as if the effects are difficult for the driver to discern when that driver is focused on their detection, then clearly the effects could be considered and rated insufficient for typical conditions.