Chipseal trial strategy

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Subject	**Task 3: Chipseal trial strategy**	

This memo investigates trials that could be initiated during the 2020/2021 sealing season to study themes around road traffic noise generation from chipseal surfaces. This investigation incorporates findings from recent research to develop experimental plans that will contribute to our understanding of chipseal surfaces and their generation of road traffic noise. The document is structured to look at the following:

1. A look at potential trial sites based on forward works programmes for the 20/21 financial year.
2. An investigation into the predominant surfaces on the State Highway (SH) network and the current and future trends in chipseals.
3. A discussion of other themes which may warrant investigation through trialling.
4. Potential trial layout plans to provide chipseal trials and corresponding controls.
5. Conclusions and recommendations.

1 Potential trial locations

This section looks where potential trial sites could be located. There is an assumption that the sites will be located within the North Canterbury Network Outcome Contract (NOC) area as the instrumentation used for taking close proximity (CPX) measurements is operated out of Christchurch. It is also assumed that each trial site will be located on a section of road with a 100 km/hr posted speed limit to allow for research at a range of speeds.

1.1 Potential measurements

There are various measurements that will be required at the trial sites and the specific characteristics of the sites may limit how effectively these measurements can be made. The measurements likely to be required at the trial sites and some of the related considerations are:

- Close proximity (CPX) measurements. CPX measurements are taken from a trailer towed over the trial road section. Ideally the section of road being tested would be reasonably flat, straight, and open to allow for consistent speed and positioning of the trailer during multiple passes over the site.
- Statistical Pass-By (SPB) measurements. SPB measurements are made at the road side and should be made as per ISO 11819-1:1997. That standard requires that the surface being measured extends a minimum of 50 m either side of the measurement position, i.e. minimum seal length of 100 m. The standard also requires that the microphone is located at a distance of 7.5 m from the centre of the nearby lane and that there are no barriers located 10 m behind or to the side of the microphone. There are also requirements about the composition of the shoulder between the lane being measured and the microphone. Past research (Jackett, 2019) found that more research is required before the CPX data can be relied upon alone to predict changes in wayside noise levels. Hence SPB and CPX data

are both likely to be required. As with CPX measurements, the ideal site would likely be flat and straight with large unobstructed shoulders.

- There are likely to be measurements which require direct access to the road surface which will require some form of traffic management to facilitate. While not essential, a flat straight and open site will make traffic management simpler.

Along with the above considerations a flat and straight site should also aid in the specific measurement of road-tyre noise, as opposed to other sources of vehicle noise such as engine and drivetrain noise. A discussion of potential sites from the North Canterbury NOC are given below in Section 1.2 with a focus on predominantly straight and flat sites.

1.1 Forward works program

The CPX trailer is currently stored and operated out of Christchurch and thus far the noise research programme has focused on the State Highway network in the adjacent NOC. Many of the roads on this network also lend themselves to these trials as they are predominately straight and flat on the Canterbury Plains.

A draft version of the forward works program for the North Canterbury NOC has been obtained and investigated for potential trial locations. There are a total of 118 sites in the forward works plan where chipseals are to be laid during the 20/21 season. At the time of writing, the forward works program had not been entirely confirmed, however the information still gives a good indication of potential trial sites. The breakdown of the proposed treatments has been shown in the charts in Figure 1. From Figure 1, it can be seen that the proposed treatments are dominated by wet lock seals with grade 2/4 and 3/5 chip.

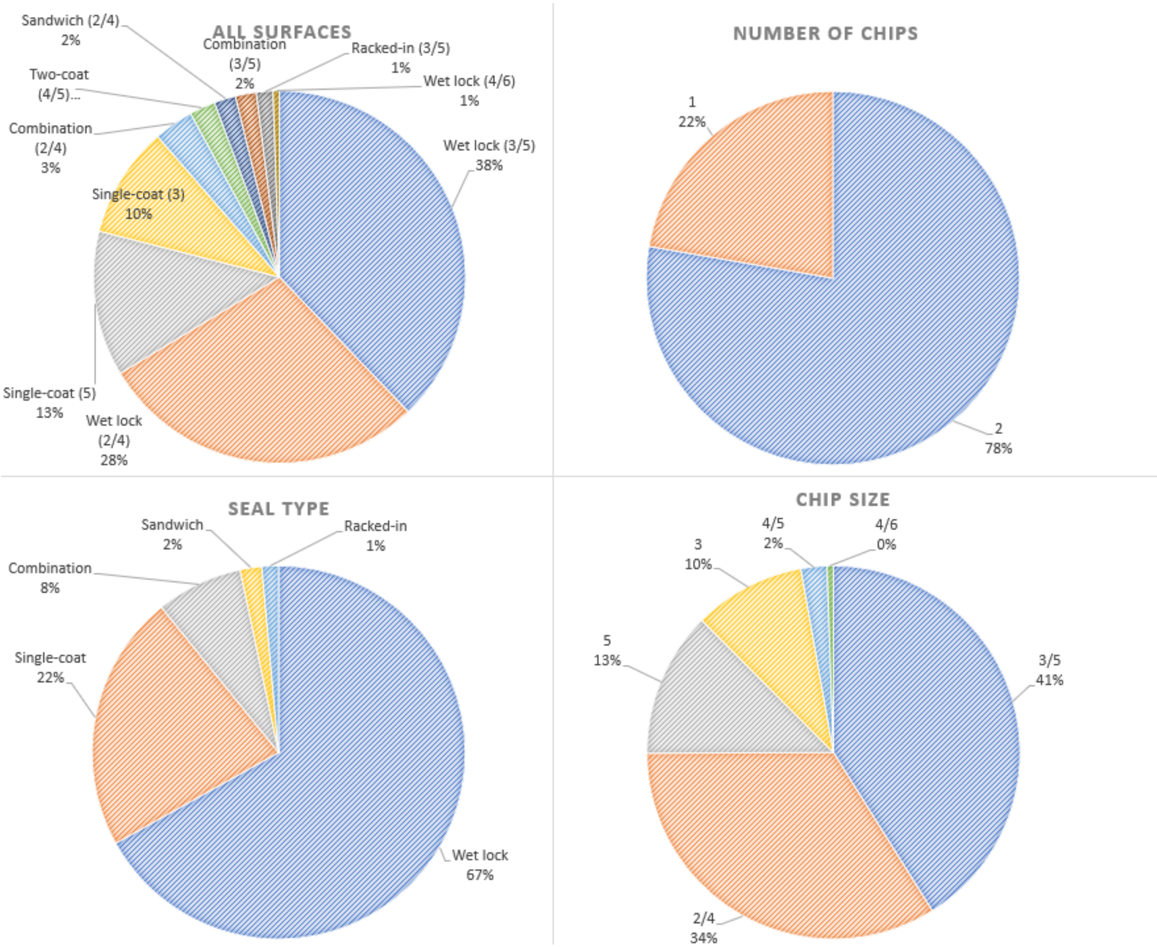

Figure 1. Charts showing the breakdown of proposed treatments for the 20/21 season for the North Canterbury NOC.

1.2 Location

The North Canterbury NOC area has been shown below in Figure 2.

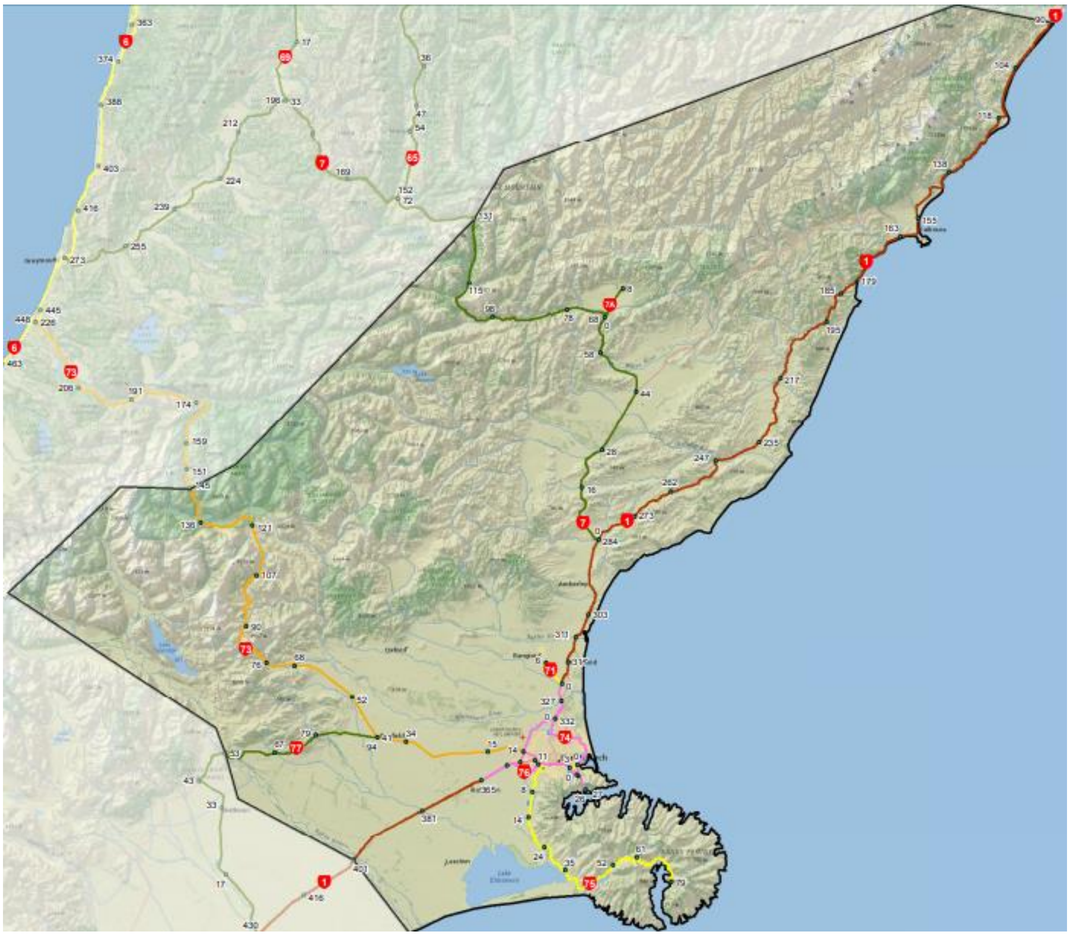

Figure 2. North Canterbury NOC area.

The worksites in the forward works program for the North Canterbury NOC are confined to five state highways (07, 01S, 73, 75, and 77). To provide an initial scan of the potential trial sites the list was narrowed to only include sites on the Canterbury Plains, i.e. SH 01S south of the Hundalee Hills, SH07 south of Culverden, SH 73 East of Springfield, SH 75 North of Motukarara and SH 77 North of Windwhistle. Each of the remaining sites were then investigated individually and the more promising sites are listed in Table 1 below. Adjacent worksites have been grouped in the table with the total lane length and the proposed treatment shown. A commentary has also been given on each of the sites listed.

Table 1. Potential trial sites from North Canterbury forward works plan.

State Highway RS	Start	End	Lane metres	Current surface	Proposed treatment	Comment
007-0016	6570	8930	4720	1 CHIP 3	3/5 Wet lock	Section of SH 01S through Hurunui just south of the Balmoral Straight. Some houses on the northern end of the site, but sufficient length available to avoid disturbance to these. The site has some large radius curvature. There is some moderate gradient in between 6570 and 6700 (around 2.5%) although the remainder of the site is generally within +/- 1 %. Traffic volume of 3,700 with 17 % heavies.
007-0016	8930	9365	870	1 CHIP 3 & 2 CHIP 3/5	3/5 Wet lock	
007-0016	9365	10550	2370	1 CHIP 3	3/5 Wet lock	
007-0028	1015	1620	1210	2 CHIP 3/5	5 Single	Section on the southern end of the Balmoral Straight. Nice straight piece of road with closest house approximately 2 km away. Some gentle undulations, max 4% gradient. Traffic volume of 3,700 with 17 % heavies.
007-0028	1620	1740	240	2 CHIP 3/5	5 Single	
007-0028	1740	2190	900	2 CHIP 3/5	5 Single	
01S-0235	10050	11550	3000	2 CHIP 2/4 & B/S RESEAL 4/5	3/5 Wet lock	Immediately north of Cheviot. On a hill with gradient around 4-5 %, There are houses at each end of the section. There may an approx. 400 m section that is reasonably flat and the hill provides protection to nearby houses. Traffic volumes of 2,600 with 19 % heavies.
01S-0247	3465	4030	1130	B/S RESEAL 3/5	2/4 Two-coat	Reasonably steep and windy section of road just south of the Hurunui River. Poor access adjacent to the road in some sections. A few houses on the route. There is an approx. 700 m straight and flat section however it has a house at one end. Traffic volume of 2,900 with 19 % heavies.
01S-0247	4030	5200	3510	B/S RESEAL 3/5	2/4 Two-coat	
01S-0247	5200	5295	190	B/S RESEAL 3/5	2/4 Two-coat	
01S-0247	5295	6456	2322	2 CHIP 3/5	3 Single	
01S-0262	5880	9995	8230	1 CHIP 5	3/5 Wet lock	Long stretch of SH 01S from 5 km south of Greta Valley to Omihi. Parts of the route with reasonable separation to the nearby houses. Reasonably flat road with a constant gradient around 2 %. Traffic volume of 3,800 with 15 % heavies.
01S-0381	1400	1520	360	2 CHIP 3/5	2/4 Wet lock	Section of SH 01S just north of Dunsandel. Dead straight and flat. Potentially a 1 km section of road with minimal impact on nearby houses. Very busy section of road with traffic volumes of 14,000 with 15 % heavies.
01S-0381	1520	1690	510	2 CHIP 3/5	2/4 Two-coat	
01S-0381	1690	2450	3040	2 CHIP 3/5	2/4 Two-coat	
01S-0381	2450	2550	300	2 CHIP 3/5	2/4 Two-coat	
01S-0381	2550	2760	420	2 CHIP 3/5	2/4 Two-coat	
073-0034	3108	4004	1792	2 CHIP 3/5	2/4 Wet lock	Just east of Darfield. Dead straight and flat. One house near the middle of the road section but reasonable separation from the road. Traffic volume of 5,700 with 13 % heavies.

1.3 Surface performance and disturbance considerations

Some consideration will need to be given to the performance of the chipseal surfaces from more than just a noise perspective. It is likely that some level of negotiation will be required with the NOC contract partners and Waka Kotahi NZ Transport Agency to find a balance between the preferred treatment and a potentially lower performing (overall) surface which provides good noise research opportunities. Another benefit of choosing straight and flat sections of road is that the stress exposure and skid resistance requirements of such sites are likely to allow for a wider range of surfaces to be acceptable.

There is some potential that the road-tyre noise generated by a surface trial may cause a significant level of disturbance to nearby residences or other sensitive receivers, particularly if multiple treatments are to be trailed at a single site. Changes in noise level and tone created by the different surfaces (and potential seal join issues if poorly constructed) could cause annoyance at nearby residences, even if the base noise levels are not at the levels normally associated with disturbance. A note has been made of nearby residences or other sensitive receivers in Table 1.

2 Predominant chipseal surfaces – SH Network

Information on the chipseal surfaces used on the SH network have been extracted from the RAMM database[1] and are shown below in Figure 3. Figure 3 shows the breakdown of all surfaces as well as by number of chips, surface type and chip size.

This same breakdown has been performed on the chipseal surfaces on the SH network that were laid in the 19/20 season. The breakdown for the 19/20 season is shown below in Figure 4.

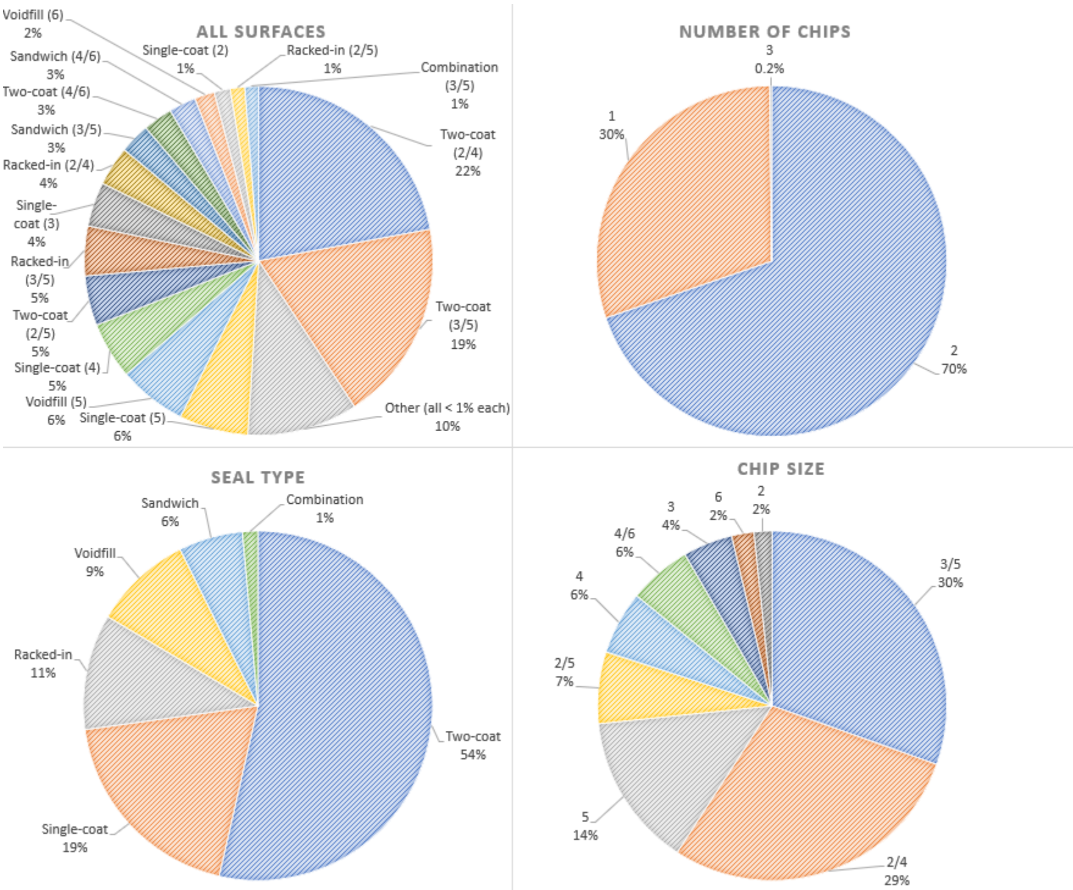

Figure 3. Breakdown of the chipseal surfaces on the state highway network.

[1] Some assumptions were used when tidying this data to avoid errors in the RAMM database. The data is accurate enough to provide a view to the chipseal surfacing trends on the SH network.

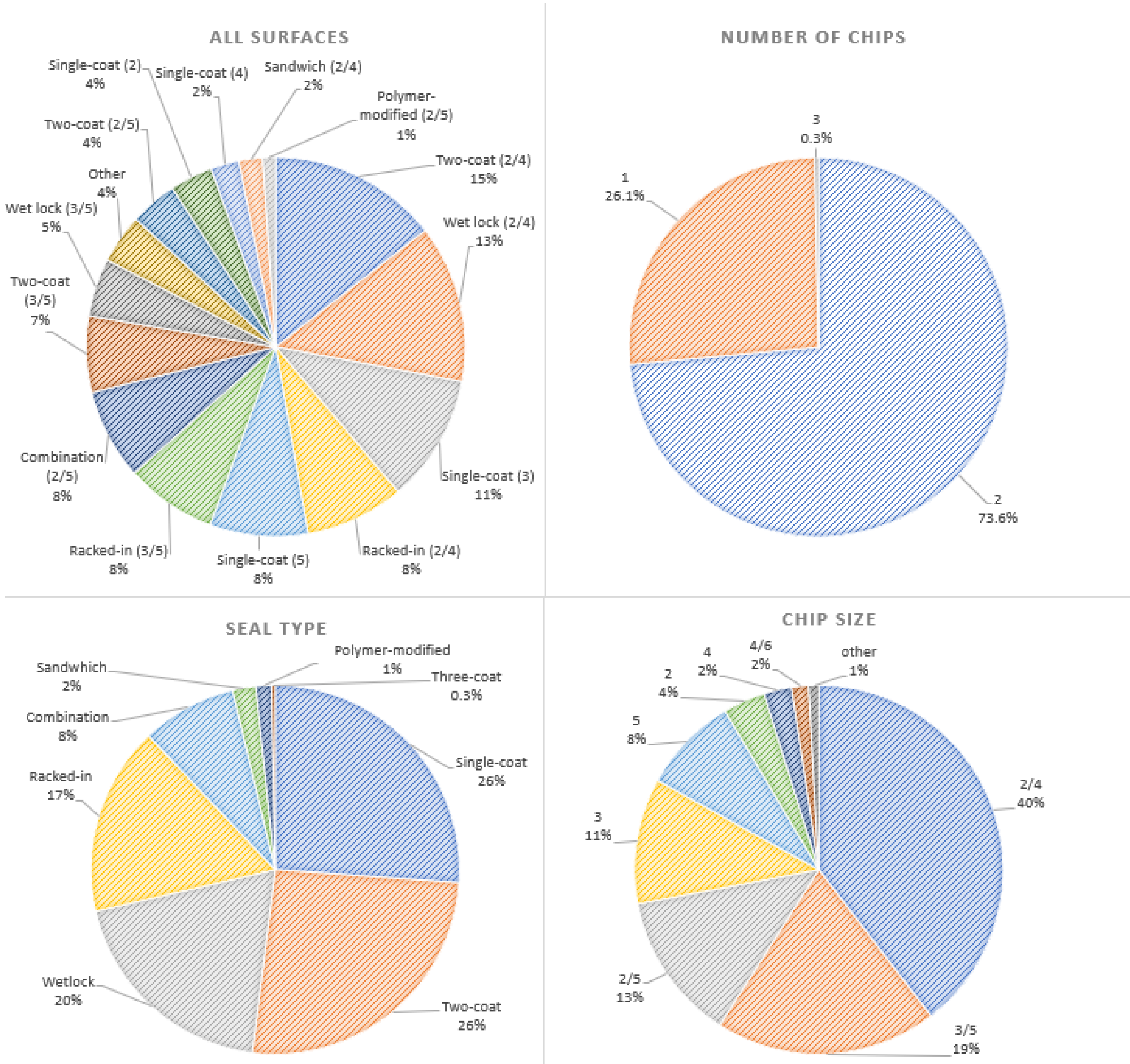

Figure 4. Breakdown of the chipseal surfaces laid on the state highway network in the 19/20 season.

From Figures 3 and 4 it can be seen that 70% of the current chipseal surfaces on the SH network contain 2 chip sizes and this trend was reflected in the 19/20 construction season with around 74% of chipseal surfaces containing 2 chip sizes. This is despite the Waka Kotahi NZ Transport Agency's stated preference for single-coat chipseals (more on this in section 2.2).

The SH network appears to be dominated by conventional two-coat chipseals although in the 19/20 season it appeared that there was shift towards seals containing two chip sizes being evenly divided between conventional two-coat seals, racked-in seals and wet lock seals. The SH network has a reasonably even split between grade 3/5 and 2/4 seals making up 30% and 29% of the chipseal surfaces respectively. The 19/20 financial year data shows a trend towards grade 2/4 seals with them making up 40% of the new surfaces laid as opposed to 19% for grade 3/5 seals.

Of the single coat seals used, grade 5 based seals (single coat and voidfill) are the most popular on the SH network making up 14% of the chipseal surfaces. Grade 3 based seals only make up 4% of the chipseal surfaces on the SH network. These trends seem to be changing in the 19/20 season with grade 3 based seals making up 11% of the seals laid and grade 5 based seals only making up 8% of the new surfaces.

2.1 Wet lock seals

The data on wet lock surfaces may be causing some confusion. The current SH network does not show any wet lock seals whereas the 19/20 season shows 20% of the newly laid surfaces were wet lock. The proposed seals for the 20/21 season on the North Canterbury NOC also show 75% of the surfaces being wet lock seals. Discussion with experienced people within the industry revealed that:

- Conventional two-coat seals are regularly, incorrectly, called wet lock seals by some contractors.
- A wet lock seal can sometimes refer to a reseal where two new layers of chipseal are laid in quick succession, i.e. over the course of two days. Or, wet lock can also refer to a new single coat of smaller chips laid over a larger chip which was laid years beforehand.

It has been confirmed that the proposed 20/21 wet lock seals on the North Canterbury NOC are in fact wet lock seals, as opposed to conventional two-coat seals. The proposed 20/21 wet lock seals on the North Canterbury NOC also appear to be two layers of chips placed in close succession rather than a new layer of small chip over an existing, larger chip.

2.2 NZTA sealing strategy

Waka Kotahi NZ Transport Agency have a policy of promoting the use of single coat chipseals with the goal of increasing seal life and reducing the need for reseals, particularly those caused by a lack of texture from two-coat seals. Despite pressure from Waka Kotahi NZ Transport Agency it appears that the NOC contracts are still predominately using multi-coat seals, as can be seen from 19/20 sealing data in Figure 4 and the proposed sealing work on the North Canterbury NOC in Figure 1.

If the NZTA strategy for a larger proportion of single coat seals becomes reality, it is likely that a strategy of alternating chip sizes between seals will become popular. For instance, an old single-coat grade 2 surface would be resealed with a single-coat grade 4 seal to in effect create a two-coat or wet lock grade 2/4 seal. The following reseal would then be with a single-coat grade 2 seal to continue the cycle. Gathering information on the noise performance of these types of seals (particularly with a new small chip layer over an old large chip layer) may be useful.

This combination of the Waka Kotahi NZ Transport Agency single-coat strategy versus the actual multi-coat seals being laid make it difficult to focus trials to provide the best value for the future.

3 Trial themes

This section narrows down potential themes that could be investigated during the chipseal trials.

3.1 Surface type

To cover the predominant surface types seen on the SH network, and the majority of those used in the 19/20 season, single-coat, two-coat and racked in seals should all be investigated. Some effort could also be spent on investigating wet lock seals, although the other seal types should take precedence for trialling.

Single-coat and two-coat chipseals have conventionally been studied for road-surface noise, although, less research has been done on racked-in seals. Racked-in seals have two layers of chips but only one layer of binder. The first layer of chips is more widely spaced than those in a conventional two-coat seal which allows for larger areas of exposed binder being available for the smaller chips to fit into and bind to the surface. Racked-in seals are used in “difficult conditions where other seals are not suitable, and where loose chip from two coats cannot be tolerated” (Chipsealing in New Zealand, 2005). The different construction of these racked-in surfaces and the related effect on macro-texture may affect the tyre-noise generation.

Previous research, (Jackett, 2019) found that corrections used for modelling noise from chipseal surfaces in New Zealand may need some refining. With the ability to take CPX and SPB noise measurements at a number of well controlled sites, these trials would be a good opportunity to further investigate the surface corrections.

Summary:

- Focus on trialling single-coat, two-coat and racked-in seals.

3.2 Chip size and shape

The predominant chip sizes for surfaces containing two chip sizes are grade 2/4 and grade 3/5. The predominant chip sizes for single chip surfaces are grades 3 and 5. These chips sizes should make up the majority of the trial surfaces, particularly if there is an effort to refine the road surface corrections for some surfaces.

As part of the research mentioned in section 3.1 that found that the surface corrections may need refinement, it was also hypothesised that "the noise emission of the two-chip surfaces is dominated by the larger chip size". These trials may present a good opportunity to investigate this hypothesis in close detail.

Recent research (Jackett and Bagshaw, 2020) considered the possibility that the shape of the aggregate used in chipseals may have an impact on the macrotexture secondary to that of chip size, and therefore on the noise produced by the surface. Here we are assuming the shape of a chip is defined primarily by the ratio of the Average Greatest Dimension (AGD) to the Average Least Dimension (ALD). The angularity has not been included for this study due to the tight criteria on angularity that already exist in the Waka Kotahi NZ Transport Agency specification M06 (NZTA M06, 2011).

An effective study of the chip size effects on noise would require involvement from a willing quarry. Ideally four batches of aggregate (nominally the same batch and grade) would be supplied by the quarry as below:

1. Normal distribution of AGD/ALD (within M6 specification for relevant grade).
2. AGD/ALD **above** a defined threshold (but below a ratio of 2.25 as required by M06 spec). To ensure the aggregate is within a reasonably tight size range the batch should meet the grade dependant M06 requirement of the least dimension of the chips being within 2.5 mm of the ALD.
3. AGD/ALD **below** a defined threshold. To ensure the aggregate is within a reasonably tight size range the batch should meet the grade dependant M06 requirement of the least dimension of the chips being within 2.5 mm of the ALD.

The logistics of producing these batches of aggregate are likely to be difficult and will require close relationship between those running the trials and the quarry. The recorded data on chip shape and other M06 requirements will need to be recorded and supplied by the quarry as not all of this data is mandatory for entry into the RAMM database.

Summary:

- Focus on trialling seals with grade 2/4, 3/5, 3, and 5 chips.
- Investigate whether the largest chip size in a multi-chip seal dominates noise.
- Investigate the effect of chip shape if data allows.

3.1 Construction effects on noise

Discussion with industry experts revealed two construction technique variations which could potentially have an impact on the noise generated by chipseal surfaces. These are, rolling of the first coat of a multi-chip surface prior to the second coat, and the use of purpose-built chip spreaders.

Rolling the first chip in a multi-chip seal has the effect of 'settling' the chips into their lowest configuration. This results in a tougher, smoother surface with less macro-texture and surface noise (Chipsealing in New Zealand, 2005). Trials could be reasonably easily organised to investigate the difference in noise achieved by this construction method while the annual network survey could be used to track the texture.

Chipseal aggregates are spread over the site during construction using two general methods, using a truck tailgate mounted device with some level of mechanisation to assist with spreading and control, or a standalone self-propelled chip spreader. While the standalone chip spreaders are more expensive and logistically challenging, they can achieve greater speed and spread width, and have a more controlled application of aggregate. The more controlled spread of aggregate is partly due to the operation of the machine but also because only one machine is being used, as opposed to tail gate spreaders where multiple trucks are used for each section of seal. There is some thought that the more consistent spreading of chip achieved by the self-propelled chip spreader could have an impact on the macro-texture and therefore the noise generating properties of the surface. As with trials of rolling between chip coats, trials of self-propelled chip spreaders could be trialled reasonably easily.

Summary:

- Trial the effect of rolling the first coat of multi-chip surfaces.
- Trial the effect of using of self-propelled chip spreaders.

3.2 Other potential investigations

The Waka Kotahi NZ Transport Agency strategy for promoting single-coat seals cites the increased rate of reseals being required on multi-coat seals due to a lack of texture. This decrease in texture with age on multicoat seals is likely to be highly variable and dependant on a number of factors such as traffic volumes and stress. This decreasing texture is likely to be causing changes to the noise properties of the surfaces and it would be useful to understand these changes for predicting long-term noise performance of multicoat surfaces and for filtering out non-representative CPX data. Annual SH survey data could be used to track the texture against noise performance. Due to the highly variable nature of the decreasing texture this effect has not been recommended for further investigation in this surface trial.

There has been some discussion about the effect of temperature on the potential noise properties of surfaces. There is some thought that the volume and stiffness changes in most binders related to temperature may affect the noise properties. This study could include Polymer Modified Binders (PMB) as these remain relatively hard throughout temperature changes. This has not been recommended for further investigation here.

4 Trial strategy

It will be important that all data relevant to the performance of trial seals are collected to ensure the knowledge gained from the trials can be maximised. Some of the data which may be important is given below:

- Chip size: ALD, AGD, grading, distribution
- Other chip properties: source, polished stone value (PSV), shape (AGD/ALD ratio)
- Binder properties:
- Meteorological information: ambient temperature, days since last rain,
- Surfacing method: Racked-in, two-coat, etc

- Construction parameters: chip application rates, chip application method, binder type, binder temperature, binder application rate, roller mass, roller frequency, roller strategy (timing and number of passes) etc.
- Information on the early traffic loading on the surface: speed, distribution across the surface, volumes etc.
- This list is not exhaustive and any trials should be specifically designed.

Table 2, below, shows some information on potential layout plans for trial sites to ensure comparisons can be made between surfaces and meaningful conclusions can be drawn from the trials. These layout plans are not intended to be complete, or to represent all of the trials which may be undertaken, but rather to help in the trial planning process. A summary of the potential trial goals is given below:

A. Focusing on a comparison between two-coat, racked-in and wet lock seals. An investigation in the effect of chip spreading and the dominance of the largest chip size has also been included.

B. Focusing on investigating the effect of chip spreading, rolling between chip layer applications and the dominance of the largest chip. These surfaces could also be used to investigate surface corrections used for noise modelling.

C. Focusing on investigating chip grading effects.

D. Focusing on investigating the chip shape, in particular the AGD/ALD ratio.

Table 2. Potential trial layout plans.

Site	Trial surface	Materials	Construction	What are we investigating?
A				
(1)	Single-coat Grade 3.	Same batch and source of grade 3 and grade 5 aggregate used throughout. Same binder used throughout (unless separate binder required for wet lock seal).	Self-propelled chip spreader used and conventional rolling.	For comparison between chip spreading devices (1) / (2)
(2)	Single-coat Grade 3.		Tailgate mounted chip spreading and conventional rolling.	For comparison of chip spreading device (1) / (2). To investigate dominance of largest chip with (2) / (3), (4) & (5).
(3)	Grade 3/5 Two coat.		Tailgate mounted chip spreading and conventional rolling.	For investigating dominance of largest chip (2) / (3), (4) & (5). For comparison between two-coat, racked-in and wet lock seals (3) / (4) / (5)
(4)	Grade 3/5 racked-in.		Tailgate mounted chip spreading and conventional rolling.	For investigating dominance of largest chip (2) / (3), (4) & (5). For comparison between two-coat, racked-in and wet lock seals (3) / (4) / (5)
(5)	Wet lock grade 3/5.		Tailgate mounted chip spreading and conventional rolling.	For investigating dominance of largest chip (2) / (3), (4) & (5). For comparison between two-coat, racked-in and wet lock seals (3) / (4) / (5)
B				

(1)	Single-coat grade 2.	Same batch and source of grade 2, 4 and 5 aggregate used throughout. Same binder used throughout.	Self-propelled chip spreader used and conventional rolling.	For comparison between chip spreading devices (1) / (2)
(2)	Single-coat grade 2.		Tailgate mounted chip spreading and conventional rolling.	For comparison of chip spreading device (1) / (2). To investigate dominance of largest chip with (2) / (3), (4) & (5).
(3)	Two-coat grade 2/5.		Tailgate mounted chip spreading and conventional rolling.	To investigate dominance of largest chip with (2) / (3), (4) & (5).
(4)	Two-coat grade 2/4.		Tailgate mounted chip spreading and conventional rolling.	To investigate dominance of largest chip with (2) / (3), (4) & (5). For investigation of rolling after first layer of chip application (4) / (5).
(5)	Two-coat grade 2/4.		Tailgate mounted chip spreading with rolling after grade 2 chip application.	To investigate dominance of largest chip with (2) / (3), (4) & (5). For investigation of rolling after first layer of chip application (4) / (5).
C				
(1)	Single-coat grade 5	Same batch and source used same aggregate grades throughout. Same binder used throughout.	Tailgate mounted chip spreading and conventional rolling.	For investigating the difference between seals and chip grades. For checking surface corrections. (1) / (2) / (3) / (4) / (n).
(2)	Single coat grade 3			
(3)	Two-coat grade 3/5			
(4)	Two-coat grade 2/4			
(n)	More chip sizes could be added. Controlling for chip source and batch, and construction methodology.			
D				
(1)	Single-coat grade 3	Same nominal grade. controlled shape ratio **below threshold.**	Tailgate mounted chip spreading and conventional rolling.	For investigating the effect of chip shape (both angularity and shape ratio). (1) / (2) / (3) / (4).
(2)	Single-coat grade 3	Same nominal grade. controlled shape ratio **above threshold.**		

5 Conclusions and recommendations

Data gathered from the RAMM database, the 19/20 sealing season on the SH network, the North Canterbury NOC forward works program, and conversations with industry experts have led to several recommendations on research themes that could have trials initiated in the 20/21 sealing season.

5.1 Short-list of trials

Trials investigating the effect on road traffic noise of the following chipseal surfaces have been recommended:

- Trials focussing on the following surface types:
    - Two-coat seals of grade 2/4 and 3/5.
    - Racked-in seals of grade 2/4 and 3/5.
    - Single-coat seals of grade 3 and 5.
- Investigate whether the largest chip in a multi-chip seal dominates noise generation.
- Investigate the effect of chip shape if data and appropriate controlled dimension ratio chips are available.
- Investigate the effect of rolling the first chip layer of multi-chip seals.
- Investigate the effect of using self-propelled chip spreaders.

5.1.1 Suggested prioritisation of trial surfaces

Priority	Reason	Surfaces
1	Investigation of seal type and gathers useful CPX and SPB data.	Two-coat 2/4, Racked-in 2/4, Wet lock 2/4
2	Investigation of chip size and dominance of the largest chip size, and gathers useful CPX and SPB data.	Single-coat 2, Single-coat 3, Single-coat 5, Two-coat 3/5, Two-coat 2/5, Two-coat grade 2/4.
3	Investigation of first layer rolling and self-propelled chip spreaders.	First layer rolled grade 2/4 (or 3/5), self-propelled and tailgate spread Single-coat grade 2
4	Investigation of high and low ALD/AGD shape ratios.	Single-coat grade 2 (or 3) with low AGD/ALD, Single-coat grade 2 (or 3) with high AGD/ALD

5.2 Shortlist of trial locations

Along with these recommended themes for trials, locations from the North Canterbury NOC have also been investigated and relevant details noted for some of the most suitable locations. These are shown in Table 1.

Finally, Appendix A has some information on potential trial site layouts to optimise the learning that can be done while ensuring controls are present to allow for meaningful performance comparisons.

6 References

ISO 11819-1:1997. Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 1. Statistical Pass-By Method.

Jackett, R., 2019. NZTA Road Surface Noise Research Programme 2018. Task A: Close Proximity versus Wayside Measurements. WSP-Opus.

Transit NZ, RCA, Roading NZ. 2005. Chipsealing in New Zealand. Transit New Zealand, Road Controlling Authorities, Roading New Zealand, Wellington, New Zealand.

Jackett, R., S. Bagshaw. 2020. Initial review of aggregates with respect to road traffic noise. Report 5-27585.00 2AGGR.

NZTA (2011). M06. Specification for Sealing Chip. Wellington, NZ.