PREVENTING AND SOLVING CHIPSEAL PROBLEMS USING A TRANSVERSE VARIABLE APPLICATION SPRAYER

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Abstract

Road delineation often causes traffic to follow the same wheel paths which create a wide disparity of trafficking effects transversely across the road. Where the wheel paths are concentrated there is more compaction of the chipseal, reorientation of chip, more embedment and more wear so less binder is required to fill existing voids in the wheel paths compared to the centreline and shoulders.

Spraying bitumen at application rates that vary transversely across the width of the road:

- provides a solution to both repairing sites with binder imbalance
- preventing the excessive build up of binder in the wheel paths.

The Sprayer applies the appropriate rate of binder transversely across the road rather than the inappropriate averaged application rate.

An application rate design method is proposed that takes into account the texture variation of the surface and the different traffic loadings that vary transversely across the road.

Introduction

New Zealand and Australian seal design procedures (1) establish a quantified method of seal design and until now seal designers have had to compromise their seal designs by producing one application rate for the chipseal site. The final calculated application rate is a compromise between enough binder to hold the chip on low trafficked or untrafficked areas and more than the optimum amount of binder on the highly trafficked areas.

In the mid-1990s, Transit New Zealand began focussing on road surface characteristics as part of a strategy to reduce the number of road accidents and deaths occurring on New Zealand state highways. One aspect of the implementation of this strategy focuses on the treatment of friction and texture deficient sites throughout the state highway network. This focus altered the balance of priorities for site selection for resurfacing so much that in recent years approximately 50% of the state highway resurfacing sites treated each year are selected because they have a deficient texture.

1 This paper was presented at the 22nd ARRB Conference – Research into Practice, Canberra Australia, 2006
2 Bryan D Pidwerbesky and Jeff C Waters are employees of Fulton Hogan Limited, New Zealand

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The standard New Zealand seal design formula RD286 (6) requires the measurement of the average texture for the site to calculate the average application rate for the site as follows:

\[ R = (0.138 \text{ ALD} + e)T_f \]

where:
- \( R \) = residual binder application rate \( \text{L/m}^2 @ 15^\circ \text{C} \)
- \( \text{ALD} \) = average least dimension of the chip in mm
- \( e \) = average surface texture correction factor
- \( T_f \) = traffic factor to adjust the binder application rate for traffic volumes

More recently a revised formula has been proposed (8):

\[ R = \text{ALD} (0.3 - T_d) + 0.2T_d \]

where:
- \( T_d \) = Average texture depth as determined in TNZ T/3 specification
- \( T_d = 57,300/d^2 \) where \( d = \) sand circle diameter in mm
- \( T_f \) = traffic factor to adjust the binder application rate for traffic volumes

Either method of using an average application rate usually requires too much binder to be applied on the wheel tracks and usually not enough to be applied on the shoulders, centreline and between the wheel tracks. Binder can be applied at appropriate rates for the traffic and texture distribution across the road surface using conventional sprayers but does create some minor problems such as increased longitudinal joints and extended time for uncovered binder while the different application runs are sprayed.

In 1996, Fulton Hogan designed and built its first variable application rate bitumen sprayer, called Multispray®, which was capable of spraying a different application rate of binder in each 100mm section across the width of the bar as illustrated in Figure 1. A single pass variable application rate bitumen sprayer with infinitely variable width adjustment produces fewer joints, while the joints produced are more accurate. The variable application rate bitumen spray bar is also infinitely variable in width from 0.6m up to 5.0m as it was constructed with telescoping bars. The Multispray® is described in more detail elsewhere in this publication.

![Figure 1. Variable transverse distribution](image-url)
Variable Application Seal Design

The current methods of seal design use measurements of the average texture for the site and the estimated AADT\(^3\) (including adjustments for the percentage of heavy vehicles in the traffic) for the site. However, if sufficient binder is applied to retain the sealing chip on the shoulders and centreline (where there is less traffic, and more texture) and there is no chip loss; as is the case for most seals constructed in New Zealand and if the same binder application rate is used for the wheelpaths (where there is more traffic and less texture), as is the case for most seals, then all of these seals have applied more binder than required onto the wheelpaths. Not only is this a waste of a non-renewable resource (bitumen) but it also shortens the life of the seal through earlier loss of texture. A subsequent reseal has to cope with a coarser texture on the shoulders than in the wheelpaths so even more binder is applied, progressively shortening the lives of the chip seals and systematically reducing the binder stone ratio in the multiple seal layers.

There are a number of simple seal design methodologies being used currently for variable application seals. The most common methods are:

- The seal design is based on a calculation for the wheelpaths using 100% of the traffic counts in the calculation and then increasing the application rate by 0.1 to 0.3 L/m\(^2\) for the shoulders and centreline. If an actual seal design is calculated for the shoulders and centreline then generally the texture measurements specific to each area (shoulders and centreline) and 40% to 50% of the total traffic counts are used in the design calculation. As the transverse position of the traffic in the lane depends on the width of the lane and shoulder, there is more wander on roads with wider shoulders and the proportion of the traffic counts has to be varied to take this into account.

- The seal design is based on a calculation for the shoulders and centreline using the specific texture measurements (for the shoulders and centreline) and 40% to 50% of the total traffic in the calculation and then reducing the rate by 0.1 to 0.5 L/m\(^2\) for the wheelpaths depending on binder present at the surface of the seal in the wheelpaths.

- The site application rate is calculated using the traditional seal design methodology and this is then reduced for the wheelpaths by 10% (where there is no binder rise), 20% (where there is minor binder rise) and 30% (where there is significant binder rise). The site application rate is used for the rest of the site.

However, the basis of these calculations is the formula RD286 (6) that includes traffic factors developed for the total traffic on site and texture measurements for the entire site. Over the past few years practitioners have lowered the calculated application rates by using site surface texture measurements that include three wheelpath measurements, one between wheel path measurement and one centreline measurement for each set of sand circle measurements. Shoulder texture measurements are not included.

The location of the texture measurements are in line with the requirement for surface texture measurement from standard TNZ P/17 (7) for measuring the chip seal performance.

There is a bias in the texture measurements caused by the methodology discussed in the previous paragraph, as the average texture calculated by this method does not represent the real average texture measurement of the site.

\(^3\)AADT is a traffic count number and stands for annual average daily traffic
The methodology of taking nine sand circles across a two lane road provides a more representative average texture for a site. The samples include: left lane shoulder (LS), left lane outer wheel path (LOWP), left lane between wheel paths (LMid), left lane inner wheel path (LIWP), centreline (CL), right lane inner wheel path (RIWP), right lane between wheel paths (RMid), right lane outer wheel path (ROWP), and right lane shoulder (RS) [based on New Zealand conventions for left and right lanes].

Using these texture measurements will change the average texture measurement for the site as 22% of the measurements are from the shoulders that have not traditionally been included in calculations. Therefore seal designs should be calculated for each of the transverse locations on the surface based on the variation of the transverse texture. While texture variability is important, it does not cause large changes in the application rates. For example a 1 mm change (which could equate to 50%) in average texture causes only a 0.2 L/m² (10%) change in a typical application rate.

Critical to the application rate calculation is the traffic factor if the transverse location of traffic is taken into account. Previously it was stated that some practitioners use 40% to 50% of total traffic in their calculations for the shoulders and centreline. Other studies (3, 11) looked at transverse locations and percentages of traffic, heavy vehicles and light passenger vehicles. One study (11) reported that the lateral displacement of traffic on rural roads at tangent (straight) sites showed that 68% of traffic ran 0.3m to 0.6m off the centreline, 11% of traffic ran on the centreline, 19% ran within 0.3m to 0.6m of the edge line and 2% ran on, or beside the edge line.

**Tai Tapu trial testing and monitoring**
Successful variable application chip seals have been in use in the Canterbury region of New Zealand for the past eight years with no chip loss in the wheel tracks. Any chip seal losses have not been related to the binder application rate. An early trial site at Tai Tapu was constructed on the state highway southeast of Christchurch on a straight section of road. The AADT was 4000 with 5% heavy vehicles (9).

The surface to be sealed was a five year old Grade 5 chipseal (5mm) with an average mean profile depth (MPD) in the wheel paths of 1.16mm with no visible binder rise. The lack of spare binder on the surface meant that the successful adhesion of the chip to the road was dependent solely on the quantity of applied binder.

This trial set out to find the limits of the application rate reduction and increases using a practical approach. The standard application rate for the site was calculated using the traditional seal design method, and this application rate (1.90L/m² cold) was used for the control sections.

The application rate was increased for both of the shoulders (LS and RS) by 10% for test section 1, 20% for test section 2 and 29% for test section 3. The application rate was altered for between the wheel paths (LMid & RMid) as follows: increased by 8.4% for test section 1, increased by 10.5% for test section 2, and decreased by 1% for section 3.

The application rate was decreased in the wheel paths by 4.2% for test section 1, 12.1% for test section 2, and 22.6% for test section 3. The actual application rates sprayed (from spray sheets) for each section and transverse location is summarised in Figure 2. The spray rates calculated by the sprayer control system were confirmed by physical dips of the sprayer tank, and measurements of the area covered for each spray run on the test sections.
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Figure 2. Tai Tapu trial variable binder application rates (L/m²)

Figure 3. Tai Tapu trial – pad test for variable application rate
On the Tai Tapu trial the traditionally designed application rate (nominal) that was applied across the road was probably too low as the control sections showed some early chip loss on the centreline and shoulders. The aim is for no chip loss and no flushing; however, some practitioners may suggest that minor chip loss on the shoulders and centreline show that the application rate is about right, because minor chip loss is regarded as being easier to remedy compared with flushing (excess binder).

The focus is on monitoring both the surface macro-texture depth and visual assessment of performance. Figure 4 shows that the increased macro-texture depth is directly related to the reduced amount of bitumen applied to the trial sections, compared with the control sections that were sealed with the traditional (transversely uniform) application rate. The rate of texture reduction due to compaction by traffic, binder rise and reorientation of aggregate is similar for all four-binder application rates but where less binder was sprayed the starting point is higher.

The control application rate was calculated using traditional application rate seal design method (RD286) that incorporates an average site texture calculated using centreline and wheel path sand circle texture measurements and the total number of equivalent light vehicles (ELV) per day.

Sealing practitioners have become accustomed to this method, which was developed to calculate the minimum binder required to adhere the sealing chip to the road surface, and would rather have some minor chip loss on the shoulders and centreline than flushing in the wheel paths. Thus, the expectation for the control sections was for good chip retention generally with some minor early chip loss on the centreline and shoulder; this has occurred on the control sections. To prevent this minor chip loss, the application rate for these sections should have been 0.1 to 0.2L/m² higher, but then this would apply extra binder to the wheel paths.

Pad tests were carried out to record the quantity of binder applied transversely across the surface. Figure 3 shows the results of one of these tests with less binder applied to the wheel paths than elsewhere.

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Texture data from the Transit NZ high speed condition surveys (2000 to 2006) was extracted and analysed for the Tai Tapu trial site to compare the texture of the right lane inner wheel path (RIWP) of the trial sections with the texture of the RIWP of the control sections.

- **Section 1** - The application rate for trial section 1 was 0.08L/m² lower than the application rate for the control sections and the average mean profile depth (MPD) texture for the RIWP of section 1 was 0.05mm deeper than the average texture depth of the control sections 6 years after chipseal construction.

- **Section 2** - The application rate for trial section 2 was 0.23L/m² lower than the application rate for the control sections and the average MPD texture for the RIWP of section 2 was 0.23mm deeper than the average for the control sections 6 years after the chipseal was constructed.

- **Section 3** - The application rate for trial section 3 was 0.43L/m² lower than the application rate for the control sections and the average MPD texture for the RIWP of section 3 was 0.75mm deeper than the average for the control sections 6 years after the chipseal was constructed.

The density of bitumen at 15°C is approximately 1g/cm³ so 1 L/m² of bitumen at 15°C is approximately 1mm in depth. The above performance is evidence that reducing the application rate increases the texture depth. In test sections 1 and 2 the comparison is good, whereas in test section 3, the texture depth increase is significantly larger than the application rate reduction, which is due to chip loss.

Independent research (11) has measured the lateral positions of traffic on a two lane road - one measurement was that 11% of the traffic runs on the centreline. If this value is used in the calculation, then the application rate is significantly affected. For example, in the case of a single coat seal, if the total ELV is 5000 vehicles, the corresponding traffic factor (Tf) is 0.876. Of this number, 11% is 550 ELV, for which the Tf is 1.192, so the application rate for the centreline would be 36% (1.192/0.876x100) higher than the traditional rate without an increase for texture.

**Tai Tapu chipseal visual assessment**

**February 2006**

The application rate on the centreline was increased by 10% for section 1 and section 3 and kept the same for section 2. There has been minimal chip loss on section 1 and some binder rise on section 3 between the wheel paths. This confirms that the nominal application rate should have been at this level for the control sections.

The application rates for the wheel paths in each section were decreased from the calculated traditional rate by 4% in section 1, 12% in section 2 and 23% in section 3. As discussed previously, the traditionally calculated rate could have been 10% higher to prevent chip loss from the control sections. If the correct application rate for the site should have been 10% higher, then the application rates for the wheel paths applied in the trials would include larger reductions than previously stated; 14% in test section 1, 22% in test section 2 and 33% in test section 3 respectively.

An assessment of the performance of the trial sections confirms that the seals in the wheel paths on test sections 1 and 2 are looking good with no chip loss while test section 3 has suffered some recent chip loss.
Other variable application seal trials
The early success of the Tai Tapu trial where the chip seals worked using application rates up to 30% lower than normal in the wheel paths over a surface without binder rise gave practitioners the confidence to reduce the application rates by 10% to 20% in the wheel paths when sealing with the variable rate sprayer. A large number of successful variable application seals constructed over the past eight years that have had a binder application rate reduction of 10% or more in the wheel paths compared to the standard application rate have performed better than the seals constructed using traditional application rates.

The variable rate seal design procedure is not complete because it has not been verified with field trials in all areas. Until that happens, a standard 10% reduction for the wheel paths is being implemented for all single coat reseals constructed using the variable rate sprayer, except on sites that have significant binder rise in the wheel paths. In these cases a 20% to 30% reduction on the standard application rate is used for the wheel paths.

Future Work
Future development work planned by practitioners includes:

1. Completing a transverse variable application seal design system that calculates the appropriate application rates for each of the transverse sections across the road based on traffic and texture data for direct input into the variable sprayer.
2. Continual improvement of design algorithm by including refinements obtained from further monitoring on variable application seal trials.
3. Trial sites will be monitored and lateral location of traffic will be measured to refine the design system.

4. Further trials of variable application seals back to back with traditional application seals will be monitored to ensure that the claims of longer seal lives and reduced risk of flushing are valid.

Sustainability
Using variable application chip seals assists sustainability of highway maintenance by reducing the quantities of bitumen sprayed when rescaling while at the same time extending the seal life. Approximately 1100km of rescaling is carried out on the state highways in New Zealand each year. If the average width of each wheel path is 1m then each kilometre of resurfacing contains 4000m² of wheel path that is having too much bitumen applied to it. Assuming the average application rate is 1.5L/m² and the application rate is reduced by 10%, 0.15L/m² of bitumen is saved in the wheel paths. This could equate to a reduction in waste of 660,000 litres of bitumen per annum (4000 x 1100 x 0.15).

Reducing the bitumen in the wheel paths extends the life of chip seals by slowing the onset of flushing, and producing a lower binder stone ratio. This means less waste of non-renewable resources from the rescaling and a longer pavement reconstruction life cycle, by preventing the build up of multiple seal layers that can result in an unstable mass in the wheel tracks.

A number of regions throughout New Zealand are now requiring that binder be applied at appropriate rates for the traffic and texture distribution across the road surface to extend seal lives. A single pass variable application rate bitumen sprayer with infinitely variable width adjustment produces fewer joints, while the joints produced are more accurate.
Conclusions
The main conclusions from the research presented in this paper are:

1. All reseals can be constructed using at least 10% less binder in the wheel paths than the standard application rate without risk of chip loss due to the lower application rate.

2. Reseals over sites with flushed wheel paths can be constructed using 20% less binder in the wheel paths than the standard application rate without risk of chip loss due to the lower application rate.

3. New Zealand trials found that the binder application rate reductions can be directly related to increased texture depths.

4. Transverse variable binder application supports sustainability by reducing the amount of binder used.

5. Transverse variable application chip sealing extends the life of chip seals by reducing the risk of flushing and reducing the binder stone ratio in multi layer chip seals.

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References
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