

IMPROVED SKID RESISTANCE THROUGH SMALL CHIP SEAL DESIGN

Murray Clarke, Peter Robinson,
Transit New Zealand

Peter Mortimer,
Downer EDi Works, New Zealand

ABSTRACT

Transit New Zealand Coastal Otago network consists of 770km of state highway network of which 707km are chip seal in rural environment (rural defined as greater than 70km/hr)

TNZ requires higher Polish Stone Value aggregate, limiting sources being used for sealing chip. Research to date has suggested that skid resistance increases linearly with percentage crushing. The use of a smaller chip ensures more crushed faces, with sharper aggregate tips thereby increasing tyre hysteresis. It has been suggested the use of 100% crushed chip has an effect of increasing PSV by 4 to 5 which, if accepted, could result in marginal PSV sources becoming more acceptable.

By constructing the seal in a way that orientates the chip to lie on the AGD, increases chip slope, generating high localised pressure between tyre tread and aggregate. The use of crushed multi grade, small chip will prolong the time to rehabilitate a pavement, for layer instability. Recent research suggests surface amalgams which contain higher percentages of sub 4.75mm stone have greater stability

Anecdotally the smaller chip seals appear to be quieter than conventional seals, that are backed up by New Zealand and UK research. It is suggested the quieter seals add to safety through reduced fatigue. Other research suggests that smaller chip size will also increase fuel economy.

This Paper presents the initial findings of initial field trials based on the theories suggested above. Further we suggest this approach is safer, more environmentally friendly and better for the overall performance of the road asset.

KEYWORDS

Chip seal design, Polish stone Value (PSV), Skid Resistance, hysteresis.

1. INTRODUCTION

The Coastal Otago State Highway network is located on the eastern coast in the lower part of the South Island, New Zealand. The 770km of network extends from Alpine areas in the centre of the region to rolling country towards the coast. Dunedin is the main city in the area and is located on the coast with a 5 year average weather summary with rainfall 812mm, 1585 sunshine hours, 58 days of ground frost and temperatures that range from -8.0 to 35.7°C. These conditions make bitumen based sealing challenging. Traffic volumes range from 300 to 22,000 vehicles per day.

This paper has developed out of techniques in chip sealing designed to address the issue of chip performance and improved skid resistance through multi layer small chip design in rural areas. Driver fatigue has also been a part of our development strategy. The paper defines the basis for this strategy and further development into a research proposal for establishment and on-going monitoring of seal performance.

2. PROBLEM DEFINITION

New Zealand State Highways are resurfaced with chip seals (apart from Motorways and some urban areas). This method has proved to be an effective low-cost resurfacing option for New Zealand Roads for over 70 years. Chip sizes used range from a grade 2 (9.5-12mm) down to grade 6 (10mm topsize) aggregates. Multi-chip treatments (primarily two-coat chip) are commonly used. For example Grade 2/5, 2/4 and 3/5 chip combinations.

With the continuing growth of traffic, particularly heavy commercial vehicle (HCV), polishing of the sealing chip caused by tyre action is increasing. This is more apparent on high stress areas such as tight radius curves and approaches to traffic signals and pedestrian crossings.

Sealing chips manufactured from sources which have modest “polished stone” values (PSV) of 55-59 have served their purpose well however with the increase in traffic volumes the stone from these traditional sources, is now lasting for increasingly shorter periods.

For instance, the stone with PSV of 57 in a high stress location may now last for only 3-4 years before the stone becomes polished and the skid resistance drops below acceptable levels.

Using stone with high PSV (defined as greater than PSV 60) is an option for high stress areas however supply is limited in New Zealand, construction is often difficult, and the cost of sealing rises significantly because of longer cartage distances and higher manufacturing costs.

High PSV stone is often partly weathered and therefore soft causing the stone to crush under traffic reducing its life in a relatively short time. Additionally the stone can “Sweat” while in stockpile through expansion / contraction. This can result in a chip that previously passed a cleanness test now being dusty causing binder adhesion problems.

2.1. Noise and Fatigue

The New Zealand chip seal designer's aim is to select a treatment that will maintain its design texture over the life of the seal. The solution is often multi layer course texture seals.

One of the down sides of these course texture seals is that they are very noisy both for vehicle occupants and residents who reside close to busy State Highways. Designing seals with smaller chip will reduce the noise.

Furthermore there is anecdotal evidence that a high level of low pitch noise in a vehicle adds to driver fatigue. (Leventhall, Dr. G, Pelmeier Dr.P, Enton Dr. S.)

2.2. Fuel consumption

Research has shown that the smaller the chip size seal results in less tire resistance and therefore less fuel consumption. (Bendtsen. H, 2004)

With a dwindling supply of fossil fuels any road surface that can be designed to reduce fuel consumption will become more important.

3. NECESSITY – THE CATALYST FOR INNOVATION

Transit New Zealand first implemented a skid resistance policy in early 1990's as a means to improve road safety through reduced wet loss control accidents. As a result the high-speed pavement condition surveys are measured annually. Currently these are conducted under contract to Transit New Zealand by United Kingdom Company WDM Ltd. using SCRIM (Sideway-force Coefficient Routine Investigation Machine). These have become the "report card" for the performance of the highway network (and its caretakers / stewards). The annual survey result is awaited with anticipation to confirm the effectiveness of maintenance strategies from the past year along with isolated proactive interventions.

The initial report from the annual survey is the Skid Resistance 'Exception Report'. This highlights areas of the network below a predetermined intervention level. The levels are based on the geometry of the road, topography or high road user demand areas (e.g. approaches to traffic lights or pedestrian crossings). The criteria are defined under Transit New Zealand standard specification T10:2002, Table 1 (TNZ T10). The exception report highlights all the sites that fall below and investigatory level which ranges from 0.55 for Category 1 sites to 0.35 for category 5, or sites that fall below the threshold level (absolute minimum skid value) ranging from 0.45 for category 1 sites to 0.25 for Category 5.

The first action upon receipt of this exception report is to field validate the result. Through this process a good feel is developed for the primary factors influencing SCRIM outputs. After many years validating the same network the practitioner can start to recognise relationships between chip age, treatment type and aggregate source. New Zealand tends to be skewed towards larger chip sizes than considered desirable by Moore (1975) (Cenek, P.D, Jamieson N.J. 2005). The drivers behind the selection of large chip treatment selections can be assumed to be influenced by the desire to maintain "water proofing" through higher binder application rates.

In Coastal Otago field observations validate the findings of the many research papers written in this area. Where seal aggregate has been crushed (particularly from alluvial sources) and not all faces are crushed, we find SCRIM exceptions occur within a relatively short time (4-8

years). This can also be the case where larger grade 3 stone and above (> 7.5mm Average Least Dimension-TNZ M/06 Specification for Sealing Chip) is used in a multi grade treatment i.e. Grade 3/5, 2/4, and 2/5. Therefore bigger is not always better.

A further reading of research conducted to date confirms that key surface profile characteristics such as the surface aggregate size, spacing and shape are important determinants of Mean Summer SCRIM Coefficient (MSSC). The MSSC represents the lowest annual assessed coefficient value. The smaller average spacing between tips of aggregates is considered necessary to satisfy both hysteresis and drainage requirements for speeds on rural state highways. The surface variable P_c (peaks /cm) increases with increasing MSSC implying that for chip seal surfaces smaller aggregate sizes (i.e. Grade 4 to 6, < 8mm) are preferable to larger sized aggregates. (Cenek et al 2005).

4. ADHESION FRICTION VERSUS HYSTERETIC FRICTION

The components contributing to skid resistance is well researched and published. It is understood that the adhesion component of friction is generally regarded as making the largest contribution to the total friction and the hysteretic component contributing approximately 20% of the total friction. (Henderson R., Cenek P.D., Patrick, J.E. 2006).

The primary cause of rolling resistance is hysteresis: "Hysteresis. A characteristic of a deformable material such that the energy of deformation is greater than the energy of recovery. The rubber compound in a tire exhibits hysteresis. As the tire rotates under the weight of the vehicle, it experiences repeated cycles of deformation and recovery, and it dissipates the hysteresis energy loss as heat. Hysteresis is the main cause of energy loss associated with rolling resistance and is attributed to the viscoelastic characteristics of the rubber." (Transportation Research Board, 2006)

Given adhesion friction is influenced by the microtexture of the stone, there is little we can do to increase this natural property. There is a limited source of aggregate supply so we are restricted to selecting stone, within the quarry, based on the degree of weathering, to influence the resulting microtexture to ensure good performance.

One factor we can influence is the hysteretic component. This component of friction is small in free-rolling, but significant for lock-wheel braking, due to the increased rubber deformation that occurs when sliding rather than rolling. Hysteretic friction would be expected to increase with chip irregularity – ‘Angular’ chips causing more deformation of the tread rubber than ‘rounded’ chips (Henderson et al 2006; Moore 1975).

It is suggested that more co-operation with tyre manufactures and the road industry could be undertaken in this area.

5. EFFECT OF 100% CRUSHED FACES

Studies by Opus Central Laboratories (Henderson, R., Cenek P., Patrick J., 2006) resulted in the following conclusions;

1. Skid Resistance increases linearly with percentage crushing. For new and unpolished aggregate the increase in skid resistance in going from 0% crushed to 100% crushed chips is approximately 20%.

2. New and unpolished crushed chips are more 'angular' in shape than uncrushed chips.
3. The degree of crushing required to meet a target level of skid resistance depends both on uncrushed and crushed (a) microtexture, and (b) chip shape.
4. Aggregates with a lower level of microtexture need to be crushed more to achieve a given level of skid resistance.
5. Polishing reduces the benefit of crushing on skid resistance by (a) reducing microtexture of crushed faces and (b) 'smoothing' sharp chip edges that are initially 'angular'.
6. The beneficial effect of crushing on microtexture remains after the equilibrium level of polish is achieved. This is equivalent to between 4 and 5 PSV after PSV polishing.

Intuitively we know this to be true. If giving a cyclist a choice to fall off on a surface of marbles or a crushed small chip surface I think you will find the choice will be marbles every time.

6. SKID RESISTANCE AND STONE SIZE

The standard PSV test requires a stone of all passing 10mm but no passing 6.2mm. In general a grade 4 size (5.5 – 8.0mm ALD) is used. However chip sealing in New Zealand is conducted with a multitude of varying chip combinations and methods. It is recognised the PSV test is a measure of relative polishing potential from one aggregate to another. It is not necessarily a good predictor of in service performance. PSV trials on a range of chip combinations at the Transport and Road Assessment Centre, University of Ulster showed a general increase in skid resistance with reducing particle size. (Woodward, W.D.H., Woodside, A.R., Jellie, J.H. 2005).

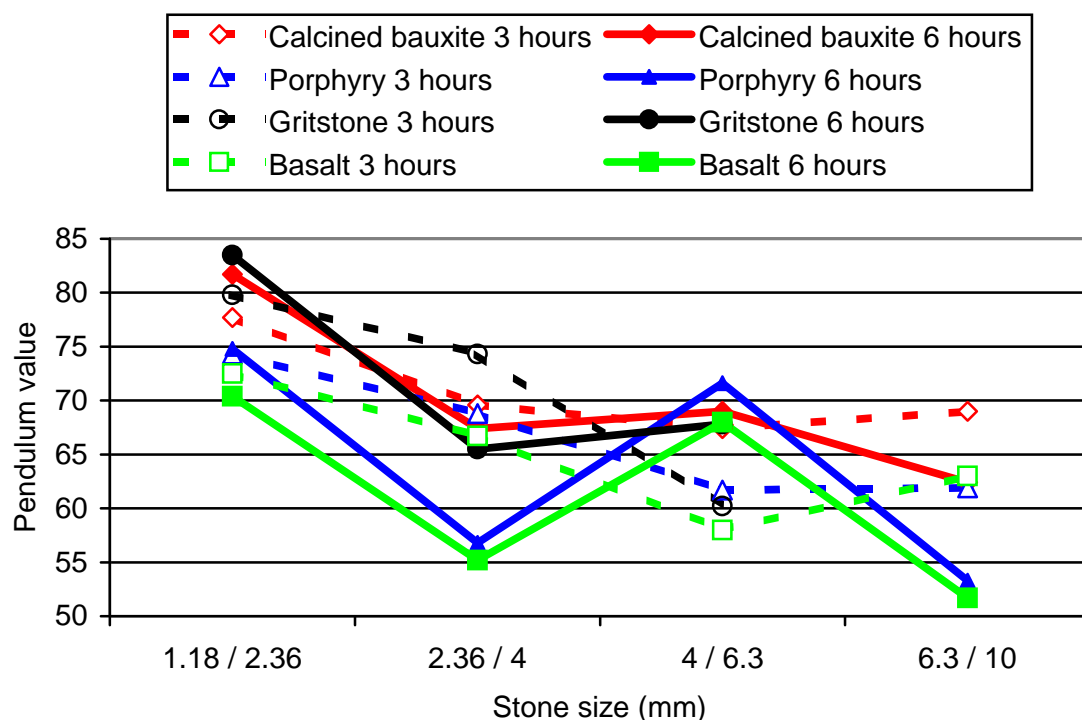


Figure 1 Effect of stone size on the polishing of different rock types

For comparison of stone size, the following figures from Transit New Zealand's specification for sealing chip TNZ M/06.

Grade of Chip	ALD (mm)	% of Least Dimensions Within 2.5mm of ALD	AGD Ratio ALD	% Passing 4.75mm Sieve	% With at Least Two Broken Faces
2	9.5 – 12.0	65 min	2.25 max	1.1	98 min
3	7.5 – 10.0	70 min	2.25 max	1.1	98 min
4	5.5 – 8.0	75 min	2.25 max	1.1	98 min

Figure 2 Table 2 of TNZ M/06 Specification for sealing chips

Test Sieve Aperture	% Passing	
	Grade 5	Grade 6
13.2 mm	100	-
9.5 mm	95 – 100	100
6.7 mm	-	95 – 100
4.75 mm	8 max	-
2.36 mm	2 max	15 max
300 µm	0	8 max

Figure 3 Table 3 of TNZ M/06 Specification for sealing chips

7. CRUSHING PRACTICE AND THE IDEAL CHIP

In New Zealand a large proportion of sealing chip and construction aggregates are manufactured by mobile crushing plants that are established at temporary quarries adjacent to riverbeds or hardrock outcrops. The types of these mobile machines vary greatly. NCHRP Report 539 (Prowell, B.D., Zhang, J. Brown E.R., 2005) offers good information regarding the four main types of crusher, jaw, gyratory, cone and impact, as follows. The first three are considered compression type crushers where the feedstock aggregate is crushed between a moving jaw and a stationary jaw. Jaw and Gyratory crushers apply the force slowly resulting in abrasion and cleavage with a narrower distribution of aggregate size but greater percentage passing 0.075mm sieve. Cone crushers apply the force twice as fast producing shatter and cleavage. Impact type crushers create a wide distribution of particle size with a greater percentage of aggregate passing the 4.75mm sieve size. There are two types of impact crushers, horizontal (Hammer Mill) and vertical shaft (Barmac) configurations.

The greatest factor affecting the shape of the crushed aggregate is the geology. Fine grained aggregates such as limestones are brittle. Basalts, quartzites and cherts fracture in a conchoidal manner as they produce curved fracture planes such as glass.

The resulting number of crushed faces on the product size is related to the size of the feedstock of the parent stone by a factor called the Reduction Ratio. It is impossible to

create a 12.5 mm crushed gravel with 100% of the particles having 1 crushed face if the feedstock is only 19mm. Therefore there is a greater likeliness to have a higher percentage of crushed faces when the product size is less than the feedstock size by at least a 2:1 reduction ratio.

The way the crusher is operated will also have an affect on the shape of the aggregate. Multi layer crushing produces more cubicle aggregate shape. This is achieved by running the crusher feed choked and full in a closed circuit manner. This requires constant feed and recirculation. The operation of crushers in chain also has an effect. For instance a jaw crusher would often be used as a primary crusher with a cone secondary crusher.

The ratio of Average Least Dimension (ALD) and Average Greatest Dimension (AGD) as shown in figure 2 (Table 2 of TNZ M/06 specification) suggests the required ratio of AGD to ALD is a maximum of 2.25. It implies a more cubic shape is preferable to aid in a more tightly packed matrix. It is suggested that chip tended to the upper end of the ratio is preferable in providing superior skid performance when constructed in a way that maximises this property.

8. CHIP ORIENTATION

In New Zealand research was conducted from 1935, when Hanson presented a paper to the New Zealand Society of Civil Engineers quantifying the chip seal process (Hanson, FM. 1935). The principles of Hanson's method are still used today, in New Zealand and internationally. Hansen and his public Works overseer Mr Tom McLoughlin, deduced that the percentage of voids in the initially laid loose state of the single layer stone, is approximately 50%. After initial rolling this reduces to 30% and further to 20% after traffic compaction. (Towler, J and Heine, J (Eds). 2005)

Generally it is accepted that a chip lands randomly prior to embedment under rolling or traffic. This presents an opportunity to support the chip in this orientation with locking stone to maximise chip slope and present the sharpness of the aggregate tip to oncoming traffic. After trafficking the chip will attempt to roll into its ALD vertical position however if it is prevented from doing so by the locking chips it is likely to remain in this 'upright' orientation. However, if this orientation of the chip could be controlled to present the sharpness of the aggregate tip to the tyre interface it is suggested that improved long term benefits to skid resistance may result. This process is anecdotal and requires further detailed analysis over time to validate the hypothesis.

9. BASIS OF SMALL MIXED CHIP CONSTRUCTION TECHNIQUE

Having decided that using smaller mixed chip in seal surfaces has sound scientific merit, it became a challenge to our sealing practitioners how to construct such a surface. In the past chip grades 5 and 6 were only considered as void fill seal coats used to provide an even texture in preparation for larger chip grades to be used.

The late Raymond Hughes, a passionate sealing manager, suggested the following theory to describe the aim of constructing the surface. The concept of the 'Arch' was suggested as

offering a good analogy. The Arch offers significant strength through particle interlock. The 'keystone' is considered critical in the arch maintaining its structure and strength.

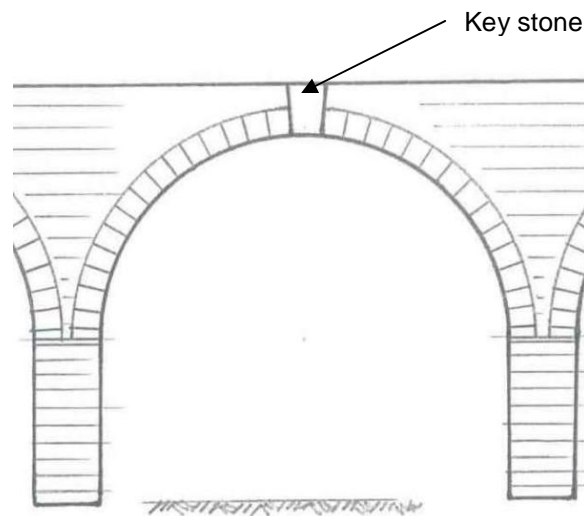


Figure 4 Analogy of the Masonic stone Arch

In a similar way if we consider the larger chip in the mixed chip layer to act as a 'keystone' supported by the surrounding 'locking' stone we are able to maintain the chip in the same configuration as it lands.

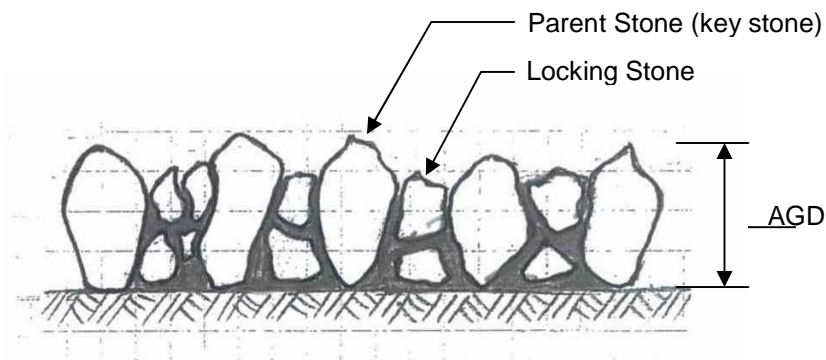


Figure 5 Schematic of construction showing keystone effect.

This has led to the development of seals that replicate this ideal solution.

10. DISCRETE TRIALS

In 2004 discrete field trials using small mixed chip seals began. The rationale of why calcined bauxite can be so effective and yet have low texture was considered and the logical conclusion reached that smaller chip, with resultant 100% crushed faces, and sharp tips and edges should provide increased skid properties to larger chip. The research referenced above merely scientifically validated what we intuitively knew to be true. The analysis below includes High Speed Data (HSD) survey information up until February 2007. The next survey is being completed as we write this paper that we will be able to present the findings of in the conference presentation.

10.1. SH1 RS651 RP7850-8660 Jefferies Rd Curves

This site is situated on SH1, which is part of the major north-south highway in New Zealand, within route station 651. The speed zone is 100 km/h with a series of TNZ T10 category 2 reverse curves. The traffic AADT is 4497 with 16% HCV. The previous surface comprised a 1995 single coat grade 3. It was decided to seal the section with a small mixed chip surface, due to the existing coarse texture (but rounded stone) which was completed 9 March 2005.



Figure 6 Image of Category two curve. Increasing direction RP 7930.

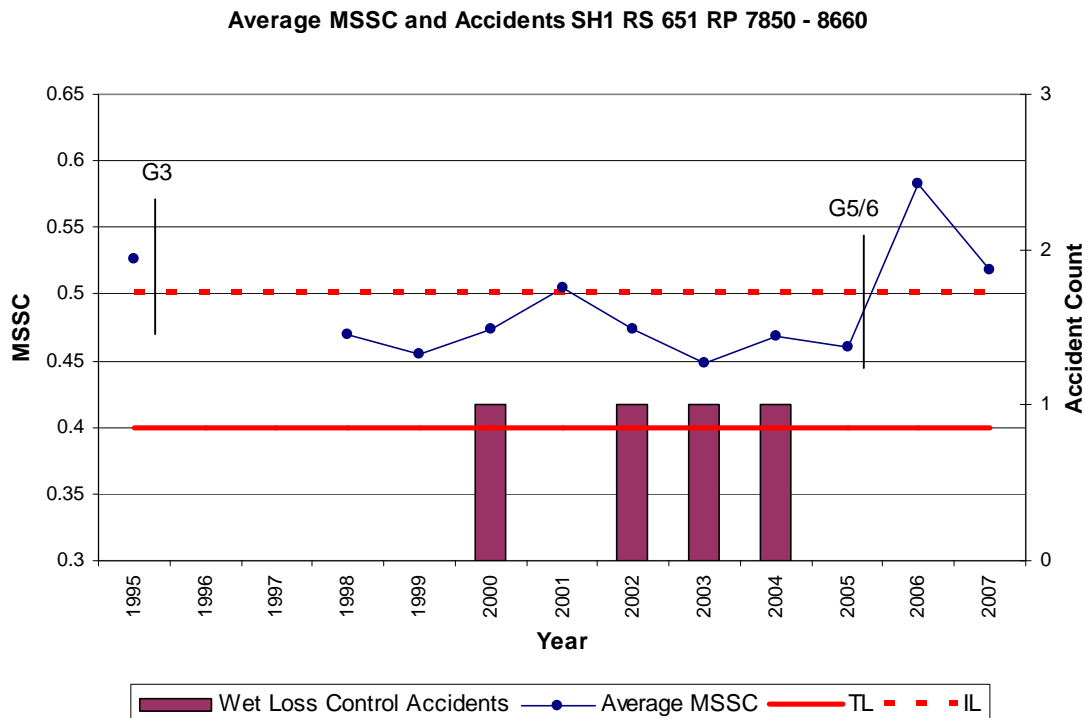


Figure 7 Chart of MSSC and Accidents for Trial section 1-651/7850-8660

The SCRIM data above shows the significant gain even one year after construction. This small mixed chip seal is a grade 5 and 6 combination. After two years of service there has been a 12% drop in available skid resistance however the equilibrium state of polish should

now have been reached. This site has subsequently suffered some 'isolated' flushing that has resulted in an early decrease in MSSC. The crash history to date indicates that the treatment has been effective in stopping the almost annual crashes.

10.2. SH1 RS666 RP610-800 Waikouaiti Curve

This site is situated on SH1 within route station 651. The speed zone is 100 km/h with a single TNZ T10 category 2 reverse curve. The traffic AADT is 4497 with 16% HCV. The previous surface comprised a 2001 two-coat grade 3 and 5. This site was reported in the SCRIM exception report and given the accident history, it was decided to seal the section with a small mixed chip surface of grade 4 and 6, which was completed 8 May 2006.



Figure 8 Image of Category two curve. Increasing direction RP 640.

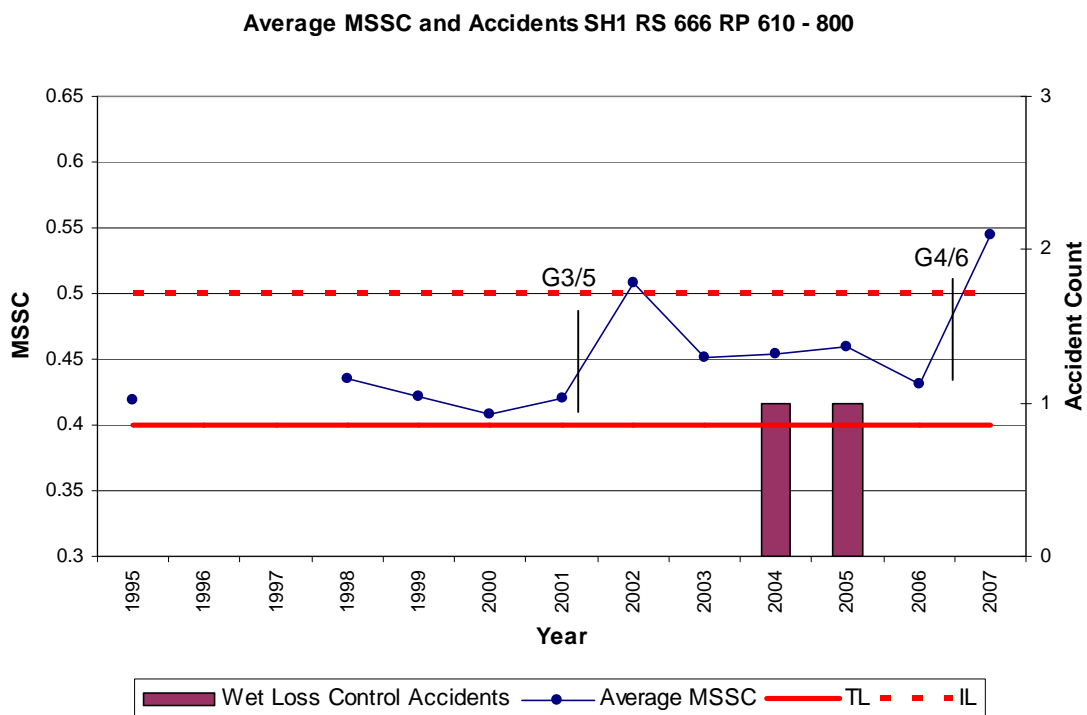


Figure 9 Chart of MSSC and Accidents for Trial section 1-666/610-800

From figure 9 we can see a trend in MSSC where skid resistance degrades significantly after the first year of treatment then flat lines once the equilibrium state of polish is reached. To date there are no loss control accidents post surfacing. The result of the next survey will be crucial to determine the plateau MSSC value. Given previous treatment degrade approximately 10% we anticipate a MSSC of approximately 0.49. This would offer a skid resistance level of service above that when the wet loss control accidents occurred.

It is also noted that a higher initial MSSC was achieved in the first year for the grade 4/6 chip than that of the 3/5 chip combination.

10.3. SH1 RS 704-D RP1100-1160 Union St Crossing

This site is situated on SH1 in Dunedin City on the north bound one way system. The approach is to a high risk pedestrian crossing heavily used by university students. The traffic AADT is 22,600 with 4% HCV. The previous surface comprised a 2001 dense graded wearing course asphalt with 10mm topsize aggregate. This site was highlighted in a SCRIM exception report post HSD survey. It was decided to seal the approach with a small mixed chip surface which was completed 08 May 2006. Figures 10 and 11 show the resulting surface.



Figure 10 Grade 5 and 6 mixed chip seal shortly after completion



Figure 11 Close up of surface showing coarse initial surface

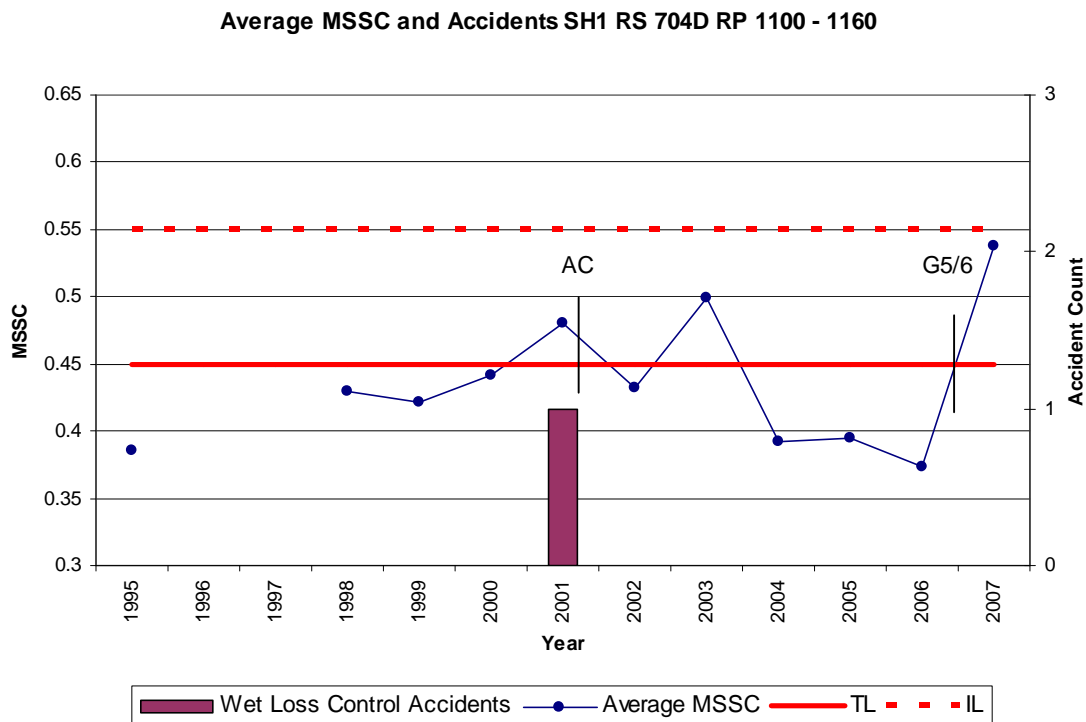


Figure 12 Chart of MSSC and Accidents for Trial section 1-704-D/1100-1160

Figure 12 shows the significant drop in MSSC value in 2004 with a gradual decline thereafter. Given the site is only 70m in length, limited readings are available and the average is sensitive to outliers, but the result shows a significant increase in MSSC after 1 year of trafficking. The accidents for this site were assessed for wet loss control on straight and pedestrian incidents.

10.4. SH8 RS417 RP1580-1760 Bowlers Creek curves

This site is situated on SH8 at route station 417 and shown in figure 13. The speed zone is 100 km/h with a series of TNZ T10 category 2 reverse curves. The traffic AADT is 1419 with 10% HCV. The previous surface comprised a 1988 single coat grade 3. It was decided to seal the section with a small mixed chip surface, due to the existing coarse texture (but rounded stone) which was completed on 17 March 2006.



Figure 13 Image of Category two curve. Increasing direction RP 1540.

The SCRIM history shown in figure 14 clearly shows the reduction in average MSSC over time. Given the surface was resealed only one month post 2006 HSD survey there is still a significant increase in MSSC in the 2007 survey after one year of trafficking. There have been no recorded wet loss control incidents on this site and the intervention treatment should ensure this trend continues.

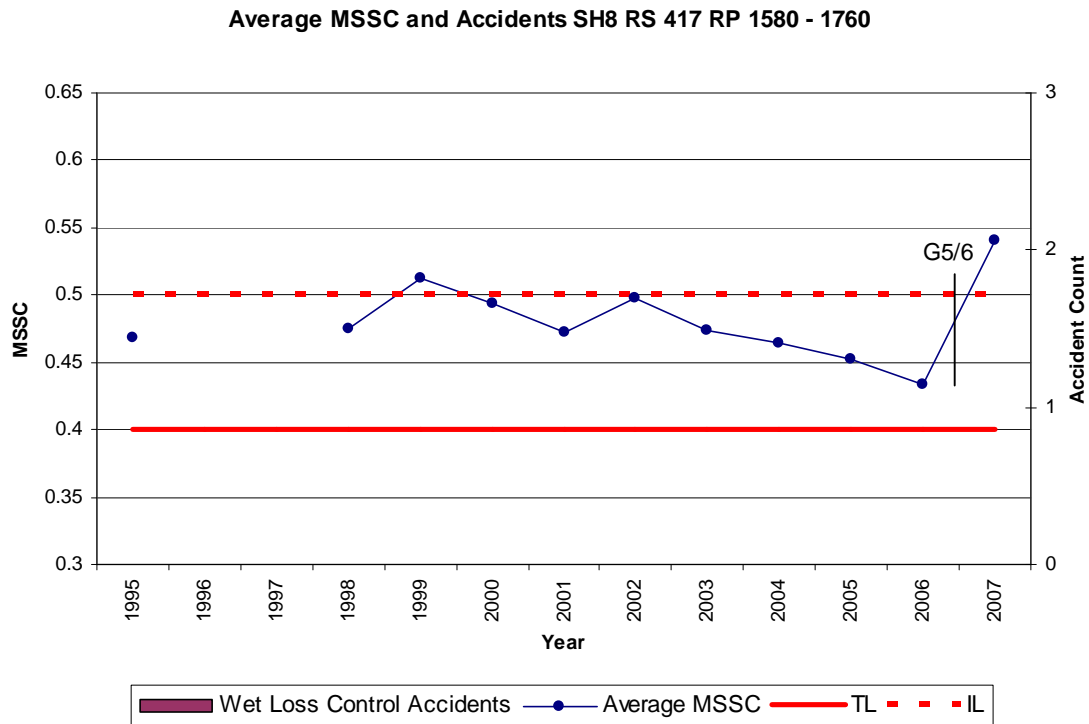


Figure 14 Chart of MSSC and Accidents for Trial section 8-417/1580-1760

10.5 SH8 RS444 RP1340-1700 Pig Hunters

This site, shown in figure 15, is situated on SH8 within route station 444 on a high stress category 2 reverse curve. The speed zone is 100 km/h with a history of loss control accidents that prompted the intervention before MSSC threshold was reached. The traffic AADT is 1800 with 9% HCV. The previous surface comprised a 2000 two-coat grade 3 and 5. It was decided to seal the section with a small mixed chip surface from a high stone PSV source, due to the existing coarse texture (but rounded stone) and the high risk and stress being applied. Surfacing was completed on 26 February 2004. This site was one of the initial mixed chip seal trials using a grade 4 and 6 combination.



Figure 15 Image of Category 2 curve. Increasing direction RP 1490.

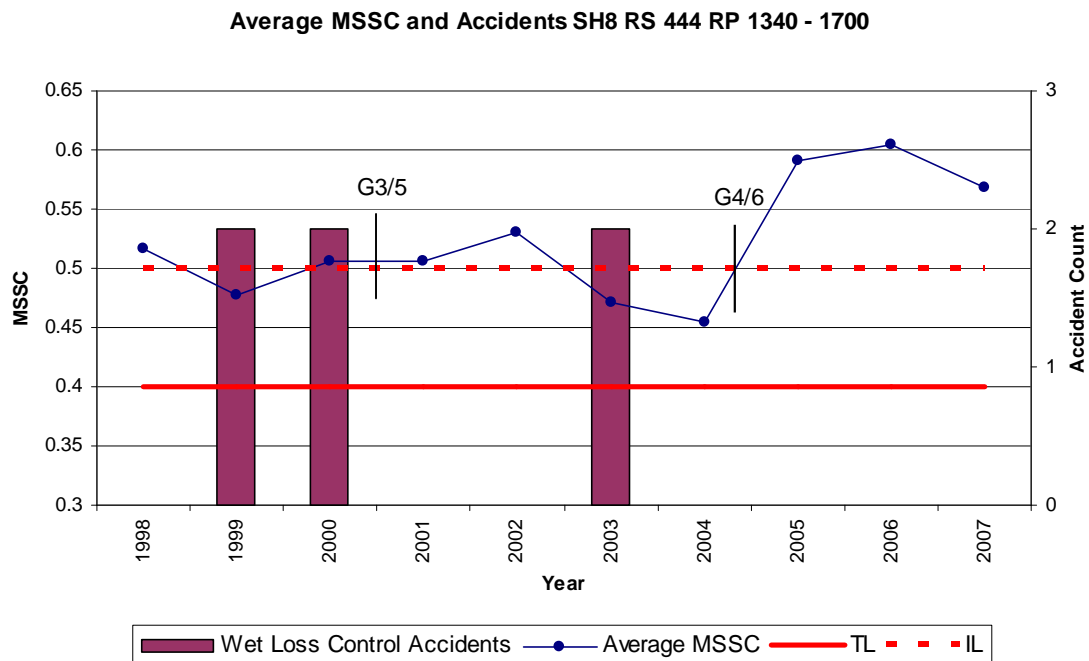


Figure 16 Chart of MSSC and Accidents for Trial section 8-444/1340-1700

From figure 16, we note the significant increase in MSSC even one year after the intervention treatment. Given this is one of our oldest small mixed chip seals the equilibrium state of polish should be reached. It is comforting to note the pattern of loss control accidents, correlating to low MSSC values, have stopped post intervention.

11. FURTHER TRIALS

To gauge the effectiveness of improved skid resistance through small mixed chip design, we are satisfied that the initial trial work completed to date warrants further, more detailed, testing and analysis of in-service performance. We propose the following methodology will be used.

11.1. SITE SELECTION

To test the effectiveness of the proposed seal design it would be necessary to choose a site where there is medium to high stress on the road surface with sufficiently consistent HVC loading. The ideal site is a relatively long category 2 curve (radius less than 250m), long enough to allow the different test surfaces to be applied.

It is proposed to have three test surfaces on the trial section:

1. Control section of a standard proven chip seal treatment selection
2. A section with high PSV stone standard chip seal treatment selection
3. Small mixed chip design

11.2. Initial Tests

- Aggregate absorption testing on samples of the aggregates as a measure of the aggregate grain density.
- PSV test as a means of comparison of one aggregate to the other.
- Surface core samples to determine existing Binder to Stone Ratio (by volume), and grading prior to sealing and post sealing.

11.3. Annual Tests

- Annual measurement of skid resistance using SCRIM as part of the annual state highway survey.
- Annual measurement of texture change over time (mean profile depth) as part of the annual state highway survey using 32 kHz lasers.
- Annual laser profiler measurements using the Transit New Zealand Stationary Laser Profiler (SLP) placed longitudinally in the outer wheel path. Refer Table 1 for measures.
- Change in chip orientation over time measured by an analysis of photographs.
- In vehicle noise testing to assess any difference between test surfaces.

Table 1

S	Mean spacing of adjacent local peaks in sampling length
HSC	High Spot Count. The number of complete profile peaks within the assessment length projecting above the mean line or a line that is some specified distance elow the gighest peak.
delq	Rms slope of the profile for the assessment length
Pc	Peak count density. The number of local peaks in an assessment length that project through a selectable band centred about the mean line.

(Cenek et al 2005)

The trial period is likely to be at least seven years allowing for three years to achieve equilibrium state of polish. It would be expected that some meaningful results would be available after four years.

The trial length needs to be homogenous through the length of the curve and constant in radius and grade. Traffic volumes, including heavy vehicle recording will be undertaken either through existing counts sites or specific installations set up as part of this study. The sites would need to have sufficient length to allow noise equilibrium to be established.

NOISE EFFECT FROM RELATED STUDIES

In New Zealand, Opus Central Laboratories have conducted noise studies in urban areas to understand the extent that typical NZ road surfaces influence traffic noise at urban driving speeds (50 km/h). 21 urban sites programmed for resurfacing were surveyed before and after resurfacing to compare with survey results from adjacent residents. Below is a table of their findings.

Ratio of light to heavy vehicles	Combined surface effect on noise from light and heavy vehicles (dBA)				
	Dense asphalt	OGPA	Fine chip #4,5,6	Medium chip #3	Coarse chip #2 and 2-coat seals
100:3	0	0.7	2.5	3.6	4.5
100:10	0	0.1	1.8	3.1	4.0
100:30	0	-0.6	0.6	2.4	2.9

Figure 17 Result of Noise measurements on various urban surfaces.

The study concluded that surface affects for traffic noise at speeds of 40-50 km/h are much greater than current knowledge suggests. Also that road surface effect is similar at 40-50 km/h as it is at 80-100 km/h. Two coat seals are no less noisy than single coat seals and the relationship between noise and texture depth is poor. (Dravitzki et al 2003).

Internationally, research work has been conducted at the Transport and Road Assessment Centre, University of Ulster. This work investigated the merit of smaller stone size surface dressing to restore skid resistance properties to polished SMA (Stone Mastic Asphalt) and HRA (Hot Rolled Asphalt) premix surfaces. HRA has been used as the control surface therefore USI for HRA = 0. The unit of measure is unique to the study apparatus however the findings demonstrate the relative noise characteristics from one surface to another.

The study concluded by reducing the stone particle size, significant noise reduction is possible. The use of 6mm chip (NZ grade 5-6 chip) may offer an optimum for noise and skid resistance properties.

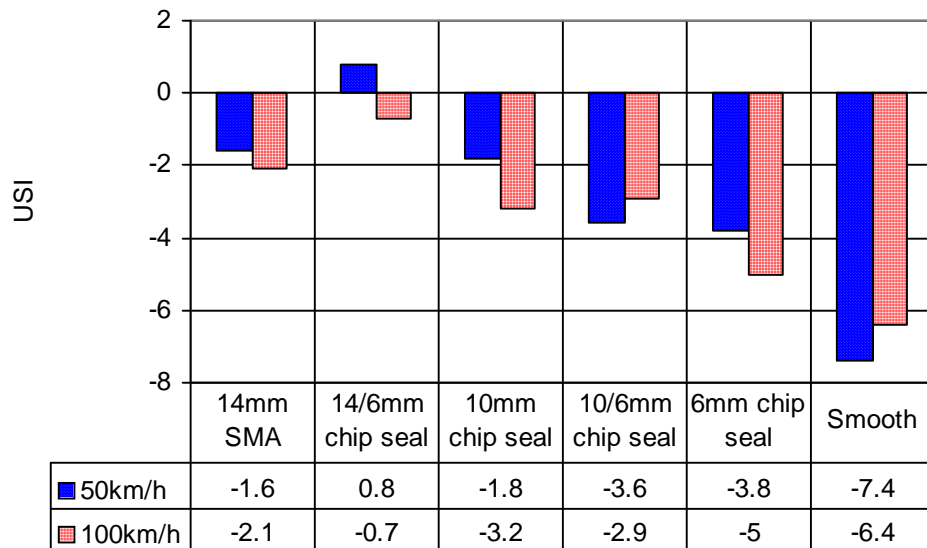


Figure 18 USI data for smooth tyre, test speed 50 and 100km/h, load 40kg and tyre pressure 138kpa.
(Woodward et al 2005)

As part of the proposed study it is intended to measure in-vehicle noise generation with different seal types. This information will then be correlated with current published research relating to the effects of low frequency noise distraction and fatigue. This published research shows the effect on concentration of low frequency noise at varying decibels and has shown that with a low “drone” the ability to notice peripheral information and react to it is affected. This supports the use of smaller and therefore quieter chips.

The proposed study would correlate the noise generation measured within the car to the various seal chip sizes and combinations.

12. EFFECT ON LAYER STABILITY

The resulting performance of multiple chip seal layers is increasingly becoming an issue. Historically New Zealand seal designers have generally followed the sequence outlined in the New Zealand Bituminous sealing manual 1993 until recently superseded by the Chip Sealing in New Zealand guide 2004. This process generally uses a grade 4 chip is for an initial single coat seal, followed the next year by a grade 3 reseal. Where the resulting texture is greater than 2mm mean profile depth (MPD). The subsequent seal would then be a grade 5 or 6 void fill seal. This is followed by a grade 3 chip and so on.

In 2004 Opus Central Laboratories (Ball, G.F.A, Patrick, J.E., Herrington, P.R. 2004), completed a Land Transport New Zealand research project that produced some interesting findings. Some multiple chip seal layers did not flush prematurely while others did. After completing compaction testing using a test apparatus that induced dynamic loading to each sample, the resulting compaction factor was measured. For sites where premature flushing has occurred the rate of compaction of samples taken outside of the wheel path were significantly higher than that occurring within the wheelpath. For non-flush sites the wheelpath and outside wheelpath rates were similar. It was suggested the reason for this

was due to the aggregate packing and binder contents being different between seals that performed well and those that did not. Also seals with a higher percentage passing the 4.75mm sieve range appeared to be more stable. Given the Transit specification TNZ M/06 (figure 3 above) the only material with significant amounts passing this range is grade 6 chip.

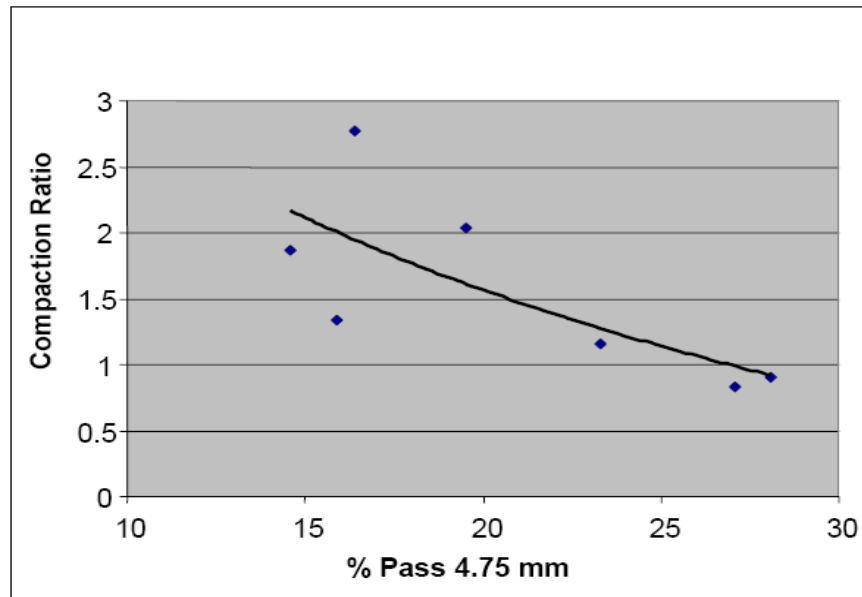


Figure 19 Effect of fines (as a percentage passing 4.75mm sieve) on compaction ratio

In 2005 Downer Edi Works conducted grading trials on small mixed chip seal samples. The intent of the testing was to determine the theoretical resulting grading of a seal amalgam of these seals. The grading of a typical combination of chip seals is shown in figure 20 below. It is noted that the coarse aggregate fraction is that material retained on the 2.36mm sieve. Figure 17 below shows the combined chip grading compared to the coarse fraction of a dense graded mix.

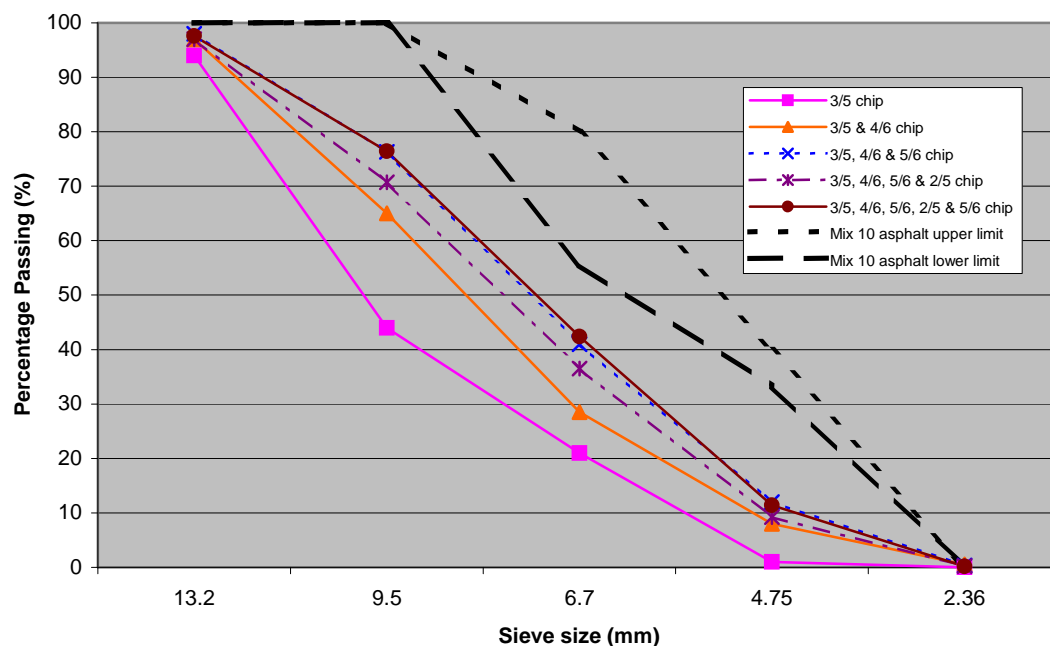


Figure 20 Gradation changes with successive reseals of two-coat chip seals

It is well known that a crushed aggregate adds to the stability of the asphalt mix. It is postulated that the blend of fine and coarse chips successively builds the aggregate to assimilate the coarse fraction of an asphalt mix. The grading envelope for a standard mix 10 wearing course (10mm topsize aggregate) asphalt has been plotted to compare the results.

Although it can be seen that the standard mix 10 asphalt grading has a larger topsize aggregate, the general ratio of each size fraction for successive seals tends to be in the same order. It is further suggested that the aggregate interlock through the 'keystone' effect in the seal design will also be adding to the stability of this coarse aggregate mix. Each successive layer of chip modifies the grading towards the stable mix proportions.

13. CONCLUSION

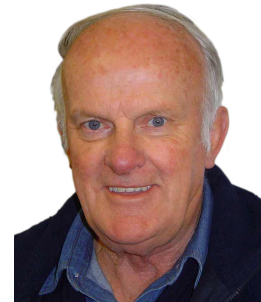
The discrete field trials undertaken on the Transit New Zealand Coastal Otago network over the past 4 years has shown that in the short term, chip sealing using small mixed chip has produced superior skid resistant surfaces. This paper summarises numerous other research relating to the skid properties of small chip seals, which validates this practice. The process outlined in this paper appears suitable to correct surfaces where low skid resistance associated with polishing are occurring with larger chip surfaces. However as with other engineering processes, it will not correct all skid deficient surfaces. The process will not correct skid resistance problems on surfaces that have already flushed, nor has it been used on surfaces subjected to significant traffic volumes (e.g. motorways). We suggest this process warrants further investigation with more intense testing and attention to variations and combinations to prove the versatility of the process.

14. REFERENCES

- Ball, G.F.A, Patrick, J.E., Herrington, P.R. (2004). Factors affecting multiple chipseal layer instability. Land Transport New Zealand Research Report 278. Wellington, New Zealand. Research Report.
- Bendtsen, Hans (2004). Rolling Resistance, Fuel consumption and emissions – A literature review, Silvia Project Report, Denmark ,
(<http://www.vejdirektoratet.dk/publikationer/Vlnot23/index.htm>)
- Cenek, P.D, Jamieson N.J. (2005). Sensitivity of in-service skid resistance performance of chipseal surfaces to aggregate and texture characteristics. 1st International Conference Surface Friction, Roads and Runways. Christchurch 2005, New Zealand. Conference Paper.
- Dravitzki, V., Walton, D., Wood, B. (2003). Effects of road surface type on traffic noise and community. 2003 REAAA Roadshow. Dunedin, New Zealand. Presentation.
- Hanson, FM. 1935. Bituminous Surface treatment of Rural Highways. Discussion on Bituminous Surface Treatment. New Zealand Society of Civil Engineers Proceedings 1934-35, 21: pp89-220. Wellington, New Zealand.
- Henderson R., Cenek P.D., Patrick, J.E. (2006). The effect of crushing on the skid resistance of chipseals. 22nd ARRB Conference. Canberra 2006, Australia. Conference Paper.
- National Roads Board. 1968, (revised 1971). Manual of Sealing and Paving Practice. Road Research Unit, National Roads Board. Wellington, New Zealand.
- Leventhall, Dr. G, Pelmeur, Dr P, Benton Dr. S. A review of Published Research on Low Frequency Noise and its effects, Report for Department of Environment, Foods and Rural Affairs, 2003 section 9.3
(<http://www.defra.gov.uk/environment/noise/research/lowfrequency/pdf/lowfreqnoise.pdf>)
- O'Docherty, P.J., Mortimer, P.F. (2006). Chip seal design using high speed data 22nd ARRB Conference. Canberra 2006, Australia. Conference Paper.
- Prowell, B.D., Zhang, J. Brown, E.R. (2005) NCHRP (National Cooperative Highway Research Programme). Report 539 Aggregate properties and the performance of superpave designed hot mix asphalt. Retrieved 3 March 2008, from
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_539.pdf. Web Page.
- Towler, J and Heine, J (Eds). 2005, Chipsealing in New Zealand, Transit, Road Controlling Authority, Roading New Zealand: Wellington, New Zealand
- Transportation Research Board, Committee for the National Tire Efficiency Study, National Research Council of the National Academies, TRB Special Report 286, Tires and Passenger Vehicle Fuel Economy Informing Customers, Improving Performance. Washington D.C. 2006.
- Transit New Zealand. 2004. M/6 Specification for Seal Chip, T10 Specification for Skid Resistance Investigation and Treatment Selection . Transit New Zealand, Wellington.
- Woodward, W.D.H., Woodside, A.R., Yacoob, H., Maguire, S.J. (2005). Smaller stone size surface dressing for high stone surface mixes. 1st International Conference Surface Friction, Roads and Runways. Christchurch 2005, New Zealand. Conference Paper.
- Woodward, W.D.H., Woodside, A.R., Jellie, J.H. (2005). Higher PSV and other aggregate properties. 1st International Conference Surface Friction, Roads and Runways. Christchurch 2005, New Zealand. Conference Paper.

15. ACKNOWLEDGEMENTS

Sadly last year we lost the experience and passion of Raymond Hughes when he passed away in March 2007. Ray was well known in southern New Zealand as a man of integrity and vast knowledge of the practical aspects of chip sealing and especially his determination to see emulsion sealing use advance in New Zealand. Much of the findings in this paper can be directly attributed to Rays' innovation. This paper is offered in memory of Ray, whose dream it was to see his work acknowledged at an international conference.



We gratefully acknowledge the support and advice received from our colleagues at Transit New Zealand, MWH Ltd and Downer EDi Works Ltd, in particular: Michael Flatters, David Hutchison and Paul O'Docherty.

Detailed analysis and reporting was undertaken by Paul O'Docherty.

Author Résumé

Peter Mortimer is Divisional Manager of Technical Services for Downer EDi Works in Dunedin. In this role he is responsible for a team performing service functions including radio telecommunications and intelligent transportation systems design and build, road asset management, lab and field testing and quality assurance auditing. Peter has attained a Diploma of Civil Engineering, New Zealand certificate in Engineering, and is a member of the Road Engineering Association of Asia and Australasia NZ chapter national committee. He has worked in consultancy, road controlling authority and contracting sectors over the past 14 years.

Murray Clarke is the Regional Network manager for Transit New Zealand Dunedin. He is responsible for the Asset management of 2050km of Otago and Southland State Highways. He has been part of the transition from the government owned Ministry of Works to outsourcing both physical and professional services. He has over 40 years involvement in road asset management and highway construction.

Peter Robinson is Transit New Zealand Area Engineer for Southland. Previously he has been involved in the Dunedin City Council Civil Engineering Laboratory and road design for 18 of his 27 years in the roading industry. Five years with MWH consultants in the transportation group prior to taking up the role with Transit New Zealand.