SKID RESISTANCE EFFECTS OF COMMON TREATMENTS FOR FROST AND ICE – MINERAL GRIT AND CMA

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ABSTRACT

Mineral grit and CMA (Calcium Magnesium Acetate) are the two treatments for frost and ice commonly used on New Zealand roads to maintain adequate level of skid resistance. This paper presents the results of a programme that combined on-road measurements (locked wheel braking) and laboratory testing (GripTester). Tests were conducted to investigate the effects of mineral grit and CMA on skid resistance, immediately after application and their performance over time. Road surface types included fine and coarse chipseal, open graded porous asphalt, asphaltic concrete and slurry seal. Comparisons of skid resistance were made between different road surface treatments and different surfaces from slurry seals, asphaltic concrete to fine and coarse chipseals. The skid resistance changes identified were combined with traffic levels to make assessments of the effects on crash risk.

INTRODUCTION

Frost, ice and snow affect various parts of the New Zealand roading network with varying degrees of regularity and severity. The affected areas include coastal and central Otago, coastal and inland Canterbury and the central North Island. On roads affected by such weather conditions there is a significantly increased risk of loss-of-control skidding crashes, unless surface treatments are used to improve skid resistance.

Two treatments are commonly used in New Zealand for frost or ice conditions. These are mineral grit, which has been used for many years, and the anti-icing/de-icing agent CMA. In a 1996 review of options for anti-icing/de-icing of state highways, Transit New Zealand (now the New Zealand Transport Agency (NZTA)) considered CMA as being most suitable for New Zealand conditions, given the low risk of vehicle corrosion and very minor effects on soil and groundwater. Trials of CMA were begun in 1998, and its use has expanded every year since.

Significant reductions in the number of crashes due to ice have seen the number of sites treated with CMA increase year by year. Figure 1 shows how the number of winter crashes in one region has varied through a five-year period during which CMA was introduced (Whiting 2007). It shows that, apart from a spike in winter crashes in 2006, which have been attributed to a number of reasons, including rainfall, driver error and tourist involvement, there has been a significant reduction following the introduction of CMA as a treatment for frost and ice.

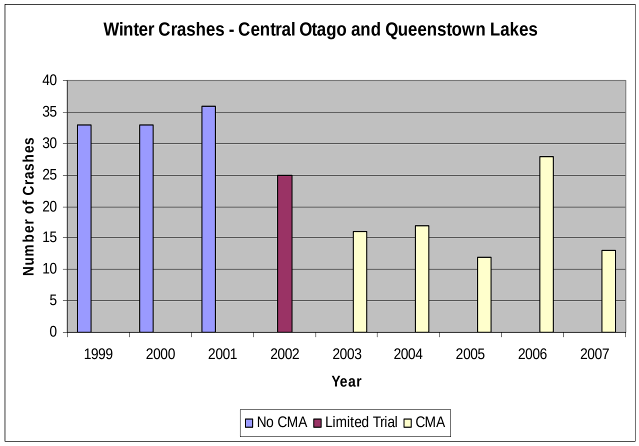

Figure 1: Winter crashes – Central Otago and Queenstown Lakes (Whiting 2007)

Roading contractors have now had considerable experience with using mineral grit and CMA as treatments for frost and ice. However, previous research carried out by Jamieson and Dravitzki (2007) highlighted a number of issues regarding the performance and use of both these treatments that needed to be resolved. The issues identified related to:

1. the effects of mineral grit on skid resistance, on the range of New Zealand road surfaces, from low-textured slurry seals and asphaltic concrete to coarse chipseals
2. the effects of grit and CMA on skid resistance immediately following application, and their performance over time
3. the effects of treatments at different times of the day, given different environmental conditions, particularly dewfall.
4. the potential risk of lowered skid resistance from (a) no treatment of frost or ice, (b) treatment with mineral grit, or (c) treatment with CMA to traffic levels at different times of the day.

The primary goal of the research programme described here was to develop input to 'best practice' procedures for assessing the level of risk associated with treating frost and ice conditions with mineral grit or CMA. This was to be achieved through the following objectives:

1. To quantify the changes in skid resistance that occurred under different grit and CMA treatment scenarios through locked-wheel braking tests on different surfaces, supported by additional skid resistance measurements using a GripTester.
2. To establish the relative levels of risk to road users by combining typical the changes in skid resistance identified for the different treatments with the variations in traffic levels with time.

RISK ANALYSIS AND CRASH RISK

Background

The friction between a vehicle's tyres and the road surface is one of the critical factors influencing road safety and the likelihood of a loss-of-control crash. As environmental conditions vary the available friction levels will also vary, and drivers will need to adapt their behaviour to the changing conditions, mainly by adjusting their speed. Drivers may see that the road is wet, with lower friction levels, and adjust their speed accordingly. However, because there are a variety of cues and because drivers are often inconsistent and do not notice or utilise these cues, drivers' perceptions of friction can be poor. Various studies reported by Wallman and Astrom (2001) showed that while drivers do typically reduce their speed as the friction drops, this is more consistent with the visual information (a wet road, snow, ice or frost, grit) available, rather than the actual friction levels. Therefore, it could be expected that where there may be poor or no visual cues, such as can occur with CMA, both the risk of a crash and the crash rate would increase.

To better understand crash risks we need to consider an approach based on 'risk analysis'. Vose (2008) describes risk analysis as 'the quantifying, either qualitatively or quantitatively, of the probability and the potential impact of some risk'. In this case we are quantifying the relative effects of different road conditions or treatments on skid resistance. To understand or analyse the risk, the skid resistance for each road condition needs to be related to:

- the crash rate for that level of skid resistance
- the level of exposure to the different levels of skid resistance.

We used locked-wheel braking tests, combined with additional GripTester measurements and information from the available literature, to help quantify the relative skid resistance levels associated with the variety of road conditions expected during winter in New Zealand. Similarly, the level of exposure to the risk of a crash could be established by determining the typical variation of the traffic levels through the day. Therefore, to be able to assess the level of risk associated, for example, with ice or frost conditions compared with a dry road, the variation of the crash rate with skid resistance needed to be identified.

The effect of skid resistance on crash risk in New Zealand

Cenek et al (2005) investigated New Zealand fatal and injury crash data between 1997 and 2002. This linked the crash data to the road condition (including skid resistance) and geometry data. The analysis used Poisson regression modelling to identify the important contributing variables and quantify their effect on the crash rate. The resulting statistical model related the road characteristics exponentially to crash risk. Figure 2, from Cenek et al (2005), presents the relationship between the crash rate and skid resistance, as expressed by the SCRIM coefficient. The SCRIM coefficient is the measure used by the New Zealand Transport Agency (NZTA) to describe the road surface skid resistance measured during the annual survey of the national state highway network. Previous work by Cenek et al (2004) also showed good correlation between SCRIM coefficients and locked-wheel braking derived coefficients of friction.

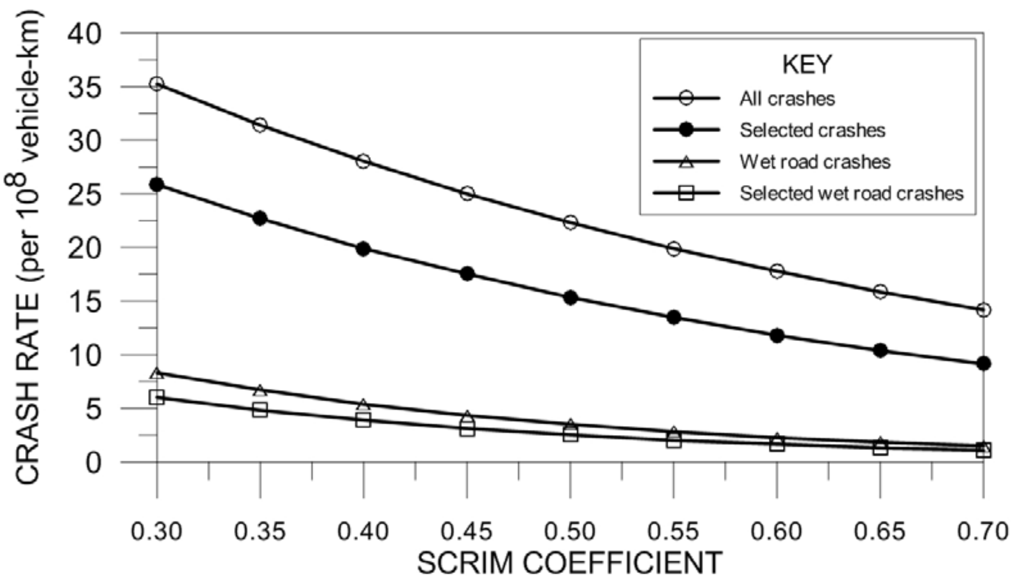

Figure 2: The crash rate – skid resistance model (Cenek et al 2005)

Figure 2 also shows the information for subsets of the overall crash data (selected crashes, wet road crashes and selected wet road crashes). For this study, all crashes have been used for comparing crash rates for the different road conditions and treatments.

Measurement of skid resistance is not a simple matter. There are often three elements involved: the road surface; the tyre and vehicle; and a contaminant or lubricant, such as water, dust, rubber, or oil. Skid resistance is dependent on all three of these elements and their interactions. Furthermore, each of these elements includes a variety of factors that affect skid resistance.

With such a large number of possible variables interacting, it is necessary to accept a potentially large variation in skid resistance, as conditions vary. It is also important to remember that any measurement of skid resistance represents the situation at that particular moment.

There is a strong relationship between skid resistance and crash risk, and so skid resistance is very important for traffic safety and road management. Accordingly, skid resistance is routinely measured in many countries in a variety of ways. The typical approach is to try to keep as many of the influencing factors constant, usually by wetting the surface with a specific amount of water, and using a standardised tyre.

In New Zealand, at least six skid testers are used on a reasonably routine basis. These are:

- the SCRIM+ truck that carries out the annual survey of the state highway network
- the Findlay Irvine GripTester, mostly used for shorter length surveys of road or runways
- the Norsemeter ROar, also generally used for shorter surveys
- the Dynamic Friction Tester (DFT) which uses a circular disc to make spot measurements
- the British Pendulum, also used for spot measurements
- vehicles instrumented to make measurements during locked-wheel braking tests.

LOCKED-WHEEL BRAKING TESTS

Site Selection

Seven sites in Coastal Otago were selected for the locked-wheel braking tests, covering a range of surface types and traffic levels. These sites were chosen on the basis of (1) being commonly exposed to frost and ice conditions in winter, (2) having regular use of CMA and mineral grit to treat frost and ice conditions, (3) being straight and flat enough so that locked-wheel braking tests could be carried out safely, (4) covering a range of surface types and traffic levels, (5) the logistical practicalities of on-road testing. The selected sites are listed in Table 1.

Table 1: Selected sites for comparative skid resistance measurements

Site	Surface type	Road Type	Traffic level
1	OGPA	State Highway	High
2	Coarse chipseal (Gr 2)	State Highway	Low
3	Slurry seal	State Highway	Low
4	Asphaltic concrete	Local Authority	High
5	Second coat chipseal (Gr 4)	Local Authority	Low
6	Slurry seal	State Highway	High
7	Asphaltic concrete	Local Authority	Low

Instrumented passenger car

The test vehicle used for the study was a Toyota Corolla which is shown in Figure 3. All of the tyres were inflated to a standard pressure of 30psi. For the purposes of the testing, the anti-lock braking system (ABS) was disabled. In this configuration the car's braking system defaulted to the standard configuration, with a distribution of braking pressure between the front and rear wheels that allowed the front wheels to lock, while allowing the rear wheels to continue rotating.

The vehicle was instrumented with a Vericom VC3000™ Traffic Accident Computer, which is routinely used by the New Zealand police to determine tyre-road friction values at the scenes of fatal crashes for use in crash reconstruction modelling. The Vericom unit is an accelerometer-based device that is attached to the inside of the car's windshield by suction cups.

Figure 3: Test vehicle – Toyota Corolla

When the 'braking' option is selected and a locked-wheel braking manoeuvre (i.e. an emergency stop) is initiated, a deceleration of 0.25g (1g = 9.81m/s2) will trigger the VC3000 to begin recording. At the end of the run the unit displays: (1) the elapsed time, (2) the distance, (3) the adjusted distance, and (4) the average coefficient of braking friction. The peak coefficient of braking friction can also be determined from the recorded run data.

Comparative locked-wheel braking tests

The primary aim of the test programme was to establish the changes in skid resistance levels on different road surface conditions. The conditions expected to be of most interest were:

1. dry road — no treatment
2. wet road — no additional treatment
3. CMA — immediately following application before frost/ice
4. CMA — following dewfall the day after application
5. grit — immediately following application
6. frost/ice — no additional treatment.

Note that previous treatments leaving residual CMA or grit on the road surface were not considered, primarily because of issues with quantifying residual levels, e.g. the amount of grit or CMA remaining. A certain number of the above conditions could be controlled, e.g. the dry road, wet road, immediately post application of CMA, and immediately post application of mineral grit. However, the dewfall and frost and ice conditions relied on environmental conditions that could not be controlled. Accordingly, at each of the seven sites listed in Table 1, a series of locked-wheel braking tests were carried out in August 2007 for those road conditions that could be controlled. The application rates for the mineral grit and CMA were around 1 tonne/lane km for grit and 30gm/m2 for CMA, these being the standard application rates used by local roading contractors on the state highway network.

The tests conducted comprised locked-wheel braking measurements carried out from an initial test speed of 30km/h. A minimum of three braking tests were carried out for each road surface condition. It was intended that the tests on dewfall and frost and ice conditions would be carried out if conditions and circumstances allowed. However, given the amount of information available about typical skid resistance on ice and frost, and the previous work carried out by Jamieson and Dravitzki (2007), these tests were not considered critical to the success of the project.

For each of the individual braking records, acceleration data files were recorded. The output data for each test run was also tabulated to provide a backup record. This included: (1) the elapsed time, (2) the initial vehicle speed, (3) the distance travelled, (4) the adjusted distance, and (5) the average coefficient of braking friction.

ADDITIONAL SKID RESISTANCE MEASUREMENTS

Measurements under dewfall and frost and ice conditions could not be carried out during the programmed on-road testing because of environmental conditions at that time. Accordingly, it was decided to carry out a limited series of tests in the laboratory on selected treatments and road conditions. These tests were carried out using Central Laboratories GripTester in push mode. The tests were carried out on an asphaltic concrete surface.

GripTester – description and operation

The GripTester is a small three-wheeled skid tester that can be either pushed by hand, or towed by a test vehicle. Its principle of operation is the simultaneous measurement of load and drag on a single smooth test wheel, which slips at approximately 15% of the travel speed. The friction values can be measured at intervals ranging from 0.04m to 0.4m. The unit of measurement is the Grip number (GN). Figure 4 shows the GripTester being used in push mode. Tests in this mode, as in tow mode, can be carried out either dry, or with water being applied at a set rate in front of the test wheel.

Figure 4: GripTester being used in push mode

The GripTester measuring tyre load is normally 11kg. With the standard contact area for this tyre load being 2200mm^2, this gives a tyre load/unit area of 0.005kg/mm^2. The typical tyre load for a passenger car is around 375kg, and the typical contact patch area is 10,000mm^2. This gives a tyre load/unit area for a car of around 0.0375kg/mm^2. This is much higher than the standard test configuration for the GripTester. This disparity is one of the issues that has been raised concerning comparisons of Griptester measurements with the results of locked-wheel braking tests. Accordingly, weights were used to increase the GripTester wheel load to around 0.018kg/mm^2 to assess how this increase in wheel load affected the GN output and the differences in GN between the different treatments.

GripTester – skid resistance measurements

Skid resistance tests in push mode were carried out for four different scenarios, these being; (a) dry, (b) wet, (c) immediately following application of grit, and (d) immediately post-CMA application. A minimum of three test runs were carried out for each surface condition. Additional GripTester measurements of skid resistance were also carried out to investigate the following specific changes in skid resistance:

1. the level of change with time following application of water
2. the level of change with time following application of CMA
3. the variation with time following dewfall on an earlier application of CMA
4. the level of change with time following application of mineral grit
5. the skid resistance following application of mineral grit on a wet road.

Testing was carried out in conditions of low temperatures, minimal wind and high humidity, the most likely conditions for frost and ice to occur. Again, three test runs were carried out in quick succession to establish the inter-run variability (±0.01). Following the application of water, CMA and grit treatments, tests were repeated every 10 minutes for the next hour. The CMA was then left for another day. Dewfall was simulated by misting lightly with a water spray and the 10 minute sequence of skid testing was repeated over the next hour. The results of these tests, and the earlier locked-wheel braking tests, are analysed and discussed in the following section.

RESULTS – SKID RESISTANCE MEASUREMENTS

Results – locked-wheel braking tests

Each of the locked-wheel braking test runs was processed to provide data for the distance travelled, the average coefficient of braking friction and the peak coefficient of braking friction, for a common reference speed of 30km/h. The data for the test runs for each road condition and treatment was combined to provide global average values. Figure 5 shows a bar chart of the average coefficients of braking friction. Also shown in Figure 5 are the approximate SCRIM coefficients calculated from relationships derived from the work of Cenek et al (2004). Please note that these relationships are approximate only, and should be treated with some caution.

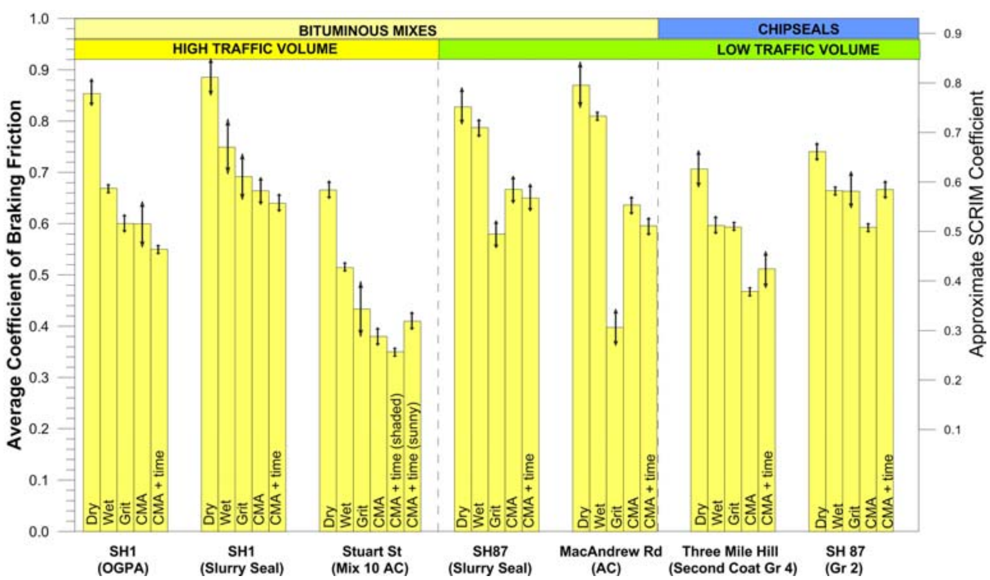

Figure 5: Average skid resistance

This shows there is considerable variation in the average coefficients of braking friction across the different surfaces and different treatments. A similar study of the effects of CMA and grit was carried out for the Dunedin City Council (Howard and Coralde 2007) under different environmental conditions, but coincidentally with the same test vehicle running on similar tyres. The average coefficients of braking friction from this study are shown in Figure 6.

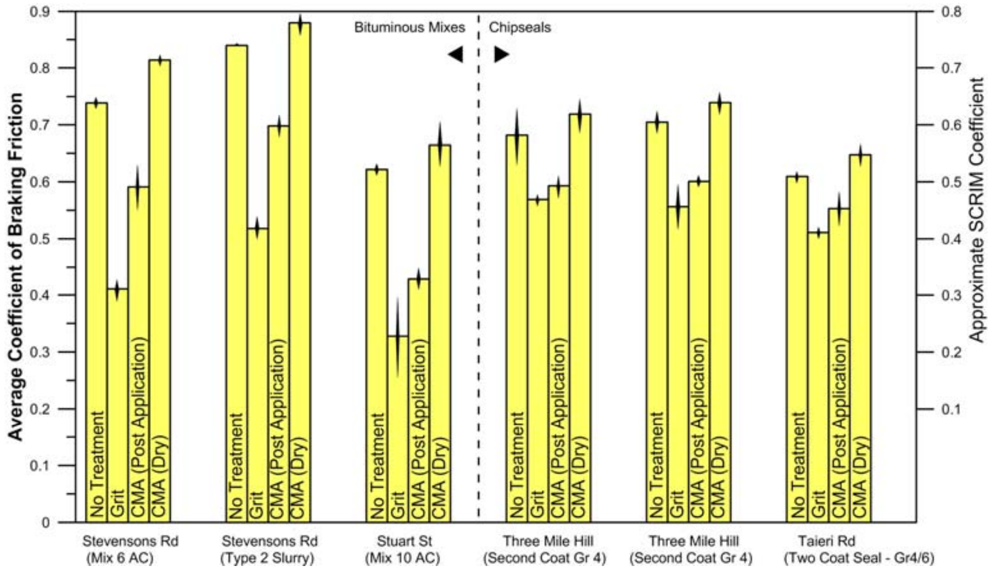

Figure 6: Average skid resistance – DCC study (Howard and Coralde)

It can be seen from Figures 5 and 6 that the treatments (water, grit and CMA) all consistently reduce the coefficients of braking friction following application. However, there appears to be considerable variation between the different surface types and the two series of tests. Because these studies were carried out under different environmental conditions the 'starting points' for both series of tests, i.e. the dry road conditions, were different. To compare the effects of the treatments, the differences in the average coefficients of braking friction and average skid resistance (approximate SCRIM coefficients) were identified. The differences in average skid resistance from the dry road values are shown in Figure 7.

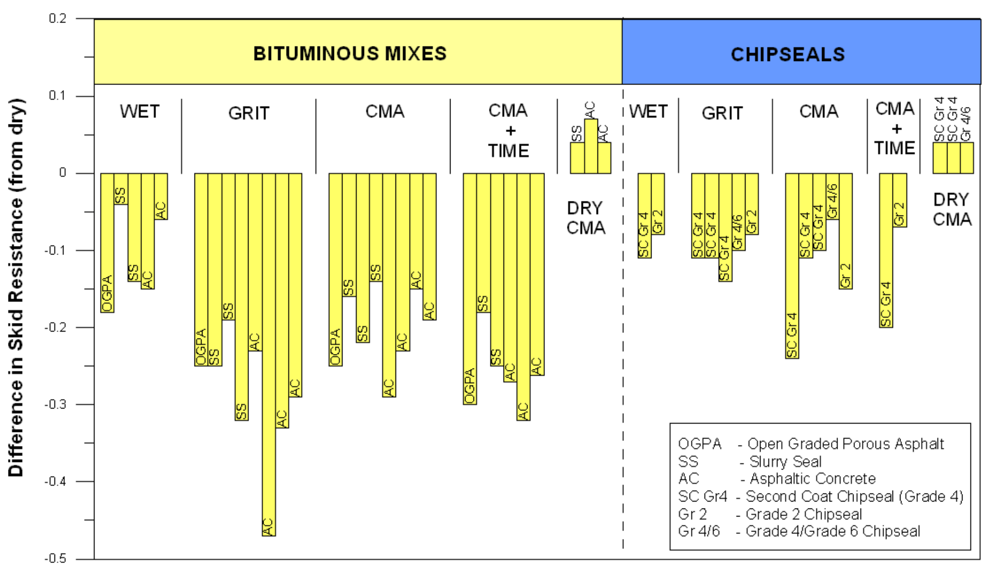

Figure 7: Changes in skid resistance with treatment compared to a dry road

The following general trends can be seen in the data shown in Figure 7:

- There is considerable variation between the performance of all treatments across the different surfaces and also across similar surfaces.
- After application, all the treatments reduce the skid resistance to below that of a dry road, except for dry CMA.

- These reductions are generally greater on the smoother-textured asphalt surfaces than on the more textured chipseals.
- Over the different surfaces, grit and CMA perform worst on the smoother asphalt surfaces.
- The performance of CMA with time following application appears to be variable, sometimes it is worse and sometimes better than immediately after application.
- When CMA is dry it performs the same or better than a dry road.

To try to simplify comparisons between the treatments, the data shown in Figure 7 was combined to give an average value for each treatment on asphalt and chipseal surfaces. The results are given in Table 2.

Table 2: Average differences in skid resistance from dry road () = ± data range

Treatment	Asphalt surfaces	Chipseal surfaces
Wet	-0.11 (0.07)	-0.10 (0.02)
Grit	-0.29 (0.18)	-0.11 (0.03)
CMA	-0.20 (0.09)	-0.13 (0.11)
CMA + time	-0.26 (0.08)	-0.14 (0.07)
Dry CMA	+0.05 (0.02)	+0.04 (0.00)
Frost/Ice	-0.51	-0.51

Assumes a value of 0.25 for the skid resistance on frost/ice

This shows that the average decrease on chipseal surfaces is generally the same for all the treatments. However, this is not the case on asphalt surfaces. This would suggest that the tendency in New Zealand to put asphaltic concrete on high stress corners might need to be tempered in areas prone to frost/ice

Results – additional skid resistance measurements – GripTester

The results of the GripTester measurements immediately following application of the different treatments are listed in Table 3. Also listed are the corresponding average results derived from the locked-wheel braking tests.

Table 3: GripTester data – immediately following application

Treatment	Average GN	Difference from dry road (GN)	Average skid resistance (LWB)	Difference from dry road asphalts (LWB)
None (dry road)	1.00	NA	0.79	NA
Wet	0.86	-0.14	0.68	-0.11
Grit	0.78	-0.22	0.57	-0.29
CMA	0.79	-0.21	0.57	-0.20

This shows that while the absolute GN values do not agree with the average locked-wheel braking values, the differences from a dry road condition are comparable. It suggests that the GripTester data can be used for comparing differences in skid resistance.

The variation of skid resistance with time following either wetting of the road through rain or dewfall, or application of mineral grit or CMA is a complex issue. Changes in skid resistance with time can be affected by environmental conditions, such as temperature, humidity, or wind, or by traffic. As described earlier, testing of the variation with time using the GripTester was carried out in conditions of low temperatures, minimal wind and high humidity. The results for the variation over the first hour following application of water, CMA and grit, and the hour following dewfall on CMA after 24 hours is shown in Figure 8.

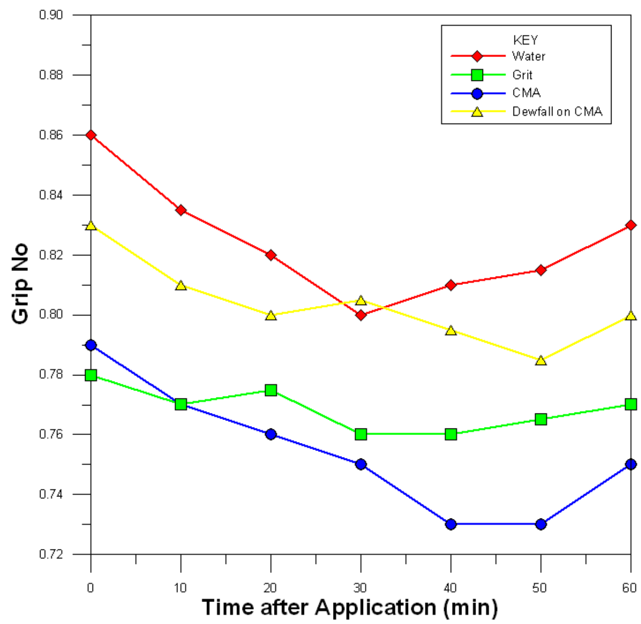

Figure 8: Variation in skid resistance over one hour after application

This shows that following application, all treatments fell further below the dry road values for periods ranging up to around 50 minutes. It also shows that even after one hour the levels of skid resistance had not risen again to the levels immediately following application. The variation of grit on a wet road is not shown in Figure 9, as measurements showed that there was little variation from those values for grit on a dry surface. Extrapolating the trends in the data would suggest that, for the conditions under which this testing was carried out, the skid resistance would rise to approximately the dry road values in around three hours for the wet, CMA and dewfall on CMA scenarios, and around six hours for the mineral grit. It is likely that in colder conditions, the water, CMA and CMA on dewfall scenarios may take as long as six hours to achieve near dry road values. The rises in skid resistance are attributed to a combination of drying and drainage for the liquid applications (water, CMA and dewfall), and to grit being crushed or moved by wheel action.

Skid resistance on frost and ice

There have been numerous studies of skid resistance on frost and ice. One of the most comprehensive of these was reported by Martin and Schaefer (1996). This presents skid resistance data for a wide variety of ice, frost and snow conditions. These show that typical skid resistance values for frost and ice conditions that might be expected in New Zealand range from around 0.15 to 0.25.

TRAFFIC LEVELS

For each of the sites listed in Table 1, hourly traffic data for the week closest to the date of the locked-wheel braking tests was extracted for the closest traffic data sites. Figure 9 shows a plot of the daily data for one of the higher trafficked sites. This figure illustrates the large differences in traffic that can occur with time on the roading network, either state highways, or local authority roads.

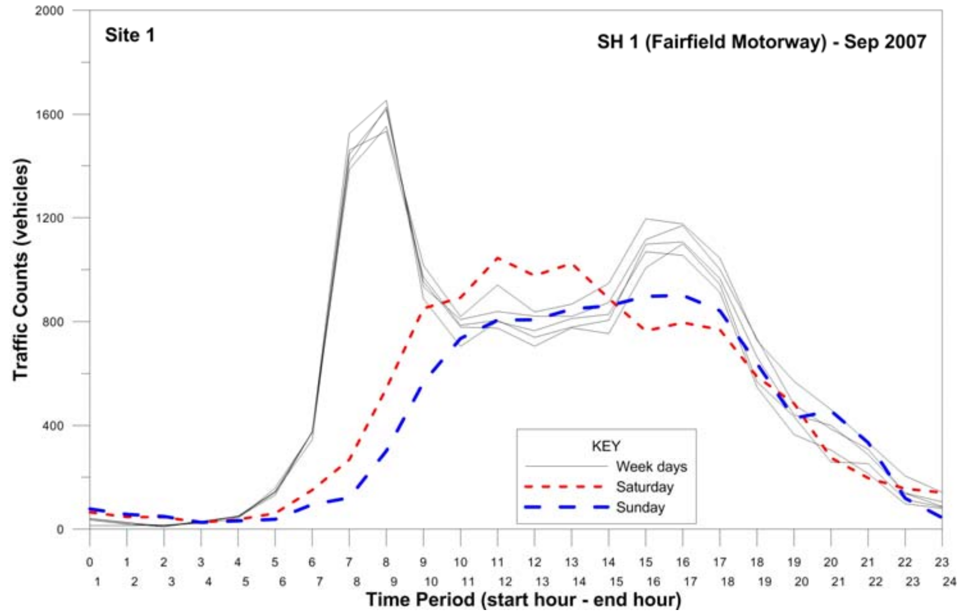

Figure 9: Daily traffic levels – high traffic sites

CRASH RISK AND MEASURED SKID RESISTANCE

We can relate measured skid resistance values to a crash rate according to the models derived by Cenek et al (2005). These crash rates are summarised in Table 4 for the average, maximum and minimum skid resistance levels. Skid resistance values for ice and frost have been based on measured values published in the literature. Skid resistance values for dewfall on CMA have been based on the differences identified from the GripTester measurements.

Table 4: Calculated crash rates for different levels of skid resistance

Treatment	Average skid resistance	Crash rate (per 108 vehicle-km)	Minimum skid resistance	Crash rate (per 108 vehicle-km)	Maximum skid resistance	Crash rate (per 108 vehicle-km)
None	0.79	11.8	0.67	15.1	0.88	9.5
Wet	0.68	15.2	0.51	21.8	0.81	11.3
Grit	0.57	19.0	0.40	28.0	0.69	14.5
CMA	0.57	19.0	0.38	29.2	0.67	15.0
CMA+time	0.55	20.0	0.35	31.3	0.67	15.0
CMA+dewfall	0.61	17.5	0.60	17.8	0.63	16.7
Ice/frost	0.20	42.7	0.15	46.0	0.25	39.0

Evaluations of the expected crash rate at the sites where the skid resistance and traffic levels are known can now be done by multiplying the measured traffic levels by the calculated crash rates for the different skid resistance levels established for the different road conditions. By knowing the variation in traffic levels through the day, the effects of any change in conditions, or any treatment, at any particular time can be established.

To illustrate the differences between treatments most likely to occur between mid to late afternoon and the early morning, a number of different scenarios were considered. It was assumed that the skid resistance changes from the dry road condition in each case lasted about six hours. This is a conservative length of time according to the plots shown in Figure 8, except perhaps for frost and ice conditions. The selected scenarios for (1) rain, (2) grit, (3) CMA , (4) CMA – followed by dewfall the following night, and (5) ice/frost formation, were for these events to occur at 3pm, 6pm, 9pm and 12am. The exception was that dewfall following CMA would occur the day after the initial application of CMA. Figures 10 and 11 illustrate the differences between an icy road condition and the application of CMA at the corresponding time for a high traffic site.

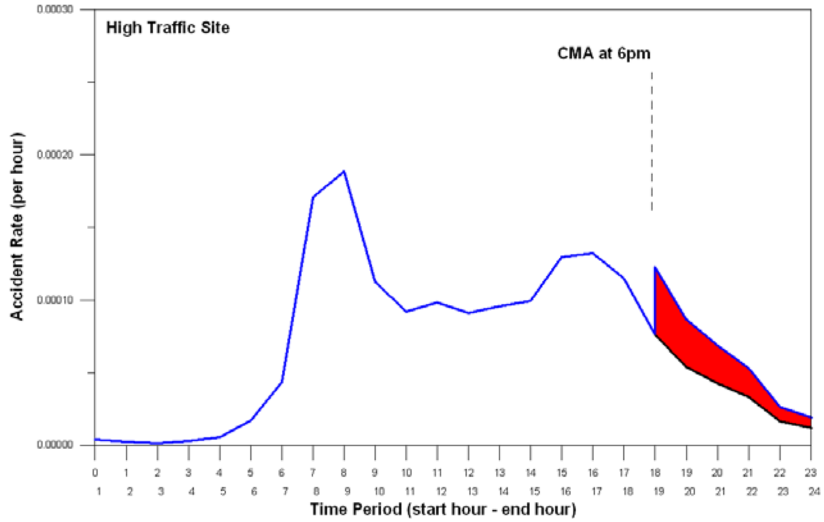

Figure 10: Accident Rates - CMA at 6pm

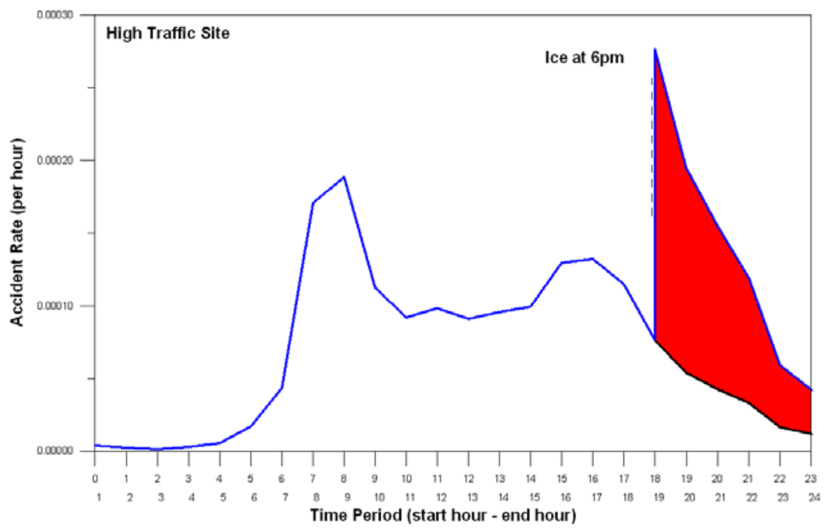

Figure 11: Accident Rates - Ice at 6pm

Figures 10 and 11 show that the application of CMA represents a considerable reduction in the crash rate compared with an icy road. This is the case regardless of the timing of the application. However, application of CMA does represent an increase in the crash rate over a dry road condition until the CMA dries. Accordingly, to assess the relative effects of each of the treatments/road conditions at the different times, the hourly crash rates were summed for each scenario to provide a net daily crash rate. These are shown in Figure 12 and Figure 13 for one of the high traffic and one of the low traffic sites respectively, as percentage differences in the daily crash rates for each of the treatments/road conditions compared to a dry road condition.

Figures 12 and 13 show that the time at which a change in the road condition occurs, either through naturally occurring changes (rain, dewfall, frost and ice), or though application of treatments for frost and ice (grit or CMA), has a significant effect on the estimated number of daily crashes. As expected, when the treatments are made later in the evening, outside the rush hour period, when traffic levels are lower, the estimated daily crash rates are also much lower. After 9pm the overall daily crash rates for the two treatments for frost and ice (grit and CMA) are only slightly higher than those for a dry road, being less than 5% greater. They are also much lower than those for frost and ice conditions without treatment.

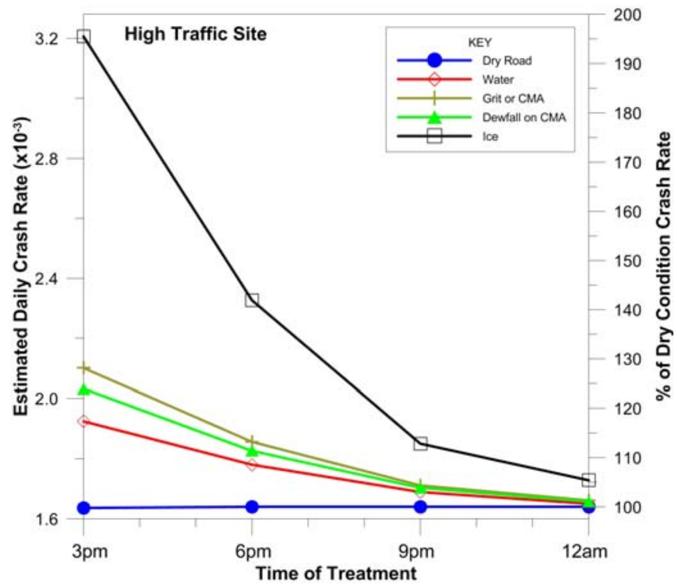

Figure 12: Comparison of estimated daily crash rates – high traffic site

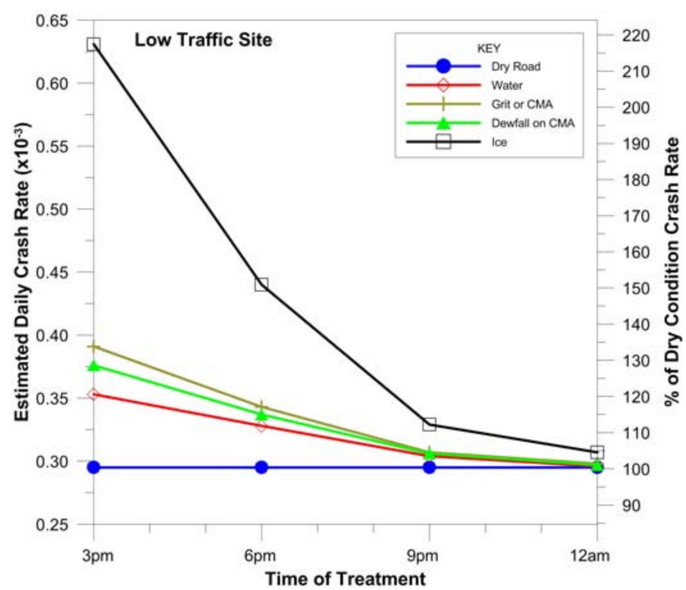

Figure 13: Comparison of estimated daily crash rates – low traffic site

For these comparisons it was assumed that the frost or ice conditions would last for a six-hour period, similar to the time that the grit or CMA treatments might reduce skid resistance to below the levels for a dry road. However, given temperatures consistently below freezing level, frost or ice conditions could last much longer, possibly through the morning traffic peak. This could significantly increase the daily crash rate for frost or ice conditions well above 200% levels.

Timing of treatments for frost or ice

It was assumed above that all the road condition changes and treatments occurred at the same time. However, application of grit is normally a reactive measure to frost or ice conditions that are already present. Therefore, the daily crash rate for gritting could be expected to be somewhat higher due to this initial period of frost or ice. In contrast CMA is normally applied proactively, when frost or ice is anticipated due to weather conditions. Accordingly, the daily crash rates could be expected to be similar to those shown in Figure 11.

There are a large number of potential scenarios that could occur in these situations. For the purposes of illustrating the differences between: (a) doing nothing, (b) applying grit after ice/frost has begun to form, (c) applying CMA proactively on the expectation of frost or ice, and (d) applying CMA as a routine maintenance procedure, a representative scenario with different treatments was considered. This was for a two-day period on the high traffic site used previously, where frost/ice was expected each night, starting at 2am, with the potential for frost or ice to last through to mid-morning (10am). The options considered were:

- no treatment – no frost or ice occurs
- frost and ice at 2am each night lasting until 10am
- grit application at 3am each night (reacting to ice/frost)
- CMA application at 12am on the first night in anticipation of frost and ice, with no application the following night, but assuming dewfall at 2am on the CMA already applied
- CMA application at 9pm on the first night as part of a routine maintenance programme, no application the following night, and assuming dewfall at 2am on the CMA already applied.

To assess the relative effects of each of the treatments or road conditions at the different times, the hourly crash rates are summed in Table 5 for each scenario to provide a net daily crash rate.

Table 5: Effects of treatment/condition over two days on high traffic site (estimated number of crashes over two days, x10-3)

Treatment/road condition	Estimated crash numbers
Dry	3.51
Ice	6.35
Grit	4.04
CMA (applied two hours before ice/frost anticipated)	3.65
CMA (applied at 9pm as standard maintenance)	3.70

The comparison of estimated crash numbers over a two-day period shows that:

- not treating frost or ice represents a very marked increase in the crash numbers
- treating with grit, or with CMA, either before ice or frost is anticipated, or as routine maintenance at a specific time, reduces the crash rate per day considerably compared with frost or ice conditions
- there is very little difference between applying CMA a short period before ice or frost is anticipated, or as a routine maintenance procedure at a specific time, provided routine application avoids the rush hour peaks
- either application of CMA is better than an application of grit, given that grit is often applied after ice or frost has begun to form.

CONCLUSIONS

The programme of locked-wheel braking tests and GripTester measurements of skid resistance on different road surfaces under different conditions (dry, wet) and following application of the two main treatments for frost and ice (CMA and mineral grit) showed that:

- There was considerable variation in the stopping distances, and average and peak skid resistances across the different surfaces, treatments and road conditions.
- Almost all the changes in the road conditions investigated, including applications of water, CMA and mineral grit reduced the skid resistance to levels below those for a dry road on all of the different surfaces. The exception was CMA when dry.

- The reductions in skid resistance were generally greater on the smoother textured asphalt surfaces (OGPA and asphaltic concrete) than on the more textured asphalt surfaces (slurry seals) and chipseals.
- CMA and grit performed worse on the smoother asphalt surfaces than on chipseals.
- The performance of CMA with time after application was heavily dependent on environmental conditions such as temperature, humidity and wind. Good drying conditions or drainage increased the skid resistance with time after application. Cool conditions, high humidity and little wind tended to slow down this change.
- When CMA was dry, it performed as well as or better than a dry road surface.
- Dewfall tended to reactivate the CMA, causing skid resistance to reduce, but not to the same degree as when first applied.
- Under cool conditions and high humidity, following dewfall, CMA or mineral grit, the skid resistance might take up to six hours to rise to levels approaching those of a dry road.
- The performance of grit with time after application tended to improve slightly, which is assumed to be as the grit was crushed or moved by the action of traffic.

Combining the changes in skid resistance due to a change in road conditions (application of water, CMA or grit) with the expected variation in crash rates with skid resistance, and the measured traffic levels, to produce an assessment of the expected crash risk, showed that:

- The time at which a change in road conditions occurred, either naturally because of rain, dewfall, frost or ice, or through application of treatments (grit or CMA) would have a significant impact on the expected number of daily crashes.
- Expected crash rates were much higher for frost and ice than for any other road conditions or treatments.
- Crash rates under all of the different changes in road conditions, except for frost and ice, were much lower when these changes occurred outside the peak traffic periods.
- Treating road surfaces with grit, or with CMA, either a short period before ice or frost was anticipated, or as a routine maintenance procedure at a specific time, reduced the crash rate per day considerably compared with untreated frost or ice conditions.
- There was little difference (1–2%) in the expected crash rate as a result of applying CMA a short period before ice/frost was anticipated, and applying it as a routine maintenance procedure at a specific time, provided the routine application avoided the rush hour peaks.
- Either of the two applications of CMA was better than an application of grit, given that grit was applied near to or after the time ice or frost had begun to form.

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