Management of Skid Resistance under Icy Conditions on New Zealand Roads

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Executive Summary

Introduction

Traditionally, treatment of frost, ice and snow on New Zealand roads has involved spreading of mineral grit on the affected areas but this has disadvantages. Common salt was used as a de-icing agent until the early 1980s when public concerns about vehicle corrosion led to its use being discontinued. A major review of options for de-icing of state highways was then carried out in 1996 by Transit New Zealand, to consider de-icing agents commonly used overseas. Calcium Magnesium Acetate (CMA) was deemed most suitable for New Zealand conditions and had lowest risk regarding skid resistance compared with other de-icing agents used in Europe and North America. However crashes occurring after CMA applications raised concerns about this risk.

This study was undertaken during the winter of 2004 on Coastal and Central Otago roads to quantify the magnitude and extent of changes to skid resistance brought about by the de-icing agent CMA, and to assess the effects of migration of CMA through tracking by vehicles on those roads.

The research was based around an on-road test programme comprising skid resistance measurements using a British Pendulum Tester (BPT), the Central Laboratories' GripTester, and a car instrumented for Locked-Wheel-Braking (LWB) tests.

An initial skid resistance survey using the GripTester was conducted on sections of the New Zealand state highway network in the Coastal Otago area where CMA had been used in the previous winter (2003). This was aimed at providing baseline skid resistance data in dry and wet conditions. Tests were also carried out following an application of CMA to investigate the duration of the effects of CMA on skid resistance with time, and also the effects of migration through tracking by vehicles.

From those longer sections surveyed using the GripTester, together with some additional road surface types, shorter test sections were chosen as being suitable for the skid testing programme. Surfaces on these test sections comprised fine chipseal, coarse chipseal, open graded porous asphalt (OGPA), asphaltic concrete, and a slurry seal.

Skid resistance measurements were carried out over a range of conditions. They included dry, wet and dewfall conditions without CMA, testing immediately following application of CMA, and testing following dewfall with CMA previously applied.

Conclusions

The GripTester measurements carried out showed that:

- Wet-road skid resistance changed significantly over very short distances, with Grip Numbers (GN) that ranged from a minimum of around 0.5 to a maximum of around 1.1 over a few kilometres, and changed by 0.2 or more in a distance of less than 100 m.
- Wet-road skid resistance at some locations can be similar to dry-road values at other nearby locations.

- Skid resistance following a night-time application of CMA was much lower than dry-road skid resistance values, by up to 0.5 Grip Number, and levels on the road treated with CMA were similar to the range of wet-road skid resistance values measured over the same road section. At some locations, the skid resistance of the road treated with CMA was significantly lower than the corresponding wet-road value.
- Following night-time application of CMA the skid resistance of the treated road tended to increase with time as the CMA drained away or dried. However, even three hours after application of CMA the skid resistance of the road was still less than the dry road values.
- Tracking of CMA by vehicles, and a corresponding lowering of skid resistance, does occur. This tracking was shown by a decrease in skid resistance over a distance of approximately 1 km past the end points of a night-time application. Within this 1 km section the skid resistance was found to rise gradually towards the dry-road values. As on the applied section, skid resistance on the tracked section also gradually increased with time.

The locked-wheel-braking tests carried out with the instrumented passenger car showed that:

- Across the five test surfaces relatively little variation in the dry-road skid resistance was recorded. However, the coarser textured surfaces of coarse chipseal, OGPA, and slurry seal produced dry-road skid resistance levels that were higher than those of the smoother textured fine chipseal and asphaltic concrete.
- Following application of CMA the skid resistance levels were reduced to between 65% and 85% of the dry-road values, and stopping distances were increased by up to 50%. The shortest stopping distances with CMA generally occurred on the coarser textured surfaces. However, at 30 km/h the differences between the five surfaces were less than 1 m of stopping distance.

The GripTester and BPT tests showed that:

- As with the instrumented car, only limited variation of dry-road skid resistance was recorded across the five different test surfaces.
- Application of CMA reduced road skid resistance levels to between 35% and 75% of the dry-road values, and typically to levels below those of wet-road values. As with the LWB tests, the coarser textured surfaces generally performed better.
- After an application of CMA had dried, road skid resistance levels were consistent with dry-road values. However, dewfall, or moisture from high humidity or light rain was shown to partially ‘reactivate’ the CMA. Road skid resistance levels were found to be lower than for dewfall alone, but not as low as those immediately following application of CMA. Generally, they fell approximately midway between the wet-road and post-CMA values.
- An assessment of the level of risk to drivers associated with applying CMA at different times of the day can be made. This assessment can be achieved by considering the typical reductions in skid resistance following application of CMA and following its reactivation by dewfall moisture levels, together with typical daily traffic levels. Mid-

afternoon and night-time applications for representative traffic levels showed around 5% difference in the 'level of risk' caused by the reduction in skid resistance.

Recommendations

From this study into the effects of CMA on road skid resistance values, the following recommendations are made.

1. Signage

- Signage specific to the use of CMA which reflects its effects on skid resistance, particularly when general road or weather conditions do not provide the driving public with an expectation by visual or other cues of lowered skid resistance, should be considered.
- If appropriate signage is chosen for use with CMA, it should be placed to include the effect of tracking of CMA and the consequent lowering of skid resistance. It therefore should be placed at least 1 km past the end points of any significant application.
- Until such time that appropriate signage is implemented, the current practice of using ICE/GRIT signs should continue to be used when ice formation is about to occur, and when either grit or CMA is applied.

2. Changes to 'best practice' procedure

- Changes to the current regional best practice procedures should include assessing the level of risk.
- The level of risk should be assessed by comparing actual traffic levels with changes in skid resistance which occur on different road surfaces immediately following application of CMA, and also under dewfall conditions.
- Further work is required to develop this risk model, particularly in terms of the variation of skid resistance with time under different environmental conditions, and particularly in association with dewfall.
- Until these risk models have been developed, in areas of high humidity CMA should be applied as close as possible to the time when ice formation is expected, i.e. when it is obvious to the motorist that it is a frosty night and that shady sections could be icy.

3. Effects of tracking

- The effects of tracking of CMA should be investigated for different traffic conditions. This might include looking at the duration and extent of changes to the road skid resistance under light, medium and heavy traffic.

4. Skid resistance v traffic

- The variation of road skid resistance following application of CMA should be investigated for different traffic conditions to determine whether this has any significant effect in reducing or extending the time for which road skid resistance is reduced.

5. Further LWB testing

- Further LWB tests following application of CMA should be carried out at different speeds to determine whether the trends are the same as, or different from, those for dry roads and wet roads.

Abstract

The effects of the de-icing agent Calcium Magnesium Acetate (CMA) on the magnitude and duration of skid resistance changes of a range of road surface types were examined through an on-road test programme on New Zealand state highways, during the winter of 2004. This involved a baseline survey of skid resistance on sites were CMA had been used in previous years, followed by a more focused series of skid resistance measurements made with different skid testers. These skid testers included an instrumented car, the British Pendulum Tester, and the GripTester.

Tests were conducted under various conditions, with and without CMA. Road surface types included fine and coarse chipseal, open graded porous asphalt (OGPA), asphaltic concrete and slurry seal. Comparisons were made between the different skid testers for the different surfaces, and different road surface conditions, both with and without CMA. Some potential implications for management of the use of CMA were examined.

1. Introduction

This research project carried out during the winter of 2004 was aimed at enhancing the management of the use of the de-icing agent Calcium Magnesium Acetate (CMA) through a better understanding of its behaviour on different surfaces and under different conditions. In this way, an objective was to minimise issues relating to wet and dewfall conditions and tracking along the road by vehicles.

This research is expected to be relevant to the management of those roads in Coastal and Central Otago, and the central North Island, New Zealand, where CMA is currently used. In addition, it is also likely to be relevant to those roads where snow or ice conditions and traffic levels might warrant its use in the future.

1.1 Background

In New Zealand during winter, certain parts of the state highway network are subject to frost and ice, with varying degrees of regularity and severity. The significant reductions in skid resistance that can occur with such conditions, together with their unexpectedness, can pose a significant hazard to motorists.

Traditionally, treatment of frost, ice and snow by roading contractors has involved spreading mineral grit on the affected areas. However, the use of grit has its own disadvantages. Grit build-up has been a factor in a number of crashes, and motorists are also concerned about potential damage to paintwork and windscreens. Furthermore, grit also covers and abrades roadmarking paint and reduces the effectiveness of raised pavement markers. Consequently, the decision was to investigate alternative methods for managing issues relating to frost and ice.

Common salt was used in New Zealand as a de-icing agent until the early 1980s when public concerns about vehicle corrosion led to its use being discontinued. These continuing concerns, and also environmental concerns, have largely prevented its re-introduction.

As a result, a major review of options for de-icing of state highways was carried out in 1996 by Transit New Zealand, to consider de-icing agents commonly used overseas.

CMA was deemed most suitable for New Zealand conditions, given its low risk of vehicle corrosion, very minor effects on soil and groundwater, and lowest risk regarding skid resistance when compared with other de-icing agents used in Europe and North America.

Since 1998, Transit New Zealand has been trialling the use of CMA as an anti-icing and de-icing agent on state highways in the central North Island and parts of the South Island, mainly Coastal and Central Otago.

Significant reductions in the number of crashes and road closures attributed to ice have seen the number of sites treated with CMA increase year by year. Draft 'Best Practice' guides for the use of CMA have been in place in different Transit New Zealand regions for several years (Transit NZ 2004). Table 1.1 shows how the number of winter crashes

(June-August) has varied through a five-year period (1999-2003) during which CMA was introduced (Whiting 2003).

Table 1.1 Crashes occurring during winter months (i.e. June-August) on Central Otago roads, between 1999 and 2003.

Year	Number of Crashes	Treatment
1999	16	Sites gritted only
2000	22	Sites gritted only
2001	30	Sites gritted only
2002	12	Gritting and limited CMA application
2003	9	CMA regularly applied

1.2 Need for research

The trials have shown that, although CMA works reasonably well as a de-icing agent, it is more effectively used to prevent ice formation, particularly when used in conjunction with appropriate ice/frost forecasting and road management tools. Consequently, the preference is to use CMA in a more proactive, rather than a reactive, way. However, a number of skid-related crashes on road sections treated with CMA have occurred. These crashes have raised issues regarding the effects of CMA on skid resistance, particularly with respect to:

1. its behaviour on different surfaces,
2. its behaviour immediately after application,
3. the magnitude and duration of its effects,
4. the degree of migration of CMA along the road through tracking by vehicles, and
5. the effects of different environmental conditions, such as dewfall, on previously treated areas.

Previous laboratory-based research (Dravitzki et al. 2003) indicated that CMA reduced road surface skid resistance to below that of a wet road, but there was uncertainty as to whether this effect would occur in the field when tracked by car tyres. Consequently, these issues needed to be addressed, particularly in relation to the current operational use of CMA.

1.3 Objectives

The research programme had the following objectives:

1. To quantify the magnitude and duration of changes in skid resistance on different road surfaces that result from the current operational use of CMA as a de-icing agent.
2. To compare the skid resistance resulting from application of CMA with typical values of wet- and dry-road skid resistances on surfaces where CMA has been used previously.

3. To assess the degree of migration of CMA through tracking by vehicles.
4. To compare the skid resistance as measured by the different skid testers with that measured using an instrumented car.

The primary goal was to better understand the behaviour of CMA on different surfaces and under different conditions, particularly immediately after application and under dewfall conditions, thereby providing inputs for the refinement of current 'best practice' guides for CMA use.

1.4 Scope of the report

This report presents the results of the on-road test programme comprising skid resistance measurements using a British Pendulum Tester (BPT), the Central Laboratories' GripTester, and a car instrumented for Locked-Wheel-Braking (LWB) tests.

Chapter 2 discusses the current practices in those Transit New Zealand regions currently using CMA in quantity.

Chapter 3 describes the results of a baseline survey of sites showing historical use of CMA. This was done using the GripTester. It includes measurements relating to the duration of the effects of CMA as well as tracking by vehicles.

In Chapter 4, the comparative skid resistance measurements using the different skid testers on five different surfaces and a range of test conditions are described.

Chapter 5 summarises results of the comparative skid resistance measurements.

The analysis of the results that was carried out and the associated findings are presented in Chapter 6.

Finally, conclusions and recommendations drawn from the research are given in Chapter 7.

2. Current best practice use of CMA

Since trials of CMA were begun in New Zealand (1998), consultants and contractors in the different Transit New Zealand regions where it has been used have established best practice guides or methodologies for CMA application. These areas include Coastal Otago, Central Otago and the central North Island. They have been formulated in conjunction with the Transit New Zealand National Best Practice Working Group. The methodologies for Coastal and Central Otago are discussed below.

2.1 Coastal Otago

Coastal Otago's best practice guide has a regional perspective, and focuses on characteristics of the Coastal Otago region. The main elements of this guide that are relevant to this study and the application of its results are:

1. CMA will be applied on an 'as and when required' basis;
2. It will usually be applied as a liquid, but can also be applied in granular form, or with grit;
3. It is ideally a pre-treatment, but in higher concentrations may be used as a de-icer;
4. It is preferred that application is restricted to specific intermittent sites, rather than area-wide treatments;
5. It is not to be applied unless there is a clear opinion that ice/snow formation has occurred, or is imminent, i.e. as close as possible to the time of ice/snow formation;
6. The standard application rate is 25g/m^2, made by mixing CMA at a rate of 0.36kg/litre of water.

Figure 2.1 Applying CMA in liquid form on a Coastal Otago state highway.

The most relevant of these elements is the requirement that CMA is not applied until there is reasonable certainty that frost, ice or snow will occur. This has come about because of concerns relating to the skid resistance immediately after application of CMA, and the effects of rehydration of CMA under dewfall conditions. Typically, it means that CMA is applied mostly during the night. Figure 2.1 shows CMA being applied to a Coastal Otago highway during part of this study.

2.2 Central Otago

Although Central Otago uses the Coastal Otago guide for best practice, their contractors apply methodology for using CMA that differs slightly to that in place for Coastal Otago area. The main difference is that, in Central Otago, CMA can be applied more as a routine preventive measure, with less stringent requirements as to the certainty of frost/ice formation.

Typically CMA is applied during the day, with a cutoff at approximately 3pm. The lower humidity and hence less dewfall, characteristic of drier Central Otago, means that the risk from skid resistance changes is perceived to be lower.

It is likely that the application of CMA during the day would have to be reviewed in those areas of Central Otago where the climate is similar to that of Coastal Otago.

3. Baseline GripTester skid resistance survey

A baseline skid resistance survey of selected road sections was conducted using the Central Laboratories' GripTester. This was to:

1. establish baseline wet-and dry-skid resistance data for the selected road sections, so that these could be compared with post-CMA road skid resistance values, and the potential differences in levels of risk assessed, and
2. determine the makeup of the specific sites for the detailed second part of the test programme.

It was also intended to take advantage of any CMA applications made to investigate post-application skid resistance changes and migration of CMA along the road through tracking by vehicles.

3.1 Road section selection

Selection of potential road sections for this baseline survey was based on:

1. histories of exposure to frosty or icy conditions, and
2. previous use of CMA.

Accordingly, records of road sections in Coastal Otago where CMA had been applied during the winter of 2003 were obtained from the contractor responsible for the application of CMA on this part of the State Highway network, i.e. Works Infrastructure. A map of the resulting road sections is contained in Appendix A, and they are listed in Table 3.1.

Table 3.1 Road sections selected for the baseline survey of Coastal and Central Otago roads.

Road Section No.	State Highway	Start RS	End RS
1	1S	667/2	667/5
2		667/7	683/1
3		683/6	700/3
4		707/0	720/2
5	8	169/11	169/14
6		202/10	202/15
7		401/0	401/6
9	87	0/4	0/11
11	88	0/0	8/0

RS Reference Station

Following discussions with Transit New Zealand's Regional Assets Manager, selection of the baseline survey sites was based on these road sections, with some modifications and additions. They cover all the primary surfacing types used in the Coastal Otago area (see Table 4.1), these being fine and coarse chipseals, open graded porous asphalt (OGPA), asphaltic concrete (AC), and slurry seal (SS).

3.2 Methodology

The road sections listed in Table 3.1 were surveyed using the GripTester during mid-June 2004. This trailer-based skid tester is shown in Figure 3.1. It operates on the principle of a treadless measuring wheel on a strain-gauged axle that slips at a speed that is approximately 15% of the test speed. The skid resistance, or Grip Number (GN), is the ratio of the horizontal drag on the wheel to the vertical load on the wheel. The GripTester can be towed behind a vehicle as seen in Figure 3.1(a), or pushed by hand as in Figure 3.1(b). Testing can also be done either dry, or with water applied in front of the measuring wheel at a rate proportional to the test speed.

Testing on the entire road section lengths (Table 3.1) was carried out in towed mode at 50 km/h, with the appropriate water rate applied, to give a measure of the 'wet' skid resistance level. Shorter sections covering a range of different surface types were also tested dry, without any applied water. Testing was done in both increasing and decreasing directions (in relation to highway Reference Stations), for the left-hand wheelpath only.

3.3 Wet- and dry-road skid resistance

Figure 3.2 shows plots of the skid resistance, both dry and wet, for one of the road sections obtained in June 2004. The data for both the increasing and decreasing directions are plotted as if in the same direction. Skid resistance data for all the road sections are given in Appendix B.

Considerable variation in the wet skid resistance is shown, with the Grip Number (GN) being between about 0.5 and 1.1. Figure 3.2 also shows that wet skid resistance can change very quickly over very short distances. Similarly, over relatively short distances of less than 100 m, even the dry skid resistance varied considerably, from around 0.7 to 1.3 (GN).

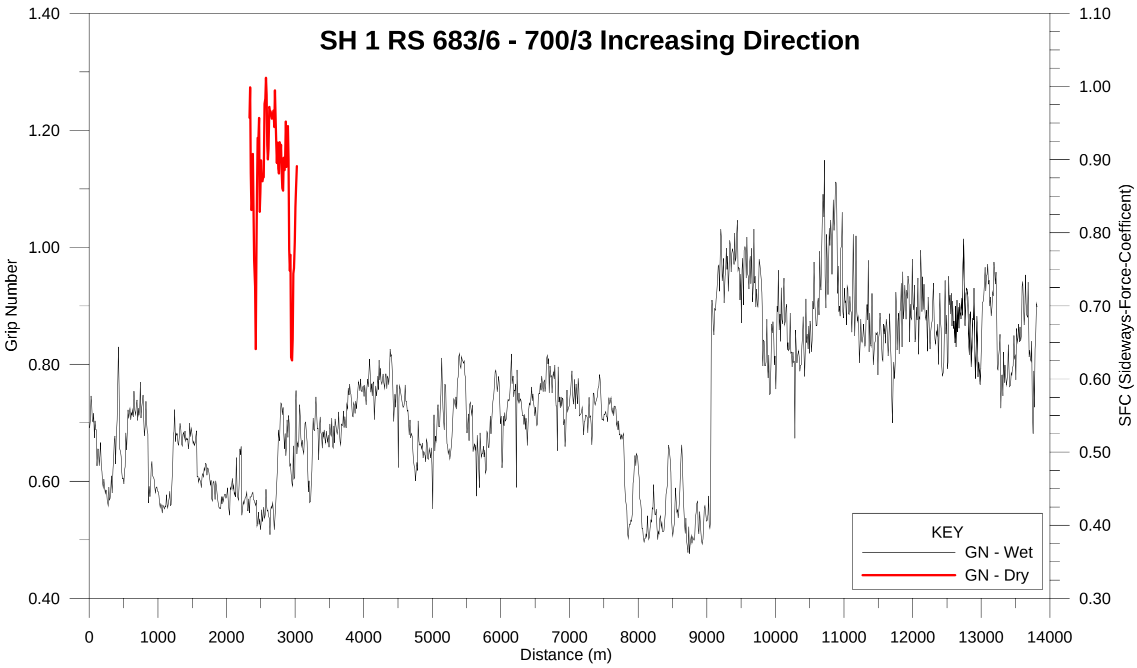
Figure 3.2 shows that the wet-road skid resistance on a section of the test site was similar in magnitude to the dry values measured on another section of the test site.

Table 3.2 summarises the mean, maximum, and minimum skid resistance values for each of the test sections. The minimum values in particular have been included as they represent the greatest potential risk to road users in any of the baseline survey sections.

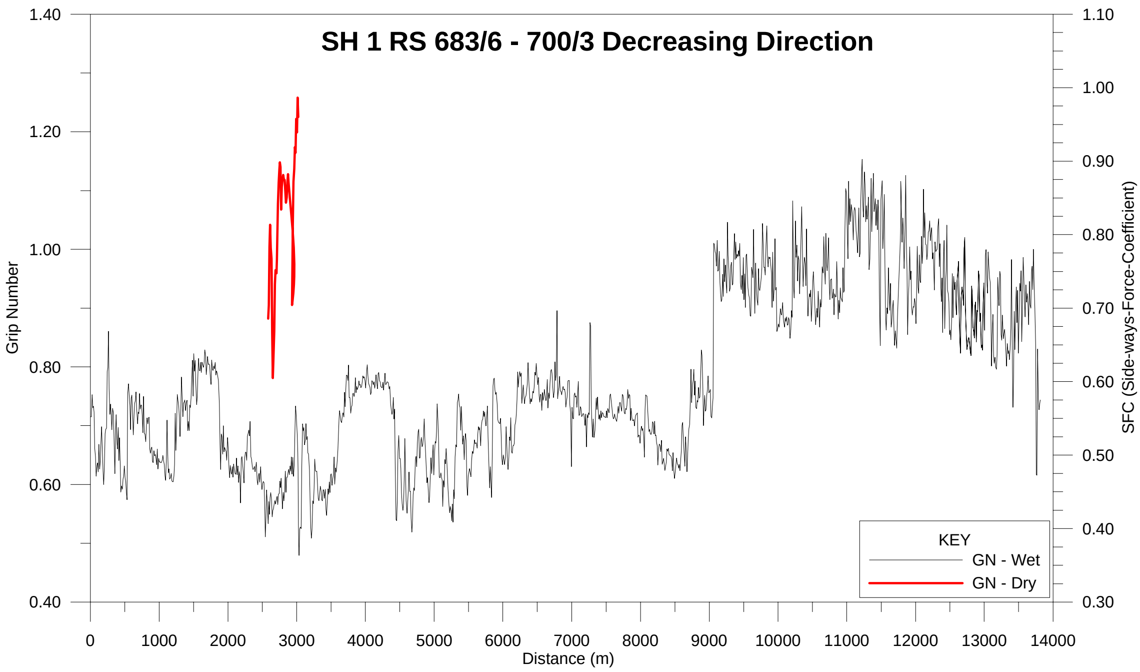
(a) Tow mode

(b) Push mode (with water being applied)

Figure 3.1 Opus Central Laboratories' GripTester in use.



(a) Increasing direction.



(b) Decreasing direction.

Figure 3.2 Wet and dry skid resistance for road section 3 (RS 683/6–700/3).

Table 3.2 Summary of data for the road sections of the baseline survey.

Section No.	State Highway	Start RS	End RS	Mean GN		Max GN		Min GN	
				Wet	Dry	Wet	Dry	Wet	Dry
1	1S	667/2	667/5	0.67	1.06	0.82	1.10	0.41	0.96
2		667/7	683/1	0.65	1.01	0.84	1.09	0.40	0.89
3		683/6	700/3	0.68	1.12	0.90	1.23	0.48	0.81
4		707/0	720/2	0.71	1.15	1.05	1.37	0.43	0.80
5	8	169/11	169/14	0.88	0.88[a]	1.08	0.96[a]	0.54	0.80[a]
6		202/10	202/15	0.86	0.92	0.98	1.11	0.68	0.82
7		401/0	401/6	0.89	–	1.13	–	0.54	–
9	87	0/4	0/11	0.66	1.13	0.96	1.30	0.26	1.00
11	88	0/0	8/0	0.75	1.07	0.94	1.28	0.51	0.72

[a] – road damp, not dry; RS – Reference Station; GN – Grip Number

Figure 3.3 summarises the data contained in Table 3.2 so that comparisons can be made between the mean, maximum and minimum values. In addition, the data can be compared with the values measured during post-CMA application measurements.

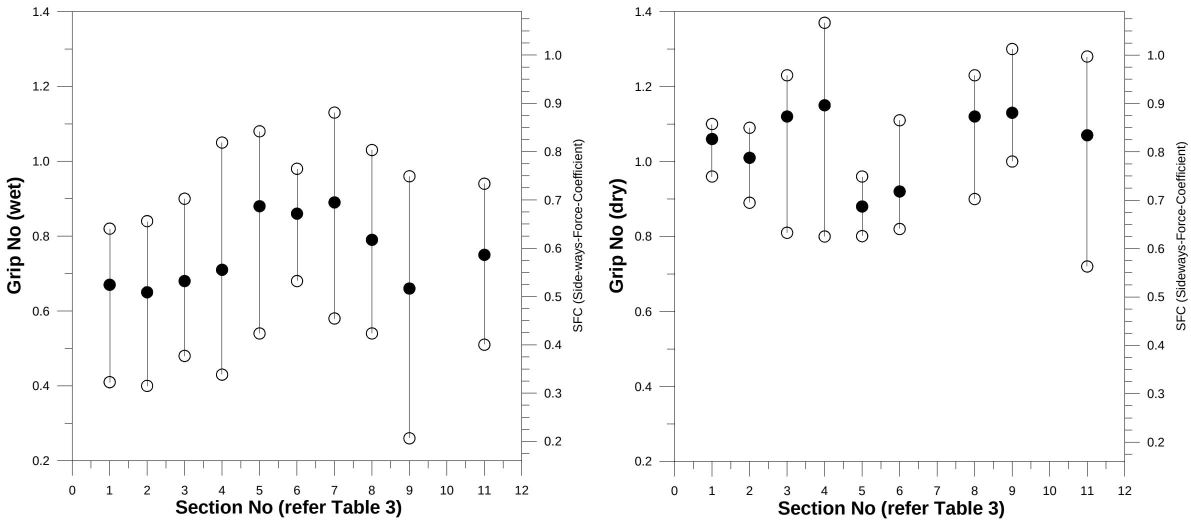


Figure 3.3 Summary of GripTester wet and dry skid resistance data for baseline survey road sections.

Figure 3.3 shows that considerable variation occurs in the mean, maximum and minimum skid resistances across the different test sections. These test sections cover all the road surface types commonly used, not only in Coastal Otago but in most areas in New Zealand that might be prone to ice and frost. Consequently, they illustrate the likely ranges of wet and dry skid resistance that could typically be expected in such areas.

3.4 Post-CMA application

During the course of the GripTester baseline survey in June 2004, advantage was taken of a standard night-time application of CMA to:

1. study the duration of its effects in the hours after application, and
2. investigate whether passing vehicles can cause migration (i.e. tracking) of CMA outside the application area.

Between approximately 0100 and 0115 hours (h) on the morning of 18th June an application of CMA was made on SH1 by Works Infrastructure in anticipation of freezing conditions. This covered part of section 2 RS 667/7 to 683/1 listed in Table 3.1.

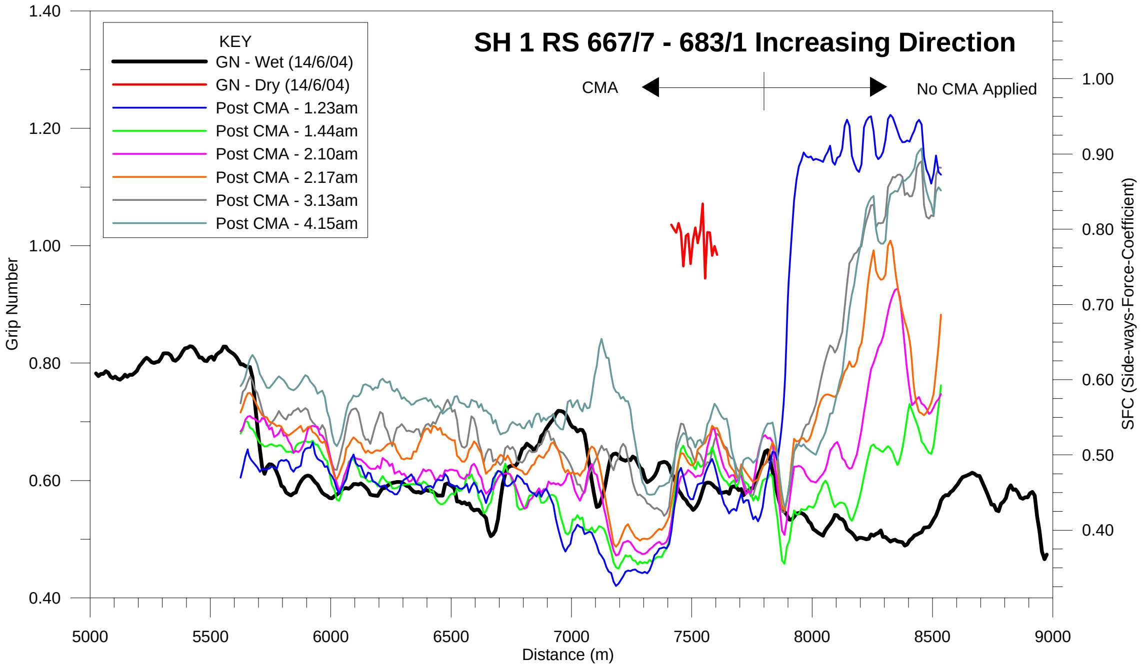
The GripTester followed the CMA truck within minutes of the start of the application, with measurements being done in both increasing and decreasing directions. No water was laid in front of the measuring wheel. Measurements were begun approximately 600 m south of the start point of the CMA application. Consequently, in the increasing (southbound) direction, this 600 m length would potentially be subject to CMA being tracked by other vehicles. In the decreasing (northbound) direction, this 600 m length would not be subject to any tracking of CMA, and the skid resistance measured was expected to be consistent with typical dry road values.

The GripTester measurements were repeated at reasonably regular intervals over a 3-hour period. The results of this series of test runs are shown in Figure 3.4. Also shown are the wet and dry skid resistance data measured on 14th June, several days earlier in the baseline GripTester survey.

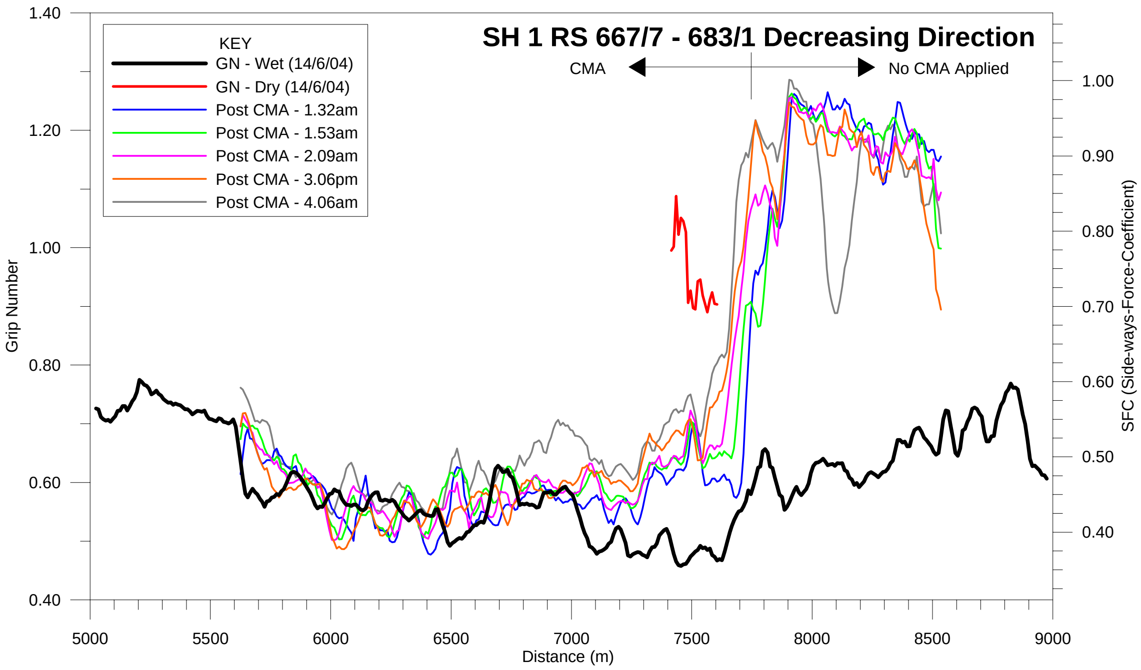
From Figure 3.4, the following observations are made regarding the duration of the effects of CMA, and its migration further along the road through tracking by vehicles:

1. Skid resistance on the section where no tracking of CMA is possible, i.e. where a dry-road value could typically be expected, is consistently high for all the test runs, and is generally similar across all the test runs.
2. Skid resistance on the section sprayed with CMA is much lower than the unsprayed section, and levels are similar to the range of wet skid resistance values measured several days earlier. On some parts of this section, the skid resistance is significantly lower than the corresponding wet-road value.
3. The skid resistance on the CMA-sprayed section gradually increases over the approximately 3-hour period after application, but does not approach the dry-road skid resistance values measured either on the 600 m non-CMA sprayed section, or the dry skid resistance values measured several days earlier.
4. On the section where tracking is likely, the skid resistance is quite high for the first test run after application, and is consistent with the dry-road values. However, by the next run, approximately half an hour after application, it has dropped to a level that is similar to both the wet-road and post-CMA section values.

   Over the subsequent testing, the skid resistance on this section gradually rises until, 3 hours following application (0415 h), the skid resistance is approximately back to the dry-road value, at around 600 m past the end point of the CMA application.



(a) **Southbound increasing direction.**



(b) **Northbound decreasing direction.**

Figure 3.4 **Skid resistance on road section 2 (RS 667/7–683/1) after CMA application to show duration and effects of tracking.**

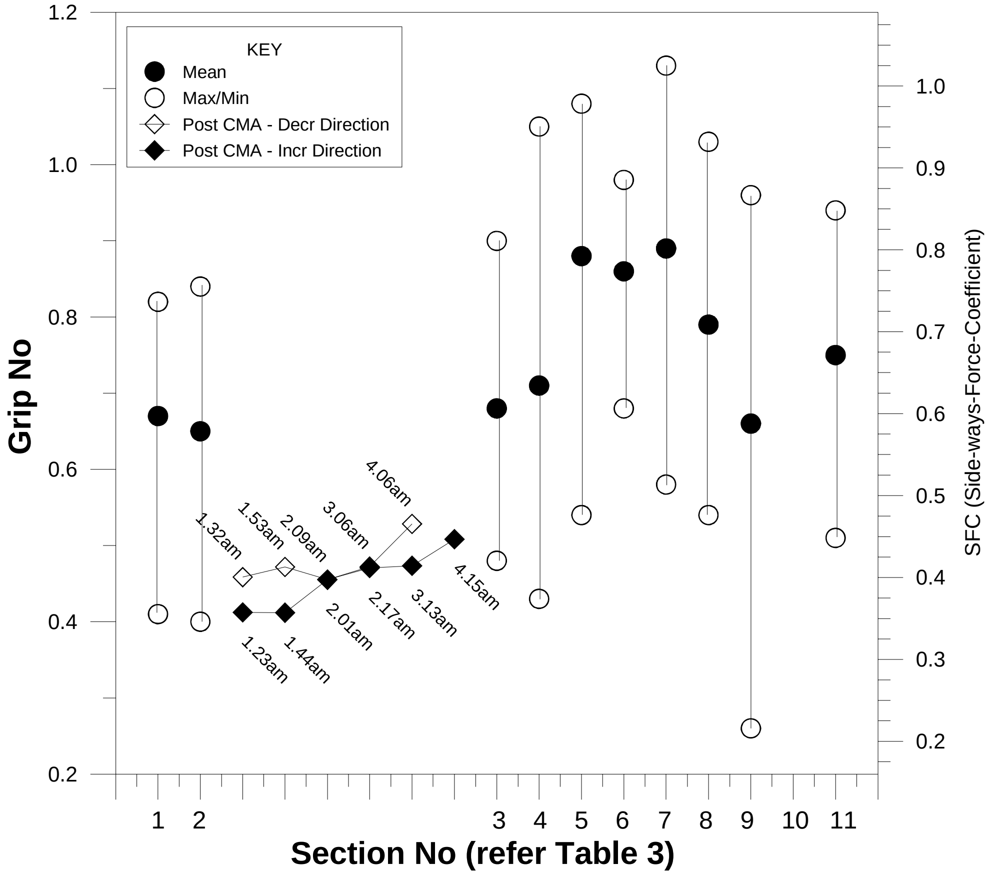


Figure 3.5 Comparison of minimum skid resistance values for wet and post-CMA (post-CMA values were measured on road section 2 (SH1 RS 667/7 – 683/1)).

Figure 3.4 shows that minimum skid resistance values on this particular road section (section 2) following the application of CMA are similar to the minimum wet-road values measured several days earlier. To determine whether they are representative of the wet-road skid resistance across a wider range of surfaces and road conditions, the minimum wet-road values for all the baseline survey sections from Table 3.2 and Figure 3.3 have been compared with the minimum post-CMA application values derived from the traces shown in Figure 3.4. The results are shown in Figure 3.5, which shows the minimum wet-road skid resistance values across the different road sections, and the variation of the minimum skid resistance over the 3 hours following a night-time application of CMA on road section 2. Once again, it is the minimum skid resistance values that are presented because the lowest skid resistance presents the greatest potential risk to drivers.

The above figures and tables show that minimum skid resistance values may be lower than the wet-road skid resistance in some areas, but are not necessarily lower than those measured on other representative road sections on which CMA has historically been used. This suggests that, while the lowered level of skid resistance following application of CMA contributes to the level of potential risk, the lack of visual cues to such skid resistance changes may be at least as important in determining the overall level of risk.

For example, wet conditions provide the visual cues, which drivers have hopefully learnt from experience, that indicate skid resistance is lower than for a dry road.

When CMA is applied, these types of cues are generally not present. Hence, drivers may have no expectation that skid resistance levels are any different from those on a dry road.

4. Comparative skid resistance measurements

4.1 Site selection

From the road sections used for the GripTester baseline skid resistance survey, and discussions with Transit New Zealand's Regional Assets Manager for Coastal Otago, five test sites were selected for the comparative skid resistance measurement programme. These were selected on the basis of:

1. covering the desired range of surface types;
2. being straight and flat enough so that locked-wheel-braking tests could be carried out safely; and
3. being potentially subject to both frost and the application of CMA, given their previous history.

The five sites selected are listed in Table 4.1 and photographs of them are shown in Appendix C.

Table 4.1 Sites selected for comparative skid resistance measurements.

Site No.	Surface Type	State Highway	Direction	Start RS	End RS
1	Coarse chipseal (Gr 2)	87	Increasing	0/4.14	0/4.20
2	Fine chipseal (Gr 5)	87	Increasing	15/8.68	15/8.76
3	Asphaltic concrete (AC)	88	Decreasing	0/1.612	1.572
4	OGPA	1S	Decreasing	715/1.755	715/1.695
5	Slurry seal (SS)	88	Decreasing	0/1.14	0/1.095

RS – Reference Station; Gr – Grade of chip

4.2 Skid testers

Three different skid testers were used for the comparative skid resistance measurements, these being (1) the GripTester, (2) the British Pendulum Tester (BPT), and (3) an instrumented car for LWB.

4.2.1 GripTester

The GripTester is described in Section 3.2. For the purposes of the comparative tests, the GripTester was operated in 'push' mode, at a speed of 5 km/h.

4.2.2 British Pendulum Tester

The BPT is one of the stationary type of skid testers. It comprises a support frame that can be levelled on the road. Attached to the support frame is a swinging arm, at the bottom of which is an ASTM[1] rubber measuring foot. This swinging arm, when released

1 ASTM – American Society for Testing & Materials

from a fixed point, sweeps across the surface underneath. The skid resistance of the surface determines how far the arm swings up on the follow-through. The arm also moves a measuring pointer that gives a value on the attached scale. Figure 4.1 shows the BPT being used on one of the test sites listed in Table 4.1.

Figure 4.1 British Pendulum Tester in use on one of the test sites.

4.2.3 Instrumented Passenger Car

The primary issue with the different skid testers available for use in New Zealand is how well they simulate the behaviour of a car, or other vehicle, under emergency (locked-wheel) braking. Cenek & Jamieson (2002) have previously reported the results of LWB tests on different surfaces.

For the purposes of this study, a Holden Astra passenger car was chosen to perform locked-wheel-braking tests as part of the test programme. This car, which was fitted with non-ABS[2] brakes, is shown in Figure 4.2.

The only instrumentation installed on the vehicle was a Vericom™ VC 2000 'Traffic Accident Computer' on loan from the New Zealand Police. This accelerometer-based instrument, which is shown in Figure 4.3, 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.

[2] ABS – Anti-lock Braking System

Figure 4.2 The Holden Astra test vehicle used for the locked-wheel-braking tests.

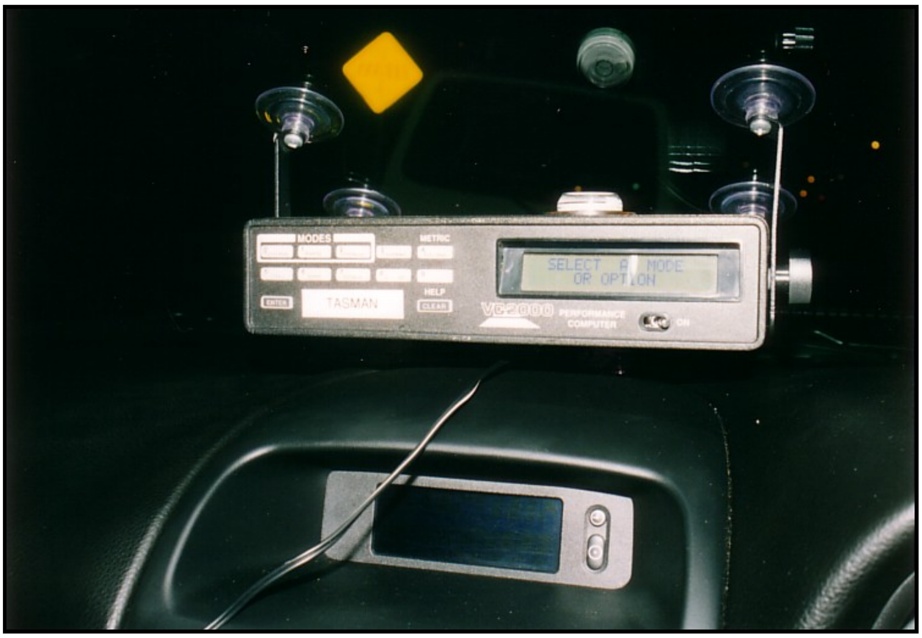


Figure 4.3 Vericom VC2000 unit mounted on the windshield of the test vehicle.

The VC 2000 is windshield-mounted and measures motion as a rate-of-change of speed. It is set to activate when the deceleration exceeds 0.2 g and deactivated at 0 g (1 g equals acceleration due to gravity, i.e. 9.81 m/s^2).

The VC 2000 has two modes of gathering data from an emergency braking test. Buttons on the front console display the following information: time to stop; speed at which braking was initiated; stopping distance; peak friction; and average friction. Here, the stopping distance is the distance travelled from the triggering of the VC2000 until the vehicle comes to a stop. Using the RS232 capability of the VC 2000, all the data from the system can be downloaded to a personal computer. The computer program provides the deceleration time history at 0.01-second intervals, which can be processed or interpreted at the user's discretion, together with the processed results of instantaneous g-force, speed and distance.

For this test programme, only the standard displayed parameters were utilised. Testing was limited to a speed of 30 km/h.

4.3 Comparative Tests

Skid resistance measurements were carried out on each of the five sites, using one or more of the skid testers described earlier. To enable comparisons between the instruments, the skid resistance measurements were conducted, where possible, according to the test matrix shown in Table 4.2. Note that CMA is used in a proactive way, i.e. it is normally applied before frost or ice occurs. As the primary aim of this project was to investigate the use of CMA and, given the amount of information available on skid resistance on ice/frost, the exploration of ice/frost conditions was only intended to be carried out if conditions and circumstances allowed.

Table 4.2 Comparative skid resistance test matrix.

Site No.	Surface Type*	SH	Skid Tester	Test Conditions					
				Dry	Wet	Dewfall	CMA	CMA Dewfall	Ice or Frost
1	Gr 2 Chip	87	GT (1)	✓	(4)	✓	✓	✓	(5)
			BPT (2)	✓	✓	✓	✓	✓	(5)
			LWB (3)	✓	(5)	–	✓	–	(5)
2	Gr 5 Chip	87	GT	✓	(4)	✓	✓	✓	(5)
			BPT	✓	✓	✓	✓	✓	(5)
			LWB	✓	(5)	–	✓	–	(5)
3	AC	88	GT	✓	(4)	✓	✓	✓	(5)
			BPT	✓	✓	✓	✓	✓	(5)
			LWB	✓	(5)	–	✓	–	(5)
4	OGPA	1S	GT	✓	(4)	✓	✓	✓	(5)
			BPT	✓	✓	✓	✓	✓	(5)
			LWB	✓	(5)	–	✓	–	(5)
5	SS	88	GT	✓	(4)	✓	✓	✓	(5)
			BPT	✓	✓	✓	✓	✓	(5)
			LWB	✓	(5)	–	✓	–	(5)

(1) – GT GripTester, (2) BPT – British Pendulum Tester, (3) LWB – Locked-wheel-braking car
(4) – Testing already carried out under GripTester baseline survey
(5) – Generally available from other sources
* – see Table 4.1 for abbreviations

GripTester measurements were carried out in push mode, at a speed of 5 km/h. Repeat measurements were done for each test condition. BPT measurements were typically made at three or more locations along the test section, with the number of readings made at each location as specified in the standard operating procedure described in Road Note 27 (HMSO 1969). LWB test runs were made from a steady speed of around 30 km/h. A minimum of four or more test runs was made for each test condition.

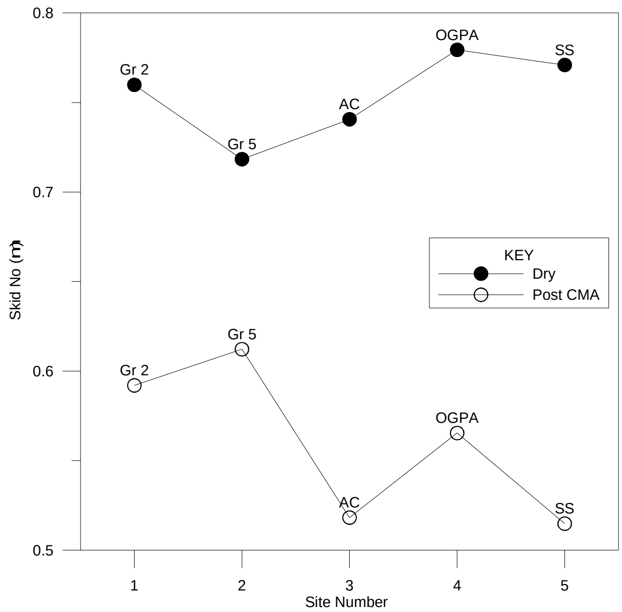
Observations made during the testing indicated that on a fine day with even a light breeze, around half an hour following application of CMA was needed for the surface to be substantially dry. As Clarke et al. (2002) have observed, “when dry, CMA on a road surface had no effect on the skid resistance”.

5. Comparative skid resistance measurement results

5.1 Locked-wheel-braking tests

The results of the LWB tests on the different surface types are presented in Figures 5.1 and 5.2. These show the stopping distances for (1) the dry and post-CMA application conditions, and (2) the post-CMA condition expressed as a ratio of the dry road values. The latter are included so the level of change can be assessed.

(a)



(b)

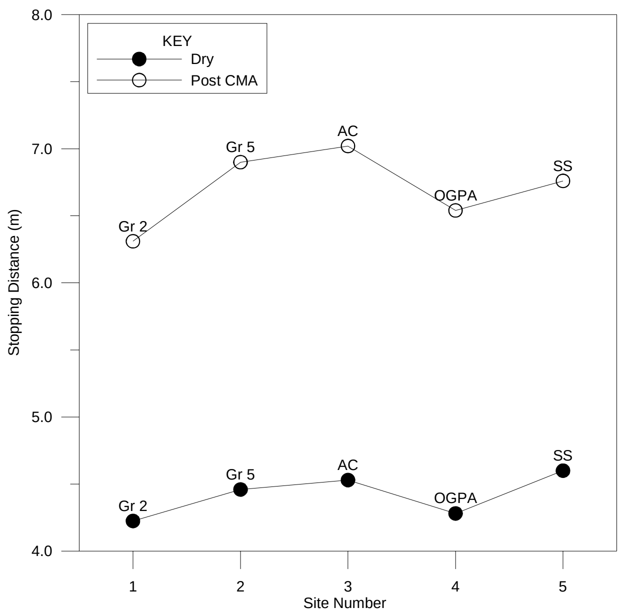
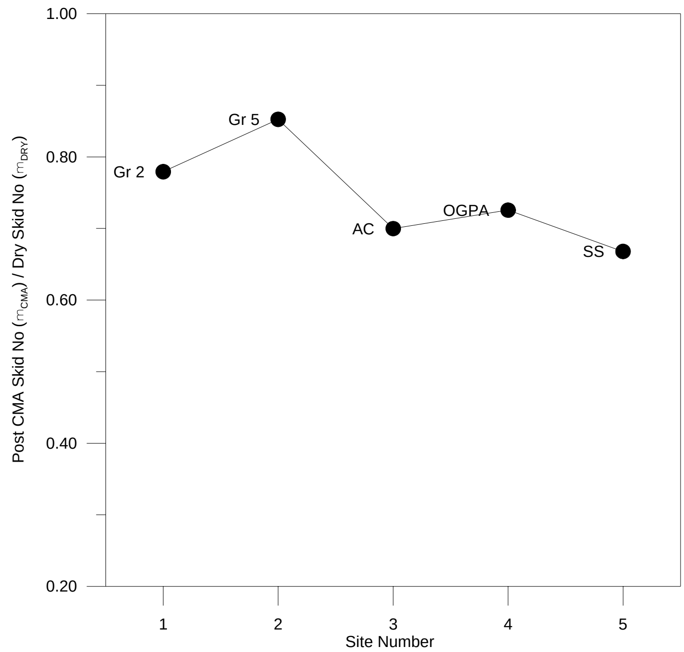


Figure 5.1 Results of LWB tests for (a) skid numbers and (b) stopping distances for dry and post-CMA conditions.

(a)



(b)

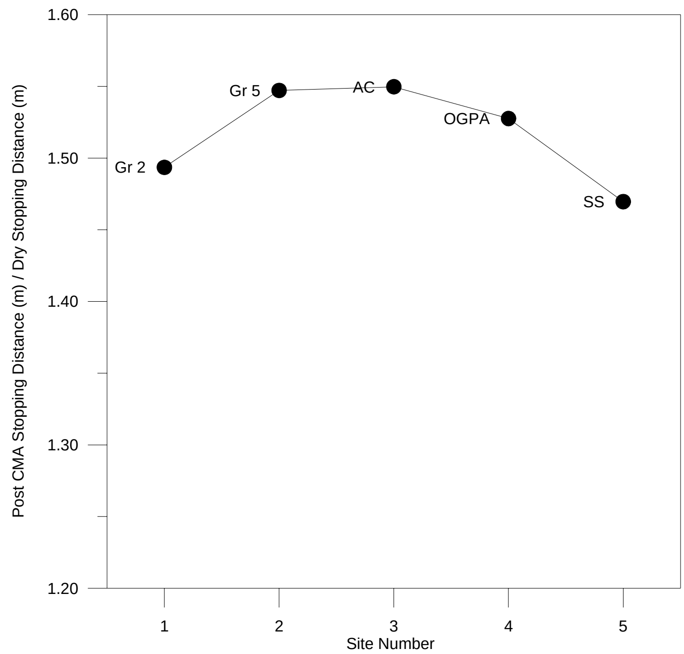


Figure 5.2 Ratios of post-CMA skid numbers to (a) dry skid numbers; and (b) dry stopping distances, as recorded by LWB tests.

From Figures 5.1 and 5.2 the following observations can be made regarding the skid numbers and stopping distances from the LWB measurements:

1. Application of CMA reduced the skid resistance on all surfaces. The fine textured chipseal showed the least reduction, followed by the coarse chipseal, with the three asphaltic mixes producing the most reduction.

2. Within each test condition, i.e. dry and post-CMA, the variation in stopping distance across all of the surfaces was less than 1 m.
3. Ratios of the post-CMA to dry-road stopping distances showed only relatively small variation across the five different surfaces.
4. Stopping distances for dry conditions were much shorter than for post-CMA applications.

The LWB tests were carried out at 30 km/h. The question here is how the LWB behaviour following application of CMA at this relatively low speed compares with that at higher speeds in both dry and, more importantly, wet conditions. Accordingly, LWB data in wet and dry conditions reported by Cenek & Jamieson (2002) for a similar range of surfaces at speeds between 50 km/h and 75 km/h, were extracted for comparison with the data measured in this study. Figure 5.3 summarises this data, together with dry-road and post-CMA data from the current study.

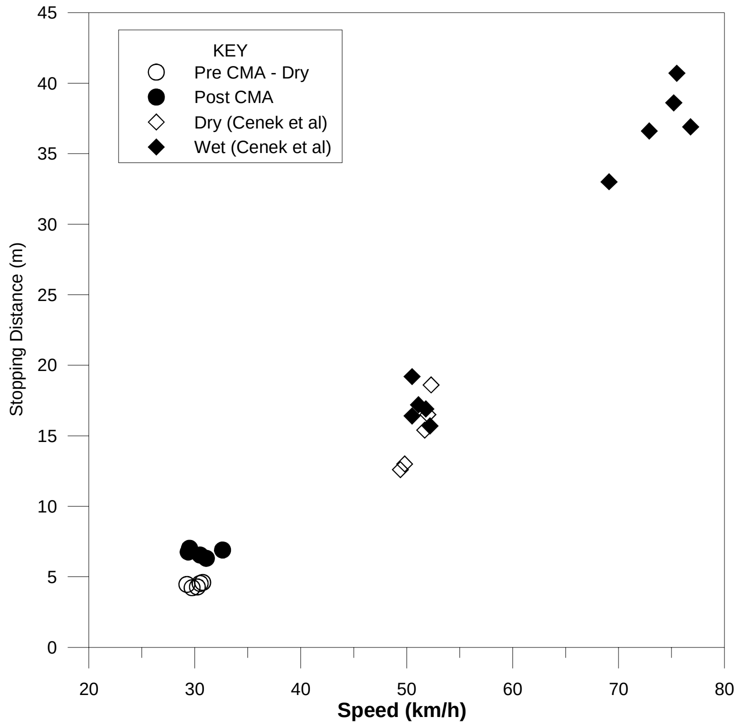


Figure 5.3 Comparison of dry, wet, and post-CMA stopping distances.

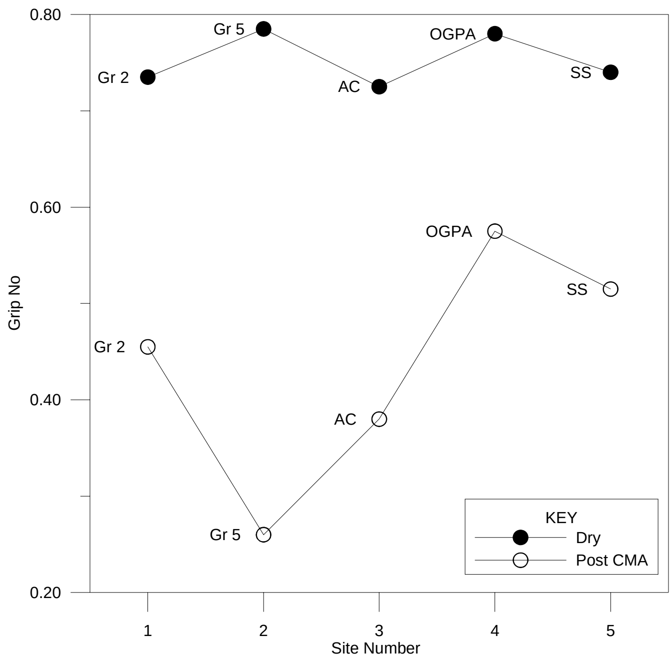
Figure 5.3 shows that:

1. the differences in stopping distances under dry and post-CMA conditions at 30 km/h are similar to the differences between dry and wet at 50 km/h, and
2. the stopping distances measured at 30 km/h in this current study are consistent with the decrease in stopping distance with speed measured by Cenek & Jamieson (2002).

5.2 GripTester measurements

The results of the GripTester measurements are shown in Figure 5.4. They show the measured values for the dry-road conditions and the post-CMA application. The post-CMA data are also expressed as a ratio of the dry-road values.

(a)



(b)

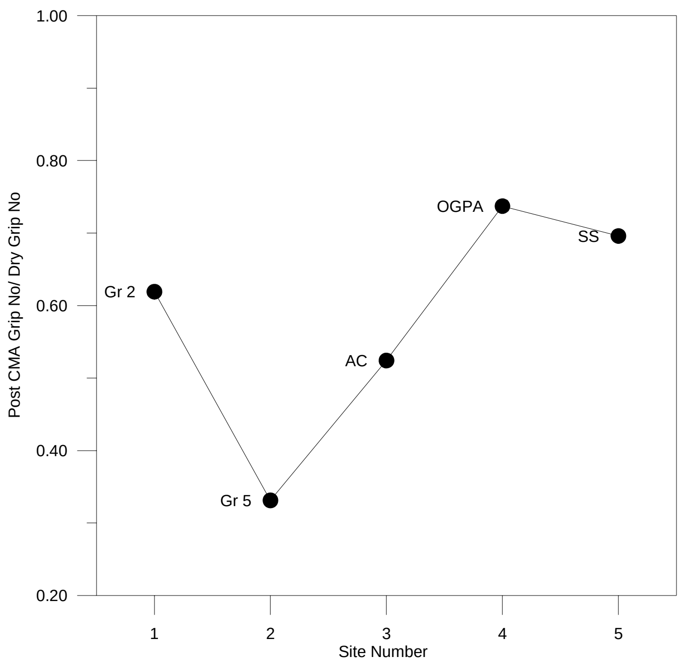


Figure 5.4 GripTester results for (a) Grip Numbers, and (b) ratios for post-CMA and dry conditions.

Within some small variation in the dry-road skid resistance the GripTester is providing very similar measures of skid resistance as the LWB. However, for the post-CMA condition a significant difference is seen between the two instruments, both with respect to the pattern of change and magnitude of change in skid resistance.

As with the LWB vehicle, the GripTester identified reductions in Grip Number across all the five test surfaces following application of CMA. However, the relative magnitudes of the reductions were larger for the GripTester, with post-CMA values decreasing by between 0.25 and 0.65μ compared to the dry-road values.

The OGPA and slurry seal performed best, followed by the coarse chipseal, asphaltic concrete, and the fine chipseal. These differences between the GripTester and the LWB vehicle data highlight the difficulties that often occur in trying to establish relationships between survey instruments.

5.3 British Pendulum Tester measurements

The results of the BPT measurements are shown in Figure 5.5. This shows the dry-road values and the post-CMA values, together with the post-CMA data expressed as a ratio of the dry road values.

The BPT data essentially shows the same trends and characteristics as the GripTester data. Application of CMA produced reductions in the BPN to between 0.4 and 0.7 of the dry-road values (Figure 5.5(b)). The OGPA and coarse chipseal performed best, followed by the slurry seal, with the asphaltic concrete and fine chipseal performing worst.

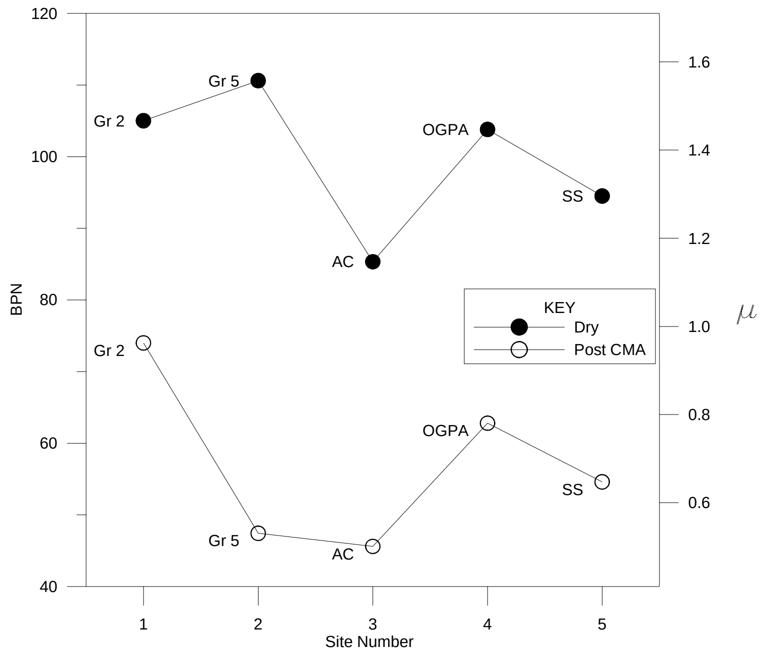
5.4 Comparison of skid tester data

Locked-wheel-braking represents a 'real-life' measure of the skid resistance of a road surface as seen by a vehicle. Accordingly, the LWB measurements should form the baseline for comparison with the other skid testers. Figures 5.1 to 5.5 show similarities between the LWB, GripTester, and BPT test results. However, they also show some notable differences.

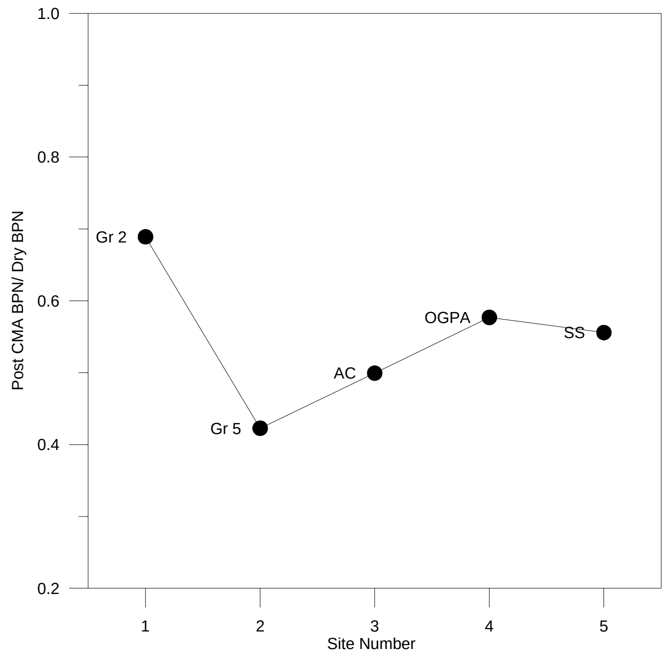
These differences may be related to the differences in either:

1. the length of the measurement (BPT measures only over a small area, the GripTester measures continuously, and LWB is a measure over the stopping distance);
2. the load of the measuring tyre on the surface; or
3. other environmental factors that may affect the devices slightly differently.

By tabulating the ratios between post-CMA and dry-road skid values for the different skid testers, the similarities can be evaluated. Table 5.1 summarises this data.



(a) Dry and post-CMA BPN,
where μ is defined by: μ = (3xBPN)/(330-BPN).



(b) Ratio of post-CMA to dry BPN.

Figure 5.5 BPN (dry and post-CMA) and ratios (post-CMA:dry) obtained from BPT tests.

Table 5.1 Ratios of post-CMA and dry-road skid data.

Surface*	Skid Tester		
	LWB Vehicle	**GripTester**	**BPT**
Gr 2	0.78	0.62	0.69
Gr5	0.85	0.33	0.42
AC	0.70	0.52	0.50
OGPA	0.73	0.74	0.67
SS	0.67	0.70	0.56

* – see Table 4.1 for abbreviations

This table shows that all three skid testers agree that the coarse Grade 2 chipseal and OGPA perform reasonably well following application of CMA. This may be due to the better level of drainage provided by these surfaces, in that the bulk of the CMA drains off the tyre contact area. The slurry seal also showed reasonable agreement across the different skid testers.

The main differences observed between the skid testers occurred on the asphaltic concrete, but were even more pronounced on the fine chipseal surface. On both of these finer textured surfaces the LWB vehicle showed proportionally higher skid values following application of CMA than either the GripTester or the BPT. This may be due to differences in the slip speeds of the different skid testers, the tyre contact area, or to differences in the interactions between the rubber and the CMA/road surface combination.

While direct comparisons between the instruments may show some differences between the instruments, these differences are no greater than those typically found under other test conditions. Often it is not possible or practical to carry out LWB testing, and other skid testers represent the best option.

5.5 Effects of dewfall with and without CMA

The tests described in the previous sections showed that skid resistance following application of CMA is reduced to levels similar to, or below, those of a wet-road surface. There is evidence to suggest (Clarke et al. 2002) that reactivation of CMA under dewfall conditions can again cause lowering of skid resistance levels. Accordingly, each of the five test sites was re-visited 24 hours after the earlier application of CMA. Skid resistance measurements were repeated under dewfall conditions using the GripTester and BPT. These dewfall tests were carried out on both CMA-treated and untreated surfaces, and the results are shown in Figures 5.6 and 5.7.

These results show that dewfall on a surface treated earlier with CMA does tend to reactivate the CMA, i.e. dewfall with CMA tends to reduce the skid resistance more than dewfall alone without CMA. This effect is somewhat more apparent for the GripTester than for the BPT. Indeed, the differences in the skid resistance for dewfall with and without CMA were 7 BPN or less, which is a relatively small difference.

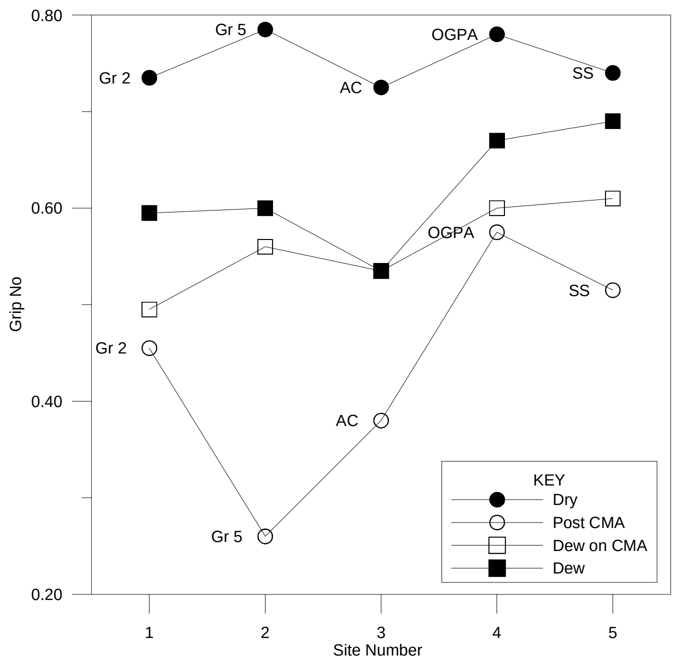


Figure 5.6 Effects of dewfall on GripTester measurements.

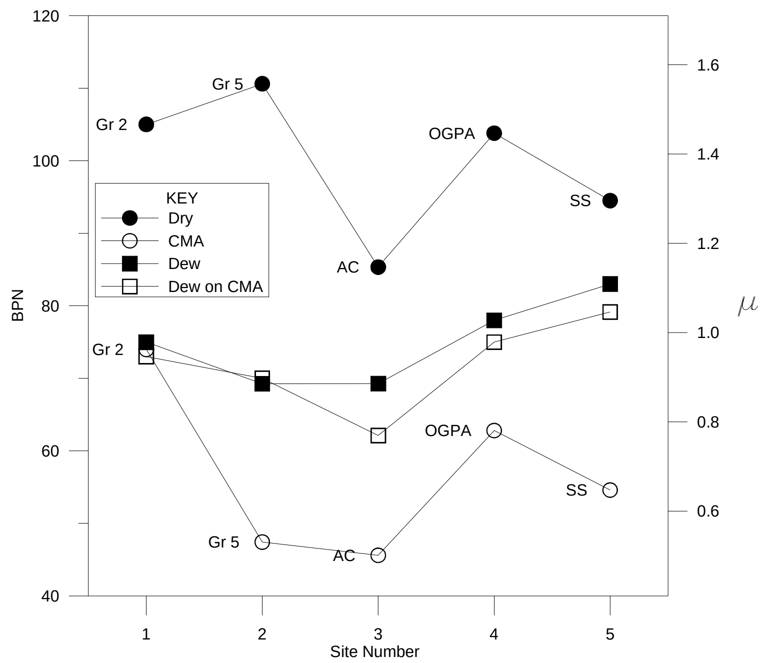


Figure 5.7 Effects of dewfall on BPT measurements.

In fact, for the two chipseal surfaces the CMA-treated and untreated BPT values were almost identical. The GripTester data indicated that dewfall reactivated the lowering effect of CMA on skid resistance more on the more coarser textured surfaces of the coarse chipseal and the OGPA, than on the finer textured surfaces.

On these other surfaces, the CMA has significantly less impact under dewfall conditions than it has immediately following application.

6. Discussion

6.1 Previous and current research

6.1.1 Previous research

Previous research (Clarke et al. 2002; Dravitzki & Wood 2001) relating to skid resistance under icy or frosty conditions and following CMA application identified the following:

- CMA reduces road skid resistance to or below values that occur on a wet road surface.
- Skid resistance immediately following application of CMA is still significantly higher than that recorded for icy or frosty conditions.
- The magnitude of the reduction in skid resistance is very similar, irrespective of the time of day at which it is applied.
- CMA, being hydrophilic, tends to encourage the road to remain moist longer than water alone.
- CMA, when dry, has little or no effect on skid resistance.
- The effects of CMA in preventing ice/frost formation can last up to around five days, depending on weather and traffic.
- Dewfall or light drizzle can 'reactivate' the CMA, with a consequent reduction in skid resistance.

The above researchers also raised the issues relating to the magnitude and duration of the effects of CMA, including migration by tracking, and the effects of dewfall or moisture in reactivating CMA.

6.1.2 Baseline survey

This present project has been aimed to increase our understanding of these issues relating to the effects of CMA on skid resistance, and the findings of the baseline survey can be summarised as follows:

- Wet road skid resistance is highly variable and can fluctuate by as much as 40-50% over a very short distance. This is important in relation to the level of change in skid resistance that can occur with CMA, and to drivers' expectation of changes in skid resistance through visual and other cues.
- Application of CMA does significantly reduce skid resistance compared to the dry road values. It can also reduce skid resistance to levels lower than might occur on a wet road.

  However, over a road section, the minimum skid resistance values recorded on that section following an application of CMA are not significantly lower than the typical minimum values of skid resistance recorded when that test road section is wet with water only. Minimum skid resistance values present the greatest potential risk to drivers.

- Following a night-time application of CMA, the skid resistance drops significantly. Over the next three hours, the skid resistance slowly increases. However, the skid resistance remains below the corresponding dry road values.
- Vehicles can track recently applied CMA for a distance of around 1 km past the end point of an application. Skid resistance levels at the start of the tracked section are consistent with those on the CMA-applied section. Skid resistance gradually increases with distance in the direction of travel, but remains well below the corresponding dry road values for up to 1 km.

  Over the following two to three hours the skid resistance rises, reaching the dry road values up to 1 km past the end point of the application. As the applied CMA slowly dries, the tracking process eventually stops.

6.1.3 Comparative skid resistance tests

Locked-wheel-braking tests

- The differences in the dry road skid numbers and stopping distances were relatively small across the five different road surfaces.
- Application of CMA reduced skid resistance to between 65% and 85% of the dry road values, and increased stopping distances at 30 km/h by around 50%.
- The shortest stopping distances following CMA application compared to the dry road values occurred on the slurry seal, the coarse chipseal and the OGPA surfaces, possibly because of their better drainage properties. Stopping distances were longer on the finer textured chipseal and the asphaltic concrete. However, less than 1 m difference in stopping distances was recorded across the five surfaces.
- Although the differences between dry and post-CMA stopping distances at 30 km/h are small (c.2 m), they increase markedly with speed. The 50% increase in stopping distance is equivalent to an additional 28 m at 100 km/h.

GripTester and British Pendulum Tester

- The GripTester and BPT also showed relatively small variations in the dry road skid resistance across the different surfaces.
- Immediately following application of CMA, the skid resistance was reduced to a minimum of 35% and a maximum of 75% of the dry-road values.
- The GripTester and BPT showed similar trends across the five surfaces. The coarse chipseal, the OGPA, and the slurry seal performed best, and the asphaltic concrete and the fine textured chipseal performed worst.

  However, the BPT ranked the coarse chipseal as having the highest skid resistance, which may be related to the size of the chip relative to the size of the rubber measuring foot.

Reactivation with dewfall

- Both GripTester and BPT indicate that dewfall does reactivate the CMA, producing skid resistance values that are somewhat lower than for dewfall alone. The magnitude of this reactivation and the variation across the surfaces are somewhat greater for the GripTester than the BPT.

6.2 Implications for road management

CMA works very effectively as an anti-icing and de-icing agent. This has been borne out through research, both internationally and in New Zealand; increasingly widespread use of CMA in New Zealand; and a demonstrable reduction in frost/ice skidding crashes.

The main issues with the use of CMA in New Zealand relate to how it is used. In particular, there are issues about the time at which CMA is applied, and how, or if, the public is advised of (1) its use and (2) its effects on reducing skid resistance, including the magnitude, extent, and duration of these effects.

6.2.1 Public perceptions, expectation, and signage

Drivers' expectations and perceptions can play a large part in the way they will drive. CMA is currently being used on New Zealand roads during the winter, and its use is increasing. At present the general driving public has little, if any, knowledge of the use of CMA on New Zealand roads and of its effects. Although the applicator vehicles are signed appropriately (see Figure 2.1), road sections where CMA has been applied will normally be signed as ICE/FROST, or as GRIT.

This research project has shown that, immediately following application, CMA will reduce skid resistance levels significantly below dry-road values. However, applying CMA represents an artificial change in skid resistance, as opposed to rain or dewfall wetting the surface.

Several options are possible for informing the public about the use and effects of CMA, and include:

1. educating the public about why, how and where CMA is being used;
2. providing specific signage about CMA to warn the driving public of the potential hazard; or
3. using the existing ICE/FROST/GRIT signs.

The latter of these options is the current practice. However, providing specific reference to the use of de-icing agents may prove counter-productive, given that when dry CMA has no impact of skid resistance, and in icy or frosty conditions it significantly improves skid resistance. Accordingly, the 'SLIPPERY SURFACE' or 'SLIPPERY WHEN WET' suggested by Dravitzki & Wood (2001) may be more appropriate.

There has been much debate about signage to inform motorists about the use of CMA and its potential effects on skid resistance, particularly during dewfall conditions when the motorist is not necessarily expecting icy surfaces.

This research has also shown that the potential reduction in skid resistance can extend significantly beyond the end points of any application of CMA because of tracking of CMA along the road by vehicles. Accordingly, if specific signage is to be considered, it should be extended at least 1 km past the application end points.

Icy or frosty conditions will often occur quite regularly through the winter at some locations. Because of rain and traffic, CMA may need to be re-applied regularly, with consequent changes in skid resistance. Furthermore, this and other research projects have shown that CMA, and its effect on skid resistance, can be partially reactivated by dewfall or light rain. Accordingly, any specific signage will need to cover these extended periods.

6.2.2 Timing of CMA application

One of the big questions regarding the use of CMA is when the best time is to apply it. This is illustrated in the differences in best practice between Coastal and Central Otago, which have been developed from research findings and the results of the trial use of CMA.

In Coastal Otago, CMA is normally applied during the night, as close as possible to the likely onset of frosty or icy conditions, while in Central Otago it is generally applied in the afternoon, typically before 3pm. The main reason for these differences is the concern about the reactivation of CMA in damp, humid, or dewfall conditions.

The daytime application practice applied in drier Central Otago appears to work reasonably well. However, as the contractors and consultants have found through past experience (Whiting 2003), monitoring of temperature and humidity is essential in determining the best time to apply CMA. On the single occasion during the winter of 2003 when CMA was applied very late in the afternoon, the result was two skidding crashes. At least one of these crashes occurred on a flushed surface. Flushed surfaces potentially exacerbate the effects of CMA on skid resistance. Whiting (2003) also suggested that additional weather stations in the network "would no doubt assist with more efficient (less wastage) and cost effective management of CMA application".

Obviously, the requirement in Coastal Otago to apply CMA only when icy or frosty conditions are imminent has significant cost implications for the contractor compared to a more routine maintenance type application. However, in considering the most appropriate time to apply CMA, we must consider the exposure of the traffic to the potential risk of lowered skid resistance.

During night-time when traffic is generally light, the CMA will take longer to dry. As was shown earlier, even three hours after a night-time application, skid resistance levels can remain well below typical dry road values.

During daytime applications CMA can dry quite quickly when the weather is fine and/or windy. It will also dry much more slowly when conditions are overcast and calm, or the area is shaded from the sun or sheltered from the wind. However, during the day, traffic levels are generally higher, particularly during the morning and evening rush hours.

Therefore, to get a picture of the level of risk, we need to compare different treatment scenarios with traffic levels. Such treatment scenarios might include:

1.	no treatment	no ice/frost	no problem
2.	no treatment	ice/frost	potentially a big problem
3.	afternoon application	no dewfall	no problem when dry
4.	afternoon application	dewfall at night	reactivation of CMA
5.	night-time application	no dewfall	no problem when dry
6.	night-time application	dewfall at night	problem as CMA stays moist

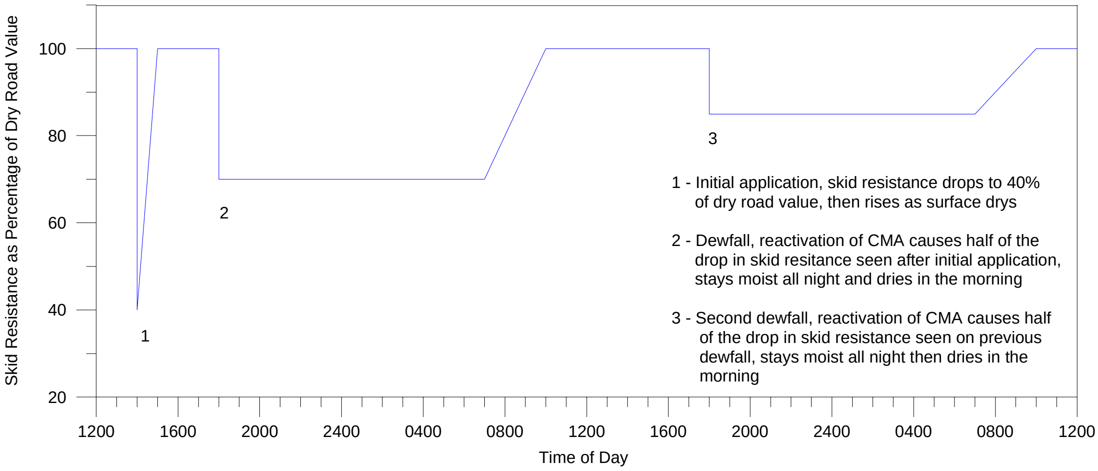
Obviously, there are many more variations, both in type and duration. Scenarios 1 and 2 represent the lower and upper bounds of risk revels irrespective of traffic level. To illustrate how the risk associated with scenarios involving use of CMA could be determined, two of these can be considered: (a) an afternoon application with dewfall overnight, and (b) a night-time application under dewfall conditions so that the CMA stays moist.

We know that the magnitude of the initial loss of skid resistance is the same irrespective of the time. We also know from the post-CMA tests during the GripTester baseline survey that, following a night-time application, even after three hours the surface is still moist and skid resistance levels are still below dry-road values.

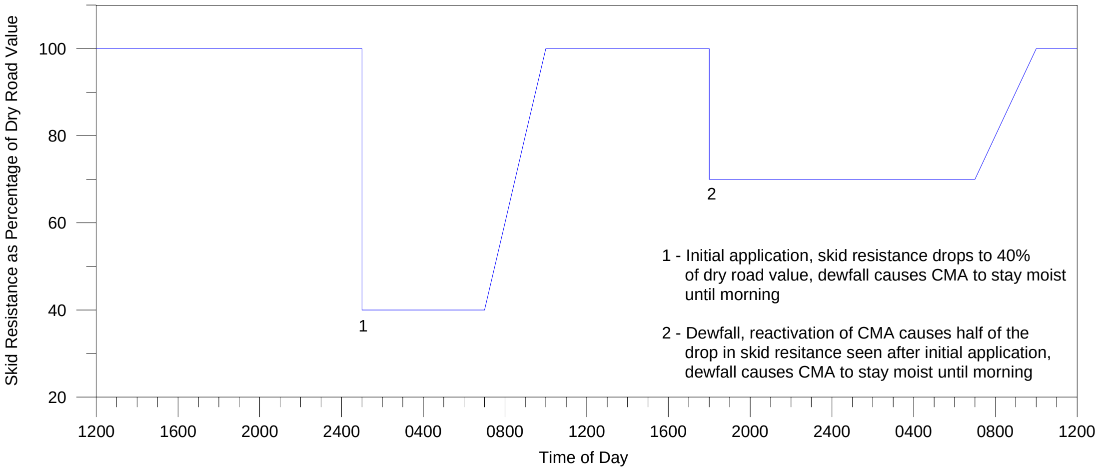
In contrast, observations from the comparative skid testing showed that following application of CMA during mid-afternoon on a fine day, the surface can be dry within half an hour or less. The tests under dewfall conditions suggest that a conservative approach would be to assume that a dewfall episode produces approximately half the loss of skid resistance that occurs immediately following application.

Figure 6.1 illustrates how these two scenarios might impact on a typical road with a typical daily spread of traffic levels. First, the expected variation in skid resistance for each of the scenarios can be plotted. Then, by considering the traffic levels, determine if the difference in risk between applying CMA at different times is significant, by multiplying the drop in skid resistance by the traffic level, and then summing these results over a two-day period. This assumes that the risk of skidding crashes is directly proportional to the level of skid resistance.

Summing the data for the two-day periods shown in Figure 6.1 gives values of 18640 and 17750 for the mid-afternoon and night-time applications of CMA respectively. This indicates that, based on representative average daily traffic levels, and on assumptions about the timing of application and dewfall, mid-afternoon application produces around a 5% increase in risk due to lowered skid resistance. Note that these diagrams show how a risk model might be applied, rather than showing any definitive differences.

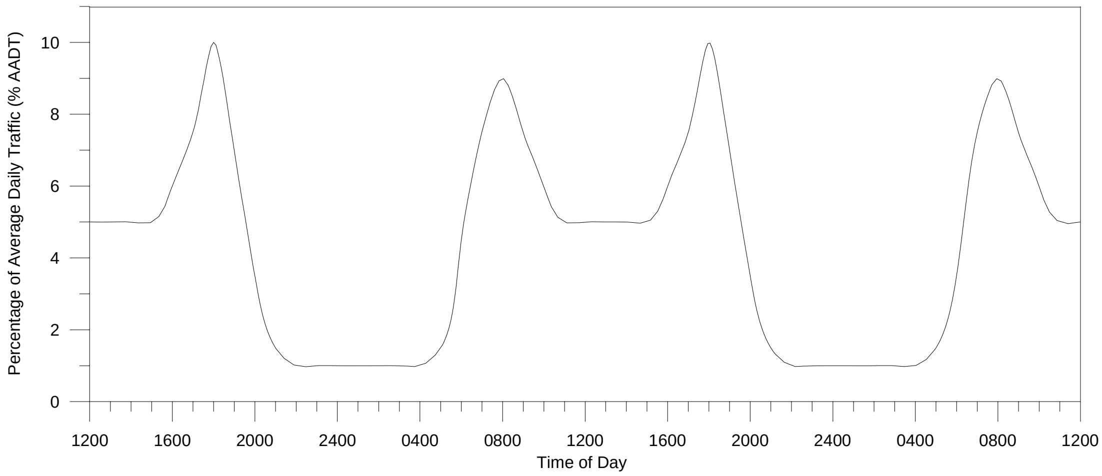


(a) **Mid-afternoon application of CMA.**

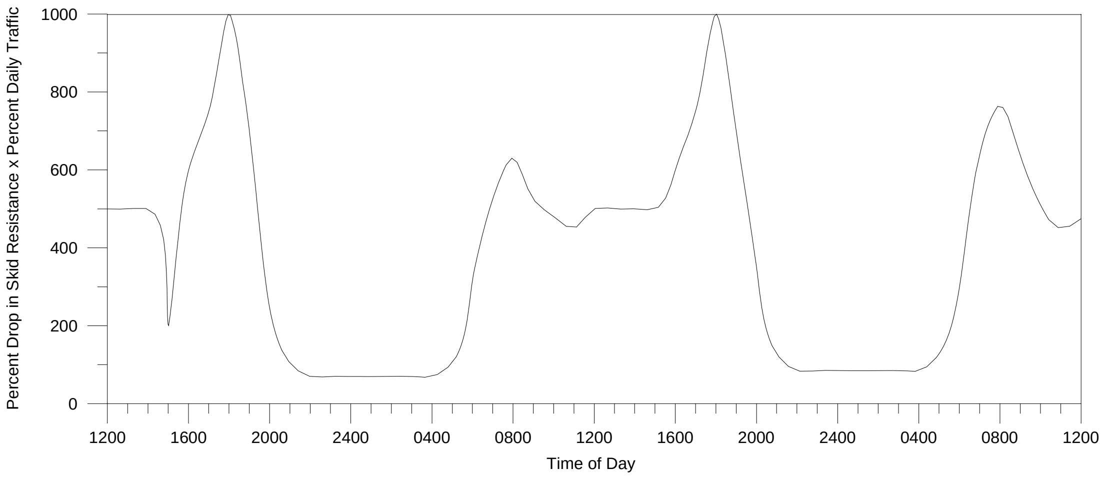


(b) **Night-time application of CMA.**

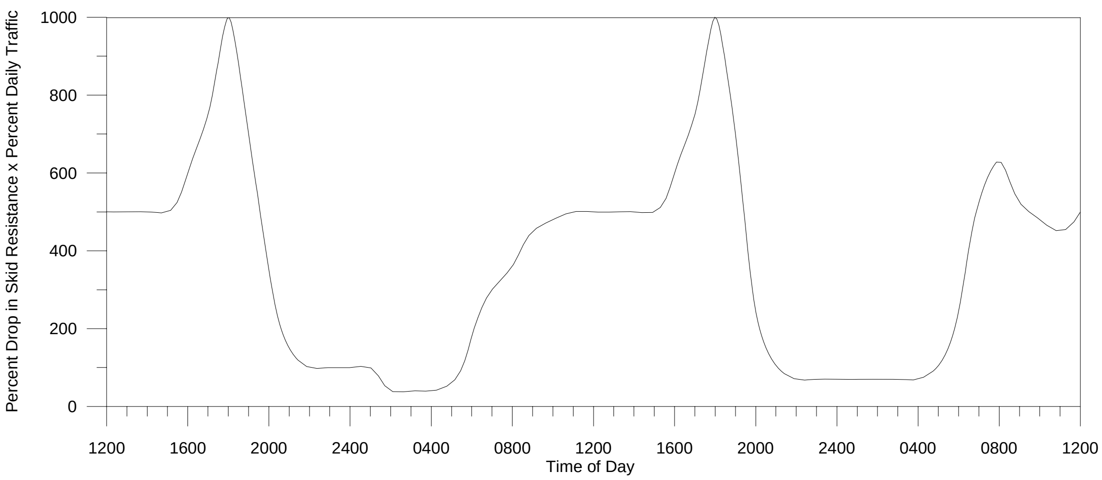
Figure 6.1 Comparison of variation of skid resistance after CMA application with time of day and traffic levels, over 2 days.



(c) Typical average daily traffic.



(d) Percentage drop in skid resistance multiplied by percentage daily traffic for a mid-afternoon application of CMA.



(e) Percentage drop in skid resistance multiplied by percentage daily traffic for a night-time application of CMA.

Figure 6.1 (continued) Comparison of variation of skid resistance after CMA application with time of day and traffic levels, over 2 days.

7. Conclusions and recommendations

Within the scope and limitations of the on-road test programme of recording skid resistance changes following application of the de-icing agent Calcium Magnesium Acetate (CMA), the following conclusions and recommendations have been made.

7.1 Conclusions

1. Baseline survey results

The baseline survey of road sections having both historical records of exposure to icy or frosty conditions, and previous use of CMA, included measurements of wet-road, dry-road, and post-CMA skid resistances. It showed:

- Wet-road skid resistance can fluctuate significantly over very short distances.
- Wet-road skid resistance at some locations can be similar to dry-road values at other nearby locations.
- Skid resistance following a night-time application of CMA is much lower than dry-road values, and levels are similar to the range of wet skid resistance values measured over the same road section. However, at some locations, the skid resistance with CMA is significantly lower than the corresponding wet value, e.g. on very fine textured or flushed surfaces.
- Following night-time application of CMA the skid resistance tends to increase with time as the CMA drains away or dries. However, even after three hours the skid resistance on the applied area was lower than the dry-road skid resistance values.
- Tracking of CMA by vehicles, and a corresponding lowering of skid resistance on the tracked sections, does occur. Over a distance of approximately 1 km past the end point of a night-time application, the skid resistance was found to rise gradually towards the dry-road values. As on the applied section, skid resistance on the tracked section also gradually increases with time.

2. Comparative skid resistance tests

The series of comparative skid resistance measurements involving the GripTester, British Pendulum Tester (BPT), and instrumented (LWB) passenger car showed the following:

- Relatively little variation was recorded in the dry-road skid resistance across a range of surfaces.
- Application of CMA reduced the road skid resistance levels significantly. The reductions were smallest for the LWB vehicle and larger for the GripTester and BPT. The shortest stopping distances and highest skid resistances with CMA occurred on the coarser textured, or better draining, surfaces. Accordingly, coarse textured surfaces are more appropriate in those areas where formation of frost or ice regularly occurs, and hence more likelihood that CMA will have to be applied.

- After CMA has dried, skid resistance levels were consistent with dry-road values.
- Dewfall or moisture from high humidity or light rain does partially 'reactivate' the CMA, with skid resistance levels being lower than for dewfall alone, but not as low as those immediately following application of CMA. This effect will be more prominent in areas of high humidity (and hence earlier longer and heavier dewfall), than in drier areas such as Central Otago.

3. Level of risk assessment

An assessment of the level of risk to drivers can be made by considering the typical reductions in skid resistance both (a) following application of CMA and (b) following its reactivation by dewfall moisture levels, with typical daily traffic levels.

This can be done for application of CMA at different times of the day. Mid-afternoon and night-time applications showed around 5% difference in the level of risk caused by the reduction in skid resistance based on a series of reasonable assumptions regarding the timing of application and the onset of dewfall.

7.2 Recommendations

1. Signage

- Signage specific to the use of CMA, and which reflects its effects on skid resistance, should be considered, particularly when general road or weather conditions do not provide the driving public with an expectation by visual or other cues of lowered skid resistance.
- If appropriate signage is chosen for use with CMA, it should be placed to include the effect of tracking of CMA and the consequent lowering of skid resistance. It therefore should be placed at least 1 km past the end points of any application.
- Until such time that appropriate signage is implemented, the current practice of using ICE/GRIT signs should continue to be used when ice formation is about to occur, and when either grit or CMA is applied.

2. Changes to 'best practice' procedure

- Changes to the current regional best practice procedures should include assessing the level of risk.
- The level of risk should be assessed by comparing actual traffic levels with changes in skid resistance which occur on different road surfaces immediately following application of CMA, and also under dewfall conditions.
- Further work is required to develop this risk model, particularly in terms of the variation of skid resistance with time under different environmental conditions, and particularly in association with dewfall.

- Until these risk models have been developed, in areas of high humidity CMA should be applied as close as possible to the time when ice formation is expected, i.e. when it is obvious to the motorist that it is a frosty night and that shady sections could be icy.

3. Effects of tracking

- The effects of tracking of CMA should be investigated for different traffic conditions. This might include looking at the duration and extent of changes to the road skid resistance under light, medium and heavy traffic.

4. Skid resistance v traffic

- The variation of road skid resistance following application of CMA should be investigated for different traffic conditions to determine whether this has any significant effect in reducing or extending the time for which road skid resistance is reduced.

5. Further LWB testing

- Further LWB tests following application of CMA should be carried out at different speeds to determine whether the trends are the same as, or different from, those for dry roads and wet roads.

8. References

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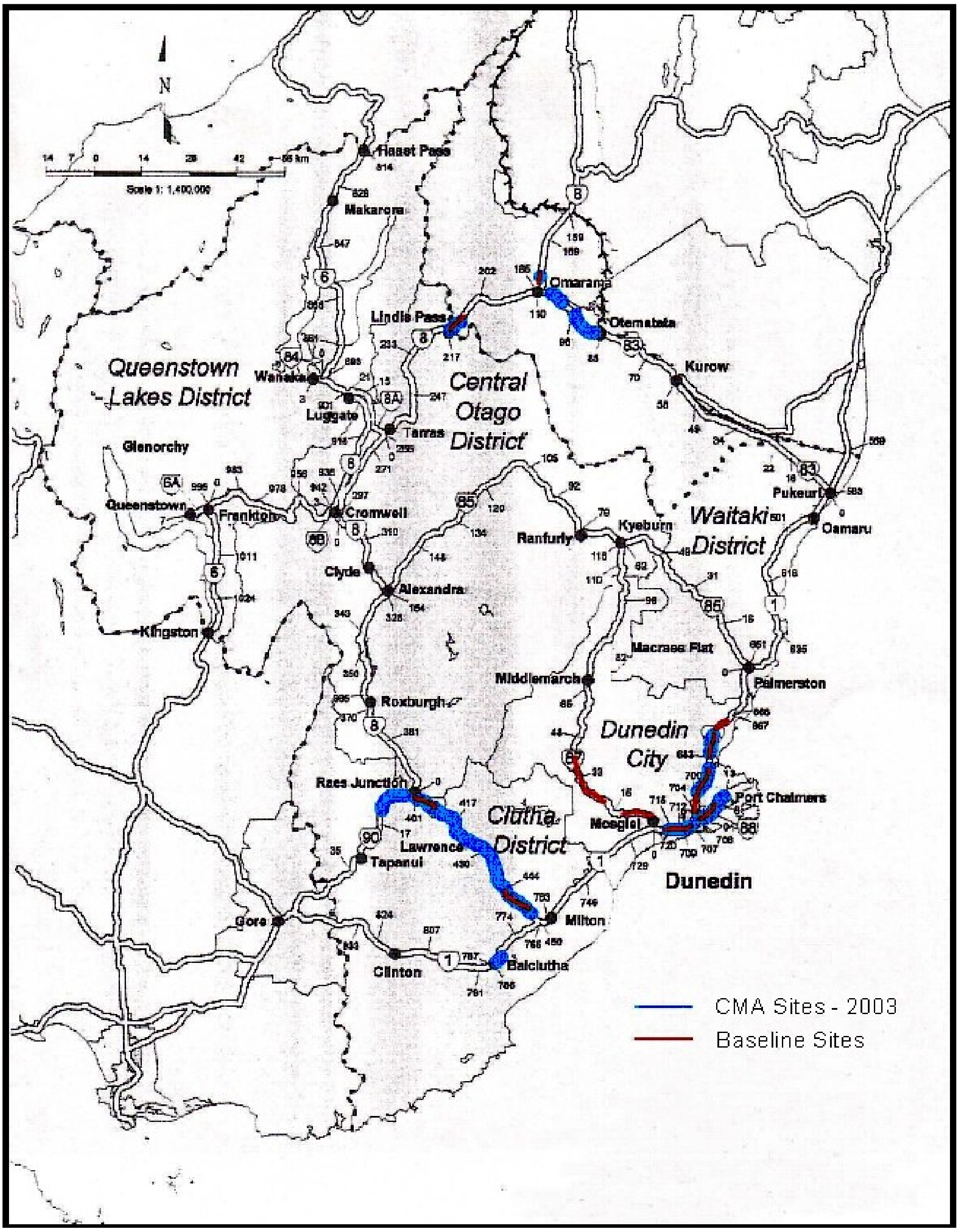
Appendix A

Potential and selected baseline sites, Coastal & Central Otago



CMA sites 2003

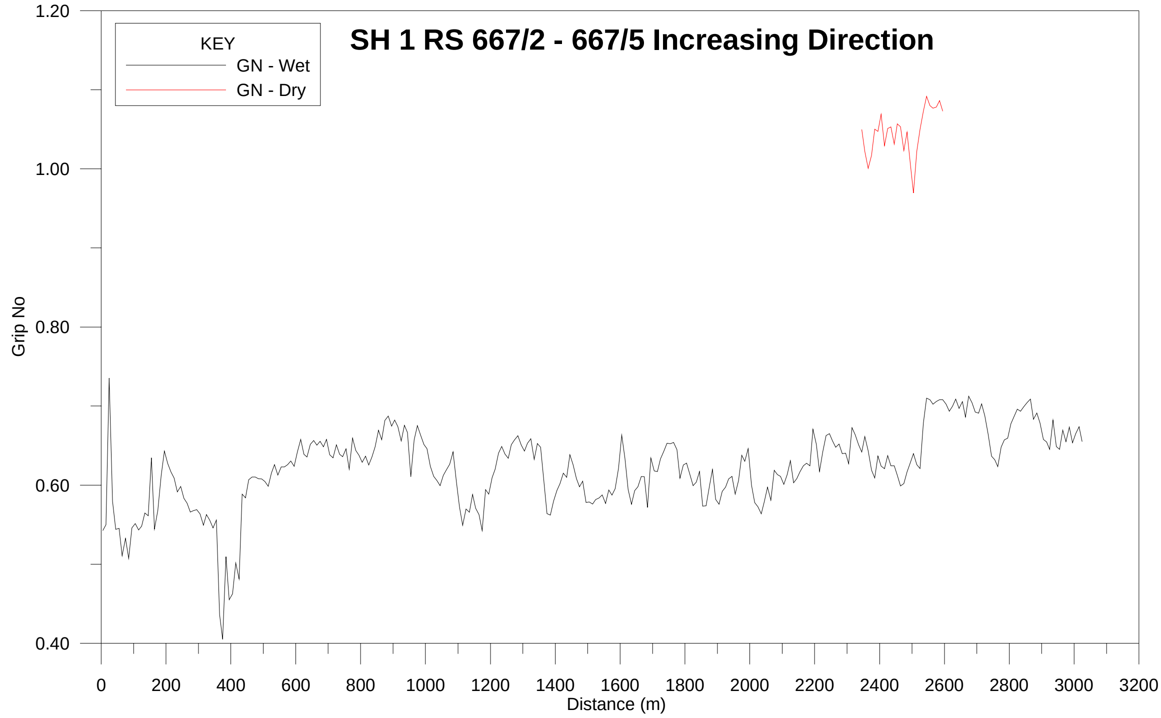
Baseline sites

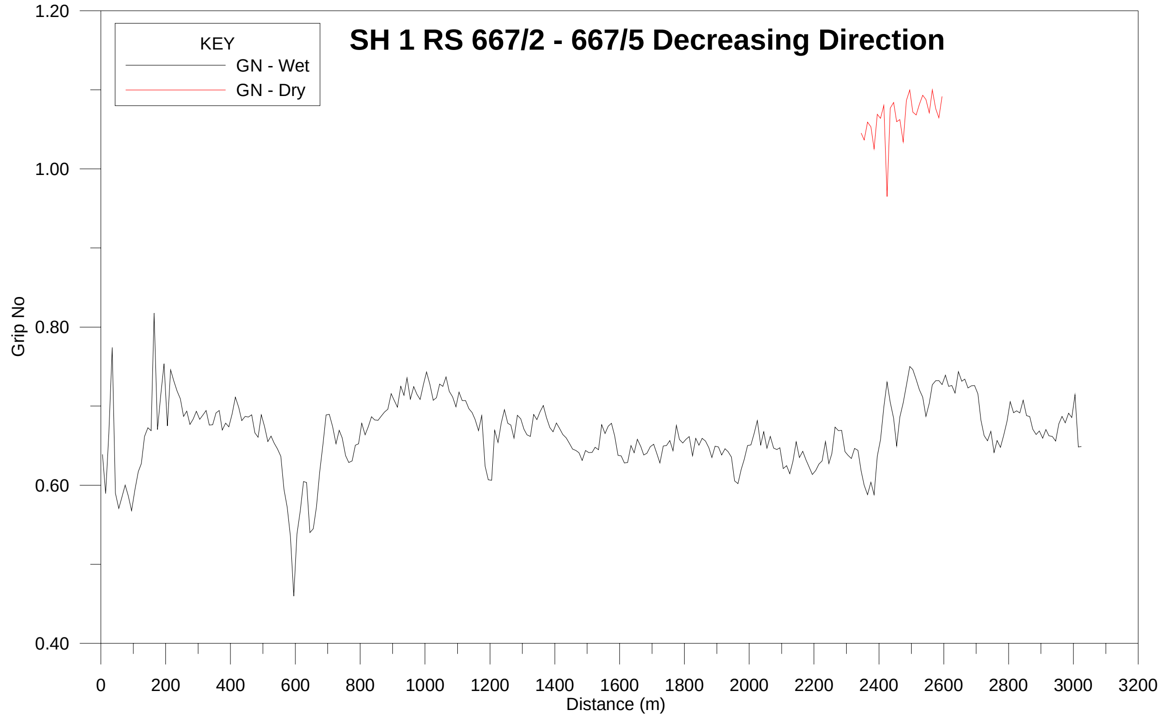
79 Reference station

Appendix B

Skid resistance results from baseline GripTester survey

Road section 1





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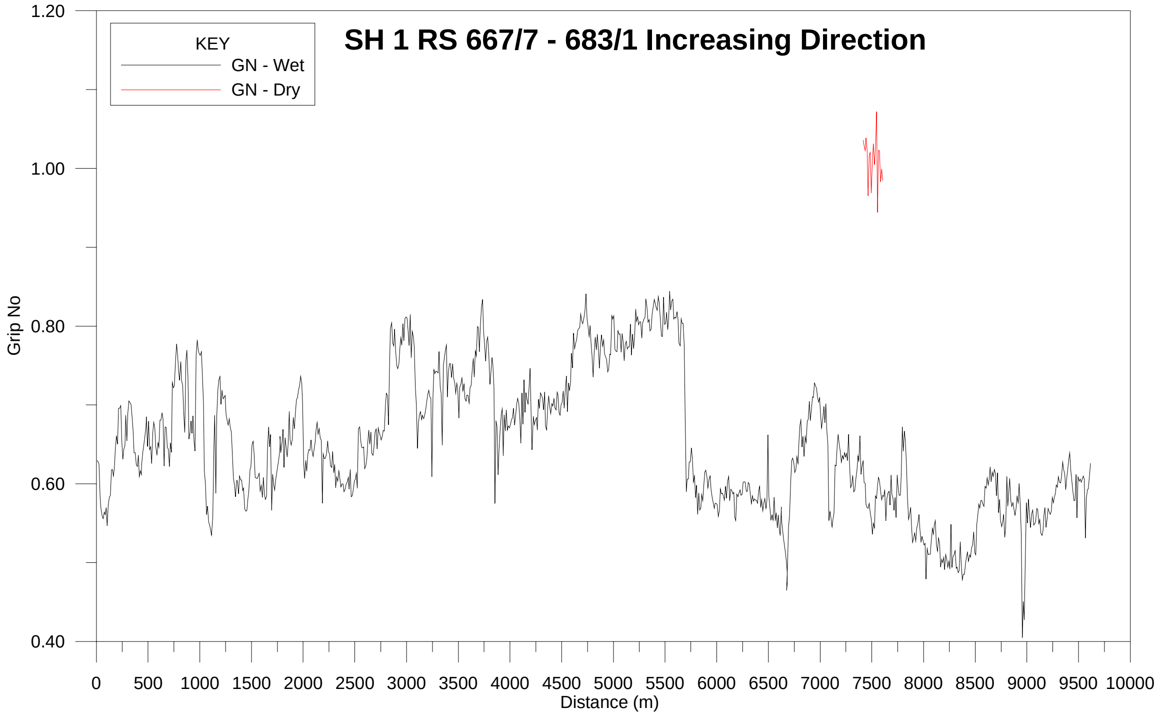

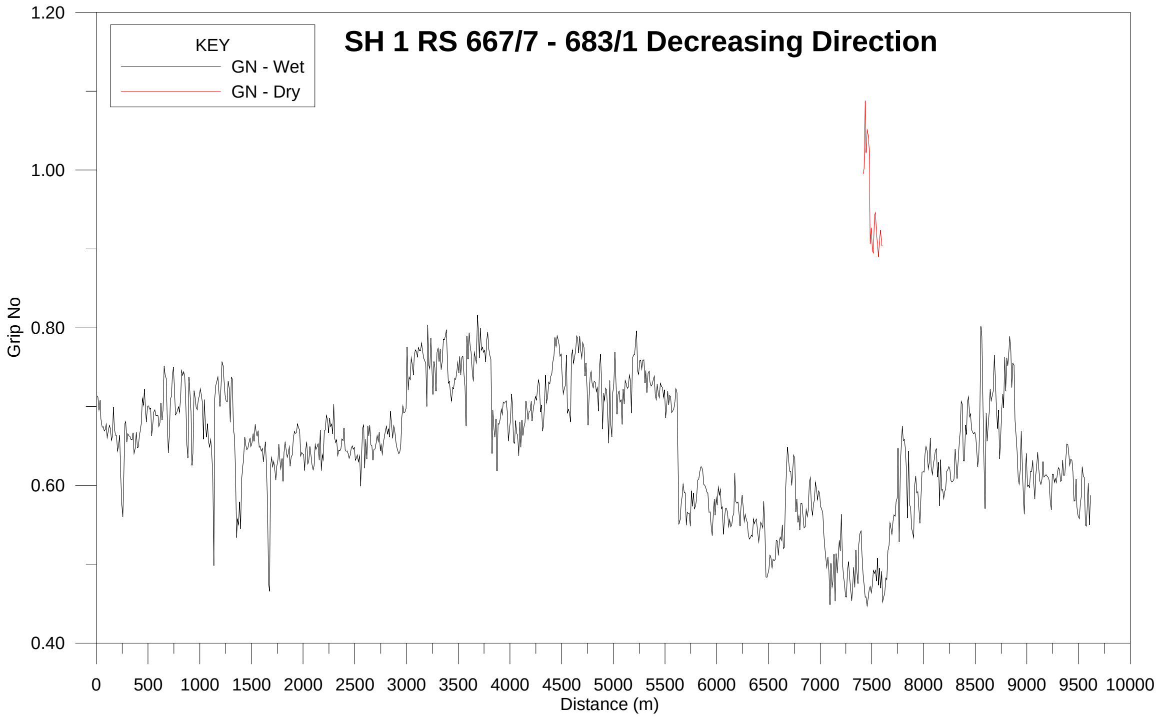

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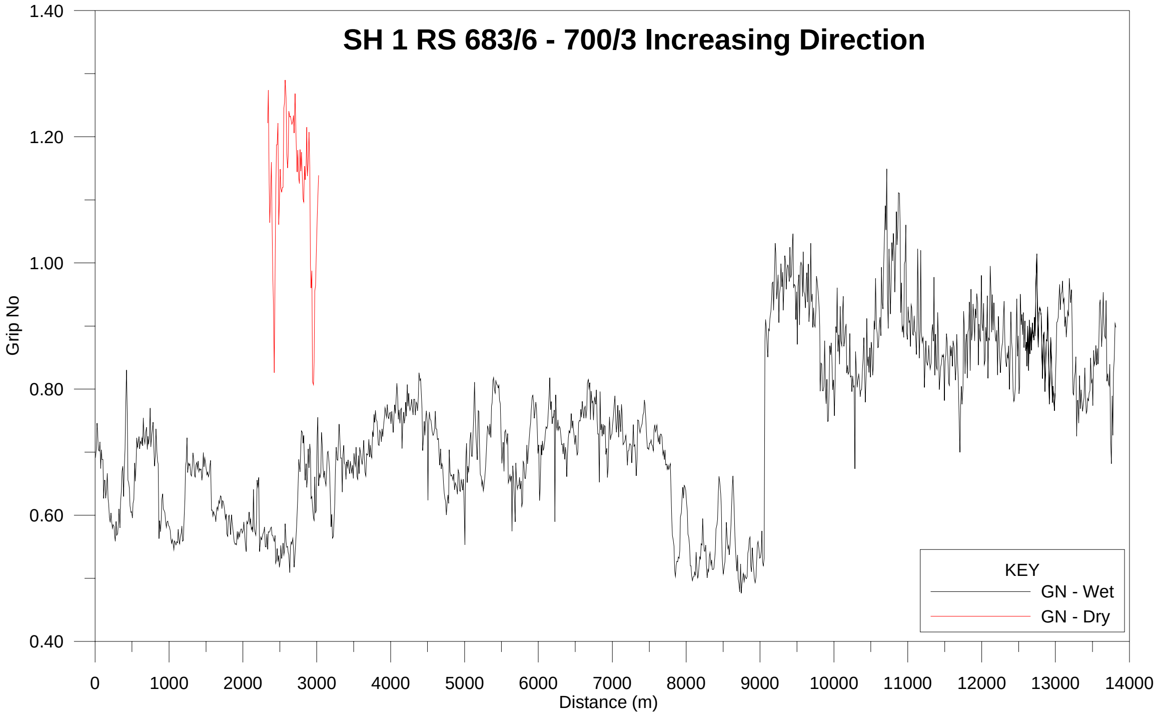

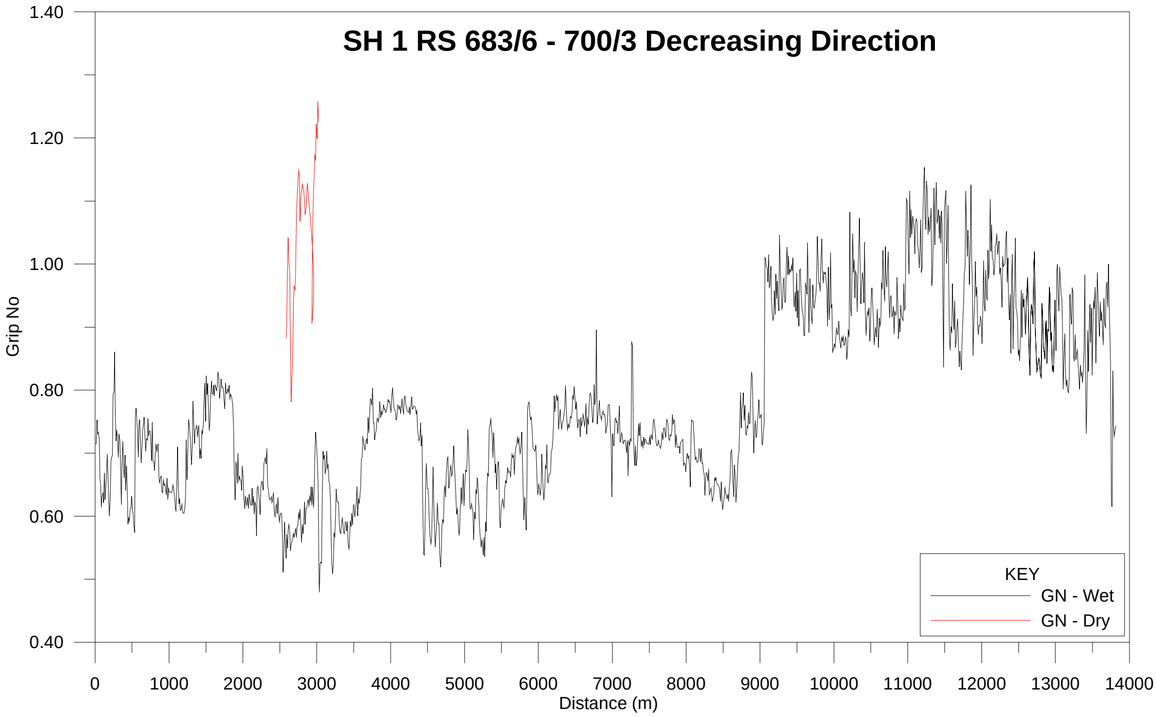

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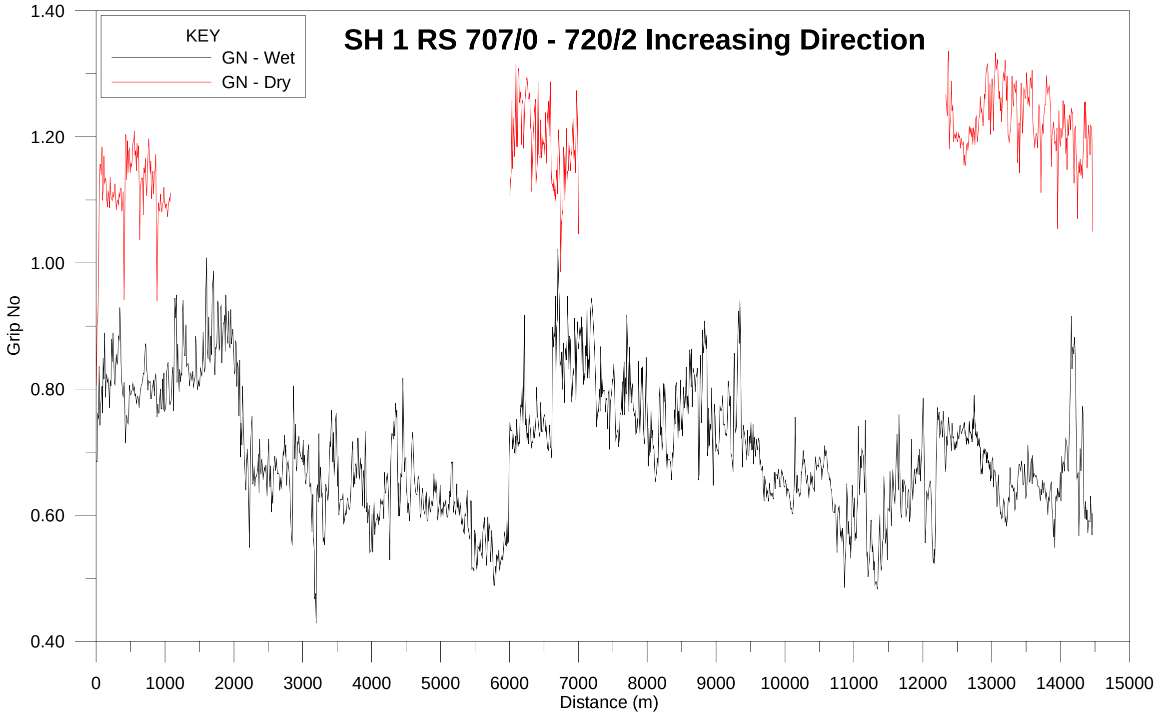
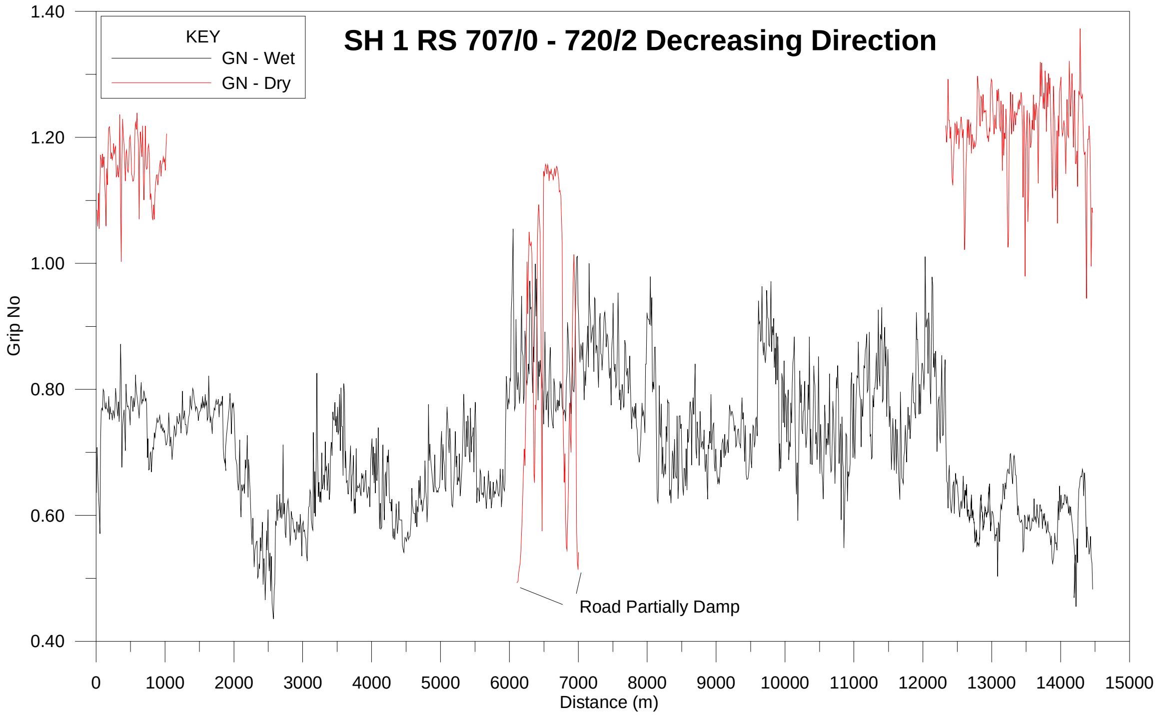
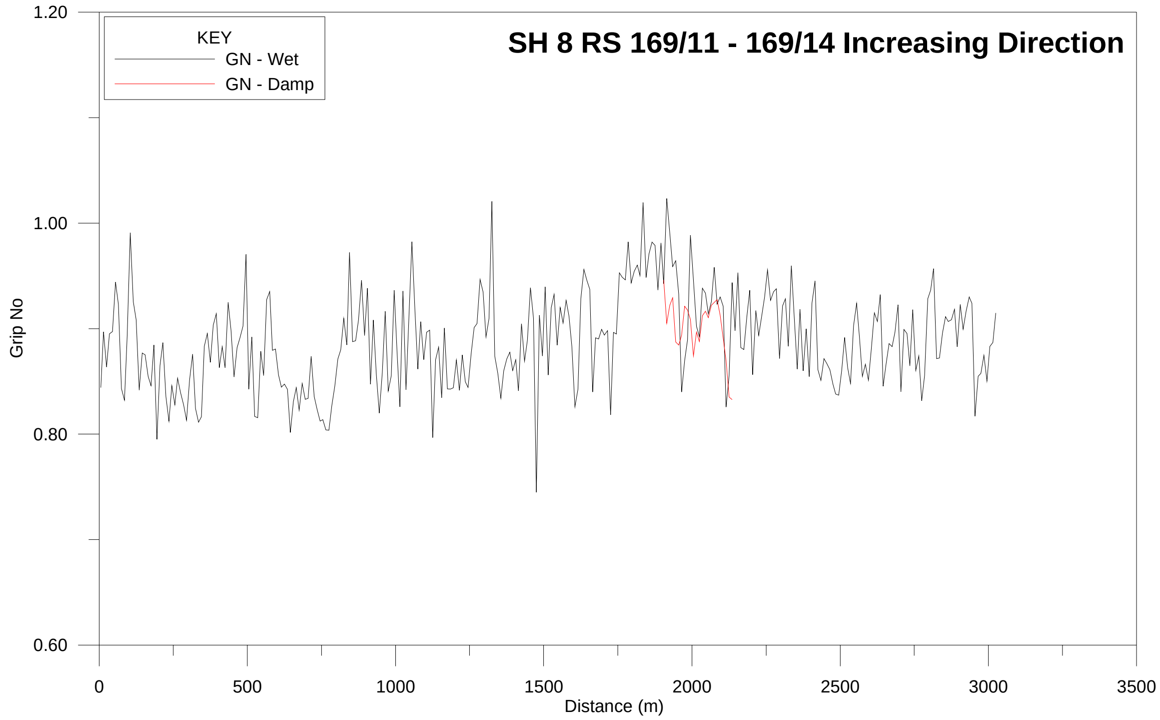
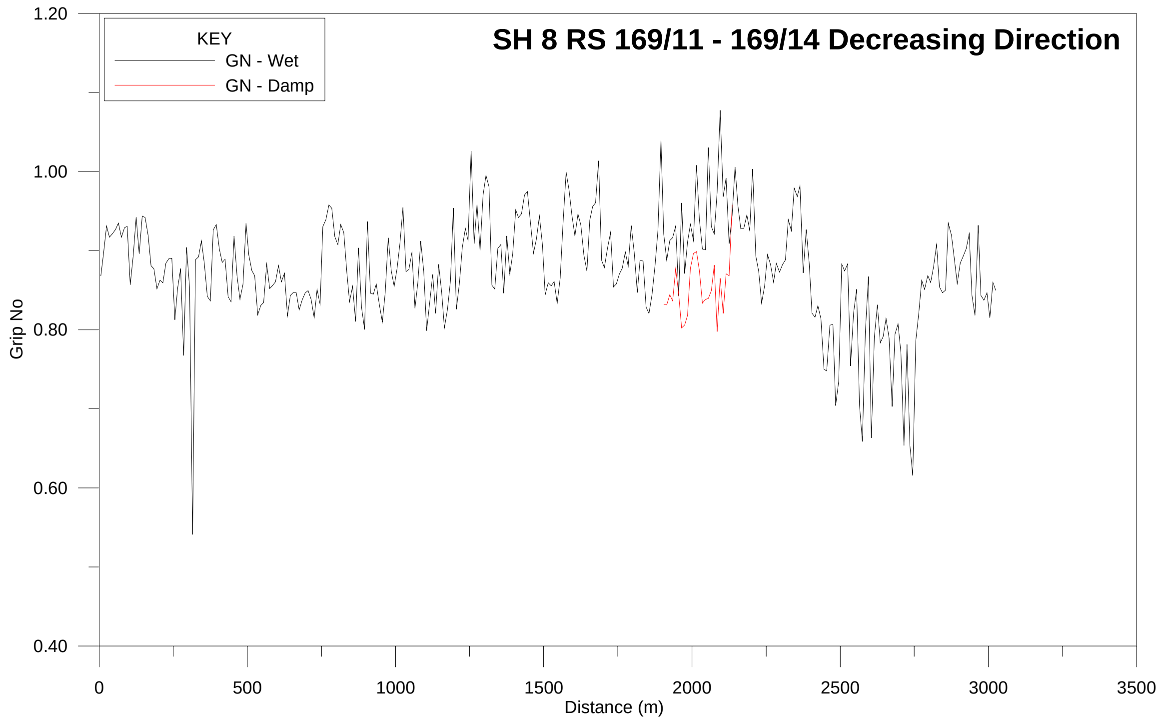




Road section 5





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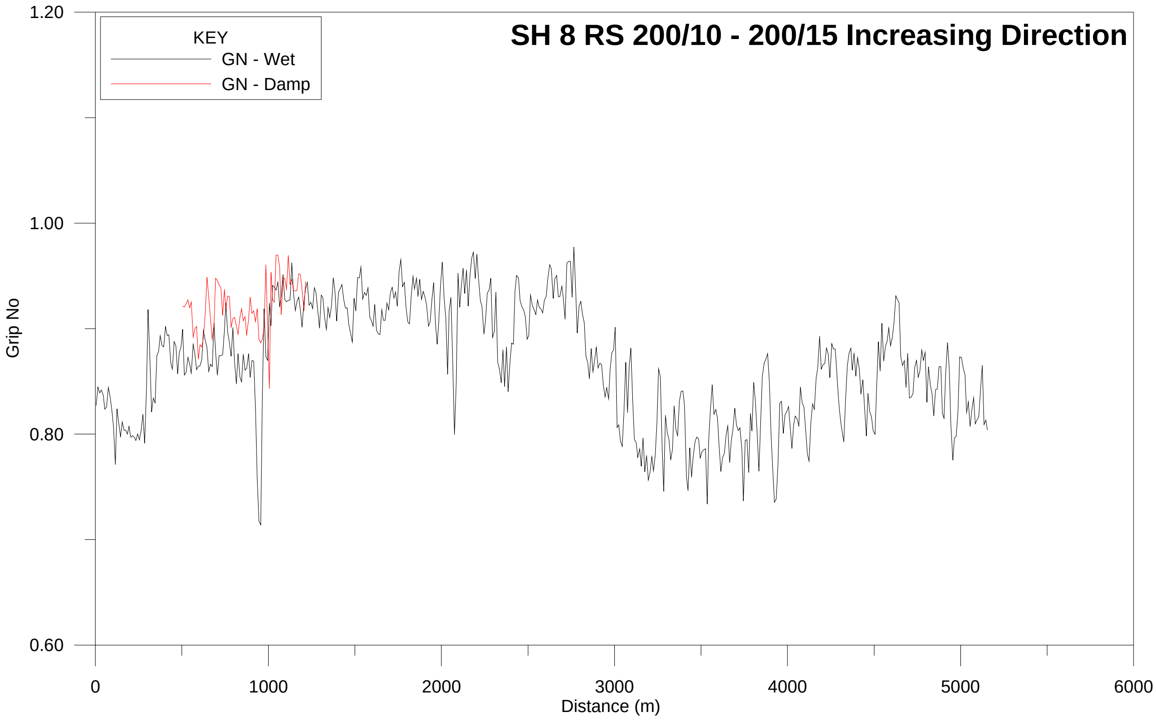

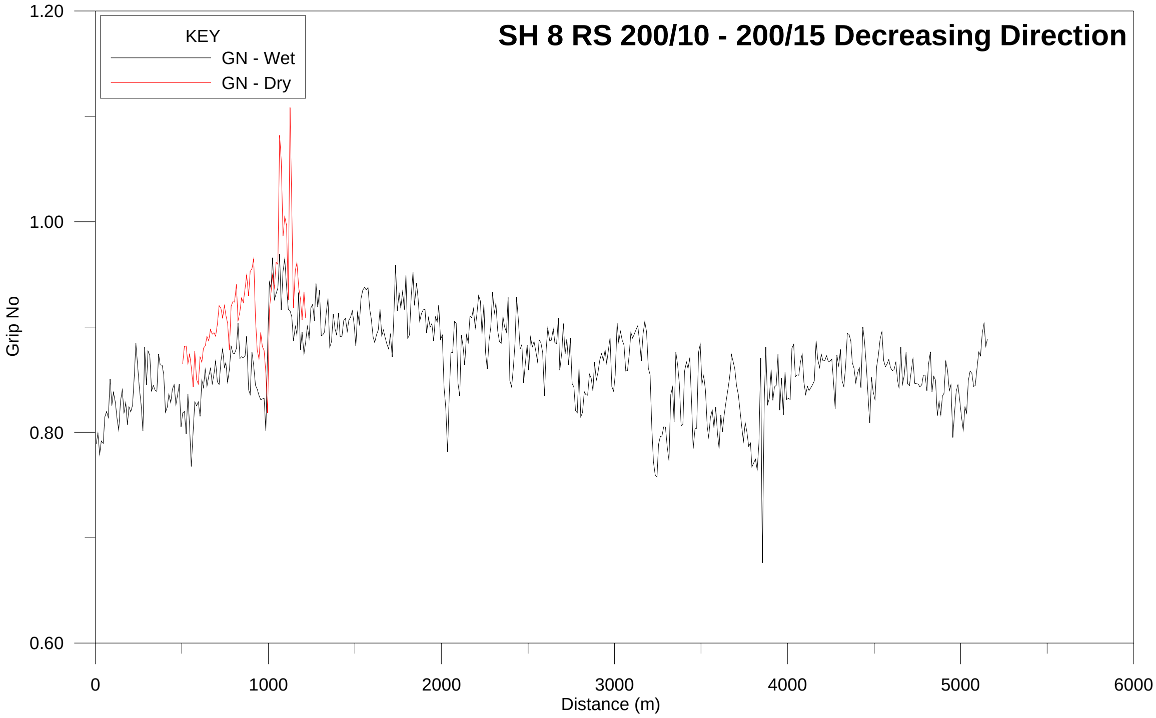

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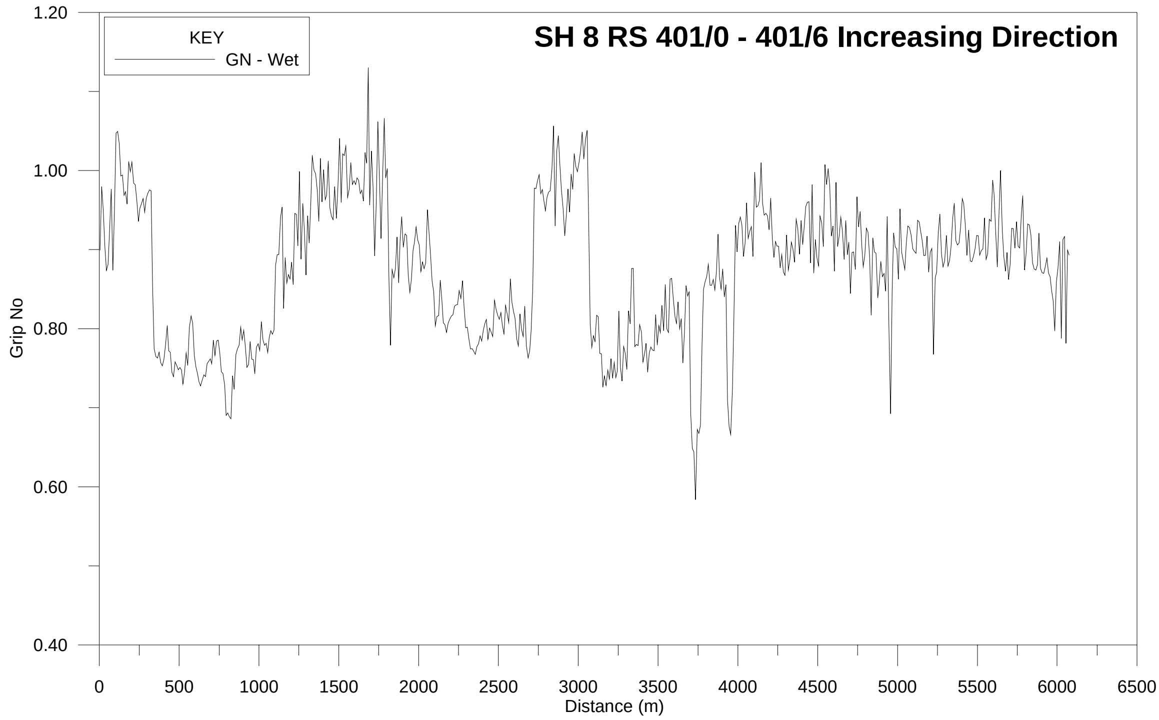

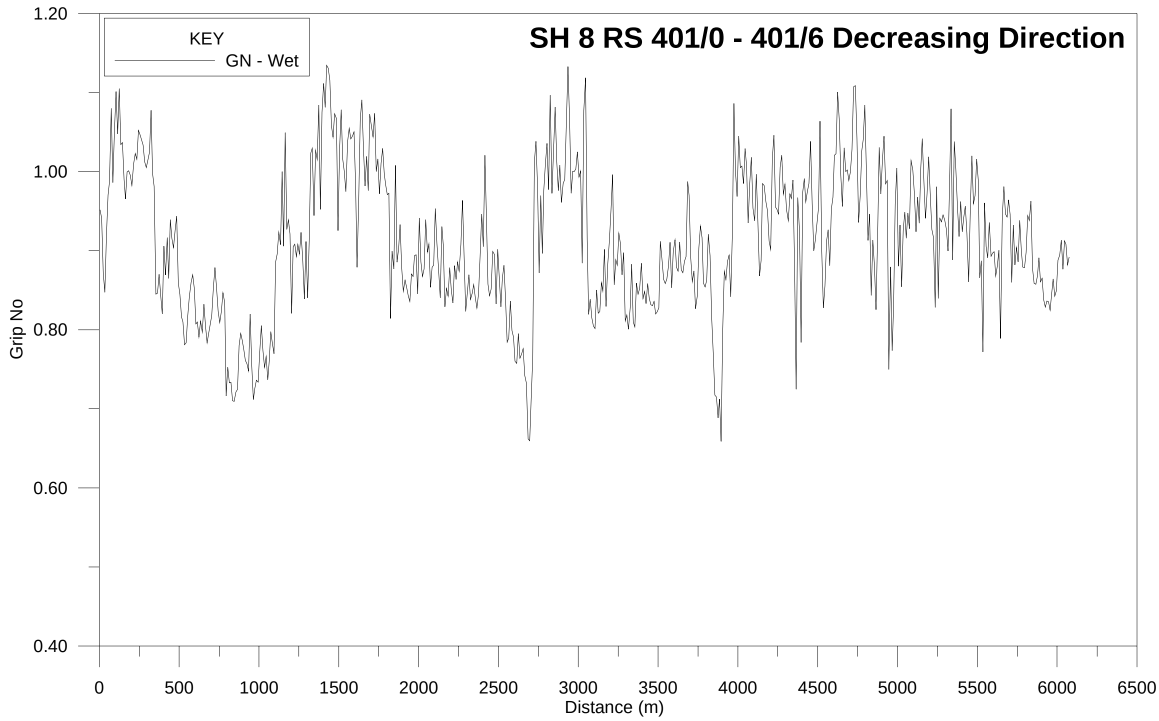

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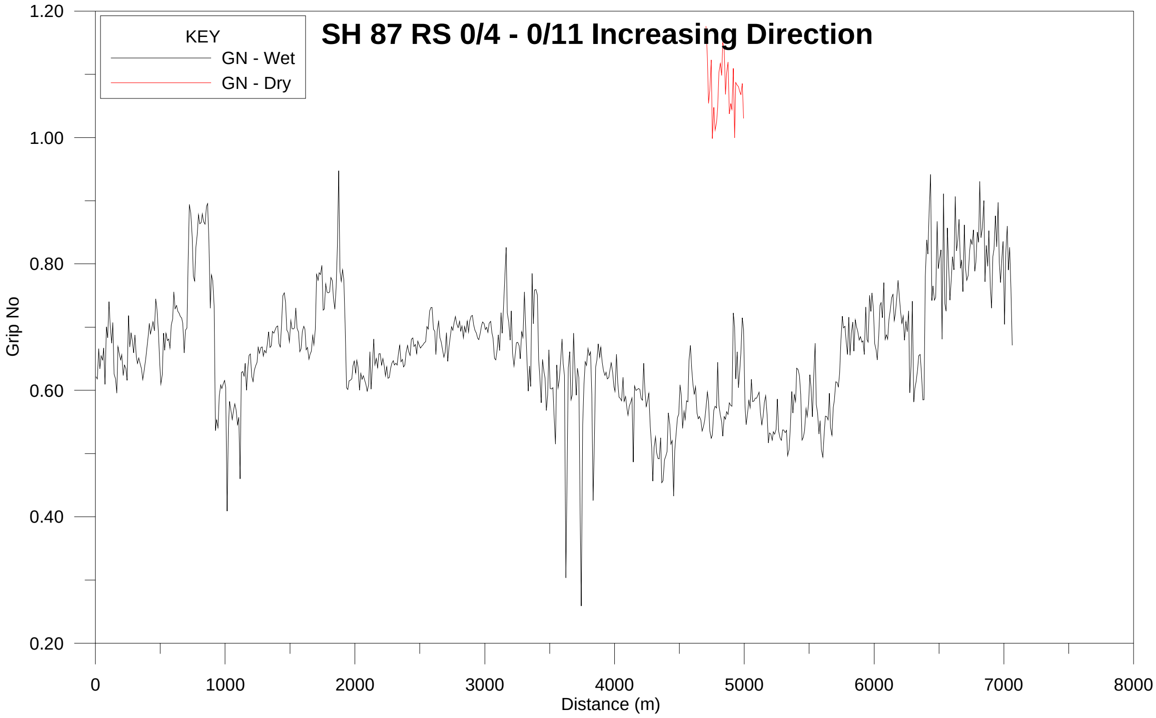
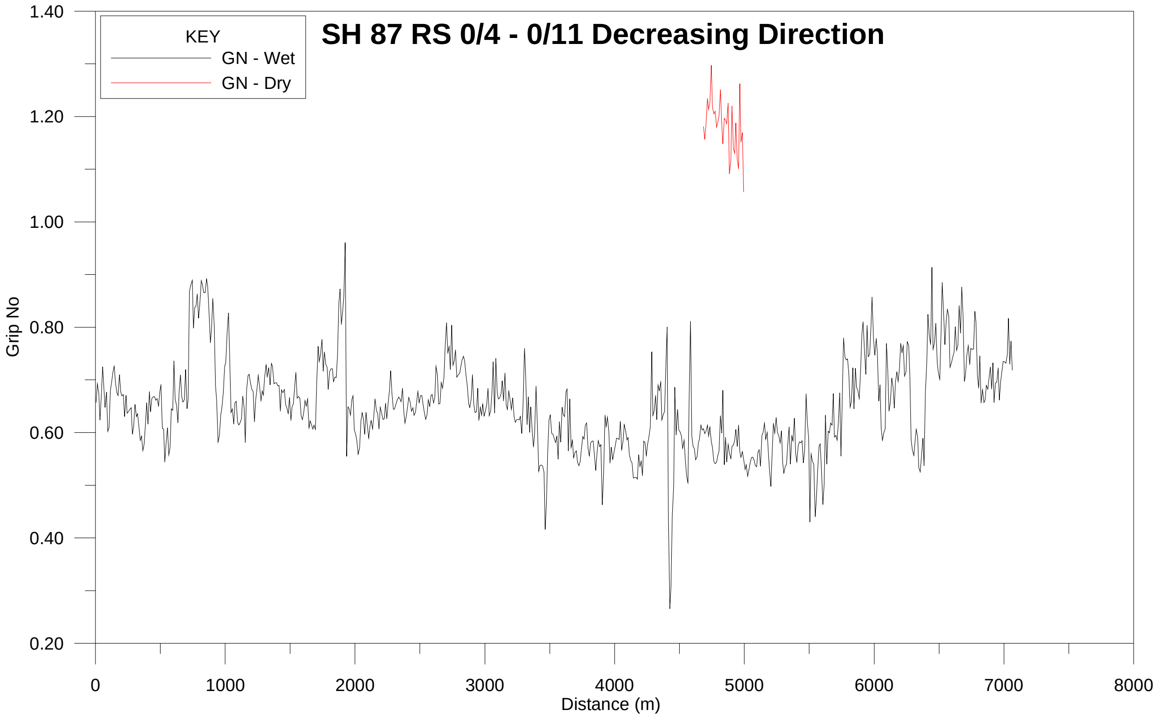
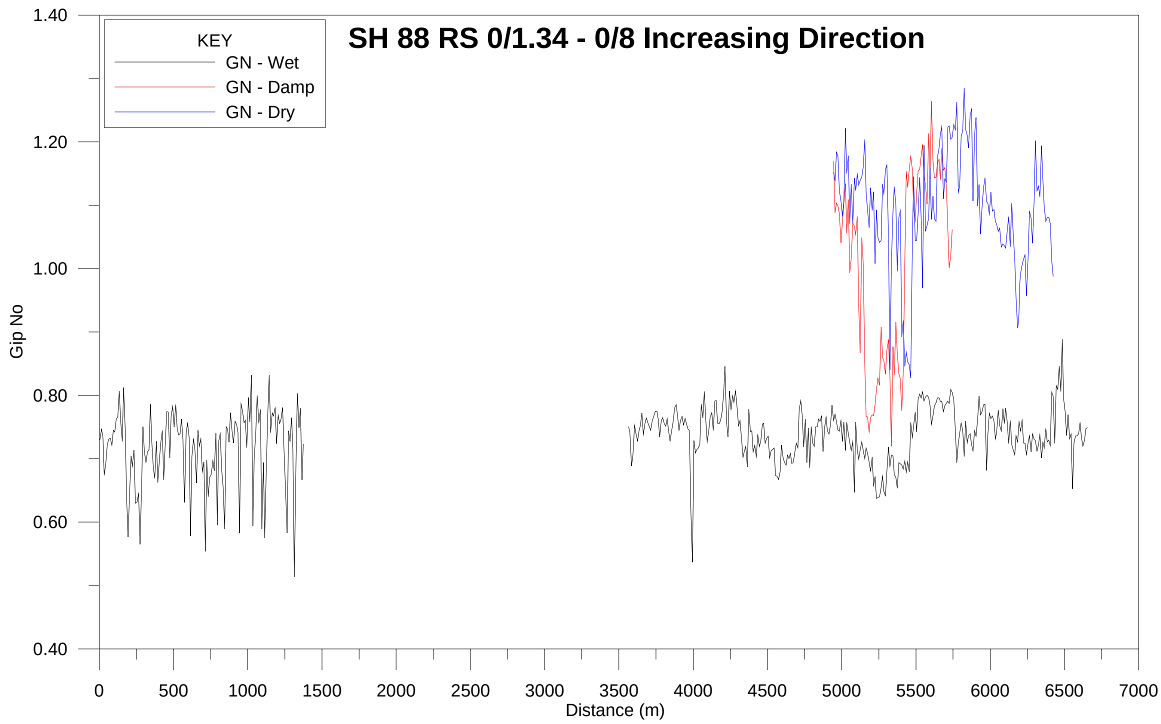
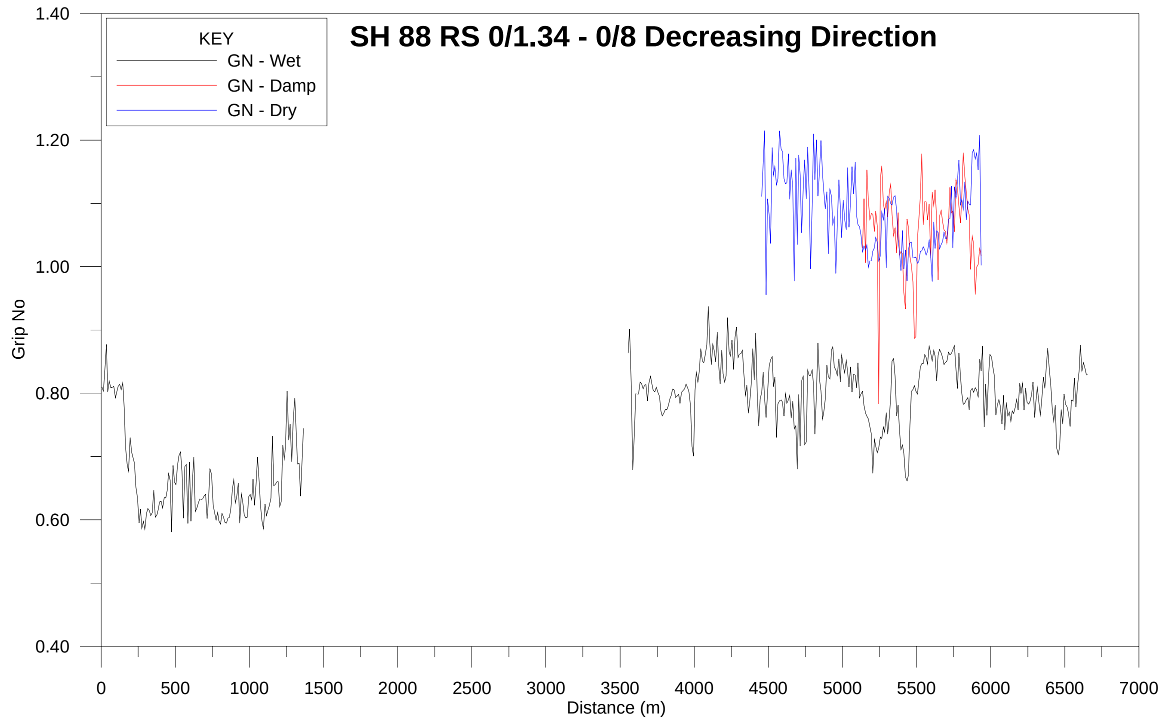




Road section 11





APPENDIX C

Photos of comparative skid resistance test sites

(a) View looking in increasing direction – west

(b) View of surface

Site 1: Coarse chipseal (Grade 2).

(a) View looking in increasing direction – west (site begins at seal change)

(b) View of surface

Site 2: Fine chipseal (Grade 5).

(a) View looking in decreasing direction – southwest (site starts at seal change)

(b) View of surface

Site 3: Asphaltic concrete.

(a) View looking in increasing direction – south

(b) View of surface

Site 4: Open Graded Porous Asphalt (OGPA).

(a) View looking in decreasing direction – south

(b) View of surface

Site 5: Slurry seal.