Lessons to Learn from Skid Resistance Monitoring in the Northland Region

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ABSTRACT

This paper discusses the results of a programme of frequent skid resistance monitoring on five sites within the Northland PSMC 002 contract over the last two year period. The skid testing was undertaken using a GripTester by the Department of Civil and Environmental Engineering at the University of Auckland in conjunction with Works Infrastructure Limited.

The analysis of the results has shown some very interesting relationships that have enabled some clear lessons to be learned. A summary of the main conclusions is:

- Short term variations in skid resistance (up to 30% variation in measurement) mean that prediction and therefore management of skid resistance levels is very difficult;
- The PSV of aggregates in itself is not a reliable indicator of the initial measured level of skid resistance after treatment nor is it a reliable measure of the long term 'equilibrium level' of skid resistance;
- The life cycle of the 'highest locally sourced PSV aggregates' in the Northland region for T/10 Site Category Two corners with reasonable traffic levels (>4,000 AADT) is economically short (less than 1 year);
- The performance of a trial site using Steelserv melter slag (PSV = 58) on T/10 Site Category Two corners is very promising as very little measured deterioration of skid resistance has occurred over a two year period;
- Timeslice analysis techniques for specific sections of test sites has demonstrated significant relationships for the economic life of a surfacing by comparing new surfacings with adjacent older sections and curved sections with straight sections.

The paper has demonstrated the benefits of undertaking an ongoing monitoring programme comprising frequent measurements of skid resistance at specific sites in the Northland PSMC002 Region. A significant outcome is the learning of valuable lessons that are transferable to other regions and countries.

1. INTRODUCTION

This paper discusses the results of an ongoing programme of skid resistance monitoring on the Northland PSMC 002 Contract. The Department of Civil and Environmental Engineering of the University of Auckland (UoA) in conjunction with Works Infrastructure Ltd (Works) have been monitoring the measured skid resistance utilising the GripTester on five sites within the Northland PSMC 002 Contract over the last two year period. This paper discusses the results of analysis of the skid testing measurements. The results show some very interesting relationships that have enabled some clear lessons to be learned.

1.1 NORTHLAND'S PSMC CONTRACT

The Transit New Zealand (TNZ) Region 1 State Highway Network is based in Northland and has 750 kilometres of mainly rural road. The average AADT in the region is 3,000 ranging between 150 in Waipoua Forest and 22,000 within Whangarei (the main city in the region). Within these extremes, the overall average AADT on the State Highways in the region is around 3,000. The TNZ Region 1 State Highways are managed under a ten year Performance Specified Maintenance Contract (PSMC002) which will reach the half way mark in October 2005.

Works have found that the skid resistance performance criterion is the most challenging to meet of its main Key Performance Measures. The contractual requirement is that no greater than 2% of the road network for each Transit NZ T/10 Site Category within each of the five regional Sub networks is allowed to be lower than the T/10 Threshold Levels as measured by the SCRIM skid testing vehicle. Site Categories Three and Four are relatively easy to meet with the other two categories being much more difficult to achieve. The challenge in meeting these targets is largely due to the extent of the variability in the measured result and the difficulty in predicting when treatment intervention is required (Wilson, Findlay and Dunn, 2003).

1.2 ROAD SAFETY IN NORTHLAND

When the Northland PSMC 002 first started, an analysis of crash statistics demonstrated that intersections were the most common location for crashes on state highways in the Region. In response to this issue the PSMC 002 safety team completed a range of inspections both at night and during the day. Action plans were developed for each of the intersections and solutions considered included signage improvements, additional turning lanes and lighting. A five year plan is currently in operation implementing these improvements. The benefits of these action plans has already been realised as intersections are no longer the greatest contributor to accidents on State Highways in Northland.

'Loss of Control' type crashes (especially those on bends) are now the main contributor to crashes on State Highways in Northland. In almost a quarter of these crashes the condition of the road was reported as a contributing factor. On a national basis the number of crashes in Northland affected by the condition of the road was higher than the average for New Zealand State Highways, although the percentage of curvature per kilometre is also expected to be high in comparison to other networks with similar traffic volumes.

The level of skid resistance was seen as a significant contributor to these statistics and therefore Works set out to address these crash types.

2. THE RESEARCH PROJECT

2.1 BACKGROUND

In seeking to better understand the variability of measured skid resistance Works and the UoA began in March 2003 a research project on five trial sites in Northland. Works had been trying to achieve their skid resistance requirements under their Performance Specified Maintenance Contract (PSMC002). Annual results indicate that overall Works has actually significantly improved the overall skid resistance levels, but not to the level required to consistently achieve and manage all of the Key Performance Measures (KPM).

One of the benefits of the PSMC002 contract is the requirement for two total network high speed data surveys, the Transit New Zealand national survey in December and the PSMC002 contract survey in April. The main benefit to the PSMC002 team of the December survey was the early indication of the state of the pavement and surfacing during the seal construction season, which it was thought would allow better management of the skid KPM. Relevant treatments could then be completed which would ensure good results in the contract survey.

However, early in the PSMC002 Contract this was identified and reported by Haydon and Hutchison (2002) to not be the case. In December results were achieved that would see all skid resistance KPM's pass the required level. In the following April survey results were achieved that would see half the skid resistance KPM's below the threshold level – a significant and unpredictable difference. This meant that either the tools available to measure and therefore predict intervention and / or the actual variability of skid resistance was greater than the ability to manage the levels of skid resistance within the TNZ T10 category levels.

2.2 ROAD MANAGEMENT ISSUES RELATED TO SKID RESISTANCE

The TNZ T/10 Site Category One sections in Northland whilst requiring the highest level of skid resistance surfacing are relatively easy to treat in comparison to the Site Category Two sections as:

- the percentage of road sections falling into site category one is relatively small (0.4%)
- one of the primary treatment solutions for Site Category One is high skid resistant surfacing utilising artificial materials such as calcined bauxite. This has a significantly greater margin of safety and therefore confidence of success.
- a much smaller percentage of the overall network is also clearly much more economically viable and efficient to treat with more expensive artificial surfaces.

In contrast, the sections of Northland's state highway region that fall into TNZ T/10 Site Category Two (some 14% of the total road network having curve radii less than 250m radii or greater than 10% gradient) is by far the most difficult of the categories to manage. The frictional demands and therefore the polishing action on the aggregate microtexture on horizontal curves increases with decreasing curve radius for similar levels of superelevation and operating speeds. This frictional demand increases where the minimum curve radiusi is close to, or less than, the desirable minimum design curve radius, thereby reducing the margin of road user safety when taking into account the speed environment of the adjoining sections.

A chosen surfacing material would desirably perform adequately without requiring further intervention for the design life of the surfacing whilst taking account of:

- the design 85 percentile speed;
- the design traffic loading; and
- all geometrical elements.

As the road surface microtexture polishes towards 'equilibrium skid resistance', the gap between the supply of frictional resistance and the frictional demands (the margin of safety for road users) diminishes. Therefore, in a clear predictable and deterministic world an important and desirable objective of a road controlling manager would be to select appropriate materials that could consistently and with statistical confidence just pass the minimum threshold levels at all times until the design life of the surfacing was reached. Unfortunately, as reported in Wilson and Dunn (2004), the variability of measured skid resistance due to both environmental factors and the existing testing methods does not currently allow this level of confidence to be achieved.

Furthermore, verifying a change or loss of skid resistance (especially due to microtexture changes) by visual techniques within the field is very difficult, if not impossible. A highly skid resistant surface can look skid resistant but actually be below the TNZ threshold level and vice versa, with a poor-looking surface actually passing. This is made more difficult with the fact that skid testing equipment and network surveys are still relatively expensive and therefore the frequency of skid testing surveys is infrequent (usually once or possibly twice a year for state highways and less for other road controlling authorities).

These primary issues led the research team to develop a time series programme of skid testing monitoring and research to try to better understand the factors responsible for the temporal variation of skid resistance.

2.3 RESEARCH OBJECTIVES

The primary objective of the research project was therefore to try to better understand the factors that were causing significant changes in skid resistance with time. Some questions that the research team sought answers to, were:

1) What was causing the variability in measurement and especially the mechanism for replenishment of the chip and over what period of time did this occur?
2) How would one know when the chip had reached its worn out state and could this be predicted?
3) What surfacing treatments would last the desired asset lifecycle.

It was recognised that if these questions could be answered and understood, then improved skid resistance asset management would occur.

One of Transit New Zealand's five strategic goals is to 'provide safe state highway corridors for all users and affected communities'. The level of skid resistance can provide one indication of the level of safety on a road surface. Part of Work's role is to ensure that the motorist is made aware of any safety concerns on the road such as slippery surfaces until an appropriate treatment is applied. It was hoped that the research would help facilitate this role and enable earlier intervention and better decision making to confidently meet the desired levels of road user safety.

The main area of concern for Works was the Category Two curves (less than 250m radius) which make up 206 lane kilometres (14% of the Regions network). These lengths of road required higher friction surfaces to comply with the TNZ T10 specification. Experience has shown that the best available locally sourced aggregate, which has been used on the majority of these types of curves, is not able to meet the required levels consistently for the desired surface life cycle.

A desirable method of treating horizontal curves with varying frictional demand would be to specify varying aggregate materials that would, when appropriately designed and constructed, give similar levels of frictional demand. The material would desirably need to perform adequately without requiring further intervention for the design life of the surfacing for the design 85 percentile speed whilst taking into account the design traffic loading and all geometrical elements.

However, this desirable outcome pre-supposes the existence of an economically viable range of surfacing materials exists that can adequately perform for the desired surfacing life cycle for such large sections, of the road network. Economically viable material options for large sections of a regions highways currently still rely on natural and where possible locally sourced aggregates.

This is not a major problem for some regions in New Zealand, although for the Northland Region this is currently a significant problem as the best material from local quarries has been shown to be unable to perform adequately with the current traffic loading and aggregate qualities. It is also important to note that inconsistency of surface treatments in terms of its skid resistance across regions throughout New Zealand is undesirable for road users due to human factors such as driver expectancy.

2.4 RESEARCH MONITORING SITES

Five separate sites, with different geometric, traffic conditions and surface treatments, were selected for skid resistance monitoring as summarised in Table 1 and below:

Brynderwyn Curve (SC2) – This site was selected because it continually recorded skid resistance results less than the threshold level and had a history of being treated on almost an annual basis. This site has had an historically high crash rate due to the heavy traffic volumes and marginal horizontal and vertical geometry. The long term solution is horizontal geometric realignment and plans are progressing towards this end.

Kaiwaka South Curve (SC2) – This site was selected because of its rolling topography, poor skid resistance history and proximity to the Glenbrook Steel Mill. The site was used as a trial site for the steel melter slag produced by Steelserv in South Auckland.

Kara Road (SC2) – This site was selected as it included a side road that intersected at the apex of a horizontal curve. The objective was to see how skid resistance changed with the additional aggregate polishing by intersection turning movements.

Snooks / Tatton (SC2) – This site was selected as it contained two sets of curves with site category two curves which were to be treated while the section between the curves remained untreated. The objective was to compare the variation of the life of a newly treated section with an untreated straight section in the same environment.

Hikurangi Control (SC4) – This site was selected as a control skid resistance section as it was a straight level section of road with a chip seal that had reached its equilibrium skid resistance level and was also one of the two seasonal SCRIM SFC correction sites within Northland.

Site Name	Length (m)	Surface Treatment	PSV	Aggregate source	Radius (m)	T/10 Cat	AADT	HCV %
Kaiwaka Slag	551	2 Coat G3/5	58	Glenbrook Steel Mill	200	2	8651	9.6
Brynderwyn Curve 03	172	2 Coat G/4	56	Bellingham Quarry	160	2	8651	9.6
Brynderwyn Curve 04	172	Racked in G2/4	53	Otaika Quarry	160	2	8651	9.6
Hikurangi Control	600	Single Coat G2		Otaika Quarry	-	4	9706	9.7
Kara Road	657	Racked in G3/5	52	Otaika Quarry	150,160	2	5514	5.5
Snooks Tatton	1737	2 Coat G3/5	52	Otaika Quarry	140-160	2	5514	5.5

Table 1: Northland's Skid Resistance Research Sites

Rain gauges were installed at each site in order to record rainfall records. This information is supplemented with local NIWA (National Institute of Water and Atmospheric Research) data in order to evaluate local and regional trends. The rainfall data collected are at best, total mm of rainfall per day, although it is recognised that the intensity and timing of the rainfall is also relevant when considering its effect on skid resistance levels.

3. RESULTS OF SKID RESISTANCE MONITORING

3.1 MEASURING SKID RESISTANCE

A GripTester (Type D - owned by the University of Auckland) was utilised to undertake skid resistance surveys of the Left Wheel Path (LWP) in both directions at maximum monthly frequencies and if possible more regularly. The GripTester is a fixed slippage Continuous Friction Measurement Equipment (CFME) device that was included in the original 1992 PIARC Harmonisation study and had been proven to correlate well with common skid testing machines (such as SCRIM and Locked Wheel Testers).

3.2 SHORT TERM VARIATIONS

Earlier results from the biannual SCRIM PSMC002 Network surveys had demonstrated that sites could vary significantly between the December and April surveys. However, results from the GripTester on the straight and level Hikurangi Control site that should have reached 'equilibrium skid resistance levels' were surprising due to the high degree of variation and the short time period over which the change occurred. The seal was over five years old and the expectation was the presence of the 'seasonal' summer / winter sinusoidal effect. Figure 1 shows the results of the skid resistance monitoring which shows up to 30% variation of measured skid resistance (a difference of 0.20 GN or approx 0.15 SFC) within a three-week period.

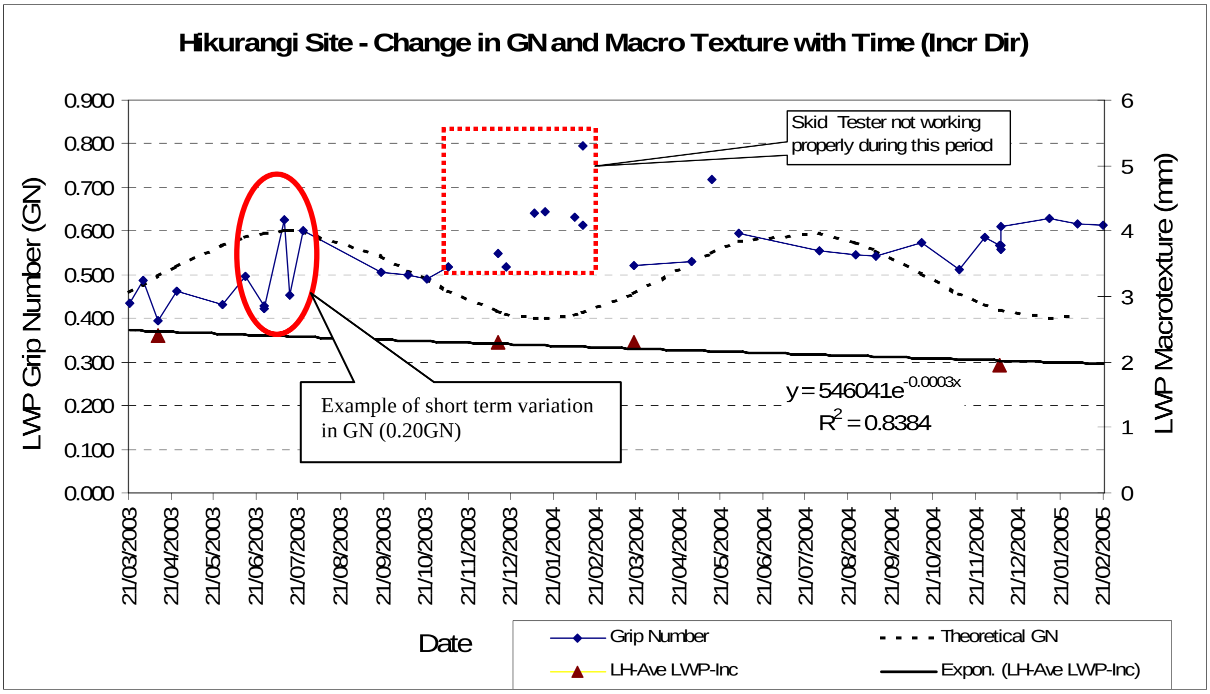

Figure 1: Variation of Skid Resistance (GN) at Control Site - Hikurangi

Figure 1 shows that macrotexture was reasonably constant over the two year period of surveys and therefore the skid resistance variation was either due to contamination of the surface or real microtexture changes during this period. Of concern is that sites that have been surveyed and have passed, can fail within weeks and sometimes even days later.

3.3 WASHING TRIALS

As contamination of the surface due to a build up of detritus was a possible reason why the skid resistance could drop so significantly, a washing trial was completed in July 2003 to evaluate whether removing contamination by cleaning the road would improve skid resistance. Three washing treatments were tested by two measuring devices, the GripTester and British Pendulum Tester.

The three treatments were as follows:

a. Washing – two passes with a water cart
b. Washing and Brooming – two passes with a water cart followed by a nylon rotary broom
c. Frimokar Hydrotexturising machine used for low pressure water blasting to ensure removal of the bound bitumen would not occur.

The results from the washing trial were reported in Wilson et al (2003). The trial did not demonstrate significant improvements could be gained by just washing the pavement and were therefore inconclusive. However, this was thought to have mainly been due to the surface prior to washing having begun in a reasonably 'clean' state after recent heavy rainfall. However, the trial inadvertently demonstrated the negative effects of contamination on measured skid resistance results where detritus was transported onto the opposing direction from the unsealed shoulders. The unusually large variation in measured skid resistance results and the significant drop in measured skid resistance over this section clearly indicate the effect over time of detritus building up on the road surface. This supports the expected hypothesis that a combination of detritus build up and rainfall with trafficking contributes to skid resistance variation.

3.4 AGGREGATE PSV AND MEASURED SKID RESISTANCE

The skid resistance monitoring sites were selected for differing purposes and/or characteristics. One of the characteristics which varies for each of the sites is the actual surface treatment that was utilised after intervention was required (refer to Table 1).

Figure 2 shows the initial skid resistance measured after each of the surfaces were treated and how skid resistance performed over repeated traffic loads as a function of Polished Stone Value (PSV). The figure demonstrates a number of important points:

- That a higher PSV aggregate does not necessarily lead to a high initial skid resistance value as measured by the GripTester;
- The PSV of the aggregate does not necessarily determine the level of equilibrium skid resistance (however, the sites do have varying loading and geometric elements which will effect the final level). This result tends to corroborate with recent research by Cenek (2004) that states there is very little relationship between PSV of aggregate and the in-field skid resistance as measured by SCRIM network surveys (even on straight level sections of road);
- The highest initial Grip Number is recorded at the Brynderwyn Curve. This is the only site of the five that were treated during the monitoring period with a Grade 2 and 4 chip size. The other sites were treated with Grade 3 and 5 chip. This result is not unexpected as the larger chips with higher macrotexture are expected to produce the highest initial skid resistance;

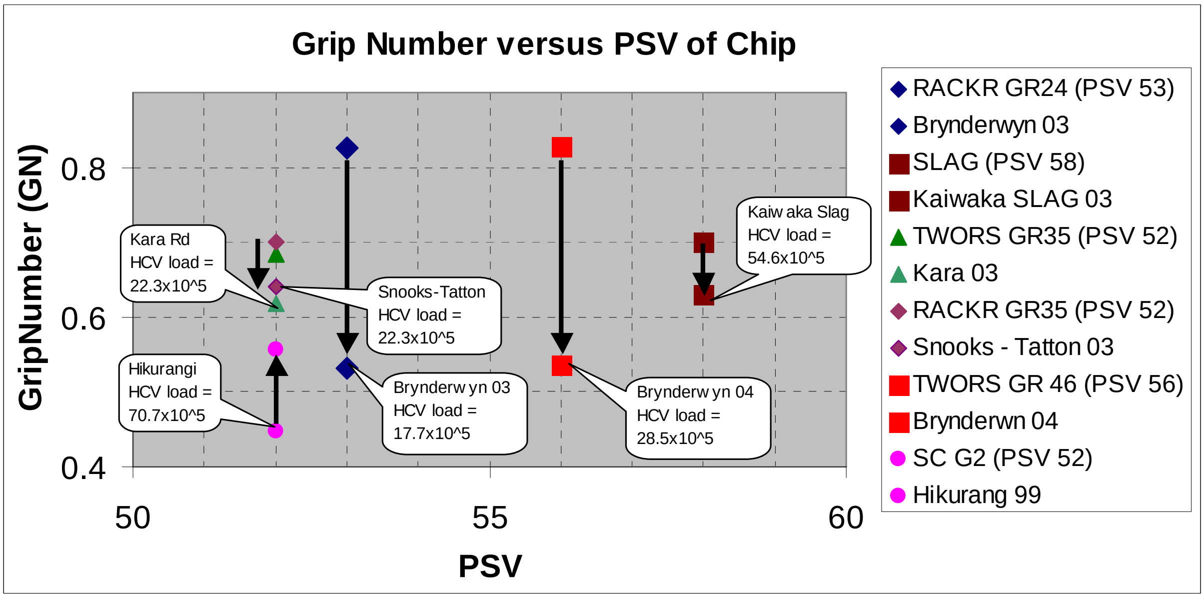

Figure 2: A comparison of Skid Resistance performance and aggregate quality

- For similar traffic loadings and curvature (eg Kara Road and Snooks Tatton) approximately the same range of skid resistance was lost over the same period;
- The above losses in skid resistance for each of the sites must be placed within the context of the control site which over the same two year period increased by approximately 0.1 GN for the highest traffic loading;
- Whilst the furnace slag from the Glenbrook Steel Mill has the highest PSV of 58 compared with 52 and 53 for the other sites, its initial Grip Number of 0.7 is the

second lowest of the results. However, when one looks at the skid resistance performance of the slag over time in comparison to the other aggregates and sites, even with much higher loading, its performance is significantly better.

3.5 PERFORMANCE OF THE TRIAL MELTER SLAG

The Kaiwaka site was resealed with sealing chip composed of melter (iron making) steel slag produced by Steelserv in South Auckland. It has been trialled at two sites in Northland, one of which is the Kaiwaka site.

The performance of the melter slag in being able to maintain its initial skid resistance is best demonstrated in Figure 3 that compares the performance of the melter slag section with Site Category Two curves with the adjacent old seal section on a straight section categorised as Site Category Four. It can be seen that for the two year period, the measured skid resistance of the melter slag sections, even on highly stressed site category two corners, has consistently remained 20% above the adjacent old road section values. Conversely, other natural aggregate sections have shown significantly reduced improvement in skid resistance to either the same, less than, or a little higher than the adjacent old sections.

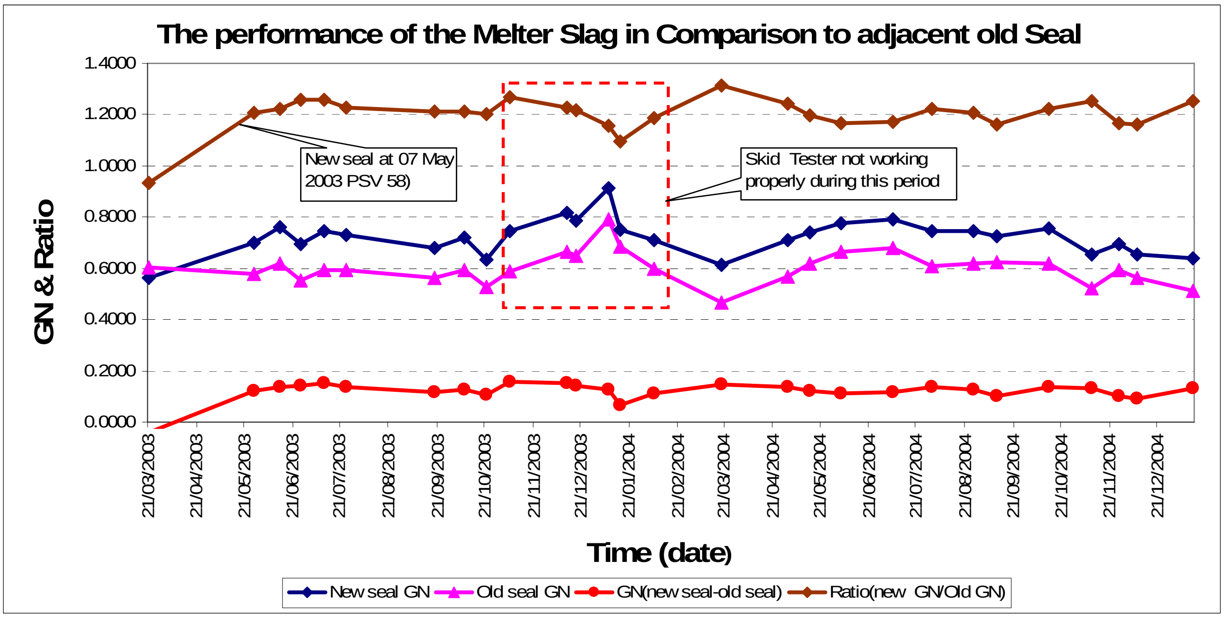

Figure 3: Performance of the Melter Slag in Comparison to adjacent old sections

In Northland the polishing of microtexture is a common problem causing loss of skid resistance in the early years of the life of a surface. Earlier than expected intervention on these sites causes both financial and practical problems. The main practical problem is seal instability which also causes low skid resistance through flushing. The results from the GripTester monitoring indicate that the skid resistance on the slag at the Kaiwaka South site is remaining constant after two years. This provides some confidence that the slag does not polish as quickly as other Northland aggregate sources.

3.6 TIMESLICE ANALYSIS THROUGH MONITORING SECTIONS

The various geometrical sections of a new surfacing will deteriorate differently due to the mechanisms of aggregate polishing such as:

- the sideways thrust on horizontal curves;
- braking areas on down grades;
- turning movements at intersections; and
- the traffic loads that are placed upon the surface.

Therefore, to always report the skid resistance surface section average for the total section length would mask changes at various sections due to varying loading requirements. The ongoing programme of monitoring skid resistance at the five sites therefore gave a very good opportunity to undertake time-slice analysis through different sections of the road and to compare how the slices performed against each other.

The skid resistance monitoring methodology consisted of testing short sections before and after new surface seals which allowed for 30m comparisons to be made between the wearing of the:

1) new straight surfaces and the adjacent older straight sections
2) the horizontal curves sections in comparison to straight sections.

Figure 4 shows on an aerial photograph, the extents of the Kara Road skid resistance monitoring site and the locations where the time-slice analysis was undertaken.

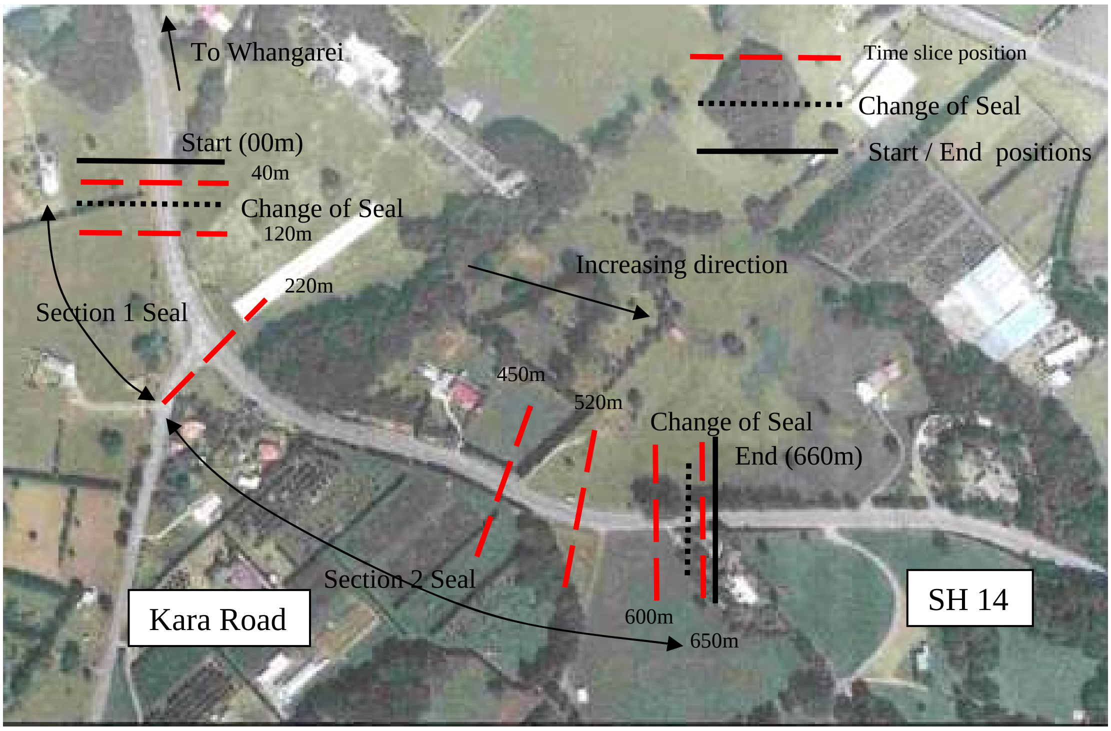

Figure 4: Timeslice Locations on Kara Road Monitoring Site

Figure 5 shows the variation of skid resistance and macrotexture over time for Section 1 of the Kara Road Section. The dotted sinusoidal line is shown to give an indication of the likely measured skid resistance value if the seal was polished to equilibrium skid resistance level and then if the seasonal summer–winter, detritus–rainfall effect was applicable.

One can see from this figure that even when ignoring the measurements taken when the GripTester was not working properly the measurements do not follow the typical sinusoidal curve. However, the effect of the different seasonal weather patterns is able to be seen as the 2003 and 2004 winter months testing results are quite different, even though one would have expected the 2004 results to be lower as initial polishing to equilibrium levels would not have been expected to have been completed at this point.

The macrotexture has also been plotted on Figure 5 in terms of Mean Profile Depth (MPD) obtained from the SCRIM laser profilometer surveys during the Northland network surveys. This shows that during the two year period there has been some loss of macrotexture due to embedment of the chip into the bitumen layer, allthough this has not been enough to significantly effect the skid resistance measurements.

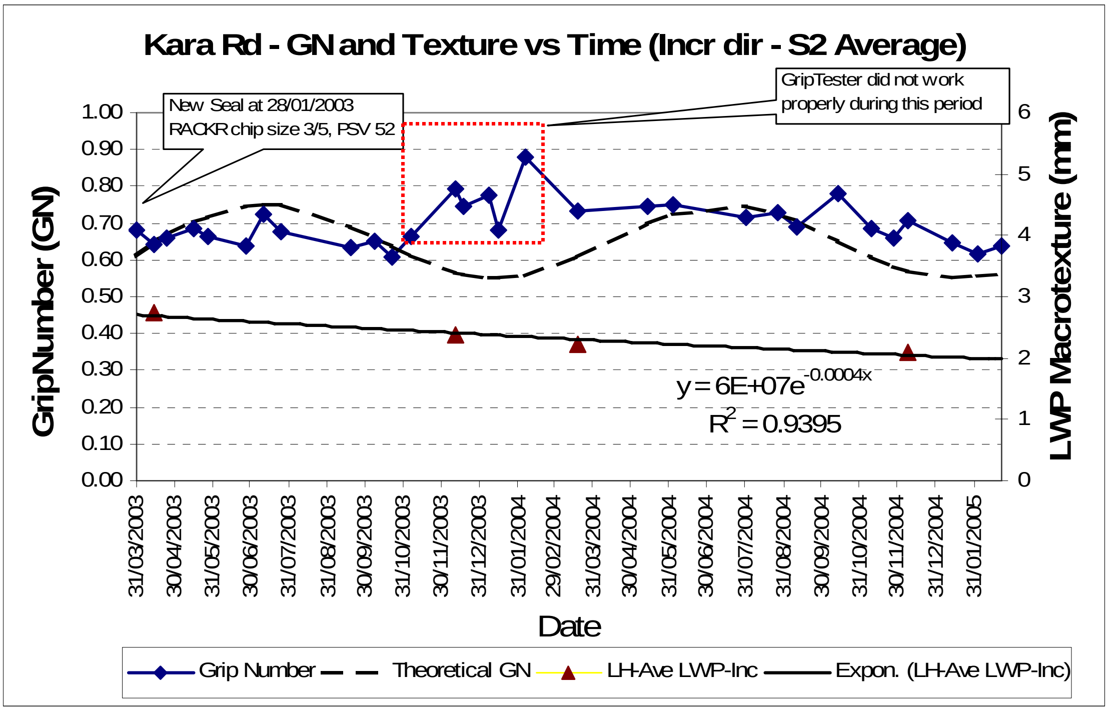

Figure 5: Variation of Skid Resistance (GN) at Kara Road site – Section average

Figures 6 and 7 demonstrate that, by undertaking time-slice analyses of carefully chosen sections (rather than taking the average seal extent result for geometrically different sections), a better understanding can be gained of how the seal sections are performing over time. The graphs show a 30m average for the time slice positions shown on Figure 4 (the bottom lines) and then a ratio of two chosen time slices to compare how the sections are performing in comparison to each other.

Figure 6 compares time-slices 120m with 40m and 600m with 650m respectively, that is a comparison of the new sealed section performance (Site Category Two) with the older adjacent seal sections on straight sections of road (Site Category 4). The data when statistically analysed clearly demonstrate that a significant negative exponential relationship exists with an R^2 of 0.74 to 0.90 for the two time-slice comparisons with 24 data points. The trend lines demonstrate that the new Racked in Grade 3/5 chip seal that was placed on the 28/01/2003 with an Otaika Quarry chip (PSV – 52):

- initially increased the measured skid resistance by 15 to 20% above the adjacent older seal sections;
- performed for 13 to 17 months before the new seal deteriorated to the point where it was the same as the seal either side of the new seal;
- has continued to deteriorate to approximately 5-10% lower than the older adjacent seal sections although this appears now to have leveled off.

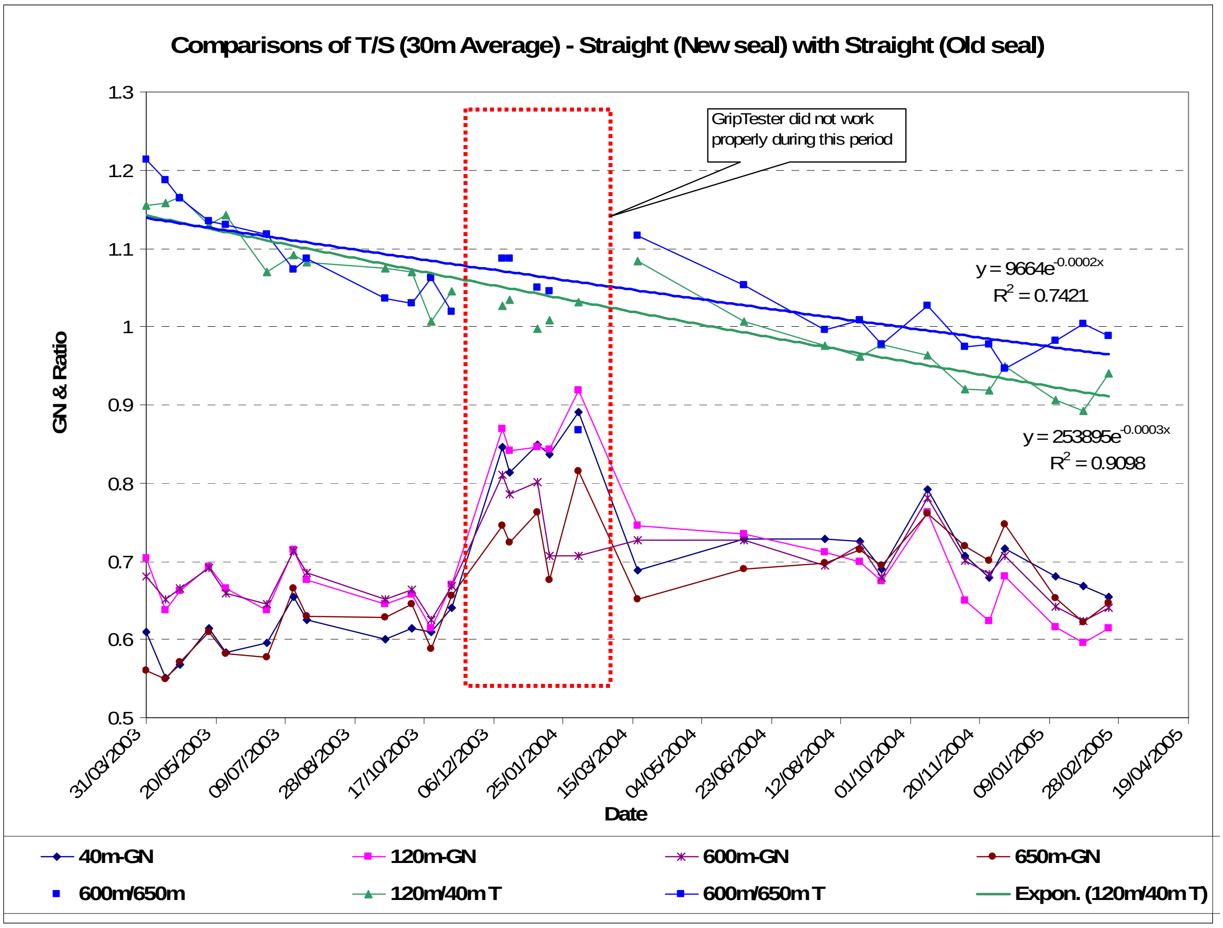

Figure 6: A 30m Time-slice Comparison of New seal versus Old (Straight alignment)

Figure 7 compares time-slices 220m with 120m and 520m with 450m respectively, that is a comparison of the new sealed straight section performance with adjacent curved sections (160m Radius). The data when statistically analysed again clearly demonstrate that a significant negative exponential relationship exists with an R^2 of 0.52 to 0.79 for the two time-slice comparisons with 24 data points. The trend lines demonstrate that the new curved sections of the Racked in Grade 3/5 chip seal that was placed on the 28/01/2003 with an Otaika Quarry chip (PSV – 52):

- initially began at the same level of skid resistance as adjacent straight sections
- steadily deteriorated faster than their adjacent straight sections and then levelled off some 12 to 16 months after the new seal surface
- the level that they deteriorated to was approximately 5% to 15% lower than the adjacent straight sections.

Experience has shown that predicting skid resistance and therefore time to treatment intervention is very difficult due to the inherent variability of skid resistance measurement. The variability is due largely to environmental factors (temperature, detritus buildup, rainfall and cyclical polishing/ abrading rejuvenation cycles) and the skid testing equipment and methodology used. Separating out these factors and determining their individual statistical significance is not easy and the research being undertaken by the University of Auckland in conjunction with Works Infrastructure Ltd is ongoing both in the field and with new laboratory equipment and procedures that have been developed to try to simulate in-field variation of skid resistance.

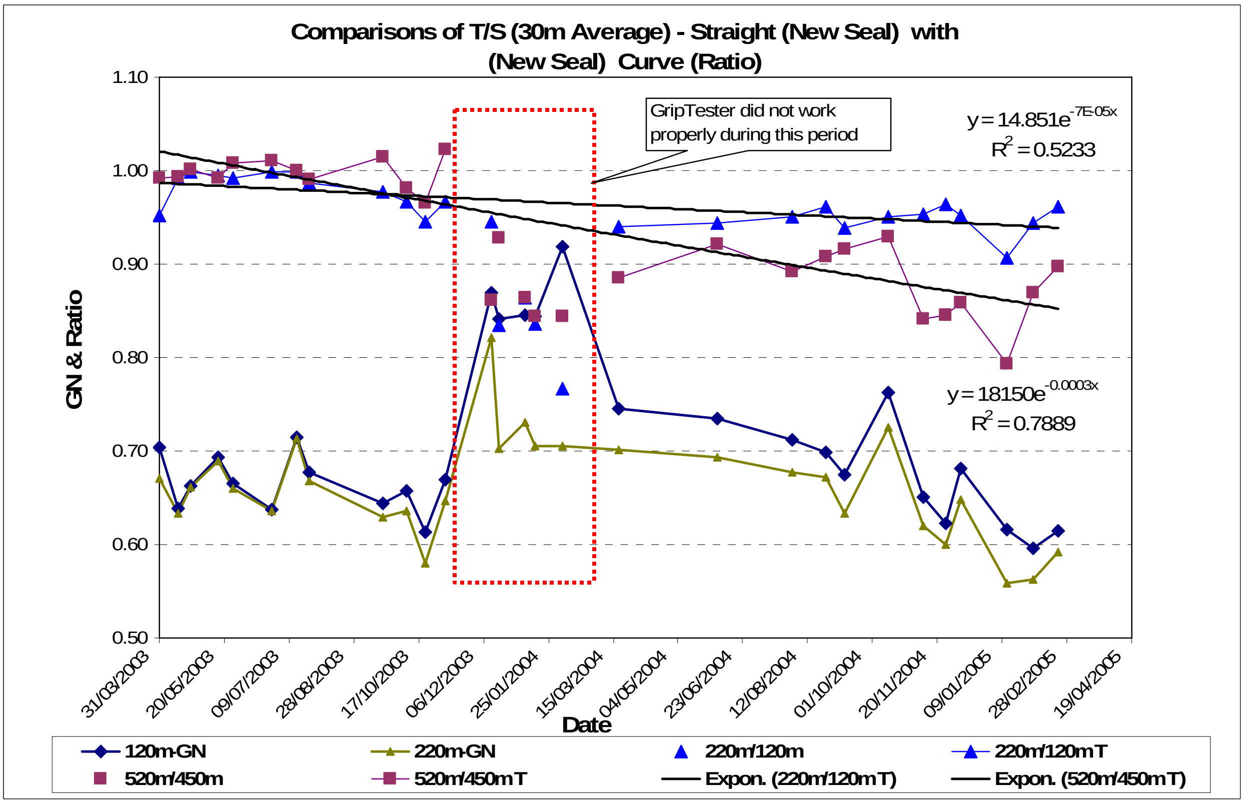

Figure 7: A 30m Timeslice Comparison of Straight (new) with Curve (new)

4. CONCLUSIONS

This paper documents an ongoing programme of research that has been designed and undertaken in the Northland PSMC 02 State Highway network to try to better understand the factors that effect this variability. In the Northland Region it is the TNZ Site Category Two sections with radii less than 250m that have proven the most difficult to manage as:

- Locally sourced aggregates have proven to be unable to achieve the required skid resistance levels over the life cycle of the asset;
- These sections represent a significant proportion of the network (14%) and therefore are uneconomic to surface with artificial high PSV surface treatments that are economic for Site Category One sites.

However, the analysis of the ongoing data from the skid resistance monitoring programme has allowed the following significant conclusions to be drawn:

- The variation in measured skid resistance is significant (up to 30% difference or 0.20 GN on a site that has reached equilibrium skid resistance level within very short time frames, i.e. over a two to three week period). This is a shift of up to 1.5 SFC site categories specified under TNZ T/10 specification;
- Cleaning the pavement surface by washing will not in itself explain the 'seasonal' effect of variation in skid resistance. Trafficking action is also required;
- The PSV of the aggregate in itself cannot be used to predict the initial skid resistance of the aggregate and or the level of equilibrium skid resistance after polishing;
- A trial melter slag sourced from Steelserv has proven to hold its initial skid resistance levels extremely well, has not deteriorated in the normal manner of microtexture polishing and has remained consistently high, which is encouraging for use at other high demand sites;
- Time slice analysis of various sections has been reported for one of the monitoring sites – Kara Road - with curve radii that range from 150 to 160m (treated in March 2003 with a Racked in Grade 3/5 seal utilising Otaika aggregate with a PSV of 52) and a traffic loading of approximately 300 HCV's per day. This analysis has shown that:
    - A significant negative exponential relationship is achieved by comparing adjacent 30m sections for various geometrical features (R^2 range from 0.52 to 0.91 for 24 data points);
    - Initially measured skid resistance (GN) was increased by up to 15 to 20% above adjacent older seals;
    - Skid resistance for straight sections lasted for approximately 13 to 17 months before decreasing below adjacent seal sections which then appear to have levelled off some 5-10% below the adjacent sections;
    - Newly sealed curved sections of radii range 150m to 160m have deteriorated in terms of measured skid resistance faster than new straight sections and have taken 12 to 16months to level off at a level 5-15% below the straight sections.

In summary, this paper has demonstrated the benefits of undertaking an ongoing monitoring programme of research into skid resistance that has high and previously unexplained degrees of variability. Significant lessons can be gained by undertaking more frequent measurements at specific sites with varying geometrical elements, surfacing types and traffic loadings. The research has also shown that the performance of melter slag placed in the field is very positive in terms of longevity of measured skid resistance even on high stressed category two type corners.

The research is ongoing and controlled laboratory experiments have recently been developed that it is hoped will determine the primary variability of measured skid resistance. It is expected that this research will enable better predictive methods to be developed and therefore enhance the management of skid resistance for Road Controlling Authorities and their respective delegated managers.

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