The influence of binder rise in reducing tyre–road friction

June 2011

RJ Henderson
PD Cenek
NJ Jamieson
Opus Central Laboratories, PO Box 30 845, Gracefield, Lower Hutt

DJ Wilson
Department of Civil and Environmental Engineering, University of Auckland, Private Bag 92019, Auckland Mail Centre, Auckland 1142

NZ Transport Agency research report 447

ISBN 978-0-478-38006-4 (print)
ISBN 978-0-478-38005-7 (electronic)
ISSN 1173-3756 (print)
ISSN 1173-3764 (electronic)

NZ Transport Agency
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
research@nzta.govt.nz
www.nzta.govt.nz

Henderson, RJ[1], PD Cenek[1], NJ Jamieson[1] and DJ Wilson[2] (2011) The influence of binder rise in reducing tyre–road friction. *NZ Transport Agency research report 447.* 46pp.

1 Opus Central Laboratories
2 Dept. of Civil and Environmental Engineering, University of Auckland

Keywords: binder rise, chipseal, dynamic friction tester, flushing, locked-wheel braking, mean profile depth, New Zealand, skid resistance, texture.

An important note for the reader

Acknowledgements

The authors gratefully acknowledge contributions to this research programme by the peer reviewers for their many helpful comments, and the NZ Transport Agency who supplied SCRIM, texture and video data, and who funded the research presented here.

In particular, the authors would like to express gratitude to Jeff Waters (surfacing engineer) of Fulton Hogan Ltd for reviewing the report from an industry perspective and providing very many perceptive, constructive and thought-provoking comments.

Abbreviations and acronyms

2D: two-dimensional

ABS: antilock braking system

AC: asphaltic concrete

DFT: dynamic friction tester

ESC: equilibrium SCRIM coefficient

HSD: high speed data

IFI: international friction index

LWB: locked-wheel braking

MPD: mean profile depth

MPD25: mean profile depth based on calculating peak heights for a 25mm segment length, rather than the standard ISO specification of 50mm

NMA: network management area

Pc: peak count

RAMM: road assessment and maintenance management system.

RMR: material/bearing ratio.

SCRIM: sideways force coefficient routine investigation machine.

NZTA: NZ Transport Agency

Contents

Executive summary

Research undertaken between 2007 and 2009 examined the influence of binder rise in reducing tyre–road friction of chipseal surfaces. The emphasis was on the most extreme form of binder rise when the binder is level or above the sealing chip, resulting in the formation of a black, slick surface. This condition is referred to as flushing.

The aims of the research were to:

- identify the best statistic to detect flushing from two-dimensional (2D) road surface profiles measured with lasers
- establish whether the dynamic friction tester (DFT) can sufficiently simulate high-speed locked-wheel braking (LWB) performance to enable its use for investigating friction characteristics of flushed sections of chipseal roads
- quantify the reduction in dry and wet road friction of chipseal road surfaces caused by the presence of flushing.

The experimental programme involved two distinct elements:

- a statistical study, which investigated the degree of correlation of various measures of surface texture with visual ratings of flushing
- on-road tests performed on the Manfeild Race Circuit and chipseal surfaced public roads involving texture profile and friction measurements. Both LWB with an instrumented vehicle and the DFT were employed for the friction measurements.

These are described in greater detail below.

Detection of flushing

The Northland state highway network was chosen to assess the suitability of various surface texture-based statistics to detect flushing in chipseal surfaces. Chipseal surfaced sections of this state highway network were ranked for the severity of flushing via a three-step visual rating scheme. Five statistics (Mean Profile Depth (MPD), MPD based on a shortened 25mm segment length (MPD25), peak count (Pc), material/bearing ratio (RMR) and the difference between MPD and MPD25 ie MPD – MPD25) were selected for investigation and calculated from 2D laser texture profiles measured by WDM Ltd. In order to set the threshold value denoting flushing for each of these statistics, the value that resulted in 6% of the 10m chipseal segments in the Northland network management area (NMA) as being flushed was chosen.

The visual ratings were compared to the calculated statistics for each 10m chipseal segment. The average percent of segments in both left and right wheelpaths that were visually rated as ‘badly flushed’ and crossed the threshold of flushing were determined for each statistic.

Effect of flushing on road surface friction

Controlled tests were performed on the Manfeild Race Circuit, which has a fairly homogeneous asphaltic concrete (AC) surface, to determine how skid resistance values derived from the DFT agreed with skid resistance values derived from LWB tests over a slip-speed range from 20km/h to 80 km/h. The AC surface had a macrotexture similar to that of a flushed chipseal surface (MPD = 0.53mm).

The effect of flushing on the level of skid resistance provided by a chipseal surface was investigated by carrying out skid resistance tests on two suburban roads displaying various degrees of flushing. One test site was Alexander Road in Upper Hutt and the other site was Old Hutt Road in Wellington. Each test site had both flushed and unflushed patches in the wheelpaths, though the Old Hutt Road site had more continuous lengths of flushing in the wheelpaths.

For both sites, specially commissioned MPD based measurements of wheelpath surface texture were made by WDM Ltd with their SCRIM (sideways force coefficient routine investigation machine) based survey vehicle, whereas two methods were used to measure the dynamic skid resistance under both dry and wet surface conditions. The first skid resistance measurement method used the DFT to obtain values at slip-speeds of 20km/h, 40km/h and 60km/h. The second was LWB slide-to-stop tests using an instrumented vehicle at braking initiation speeds of 30km/h and 50km/h.

Comparisons were therefore able to be made between road sections defined as flushed or not (using a visual condition rating scheme that had four graduations) and the skid resistance results obtained using the two different measurement methods.

Conclusions

The results of the statistical study of the Northland data suggest that the texture statistics best suited to flag flushing appear to be MPD – MPD25, MPD and RMR. Surprisingly, the results indicated that the routinely used MPD statistic flags only 50% of the 10m segments in the Northland NMA that were deemed visually as 'badly flushed'. This emphasises that MPD may not always identify all segments that are flushed. These and other results suggest that attempts to identify flushing from texture-based statistics derived from 2D road surface profiles are unlikely to be successful unless complemented with other information such as skid resistance or surface reflectance.

For a given slip-speed, the DFT gave skid resistance values that were higher than LWB.

Wet road coefficients of longitudinal deceleration measured directly by LWB agreed closely with those derived by applying the integral form of the International Friction Index (IFI) equation to DFT values of skid resistance obtained for a slip-speed of 60km/h.

The DFT was found to be suitable for investigating the friction characteristics of wet chipseal surfaces only. Under dry conditions, any bitumen present on the chipseal surface tends to melt and adhere to the sliders of the DFT, causing spurious measurements of friction.

Skid resistance values measured by the DFT appeared to be sensitive to the wear history of its rubber sliders, this sensitivity increasing with increasing slip-speed. Differences of up to 17% were observed between the first run and subsequent runs with a new slider on an AC surface, with the first run giving the lowest values. This finding suggests that the DFT rubber sliders should be conditioned by making some preliminary runs on the road surface of interest prior to taking the readings.

Both the DFT and LWB tests confirmed that the presence of flushing on chipseal surfaces has a detrimental impact on the level of skid resistance provided for the travelling public. The following points are of particular interest:

- The reduction in skid resistance as measured by the DFT on a wet flushed chipseal surface is 0.1 units at a slip-speed of 40km/h compared with the same surface when unflushed.
- For braking initiated at a speed of 30km/h, LWB tests showed the deceleration on a wet and relatively consistently flushed chipseal surface is about 0.08g less than on the same surface unflushed.

- When LWB was performed on dry chipseal roads, skid resistance consistently reduced compared to unflushed surfaces. This reduction in the dry was greater than the associated reduction in the wet.
- The IFI-derived wet road coefficients of longitudinal deceleration from the DFT are of comparable magnitude to those reported directly from the LWB tests and indicate that when flushing is extreme, the value of this coefficient is reduced by 0.1–0.14, representing about a 20% reduction. This reduction is calculated to cause an increase in the braking distance of about 6–7m for emergency braking initiated at 50km/h and 23–28m for emergency braking initiated at 100km/h.

Recommendations

- The use of the DFT to characterise the in situ high-speed skid resistance properties of the road surfaces used in New Zealand networks holds considerable promise, given the safety concerns associated with the only practical alternative at present, ie locked-wheel slide-to-stop tests with an instrumented vehicle. However, additional DFT and LWB tests on lengths of road where the surface is homogeneous along the wheelpaths need to be undertaken to better establish the relationship between DFT and LWB results. These additional controlled tests will serve to establish the sensitivity of the DFT to road surface macrotexture and surface type, and whether these sensitivities mirror the LWB of a passenger car tyre with legal tread depth.
- Additional work is required to determine whether the main contributor to loss of skid resistance on flushed surfaces is the masking of microtexture or the loss of macrotexture. DFT and LWB tests on wet flushed surfaces (ie road surfaces blackened with bitumen) over a range of textures (eg 0.5–1.5mm) are necessary.
- Flushing has been shown to reduce road friction by as much as 20–25% in both dry and wet conditions, and so has a significant impact on road safety. Therefore, it is important that research effort be put into developing more robust automatic means of identifying the presence of flushing and its extent within a lane for improved safety management of the state highway network.
- For more proactive management of flushing, a well-graduated, consistent and potentially automated method of determining the levels of binder that are visible at the road surface needs to be developed.
- A better definition of flushing should also be developed. A suggestion is: ‘A pavement surface defect in which the binder is near the uppermost surface of aggregate particles and skid resistance reduces as a result.’
- The statistical flushing detection study using state highway data should be repeated using the latest data extracted from the NZ Transport Agency (NZTA) road assessment and maintenance management system database to confirm findings of this report. The analysis should focus on the statistics MPD – MPD25 and RMR to confirm their level of correlation with visually rated levels of flushing when compared with MPD.
- Rather than relying on visual assessments of flushing, it may be possible to use some of the NZTA’s 113 seasonal control sites throughout the country to relate changes in skid resistance over a summer period, as measured by SCRIM, to changes in the various texture measures. As flushing can be generated within a summer, it should be possible to combine the video images of the road surface with the skid resistance measurements to identify the formation and development of flushing. The texture-related measure that best detects flushing from the 2D road surface profiles can be found by correlating changes in the texture measures to changes in skid resistance caused by flushing.

Abstract

Research undertaken between 2007 and 2009 examined the influence of binder rise in reducing tyre–road friction of chipseal surfaces. The emphasis was on the most extreme form of binder rise when the binder is level or above the sealing chip resulting in the formation of a black, slick surface. This condition is referred to as flushing.

The research involved performing texture profile and friction measurements on chipseal surfaced public roads. Both locked-wheel braking with an instrumented vehicle and the dynamic friction tester were employed for the friction measurements.

The key finding was that the presence of flushing in chipseal surfaces reduced tyre–road friction by about 20% to25% under both wet and dry conditions. Therefore, a robust means of identifying the presence, degree and extent of binder rise in chipseal road surfaces will be beneficial in improving the safety management of road networks. A secondary finding was that attempts to identify binder rise from texture-based statistics derived from two-dimensional road surface profiles are unlikely to be successful even for the flushing condition unless complemented with other information such as skid resistance or surface reflectance

1 Introduction

Binder rise is a natural action which occurs during the life of a chipseal surface. In its most extreme form, a black, slick surface is formed when the binder is level or above the sealing chip. This condition is commonly referred to as flushing. Flushing may occur as the natural end-of-life condition of a well-designed chipseal surface, or as a seal design or construction fault (Transit New Zealand et al 2005).

Three components are generally accepted as creating the skid resistance of a road surface: the drainage paths for water removal, tyre rubber hysteresis effects created from the macrotexture, and the adhesion effects created by the microtexture of the sealing aggregate.

As the amount of binder at the surface of a road increases (ie as the amount of binder that covers the aggregate particles or fills the voids between aggregate particles increases), the microtexture component of skid resistance is reduced as the microasperities are filled with binder and the macrotexture is reduced as the interaggregate voids are also filled.

Annual surveys of New Zealand's state highway network made with the Sideway-force Coefficient Routine Investigation Machine (SCRIM) show that flushed chipseal surfaces can have skid resistance values as low as 0.15 to 0.2 equilibrium SCRIM coefficient (ESC). By comparison, the trigger level for priority treatment of skid deficient sites has been set at 0.3 ESC for event-free undivided carriageways (refer to the NZ Transport Agency (NZTA) T10:2002 specification (Transit New Zealand 2002a)). Given the potential safety issue flushed chipseal surfaces pose, it is surprising that very little international research considers how the presence and extent of flushing can be reliably detected from high-speed road condition surveys, and the resulting effect on vehicle braking and cornering performance. This paucity of research may be partly because flushing is more of an issue for countries that use chipseal surfaces extensively on their road networks, such as Australia, New Zealand and South Africa.

A field-based research programme was therefore formulated to address these knowledge gaps. The research builds on the findings of NZTA operational research (Henderson and Cenek 2006), which has identified that the material/bearing ratio (RMR) and peak count (Pc) statistics may be preferable to the currently used texture statistic, mean profile depth (MPD), to detect flushing from two-dimensional (2D) laser profiles. Refer to the glossary in the appendix for definitions of these surface profile descriptors.

This report summarises the principal findings from the field testing, which was performed between 2007 and 2009, and is structured as follows:

- Chapter 1 details the context of the research and its associated aims.
- Chapter 2 provides an overview of skid resistance theory and presents two key measures used internationally in road asset management, the international friction index (IFI) and MPD.
- Chapter 4 assesses the statistics used to detect binder rise, using a section of road in Northland.
- Chapters 5 and 6 present the skid resistance tests and results, respectively.
- Chapter 7 uses the IFI to investigate the relationship between locked-wheel braking (LWB) and dynamic friction tester (DFT) derived friction measurements, and to quantify the effect of flushing on road safety.
- The conclusions and recommendations are presented in Chapter 8.
- Appendix A contains a glossary of key terms used in the report.

2 Research context and aims

2.1 Research context

Flushing can cause a reduction in skid resistance by a number of mechanisms. For example, in late summer, when road surface temperatures are at their highest, vehicle tyres can pick up binder and track it down the road. This can not only look unsightly, but the bitumen coating can reduce the aggregate microtexture that is exposed to vehicle tyres and cause a reduction in skid resistance. Second, flushing reduces the macrotexture of the road surface. This can have three effects:

- A road surface with a low macrotexture can have inadequate drainage paths for water removal. The consequence of this is a reduction in skid resistance when the road surface is wet, particularly at higher travel speeds when less time is available for water removal.
- The tyre on a flushed surface contacts the bitumen film as well as the aggregate.
- Tyre hysteretic friction caused by rubber deformation is reduced (Henderson et al 2006).

Furthermore, flushing can be problematic on dry chipseal surfaces as well as wet, not only because of the reduction of tyre hysteretic friction but also the possibility of the bitumen melting at the road–tyre interface under severe braking, causing sliding. Bullas (2007) used the term bituplaning to explain why dry bitumen-rich surfaces may have worse skid resistance in the dry than in the wet.

The NZTA T10:2002 specification (Transit New Zealand 2002a) for skid resistance investigation and treatment selection defined flushing as: 'A low textured road surface due to the upward migration of binder, reducing macrotexture.' The Austroads definition for flushing is: 'A pavement surface defect in which the binder is near the uppermost surface of aggregate particles. The uppermost particles are still visible, but minimal surface texture exists.' Both these definitions of flushing place the focus on low texture depth rather than loss of skid resistance.

The NZTA has a key performance indicator that looks at the percentage of the network where the macrotexture of the road surface is less than 0.5mm mean profile depth (MPD). With reference to page 71 of Transit New Zealand's *Annual report 2007/08* (NZTA 2009) and also the NZTA's *Memorandum MA1-0018* (Transit New Zealand 2002b), it can be inferred that this level of macrotexture is considered to be unsafe for state highways and corresponds to flushing in chipseal surfaces.

At present, about $45 million per annum is spent by the NZTA on treating flushing (pers. comm. from Chris Parkman, former assets manager, NZTA). However, each year in New Zealand, some sections of the state highway network can be incorrectly identified as requiring flushing treatment. Alternatively, other surfaces that are genuinely flushed are not correctly flagged as requiring possible treatment. This may be primarily because the MPD statistic currently used by the NZTA to infer flushing can give high values when a single aggregate protrudes from an otherwise essentially flat flushed surface.

Another problem with the MPD statistic is that it takes no account of the chip size (grade) and may give similar values for a new and unflushed grade 6 surface and a partially flushed grade 2 surface.

These observations highlight that the MPD statistic alone is insufficient to identify the presence and extent of flushing in chipseal surfaces. For safety management purposes, what is needed is a measure that accounts for the amount of binder that is presented to the tyre.

2.2 Research aims

Focusing on New Zealand chipseal road surfaces, the research presented in this report was formulated to answer two key questions:

- What impact does the amount of binder presented to the tyre (binder rise) have on skid resistance?
- What is the best high-speed data texture measurement to detect the amount of binder presented to the tyre?

The specific aims of the research were to:

- identify the best statistic to detect the extent of binder rise (where a fully flushed surface corresponds to 100% binder rise) from 2D laser profiles of the road surface
- quantify the reduction in friction associated with binder rise by using University of Auckland's DFT
- quantify the reduction in braking performance that occurs on flushed surfaces under dry and wet conditions as represented by the coefficient of longitudinal deceleration.

3 Overview of skid resistance theory

3.1 Role of microtexture and macrotexture

The skid resistance provided by a road is primarily a function of its surface texture. It is convenient to divide texture into two components: microtexture and macrotexture. Microtexture is composed primarily of sand particles and microscopic roughness (less than 0.5mm in size) on the surface of roading aggregates. It can usually be determined by the feel of harshness experienced when sliding your hand over the roading aggregate. Microtexture can be qualitatively described as being either harsh or polished. The individual stones or aggregates in a road surface constitute the macrotexture. It is the protrusions or surface relief visible to the naked eye, and comprises macroroughness that is 0.5–5mm in size. Macrotexture can be qualitatively described as being either fine or coarse. For chipseal roads, microtexture is superimposed on macrotexture. Microtexture is generated by the surface texture of the individual roading aggregates. By comparison, macrotexture is generated by the size, shape and spacing of the roading aggregates. Both microtexture and macrotexture may be reduced by the presence of bitumen binder, which is used to hold the road aggregates in place.

Under wet conditions, microtexture penetrates the thin water film that remains between the tyre and the road to establish direct contact with the moving tyre. It dominates skid resistance at low speeds (less than 70km/h). However, at high speeds (greater than 70km/h), both microtexture and macrotexture are required to provide a high level of skid resistance. This is because at faster speeds, macrotexture is needed to allow surface water to escape and prevent partial or full aquaplaning. Therefore, macrotexture determines how quickly skid resistance in the wet decreases with speed. However, even at high speeds, microtexture remains the major influence because a low level of microtexture will always lead to low skid resistance regardless of the level of macrotexture.

3.2 Skid resistance mechanisms

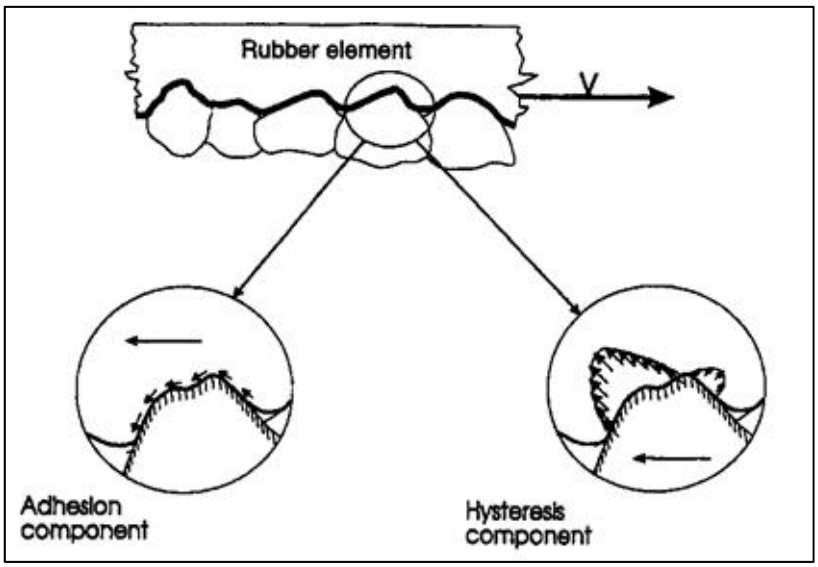
3.2.1 The components of friction

The friction between a tyre and a road surface has two main components: adhesion friction (F_a) and hysteretic friction (F_h) (Moore 1975). While published research is somewhat inconclusive in terms of quantitative analysis, the adhesion component of friction (F_a) is generally regarded as making the largest contribution to the total friction, and the hysteretic component (F_h) makes a smaller contribution (eg 20% of the total friction (Anderson and Henry 1979)). Figure 3.1 shows the mechanisms of the adhesion and hysteretic components of friction in schematic form.

3.2.2 Adhesion

The adhesion component of friction results from intermolecular attraction between the tread rubber of tyres and aggregate chips. For perfectly dry surfaces, maximum adhesion is obtained for flat, smooth surfaces. For wet surfaces, adhesion friction rises with microtexture. The microtexture asperities pierce the water film and provide dry pavement–tyre contact regions (Moore 1975). Accordingly, when aggregates are polished by tyre trafficking, this reduces skid resistance (eg Cenek et al 2008). Macrotexture assists with water drainage and maximises dry contact areas.

Figure 3.1 Adhesion and hysteretic components of friction (Choubane et al 2004; Meyer and Kummer 1962)



3.2.3 Hysteresis

The hysteretic component of friction results from deformation of the tread rubber as it contacts asperities. Damping in the rubber means that not all of the energy absorbed in deforming the rubber is returned when the tread rubber resumes its undeformed shape (Clark 1981).

With reference to the schematic in the right-hand circle of figure 3.1, hysteresis results in a horizontal component of force that acts in the opposite direction to tyre movement. This component of friction is small in free-rolling braking, but significant for LWB (Moore 1975) because of the increased rubber deformation that occurs when sliding rather than rolling.

3.3 Key international measures of skid resistance

3.3.1 The international friction index

The IFI is a common scale for quantifying wet friction from combined skid resistance and texture measurements (Wambold et al 1995). It consists of two parameters: F_{60} and Sp. F_{60} is the harmonised estimate of wet friction at 60km/h skidding speed. F_{60} approximates the average wet coefficient of friction experienced by a car with four treadless tyres in a 60km/h locked-wheel skid. Sp is the speed number, which provides a measure of how strongly the wet friction depends on the skidding speed of a car tyre. When F_{60} and Sp are known, the wet friction level at any other skidding speed, S, can be calculated using equation 3.1.

$$F(S) = F_{60}\, e^{\left(\frac{60-S}{Sp}\right)} \qquad \text{(Equation 3.1)}$$

where:

- $F(S)$ = coefficient of friction at a slip-speed of Skm/h
- F_{60} = coefficient of friction at a slip-speed of 60km/h (equivalent to a LWB reading at a slip-speed of 60km/h)
- S = LWB slip-speed (km/h)
- S_P = speed constant (km/h) = 9.74 + 104.71 × *MPD*

- *MPD* = mean profile depth (mm)

Equation 3.1 highlights that wet friction reduces with increasing slip-speed, and that this reduction is greater for surfaces with lower macrotexture. The major mechanism for this is the decreased time for establishing the 'dry' tyre–pavement contact regions at higher speeds.

Equation 3.1 allows the estimation of the wet road coefficient of friction at a specified slip-speed from standard measures of skid resistance and texture depth. An estimate of the coefficient of longitudinal deceleration (μ_{wet}) can also be obtained. This is the average coefficient of friction during a slide-to-stop LWB manoeuvre, and is used as an input in road design and crash investigations to calculate braking distances. The expression that results is as shown in equation 3.2:

$$\mu_{wet} = \frac{1}{S}\int_0^S F_{60}\, e^{\left(\frac{60-S}{S_P}\right)} dS = \frac{\left[-S_p F_{60}\, e^{\left(\frac{60-S}{S_P}\right)}\right]_{S=0}^{S=V_B}}{V_B} \qquad \text{(Equation 3.2)}$$

where:

- μ_{wet} = wet road coefficient of longitudinal deceleration
- S_P = IFI speed constant
- F_{60} = IFI harmonised wet coefficient of friction for a 60km/h slip-speed
- S = slip-speed (km/h)
- v_B = vehicle speed at initiation of LWB

Estimates of μ_{wet} using equation 3.2 have been found to agree reasonably well with those obtained from LWB tests so long as the volumetric texture depth of the tyres of the test vehicle is combined with the texture depth of the road surface (Cenek et al 2000). Table 3.1 provides representative values of tyre volumetric texture depth for tyres when new and when the tread is at the legal minimum depth.

Table 3.1 Measured tyre texture depths for different tyre types

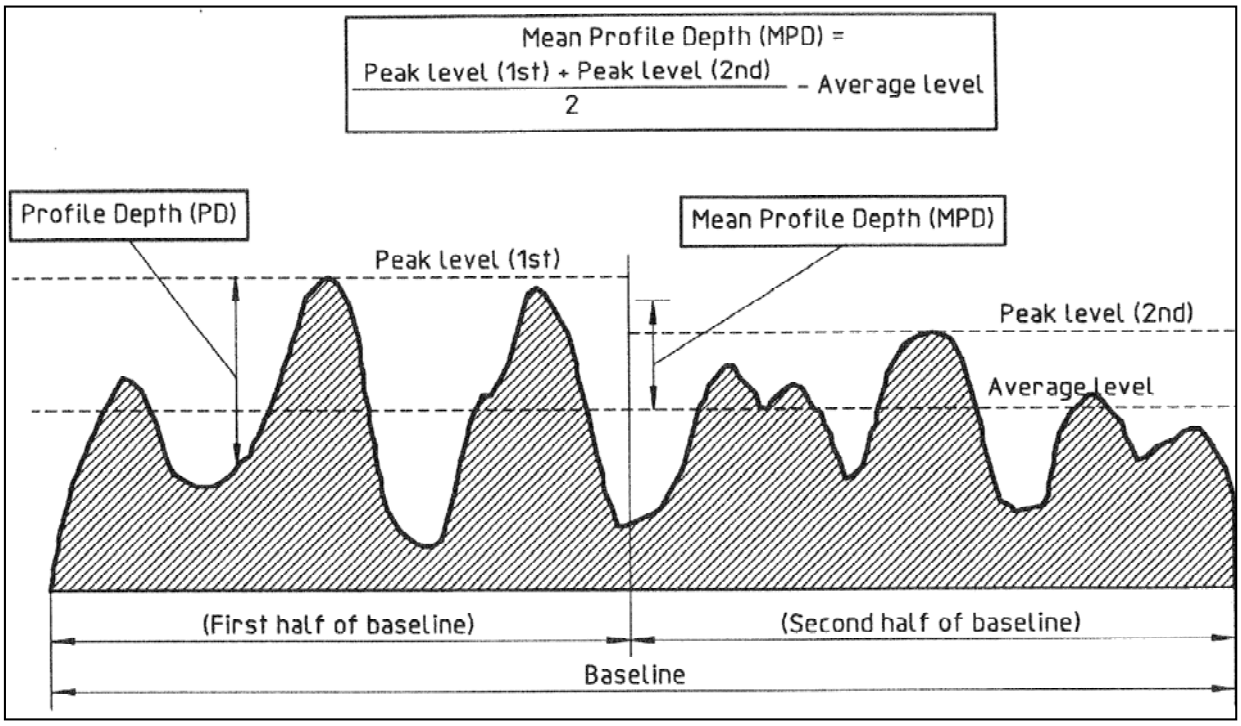
Vehicle class	Load	Effective tyre texture depth (T_t)	
		Legal minimum (mm)	New (mm)
Passenger car (small)	1 driver	0.37	2.39
Passenger car (small)	1 driver, 3 passengers	0.37	2.40
Passenger car (medium)	1 driver	0.31	2.80
Passenger car (large)	1 driver	0.42	1.80
Truck (average of two tyres)	1 driver	0.40	2.51

3.3.2 Mean profile depth

MPD is the primary index used to characterise the macrotexture of a road surface, as it was found in the international Permanent International Association of Road Congresses (PIARC) experiment to be the best texture measure for determining the IFI speed constant (S_P) (Wambold et al 1995). It is calculated from 100mm segments of the2D elevation profile of the road surface as follows.

Each 100mm segment is divided into two lengths of 50mm and the peak elevation value of the profile is determined for each of the 50mm subsegments. The average of the two peaks is then calculated. MPD is determined by subtracting the average elevation over the 100mm segment from the average peak elevation. Figure 3.2 illustrates the definitions of baseline, profile depth (PD) and mean profile depth (MPD).

Figure 3.2 Illustration of the terms baseline, profile depth (PD) and mean profile depth (MPD) (from International Organisation for Standardisation 1997)



The baseline length of 100mm has been selected to be of the same order of size as the tyre–road interface.

Lasers are the preferred method for measuring the road surface elevation profiles.

It should be noted that aggregate size, shape and distribution are features that are not addressed by MPD. MPD is also considered to be insensitive to microtexture and unevenness characteristics of the pavement.

4 Assessment of statistics to detect binder rise

4.1 Initial study

4.1.1 Background

An initial study was undertaken on flushed surfaces in the Wellington region. These surfaces had been surveyed by WDM Ltd specifically for flushing study projects. The five statistics MPD, Pc, RMR, MPD25 and MPD – MPD25 were calculated from 2D laser profiles of the road surface. These statistics are defined in table 4.1 and also in appendix A. Visual ratings of flushing were made from video images. The rating schedule used is given in table 4.2 below.

Table 4.1 Statistics used for evaluating binder rise and flushing

Statistic	Abbreviation	Unit	Definition
Mean profile depth	MPD	mm	The difference between peak height and average height of the profile over a 100mm length; see section 3.3.2.
Peak count	Pc	peaks/cm	The number of local peaks in a profile that project through a selectable band surrounding the mean line.
Material/bearing ratio	RMR	%	The length of the bearing surface as a percentage of the profile length at a depth 1.0mm below the highest peak.
Mean profile depth (25)	MPD25	mm	The difference between peak height and average height of the profile over a 25mm segment length.
–	MPD – MPD25	mm	The difference between MPD and MPD25.

Table 4.2 Visual rating schedule for initial study

Rating	Description
1	Badly flushed; requires immediate treatment.
2	More than 3 but less than 1
3	Flushed; requires treatment within the next year
4	More than 5 but less than 3
5	Not badly flushed: recommended that treatment be scheduled within >2 years
6	More than 7 but less than 5
7	Not flushed

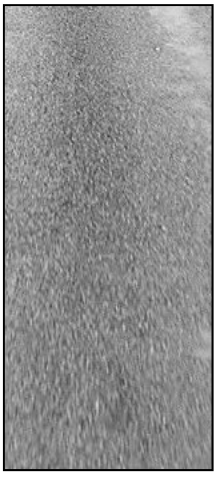
4.1.2 Examples

Examples of two surfaces are shown in figures 4.1 and 4.2. Corresponding profiles are shown in figure 4.3. Statistics are recorded in table 4.3.

Figure 4.1 Flushed surface image: Cambridge Terrace, Lower Hutt, left wheelpath*

*Surveyed and videoed May 2007, visual rating = 2

Figure 4.2 Unflushed surface image: Cambridge Terrace, Lower Hutt, middle of wheelpath*

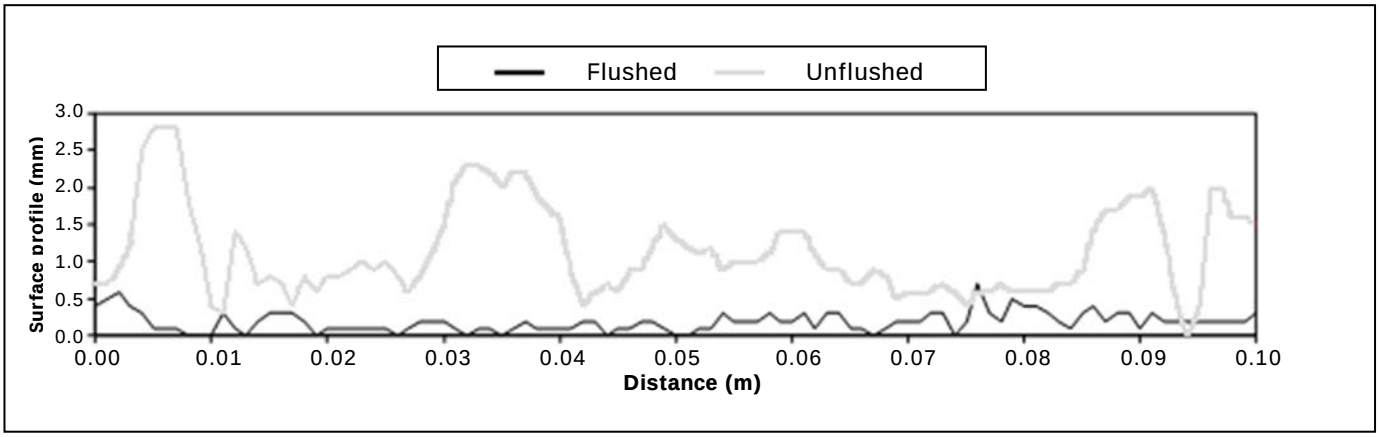


* Surveyed and videoed May 2007, visual rating = 7

Table 4.3 Statistics for surfaces shown in figures 4.1 and 4.2

Statistic	Figure 4.1 (flushed surface)	Figure 4.2 (unflushed surface)
MPD (mm)	0.44	1.34
Pc (peaks/cm)	0.00	0.40
RMR (%)	100.0	21.8
MPD25 (mm)	0.25	1.03
MPD25 – MPD (mm)	-0.18	-0.31

Figure 4.3 Profile of surfaces shown in figures 4.1 and 4.2



The surfaces shown in figures 4.1 and 4.2 are identical (ie the same aggregate, binder and pavement age), aside from being in a different wheelpath and having a different level of flushing, as shown in table 4.3 and figure 4.3.

4.1.3 Results

Table 4.4 correlates the visual ratings with the calculated statistics for different areas of the road surface.

Table 4.4 Correlations (R^2) of statistics with visual binder rise ratings

Statistic	Left wheelpath	Middle of wheelpath	Right wheelpath
MPD (mm)	0.88	0.33	0.48
PC (peaks/cm)	0.61	0.39	0.53
RMR (%)	0.8	0.44	0.53
MPD25 (mm)	0.99	0.35	0.48
MPD25 – MPD (mm)	0.29	0.24	0.39

Because of the reviewers' concerns related to the accuracy of the visual rating process, this study was deemed unsatisfactory and another study was undertaken, which is outlined in the next section.

4.2 Statistical study: Northland network management area

4.2.1 Data

The data used for this study was collected during the 2007/2008 state highway survey season and either:

- emailed to the authors of this report on 16/09/2008 as comma-delimited text files (It is our understanding that this data was later to be loaded into the Road Assessment and Maintenance Management system (RAMM) database)
- extracted from the RAMM database.

4.2.2 Methodology

1 Thresholds were selected for each of the statistics MPD, Pc, RMR, MPD25 and MPD – MPD25, so that approximately 6% of the chipseal segments in the Northland network management area (NMA) were flagged as potentially flushed.

2 From the entire Northland NMA network, lane-width patches of at least 30m in length with lane maximum ESC ≤0.25 were identified. The length criterion of ≥30m was chosen to minimise any video image versus statistic location issues, and the 0.25ESC figure was suggested by a reviewer.

3 The resulting sub-dataset was then visually rated as described in section 4.2.3 using the network videos.

4.2.3 Visual rating

For each 10m segment of the sub-dataset of step 3, we visually rated the level of flushing, using the 2007/2008 state highway network video according to the following rating schedule:

- 0: not flushed
- 1: badly flushed
- 0.5: between 0 and 1 (ie somewhat flushed).

This rating schedule was deliberately simplified from more complex rating schedules with more categories (eg those of table 4.2) in an effort to address reviewers' concerns that using a schedule with more categories can result in undesirably subjective ratings.

We adopted the convention that the video view reduced by 15m in the direction of travel (ie reduced by three video frames) corresponded with the RAMM chainage, since the displayed chainage on the viewing software corresponds to the chainage being surveyed (and therefore out of view beneath the survey truck).

4.2.4 Surface types

Only chipseal surfaces were analysed. It was assumed that these were represented in the RAMM database by the following codes:

- 1CHIP (ie a single-coat chipseal, comprising a single sprayed application of sealing binder followed immediately with a single application of chip, which is spread and rolled into place)
- 2CHIP (ie a two-coat chipseal, comprising a chipseal with two applications of binder and two applications of chip)
- LOCK (ie a locked-in chipseal, comprising dry or wet application of small chip to a new chipseal)
- RACK (ie a racked-in chipseal, comprising one application of binder and two applications of chip)
- VFILL (ie a voidfill seal, comprising a single very light application of binder, followed by a single application of fine chip designed to fill the voids in an existing coarse-textured chipseal surface).

4.2.5 Results

The visual ratings were compared to the calculated statistics for each road segment. The average percent of segments in both left and right wheelpaths that were visually rated as 'badly flushed' and crossed the threshold of flushing were calculated for each statistic. The results of this comparison are shown in table 4.5.

Table 4.5 Average percent of 'badly flushed' road segments crossing the threshold of flushing for the calculated statistics

Statistic	Average %*
MPD	50%
Pc	39%
RMR	48%
MPD25	17%
MPD – MPD25	51%

* Average % of left and right wheelpath segments of the sub-dataset visually rated as 'badly flushed' and also crossing the flushing threshold for the statistic.

These results suggest that of the five statistics considered, MPD – MPD25, MPD and RMR, calculated from 2D laser texture profiles, have the greatest potential to flag flushing accurately. Surprisingly, table 4.5 shows that the MPD statistic flagged only 50% of the 10m segments in the Northland NMA that were deemed visually as 'badly flushed'. This emphasises that MPD may not always identify all segments that are flushed.

These results suggest that attempts to identify flushing from the 2D profile statistics MPD, Pc, RMR, MPD25 and MPD – MPD25 can be disappointing. The suggestion is, therefore, that these results should be confirmed and, depending on the findings of this confirmation, it is recommended that attempting to identify flushing from these 2D texture profile statistics alone should not be pursued further.

Possibly, the 2D texture profile statistics MPD, Pc, RMR, MPD25 and MPD – MPD25 complemented with other information (eg ESC skid resistance results) might be worth assessing. Alternatively, other 2D texture measures might warrant investigation.

However, detailed consideration of the option of supplementing texture with other information, use of other texture statistics or non-texture based flushing detection methods is outside the scope of this report, which has focused on assessing only some of the 2D profile texture statistics.

5 Skid resistance tests

5.1 Skid resistance measurement

5.1.1 Test equipment

To enable the change in skid resistance with speed to be investigated, two different test methods were employed: the DFT and slide-to-stop LWB using an instrumented vehicle. These two test methods are expanded on below.

5.1.2 Dynamic friction tester

The DFT is a stationary skid resistance testing device designed to measure the dynamic coefficient of friction of road surfaces (Nippo Sangyo Co. 2004). It uses a rotating disk fitted with three rubber sliders (see figures 5.1 and 5.2).

Figure 5.1 Top view of DFT machine

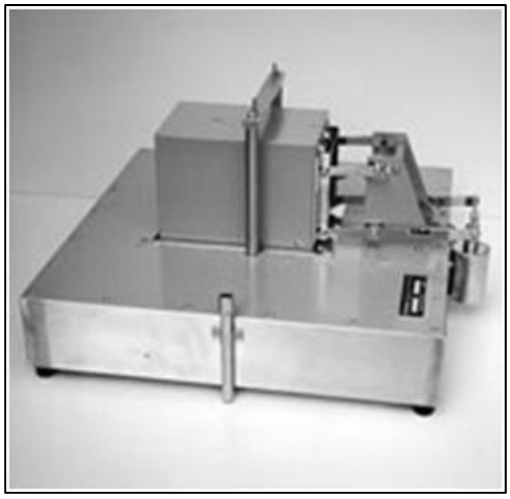


Figure 5.2 Underside view of DFT machine

DFT skid resistance results have been proven to correlate well with the skid resistance results from common continuous skid testing machines such as the SCRIM, the GripTester and locked-wheel testers,

and highly correlated with the more commonly known stationary device – the British pendulum tester (Wilson and Black 2006). Key DFT features are:

- measured skid resistance values are a continuous spectrum of the dynamic coefficient of friction with slip-speed
- skid resistance values are reported as a function of slip-speed from 0 to 80km/h at a contact pressure similar to that of typical motor vehicles.

5.1.3 Locked-wheel braking

The vehicle used for the LWB tests was a non-antilocking braking system (ABS) braked Nissan Primera four-door sedan carrying one driver and one passenger. This was fitted with new tyres (tyre brand = 'Supercat', designation = 195/60R14 68H) inflated to the manufacturer's recommended pressure. When the tyres became worn as testing progressed, they were replaced with identical new tyres fitted to different rims.

Vehicle deceleration was recorded with an accelerometer-based instrument mounted via suction cups to the lower middle of the windscreen. Vehicle speed and distance were obtained from the acceleration–time trace via integration through the use of proprietary software (Vericom Computers 2006). Figure 5.3 shows an example of a LWB test being undertaken at Manfeild Race Circuit.

ry surface

5.2 Test surfaces

5.2.1 Asphaltic concrete tests

The tests on asphaltic concrete (AC) were carried out on a motor vehicle racetrack (Manfeild Race Circuit) at LWB initiation speeds of up to 100km/h. The surface was AC and had a macrotexture similar to that of a flushed chipseal (MPD = 0.53mm).

5.2.2 Chipseal tests

In order to determine the amount of flushing present at the chipseal test sites, a visual rating scheme was adopted. The visual rating was carried out by looking at a video of the road surface. Visual ratings of flushing are subjective and can vary considerably between rating personnel (Henderson and Cenek 2006), so the rating was completed by a single person in order to reduce any inconsistency in the defined

condition of the road. With reference to table 5.1, the rating schedule employed was relatively coarse. This resulted in a broad range of levels of flushing all being included in a single bin.

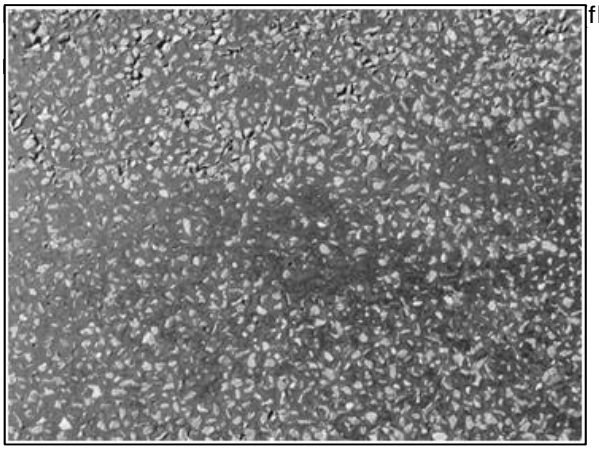
Table 5.1 Flushing rating descriptions used for chipseal test surfaces

Numerical rating	Condition	Description
1	No flushing	Unflushed
2	Numerical rating more than 1 but less than 3	Moderately flushed
3	Flushed surface with little macrotexture (MPD ≤0.6mm).	Flushed
4	Badly flushed surface with little macrotexture (MPD ≤0.4mm). All of the aggregate chips have at least 90% of their surface area submerged in binder. Only their tips protrude above the bitumen surface.	Badly flushed

The skid resistance tests on chipseal surfaces were carried out on suburban roads (Alexander Road, Upper Hutt, and Old Hutt Road, Wellington). Further details on these surfaces are recorded in table 5.2.

LWB initiation speeds were limited to a maximum of 50km/h (the posted speed limit). Given that LWB tests were carried out on closed public roads with moderate to low traffic volumes, the amount of binder rise was limited to patches rather than the significant lengths that can be found on higher volume roads. The skid resistance reduction created by binder rise was expected to be more muted compared to what would have occurred on higher volume and higher speed roads.

In the absence of flushing, we would expect the surface constructed with the coarser chip (Old Hutt Road) to have the greater macrotexture. Where this was not the case, the test sections on Old Hutt Road had more sustained flushing, which leads to a lesser 10m average value of MPD.



flushed) and figure 5.5 (moderately flushed).

Figure 5.5 Moderately flushed patch on Old Hutt Road

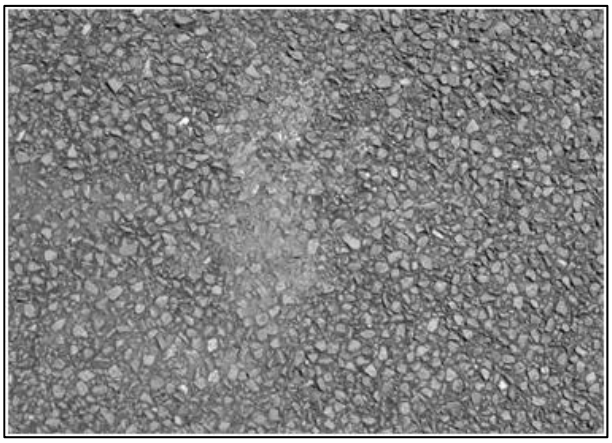


Table 5.2 Chipseal site surface descriptions

Surface type		Alexander Road	Old Hutt Road (left lane)[a]	Old Hutt Road (right lane)[a]
		Chipseal (single-coat)	Chipseal (single-coat)	Chipseal (single-coat)
Chip grade		3	2	2
Aggregate polished stone value		Unknown	58	58
Source quarry		Unknown	Winstone	Winstone
Flushing description		Good surface with very patchy flushing, especially in the right wheelpath	Flushed, especially in wheelpaths	Unflushed
Left wheelpath MPD[b, c] (mm)	Minimum	1.13	0.75	1.38
	Maximum	2.67	3.07	3.09
	Average	1.95	1.69	2.47
Right wheelpath MPD (mm)	Minimum	0.52	0.73	1.52
	Maximum	2.61	2.06	2.75
	Average	1.94	1.56	2.33
Site length (m)		498.5	510.0	506.0

Notes to Table 5.2:

a Old Hutt Road has two lanes in each direction.

b The MPD texture measurements recorded in rows 6–11 (left wheelpath MPD and right wheelpath MPD) were measured by a SCRIM survey vehicle in surveys specially commissioned for flushing studies.

c The MPD values given are 5m averages.

5.3 Test regime

Tests were carried out with the surfaces both wet and dry. For the wet tests, water was applied to the pavement surface from a water tanker fitted with a sprayer. Dry DFT tests are not discussed in this report, even though they were undertaken, because of the propensity of the bitumen to melt and adhere to the rubber slider of the DFT and give spurious skid resistance readings.

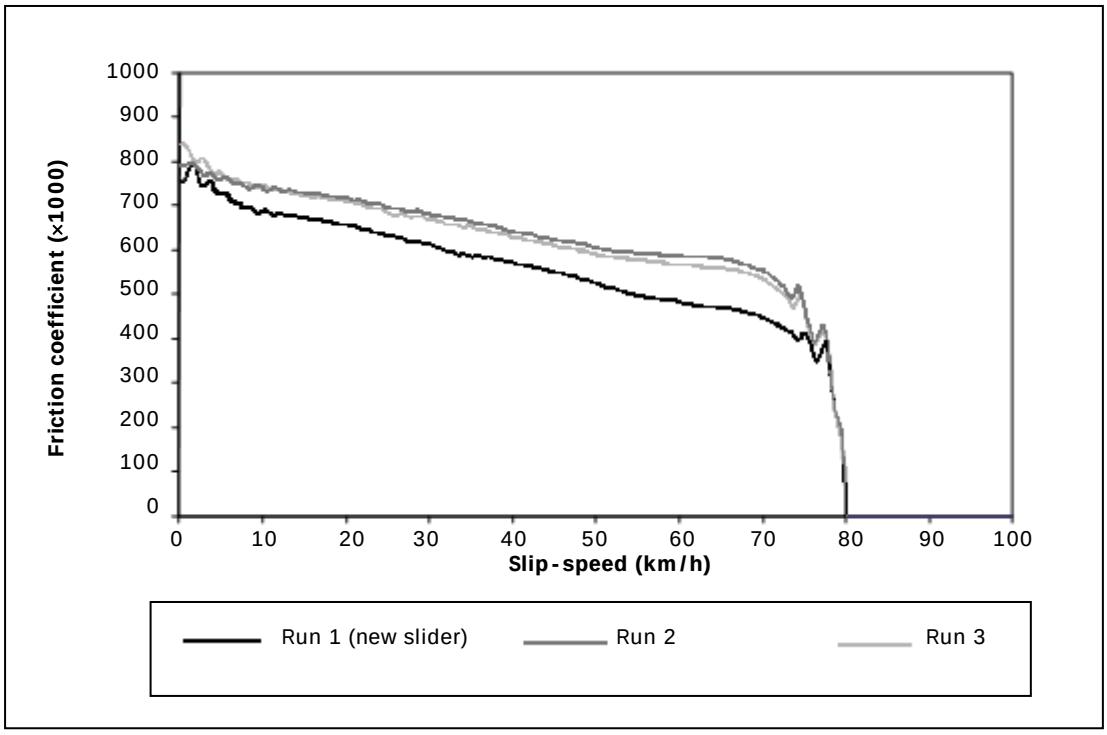
The test sites on the suburban chipseal surfaces described in table 5.2 had both flushed and unflushed patches, but were otherwise uniform. In other words, for each surface, the aggregate, surface age, binder and trafficking were uniform. Carrying out the skid resistance measurements on lengths of road that were constructed at the same time using the same aggregate source and aggregate processing method meant that the effects of vehicle trafficking, for example, could be ignored.

6 Skid resistance results

6.1 DFT slider wear

For an atypical test, in which a new and unused slider was fitted, the skid resistance values measured by the DFT appeared to be sensitive to the wear history of the rubber slider, as shown in figure 6.1 below. In figure 6.1, which plots DFT readings on the AC surface of the Manfeild Race Circuit, a new and unused rubber slider was installed for the first run. This same slider was retained for runs 2 and 3, which were carried out at similar positions.

Figure 6.1 Effect of slider wear on DFT test results



6.2 Manfeild Race Circuit: wet AC

Figure 6.2 shows the skid resistance values reported by the DFT and LWB on wet AC. It is apparent that the DFT gives a greater skid resistance than LWB by approximately 0.15 for these tests.

The data used to plot figure 6.2 was derived as follows:

- Each plotted DFT skid resistance point is the average of three replicate runs.
- DFT skid resistance data was measured directly, as the DFT reports instantaneous skid resistance values with the slip-speed.
- LWB skid resistance was averaged over the nominal speed ±2.5km/h at vehicle speeds of 20, 40, 60 and 80km/h for each of the LWB runs. For example, in figure 6.3, the circles indicate where data was extracted from for use in figure 6.2.

Figure 6.2 Comparison of DT and LWB ski resistance tests on wet AC

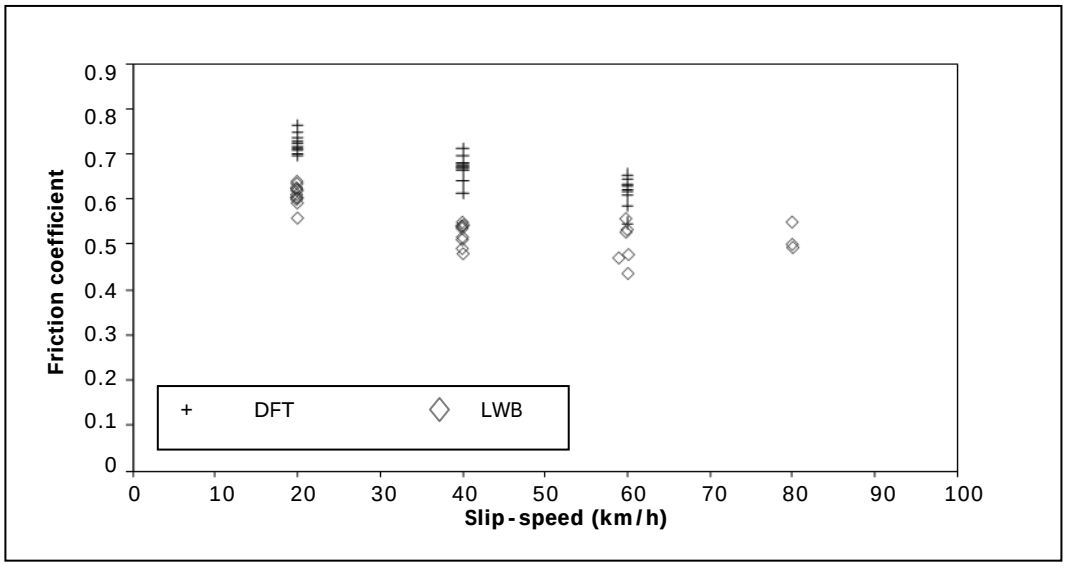
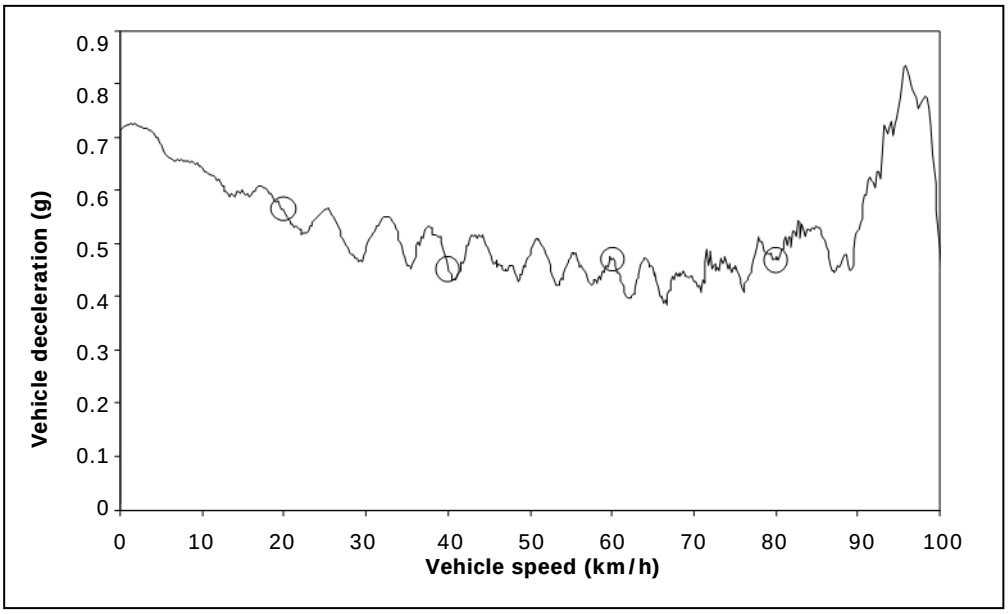


Figure 6.3 Example of LWB trace (vehicle deceleration (g) versus vehicle speed (km/h)) on wet AC*



* Circles indicate the data points used for comparing DFT and LWB skid resistance.

6.3 Chipseal roads

6.3.1 DFT results and MPD

Figures 6.4 to 6.6 show the DFT skid resistance values for three levels of flushing (see table 5.1 for the rating system) at slip-speeds of 20, 40 and 60km/h on Alexander Road and Old Hutt Road in wet conditions. Each plotted point is the average of three replicate runs. The data used to plot figures 6.4 to 6.6 is shown in table 6.1.

Figure 6.4 DFT skid resistance on unflushed wet chipseal surfaces

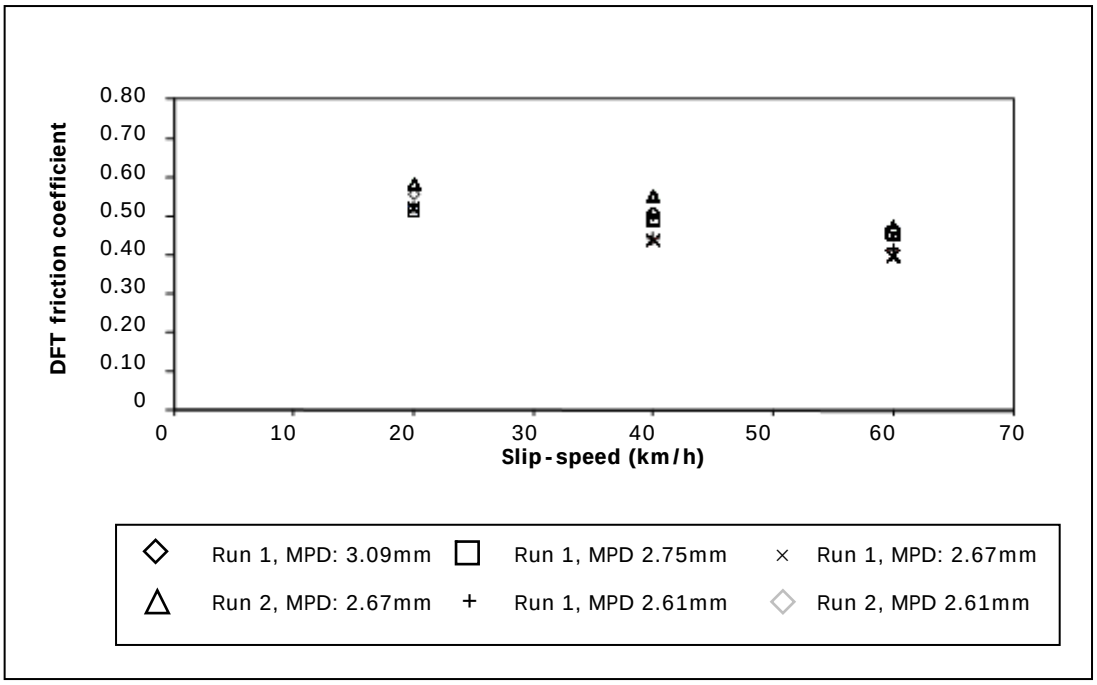


Figure 6.5 DFT skid resistance on moderately flushed wet chipseal surfaces

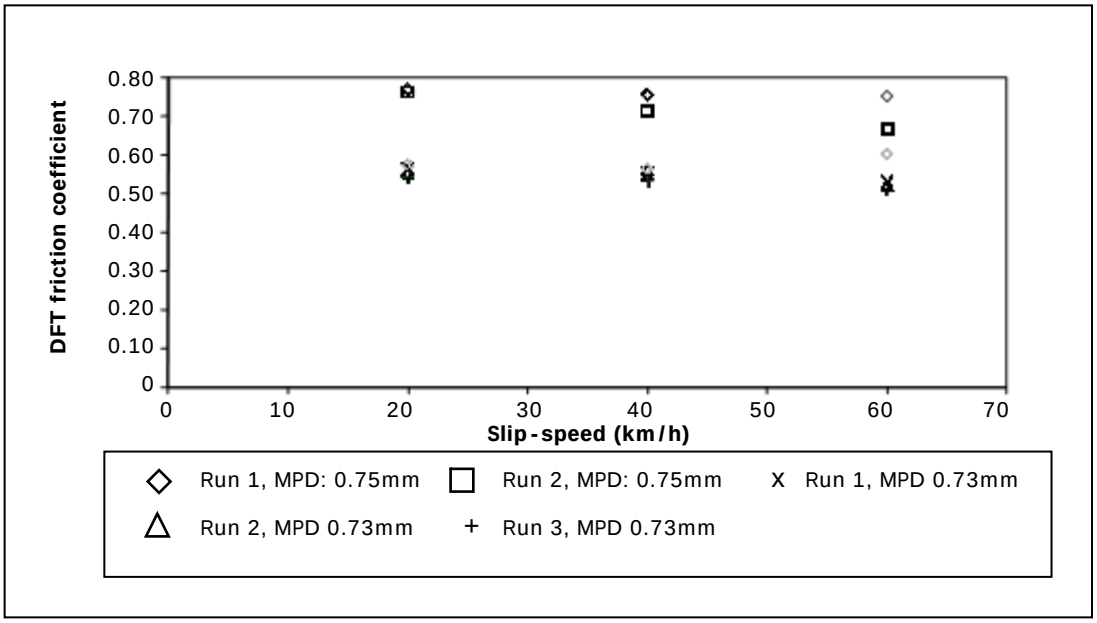


Figure 6.6 DFT skid resistance on flushed wet chipseal surfaces, MPD = 0.52mm

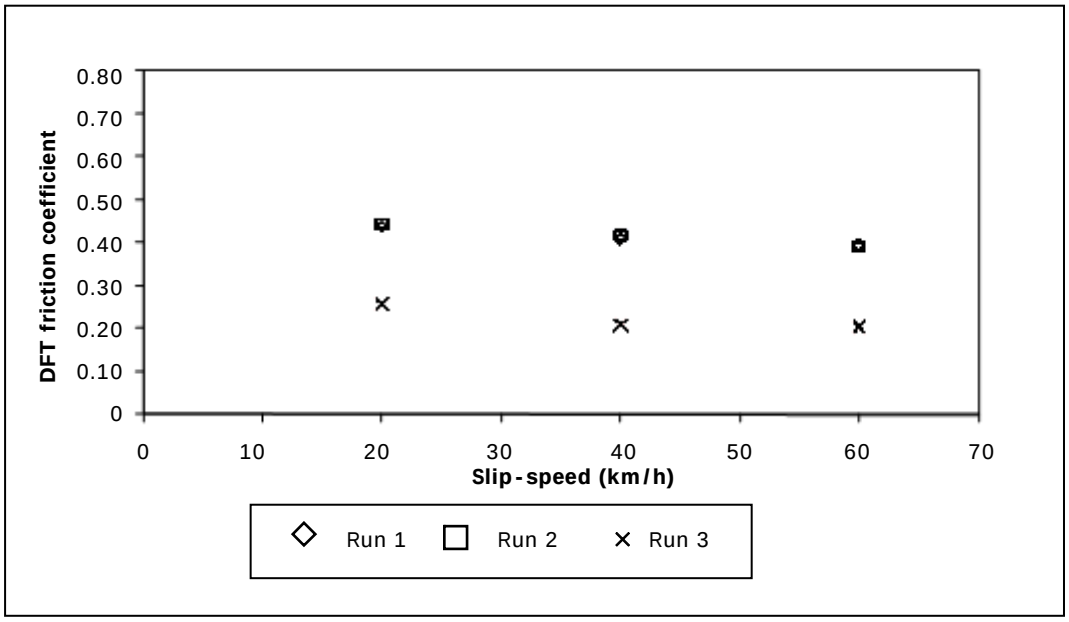


Table 6.1 DFT skid resistance on wet chipseal surfaces at a range of slip-speeds

Slip-speed (km/h)			MPD[a,b] (mm)	Condition rating	Location
20	40	60			
0.54	0.53	0.51	2.61	Unflushed	Alexander Road
0.56	0.55	0.53	2.67		
0.57	0.56	0.60	2.61		
0.56	0.56	0.52	2.67		
0.76	0.71	0.67	2.75		Old Hutt Road
0.77	0.75	0.75	3.09		
0.52	0.44	0.41	0.73	Moderately flushed	
0.52	0.44	0.40	0.73		
0.56	0.51	0.46	0.75		
0.58	0.55	0.47	0.73		
0.51	0.49	0.46	0.75		
0.44	0.42	0.39	0.52	Flushed	Alexander Road
0.26	0.21	0.20	0.52		
0.44	0.41	0.40	0.52		

*Notes to table 6.1:

a The MPD texture measurements may not coincide precisely with the position at which DFT measurements were made.

b The textures were measured ~1 year prior to the DFT (and LWB) tests being undertaken and will have changed slightly (because of vehicle trafficking, for example) over this period (the surfaces have not been treated or repaired over this period).

6.3.2 DFT results on Alexander Road

Figure 6.7 and table 6.2 show a summary of the DFT skid resistance results for Alexander Road. Eighteen data points (3 replicate runs × 6 test positions) were recorded on the flushed surfaces for each of the three slip-speeds (20km/h, 40km/h, 60km/h), and 12 data points (3 replicate runs × 4 test positions) were recorded on the unflushed surfaces at each slip-speed.

Figure 6.7 DFT skid resistance on Alexander Road in wet conditions

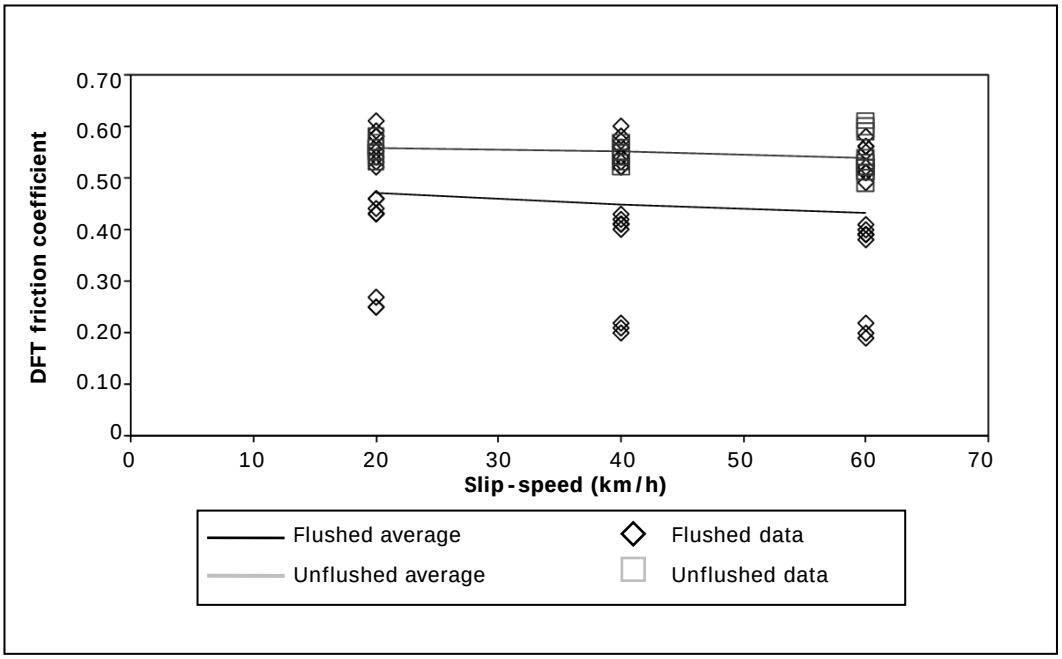


Table 6.2 DFT skid resistance on Alexander Road in wet conditions

Slip-speed (km/h)	Skid resistance		
	Average (flushed)	Average (unflushed)	Difference (unflushed – flushed)
20	0.47	0.56	0.09
40	0.45	0.55	0.10
60	0.43	0.54	0.11

This data indicates the following:

- Flushing on Alexander Road reduces wet DFT skid resistance by around 0.1 units.
- For the range of slip-speeds (20–60km/h), DFT skid resistance decreases linearly with slip-speed.
- Surfaces deemed to be flushed have a wider scatter of DFT skid resistance than unflushed surfaces.

6.3.3 LWB results

Figures 6.8 to 6.11 compare the results of the wet and dry LWB tests carried out on the flushed and unflushed sections of Alexander Road and Old Hutt Road.

Figure 6.8 LWB skid resistance on wet chipseal surface (Alexander Road)

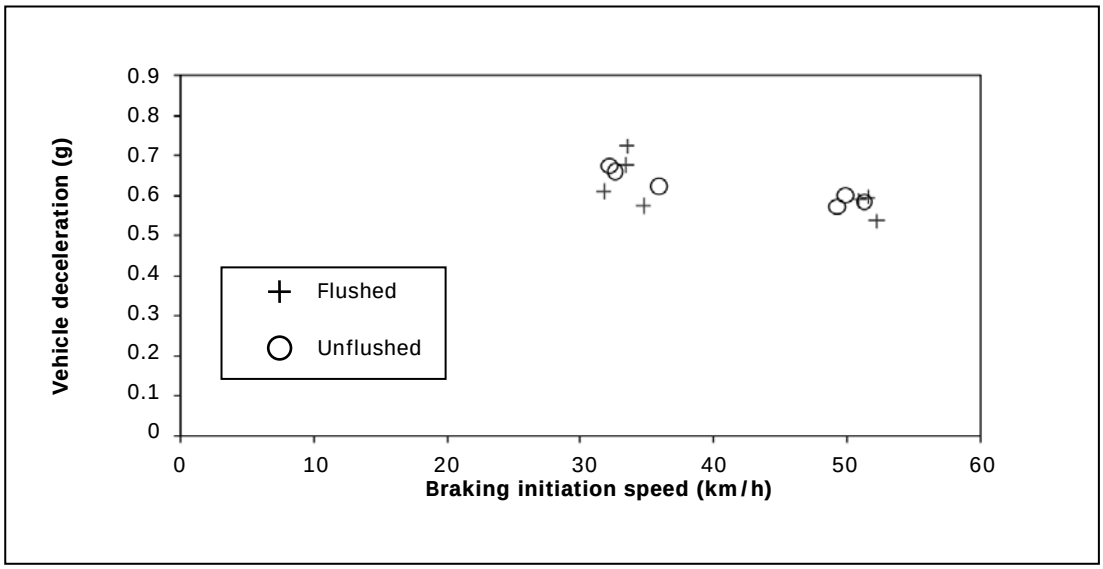


Figure 6.9 LWB skid resistance on wet chipseal surface (Old Hutt Road)

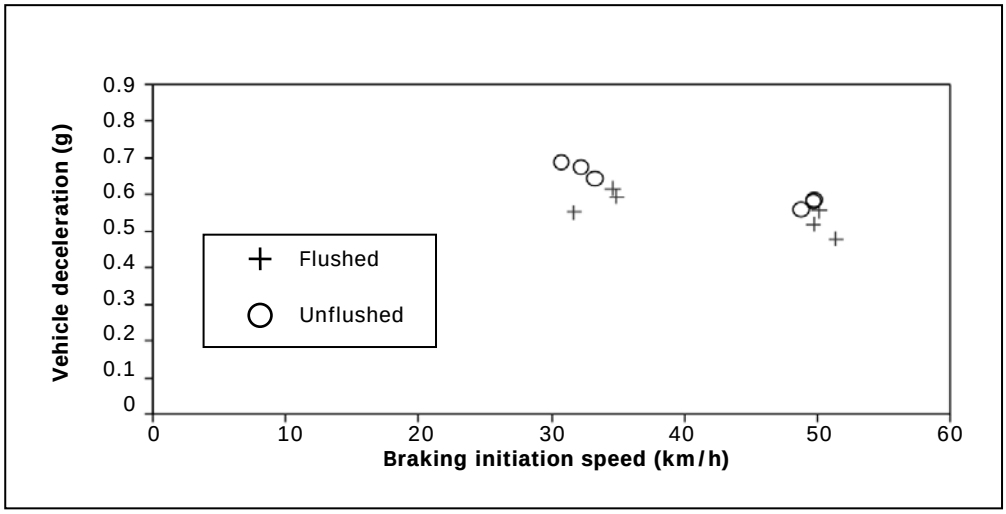


Figure 6.10 LWB skid resistance on dry chipseal surface (Alexander Road)

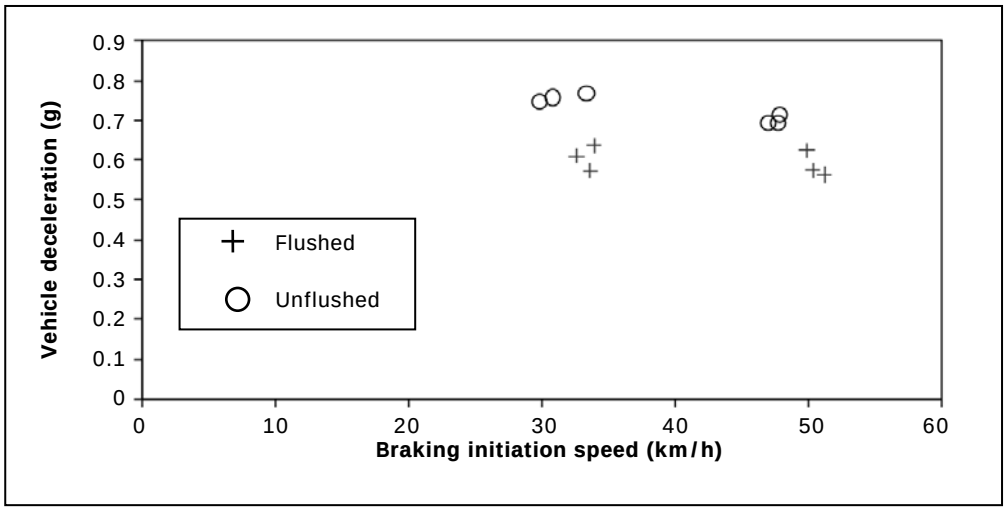
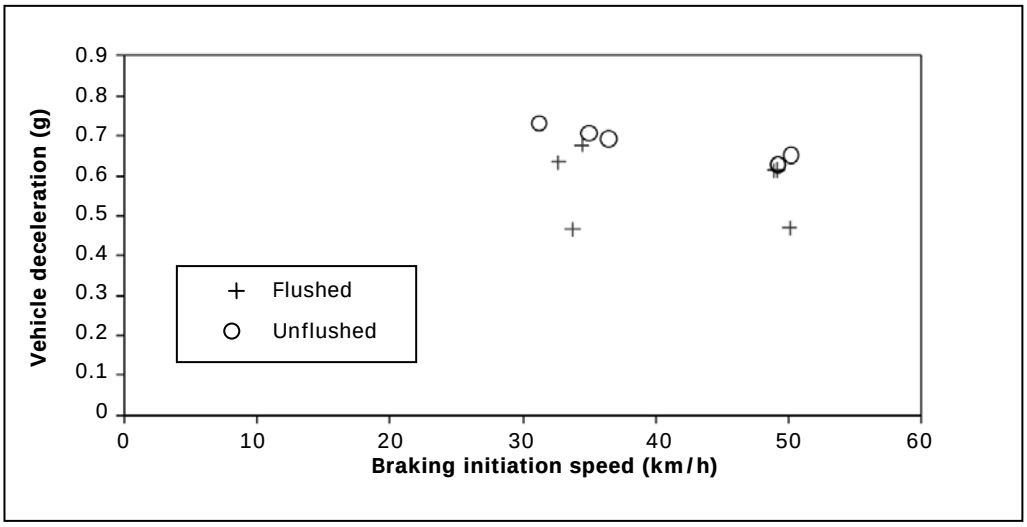


Figure 6.11 LWB skid resistance on dry chipseal surface (Old Hutt Road)



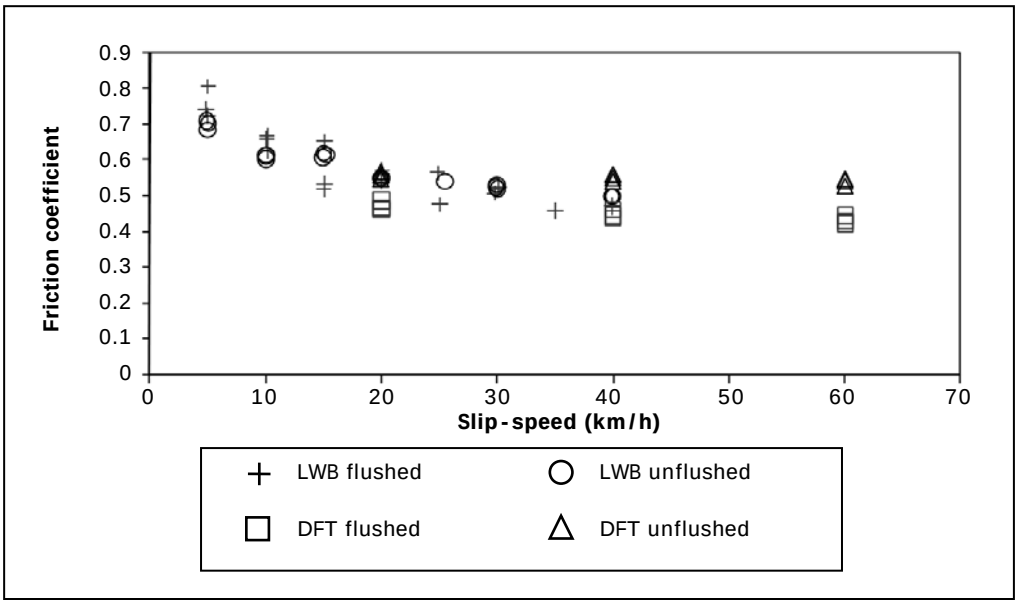
Figures 6.8 to 6.11show that the reduction in LWB skid resistance with flushing is not consistent for wet chipseals but is for dry chipseals. Perhaps this is because of the greater propensity of the bitumen to become molten in the absence of water.

Another noteworthy observation is that the reduction in LWB skid resistance caused by flushing is greater under dry conditions than under wet conditions.

6.3.4 Comparison of DFT and LWB results

Figure 6.12 compares the effect of flushing on the skid resistance measured by LWB and the DFT on the wet chipseal surface of Alexander Road. The procedure outlined in section 6.2 of this report was used to calculate LWB skid resistance.

Figure 6.12 DFT and LWB skid resistance on a wet chipseal surface (Alexander Road)



From the DFT skid resistance results shown in figure 6.7, it appears that flushing reduces DFT skid resistance on wet chipseal surfaces. However, LWB skid resistance results appear to be more scattered and do not show a consistent reduction.

7 Application of the IFI

7.1 The index

The IFI (eg Cenek et al 2004; Wambold et al 1995) and its integral form were applied to confirm the observed relationships between DFT- and LWB-derived skid resistance values, and to quantify the effect of flushing on road safety by considering braking distances. The principal findings are presented below.

7.2 Manfeild Race Circuit

The surface of the Manfeild Race Circuit was comparatively homogeneous across the entire distance taken by the instrumented vehicle to slide to a stop during the LWB tests. Therefore, DFT and LWB data from skid resistance tests on the Manfeild Race Circuit was used to confirm that the University of Auckland's DFT was working as expected. This was achieved by applying the IFI equations to the DFT measurements and comparing the resulting estimates of road surface friction with the LWB-derived measures for various slip-speeds.

The equation for converting DFT skid resistance measures to IFI F_{60} values so that equations 3.1 and 3.2 can be applied is shown in equation 7.1.

$$F_{60} = A + B \times FRS \times e\left(\frac{S-60}{S_p}\right) \qquad \text{(Equation 7.1)}$$

where:

- F_{60} = road friction at a slip-speed of 60km/h (equivalent to the LWB reading at a slip-speed of 60km/h)
- A = constant for converting DFT road friction to LWB road friction (see table 7.1)
- B = constant for converting DFT road friction to LWB road friction (see table 7.1)
- FRS = output of the DFT at a slip-speed of S (km/h)
- S = DFT slip-speed (km/h)
- S_p = constant = 9.74 + 104.71 × TD
- TD = texture depth in terms of MPD (mm)

Table 7.1 Constants for converting DFT road friction to LWB road friction

DFT slip-speed (km/h)	Constant	
	A	B
20	-0.3765	0.77098
60	0.08114	0.73158

The values of the constants in table 7.1 indicate that the DFT is expected to provide skid resistance values that are higher than those from LWB for the same slip-speed. This is as observed in figure 6.2.

When equation 7.1 is combined with equation 3.1, the wet road friction (F) at slip-speeds other than 60km/h can be calculated. Applying this procedure to the data in figure 6.2 gives the following results:

- A 0.725 DFT reading at a slip-speed of 20km/h corresponds to a calculated F_{60} value of 0.57 compared to a measured value of 0.6.
- A 0.625 DFT reading at a slip-speed of 60km/h corresponds to a calculated F_{60} value of 0.45 compared to a measured value of 0.5.

In converting the DFT skid resistance readings to F_{60} values, the 'effective' texture depth was used in the calculation of S_p, ie the volumetric texture depth of a test vehicle tyre was added to the MPD texture depth of the Manfeild Race Circuit because the LWB test vehicle was fitted with treaded tyres, not slick tyres. (The volumetric texture depth of a tyre is the total volume of grooves within the tyre–road contact patch divided by the area of the contact patch.) A volumetric texture depth of 0.3mm has been assumed, corresponding to a tyre tread depth at the legal minimum of 1.5mm (refer table 3.1). Therefore, 0.3mm was added to the 0.53mm MPD measured on the Manfeild Race Circuit to give an effective texture depth of 0.83mm. This value of 'effective texture' was used in converting both the DFT skid resistance at a slip-speed of 20km/h and the DFT skid resistance at a slip-speed of 60km/h to F_{60} road friction values.

The closeness of the agreement between converted/calculated and measured F_{60} values provides a degree of confidence that the DFT was operating properly.

7.3 Effect of flushing on road surface friction

The LWB results for Old Hutt Road and Alexander Road, presented graphically in chapter 6, are summarised in tables 7.2 and 7.3. The values represent the average friction coefficient over the 10–15m needed for the test vehicle to come to a complete stop from 30km/h and 50km/h, respectively. For this reason, this friction coefficient is referred to as the coefficient of longitudinal deceleration (μ in equation 3.2) to emphasise that it covers a range of slip-speeds, rather than a particular slip-speed, as is common with friction testers.

Of the two roads, Old Hutt Road is the one that had more continuous lengths of flushing in the wheelpaths. Therefore, Old Hutt Road is likely to show the effect of flushing more markedly than Alexander Road.

Table 7.2 shows that when continuous flushing is present, the difference between flushed and unflushed conditions amounts to a difference of approximately 0.1 in the coefficient of longitudinal deceleration, irrespective of surface moisture and speed. Therefore, the reduction in skid resistance brought about by flushing is also considered to be problematic under dry conditions because vehicle handling may unexpectedly approach that of wet conditions when driving over dry flushed surfaces, catching the driver unaware.

Table 7.2 LWB-derived coefficient of longitudinal deceleration on Old Hutt Road

Surface moisture	Braking initiation speed (km/h)					
	30			50		
	Flushed	Unflushed	Difference	Flushed	Unflushed	Difference
Wet	0.59	0.67	0.08	0.52	0.58	0.06
Dry	0.59	0.71	0.12	0.57	0.64	0.07
Difference	0.00	0.04		0.05	0.06	

Table 7.3 LWB-derived coefficient of longitudinal deceleration on Alexander Road

Surface moisture	Braking initiation speed (km/h)					
	30			50		
	Flushed	Unflushed	Difference	Flushed	Unflushed	Difference
Wet	0.65	0.65	0.01	0.57	0.59	0.01
Dry	0.61	0.76	0.15	0.59	0.70	0.11
Difference	-0.04	0.10		0.01	0.11	

Moisture effects appear to be more pronounced for the unflushed condition than the flushed condition, which is surprising (tables 7.2 and 7.3). Another result that runs contrary to expectation is that dry–wet coefficient differences do not appear to become markedly greater with braking initiation speed.

Estimates of the wet coefficient of longitudinal deceleration (μ_{wet}) can be obtained from DFT measures of skid resistance, MPD measures of texture, tyre volumetric texture depth and the integral form of the IFI as shown in equation 3.2.

The required DFT skid resistance and MPD measures over the flushed and unflushed sections of the Old Hutt Road and Alexander Road test sites to allow application of equation 3.2 are given in table 7.4.

Table 7.4 Averaged test site surface characteristics for input to equation 3.2

Road surface characteristic	Old Hutt Road		Alexander Road	
	Flushed	Unflushed	Flushed	Unflushed
DFT skid resistance at 60km/h	0.44	0.71	0.33	0.54
MPD (mm)	0.74	2.92	0.52	2.64

As with the Manfeild Race Circuit calculations, 'effective' texture was employed when applying the integral form of the IFI (equation 3.2) to calculate the coefficients of longitudinal deceleration on the chipseal roads so to account for the additional volumetric texture provided by the tyre tread (ie a tyre volumetric texture depth of 0.3mm, corresponding to a tyre tread depth of 1.5mm, was added to the MPD values in table 7.4.).

Table 7.5 summarises the DFT-derived estimates of the wet road coefficient of longitudinal deceleration (μ_{wet}) for both Old Hutt Road and Alexander Road.

Table 7.5 IFI-derived wet road coefficients of longitudinal deceleration (μ_{wet})

Test road	Braking initiation speed, V_B (km/h)					
	30			50		
	Flushed	Unflushed	Difference	Flushed	Unflushed	Difference
Old Hutt Road	0.46	0.59	0.13	0.42	0.56	0.14
Alexander Road	0.36	0.45	0.09	0.33	0.43	0.10

The DFT-derived wet road coefficients of longitudinal deceleration (μ_{wet}) for Old Hutt Road and Alexander Road (table 7.5) are much more consistent than those measured directly by LWB tests. This is thought to

be a result of the considerably smaller measurement area of the DFT, which permitted measurement on homogeneous flushed and unflushed sections of the test sites.

The IFI-derived wet road coefficients of longitudinal deceleration (μ_{wet}) from the DFT are of comparable magnitude to those reported directly from the LWB tests and support the finding that when flushing is extreme, the value of this coefficient is reduced by 0.1–0.14, representing about a 20% reduction.

Such a 20% reduction in the coefficient of longitudinal deceleration results in an increase in braking distance of 1.7–2m at 30km/h and of 6–7m at 50km/h, equating to a percentage increase of between 25% and 33%.

The effect of flushing on rural state highways where a speed limit of 100km/h applies can be estimated by assuming that the values of μ_{wet} given in table 7.5 apply equally for emergency braking initiated at 100km/h as at 50km/h. The basis for this assumption is the very small change observed in μ_{wet} values between braking initiated at 30km/h and 50km/h.

The increase in braking distance caused by flushing for emergency braking initiated at 100km/h is estimated to be between 23m and 28m. This corresponds to 5–6 car-lengths, suggesting that flushing is more of a safety issue on high-speed sections of state highways.

8 Conclusions and recommendations

8.1 Conclusions

8.1.1 Correlation between DFT and LWB tests

For a given slip-speed, the DFT gave skid resistance values that were higher than LWB, which is consistent with the international PIARC experiment.

The wet road coefficients of longitudinal deceleration measured directly by LWB agreed closely with those derived by applying the integral form of the IFI equation to the DFT values of skid resistance obtained for a slip-speed of 60km/h.

The DFT-derived IFI coefficients of longitudinal deceleration on the wet chipseal surfaces tested are more consistent than those measured directly by LWB tests. This is thought to be a result of the considerably smaller measurement area of the DFT, which permitted measurement on homogeneous flushed and unflushed sections of the test sites

The DFT was found to be suitable for investigating the friction characteristics of wet chipseal surfaces only. Under dry conditions, any bitumen present on the chipseal surface tends to melt and adhere to the sliders of the DFT, causing spurious measurements of friction.

Skid resistance values measured by the DFT appeared to be sensitive to the wear history of its rubber sliders, this sensitivity increasing with increasing slip-speed. Differences of up to 17% were observed between the first run and subsequent runs with a new slider on an AC surface, with the first run giving the lowest values. This finding suggests that the DFT rubber sliders should be conditioned by making some preliminary runs on the road surface of interest prior to taking the skid resistance readings.

8.1.2 Effect of flushing on skid resistance

Both the DFT and LWB tests confirmed that the presence of flushing on chipseal surfaces has a detrimental impact on the level of skid resistance provided for the travelling public. The following points are of particular interest:

- The reduction in skid resistance as measured by the DFT on a wet flushed chipseal surface is 0.1 units at a slip-speed of 40km/h compared with the same surface when unflushed.
- For braking initiated at a speed of 30km/h, the LWB tests showed the deceleration on a wet and relatively consistently flushed chipseal surface is about 0.08g less than on the same surface unflushed.
- When LWB was performed on dry chipseal roads, skid resistance reduced consistently compared to unflushed surfaces. The reduction in the dry was greater than the associated reduction in the wet.
- The IFI-derived wet road coefficients of longitudinal deceleration from the DFT are of comparable magnitude to those reported directly from the LWB tests, and indicate that when flushing is extreme, the value of this coefficient is reduced by 0.1–0.14, representing about a 20% reduction. This reduction is calculated to cause an increase in the braking distance of about 6–7m for emergency braking initiated at 50km/h and 23–28m for emergency braking initiated at 100km/h.

8.1.3 Flushing detection

An initial flushing detection study and a statistical study of Northland data were completed to assess the suitability of five texture-based statistics (MPD, Pc, RMR, MPD25 and MPD – MPD2) to detect binder rise from 2D profiles of the road surface as measured by lasers fitted to vehicles. (Other statistical studies were completed but are not discussed in this report because of accuracy concerns.) Of these five statistics, the best suited to flag flushing appear to be MPD – MPD25, MPD and RMR. Surprisingly, the results indicated that the MPD statistic flags only 50% of the 10m segments in the Northland NMA that were deemed visually as 'badly flushed'. This emphasises that MPD may not always identify all segments that are flushed. These and other results suggest that attempts to identify flushing from texture-based statistics derived from 2D road surface profiles are likely to be disappointing unless complemented with other information eg skid resistance or surface reflectance.

8.2 Recommendations

8.2.1 DFT measurements of skid resistance

The use of the DFT to characterise the in situ high-speed skid resistance properties of the road surfaces used in New Zealand road networks holds considerable promise, given the safety concerns associated with the only practical alternative at present, which is locked-wheel slide-to-stop tests performed with an instrumented vehicle. However, additional DFT and LWB tests on lengths of road where the surface is homogeneous along the wheelpaths need to be undertaken to better establish the relationship between DFT and LWB results. These additional controlled tests will serve to establish the sensitivity of the DFT to road surface macrotexture and surface type, and whether these sensitivities mirror the LWB of a passenger car tyre with legal tread depth.

8.2.2 Skid resistance

Additional work is required to determine whether the main contributor to loss of skid resistance on flushed surfaces is the masking of microtexture or the loss of macrotexture. To this end, DFT and LWB tests on wet flushed surfaces (ie road surfaces blackened with bitumen) over a range of textures (eg 0.5–1.5mm) is necessary.

8.2.3 Flushing detection

Flushing been shown to reduce road friction and the coefficient of longitudinal deceleration by as much as 20–25% in both dry and wet conditions and so has a significant impact on the safety of road users. Therefore, it is important that research effort be put into developing more robust automatic means of identifying the presence of flushing and its extent within a lane for improved safety management of the state highway network.

Related to the above, it is also recommended that for proactive management of flushing, a well-graduated, consistent and potentially automated method of determining the levels of binder that are visible at the road surface needs to be developed. (The advantage of an automated system is that it is potentially less subjective than human assessment.)

A better definition of flushing should also be developed. A suggestion is: 'A pavement surface defect in which the binder is near the uppermost surface of aggregate particles and skid resistance reduces as a result.'

The statistical flushing detection study using state highway data should be repeated using the latest data extracted from the NZTA's RAMM system database to confirm findings of this report. The analysis should focus on the statistics MPD – MPD25 and RMR to confirm their level of correlation with visually rated levels of flushing when compared with MPD.

Alternatively, rather than relying on visual assessments of flushing, it may be possible to use some of the NZTA's 113 seasonal control sites located throughout the country to relate changes in skid resistance over a summer period, as measured by SCRIM, to changes in the various texture measures. The SCRIM machine surveys the 5km long seasonal sites three to four times over the summer period. A video of the road surface is also recorded. As flushing can be generated within a summer period, it should be possible to combine the video images of the road surface with the skid resistance measurements to identify the formation and development of flushing. The texture-related measure that best detects flushing from the 2D road surface profiles can be found by correlating changes in the various texture measures to changes in skid resistance brought about by flushing.

9 References

Anderson, DA and JJ Henry (1979) The selection of aggregates for skid resistant pavements. *Asphalt paving technology. Proceedings of the Association of Asphalt Paving Technologists, Technical Sessions, Denver, Colorado*: 587–610.

Bullas, JC (2007) Bituplaning: a low dry friction phenomenon of new bituminous road surfaces. Thesis submitted for the award of Doctor of Philosophy, University of Southampton, Faculty of Engineering, Science and Mathematics, School of Civil Engineering and the Environment, Southampton, UK.

Cenek, PD, NJ Jamieson, MW McLarin and EC Brown (2000) Use of the International Friction Index (IFI) to predict actual vehicle braking performance. *The New Zealand Land Transport Symposium 2000 – Engineering for Road Safety, Rotorua*, 9–11 October 2000.

Cenek, PD, RH Henderson, MJS Loader and N Locke (2002) Texture depth requirements for state highway asset management purposes. *Opus Central Laboratories report 02-529293.00.* Lower Hutt: Opus Central Laboratories.

Cenek, PD, P Carpenter, N Jamieson, and P Stewart (2004) Prediction of skid resistance performance of chipseal roads. *Transfund New Zealand research report no. 256.* Wellington: Transfund New Zealand. 114 pp.

Cenek, PD, RD Davies, and RJ Henderson (2008) Factors influencing the in-service skid resistance performance of aggregates. *International Safer Roads Conference,* Cheltenham, UK, 1–14 May 2008.

Choubane, B, CR Holzschuher and S Gokhale (2004) Precision of locked-wheel testers for measurement of roadway surface friction characteristics. *Transportation Research Record 1869*: 145–151.

Clark, SK (Ed.) (1981) *Mechanics of pneumatic tires.* Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Davies, RB, PD Cenek and RJ Henderson (2005) The effect of skid resistance and texture on crash risk. Accessed 20 June 2011. *http://www.robertnz.net/pdf/SkidResistanceTextureCrashRisk.pdf.*

El Gendy, A and A Shalaby (2007) Mean profile depth of pavement surface macrotexture using photometric stereo techniques. *Journal of Transportation Engineering 133 (7)* July 2007: 433–440.

Henderson, RJ and PD Cenek (2006) Measurement of flushing. *Central Laboratories report no. 06-529755.00.* Lower Hutt: Opus Central Laboratories.

Henderson, R, G Cook, P Cenek, J Patrick and S Potter (2006) The effect of crushing on chipseal skid resistance. *Land Transport New Zealand research report 802.* Wellington: Land Transport New Zealand.

International Organisation for Standardisation (1997) Characterisation of pavement texture by use of surface profiles – part 1: determination of mean profile depth. *ISO 13473-1:1997.* Geneva: International Organisation for Standardisation.

International Organisation for Standardisation (2002) Characterisation of pavement texture by use of surface profiles – part 2: terminology and basic requirements related to pavement texture profile analysis. *ISO 13473-2: 2002.* Geneva: International Organisation for Standardisation.

Meyer, WE and HW Kummer (1962) Mechanism of force transmission between tire and road. *Society of Automotive Engineers (SAE) report 490A, March 1962.* Warrendale, PA: SAE International. 18 pp.

Moore, DF (1975) *The friction of pneumatic tyres.* Amsterdam: Elsevier Scientific Publishing Company.

Nippo Sangyo Co. Ltd (2004) Dynamic friction tester. Accessed 8 February 2011. *http://www.nippou.com/en/products/dft.html* .

NZ Transport Agency (2009) State Highway National Pavement Condition Report 2008 http://www.busway.co.nz/resources/state-highway-national-pavement-condition-report-2008/index.html

Transit New Zealand (2002a) Specification for skid resistance investigation and treatment selection. *TNZ – T/10.* Wellington: Transit New Zealand.

Transit New Zealand (2002b) Highway management division memorandum No. SM 8/02/01. Accessed 8 February 2011. *http://www.nzta.govt.nz/resources/macrotexture-requirements/docs/interim-macrotexture-requirements.pdf.*

Transit New Zealand, Road Controlling Authorities and Roading New Zealand. 2005. Chipsealing in New Zealand.

Transit New Zealand (2008) Transit New Zealand annual report 2007/08. Wellington: Transit New Zealand.

Vericom Computers (2006) *Vericom VC3000 Brake Meter condensed owners' manual, July 28.* Rogers, MN: Vericom. 21 pp.

Wambold, JC, CE Antle, JJ Henry Z Rado (1995) International PIARC experiment to compare and harmonise texture and skid resistance measurements. Final report. *PIARC publication AIPCR-01.04.T-1995*. Paris, France: Permanent International Association of Road Congresses (PIARC).

Wilson, DJ and P Black (2006) The effects of rainfall and contaminants on skid resistance variability. *22nd ARRB Conference – Research into Practice*, 29th October–2nd November, Canberra, Australia.

Appendix A Glossary

Binder rise: A fully flushed surface corresponds to 100% binder rise.

Braking distance: Distance for a vehicle to come to a complete stop after brakes have been applied.

Coefficient of friction: Ratio of the friction force between the tyre and the road and the normal force between the tyre and the road. Normally measured at a specified slip-speed using a locked wheel.

Coefficient of longitudinal deceleration: The average coefficient of friction during a slide-to-stop (locked-wheel) braking manoeuvre.

MPD: The difference between the mean of the peak heights of each 50mm segment and the average height of a profile measured over a 100mm long profile sample (ISO 13473-2: 2002 (International Organisation for Standardisation 2002)). This measure is purported to correlate well with texture measures derived from the sand circle method.

MPD25: Mean profile depth based on calculating peak heights for a 25mm segment length, rather than the standard ISO specification of 50mm. In other words, MPD25 is the difference between the mean of the peak heights of each 25mm segment and the average height of the 100mm profile.

Peak count: The number of local peaks in a profile that project through a selectable band (width = 0.6mm in this report), centred on the mean line.

RMR: The length of the bearing surface as a percentage of the profile length at a depth 1.0mm below the highest peak.

SCRIM: The skid resistance tester employed in annual high-speed data surveys commissioned by the NZTA on New Zealand's state highway network.

Skid resistance: A condition parameter to characterise the contribution that a road makes to the friction between a road surface and vehicle tyre during acceleration, braking and cornering manoeuvres. Normally measured on wet surfaces.

Slip-speed: The relative velocity between the rubber and the road surface. At the 100% slip condition (locked-wheel braking), the slip-speed is equal to the vehicle speed.