Prediction of Skid Resistance Performance of Chipseal Roads

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Executive Summary

Introduction
A four-year programme of research was undertaken in New Zealand (from 2000 to 2003) to determine how aggregate size, shape and spacing (i.e. macrotexture) impacts on the provision of low- and high-speed wet coefficients of tyre-road friction. This research programme involved a combination of field, laboratory-based and statistical modelling studies.

Emphasis was placed on the in-service skid resistance performance of straight and level sections of state highway where horizontal tyre forces will be at their lowest and least variable. This eliminated any confounding effects brought about by vehicle manoeuvres that generate higher but more variable tyre forces, such as when accelerating from rest, braking, cornering, and hill climbing.

The primary aim of the research was the development of a model, validated for conditions found on the New Zealand State Highway network, that allows reliable prediction of in-service skid resistance performance of chipseal surfaces from readily determined surface and traffic characteristics. The intended uses of the model are to guide design; allow more effective safety management of road networks through the ability to forecast the need for skid resistance restoration treatments; and to identify aggregate properties that have the greatest influence on skid resistance so that laboratory test procedures utilised for prequalifying surface course aggregates on the basis of their long-term skid resistance can be improved.

Secondary aims were to:

• determine relationships between common skid resistance measures employed in New Zealand and the friction coefficient of car tyres as derived from emergency braking tests;
• gain an improved understanding of contamination mechanisms, notably tracked binder film and detritus build-up over dry spells and their adverse effect on skid resistance; and
• quantify the contribution of macrotexture to low-speed and high-speed wet coefficients of braking friction.

The following conclusions and recommendations have been derived within the scope and limitations of the research programme.

Field Study – Emergency Braking Tests
Emergency braking tests, involving both four-wheel locked braking and ABS (independent anti-lock braking system on all four wheels) were performed on six test sites to obtain accurate measurement of wet and dry stopping distances and associated average coefficients of friction. These sites comprised 4 chipseal and 2 asphaltic concrete surfaces, and covered a wide range of microtexture and texture depth levels so that the various aggregate contributions to tyre–road friction could be assessed. The limited emergency braking tests provided evidence that:
1. The reported influence of road surface texture depth on low and high speed friction is negated by vehicles fitted with anti-lock braking systems (ABS) and tyres with adequate tread depth (i.e. ≥ 1.5 mm). Under such operating conditions, wet tyre-road friction appears to be insensitive both to speed over a 25 to 100 km/h range and to texture depth.

2. Under locked-wheel braking initiated at typical urban speeds (i.e. ≤ 50 km/h), wet tyre-road friction reduces with increasing speed but not at the rate predicted by International Friction Index (IFI).

3. Skid testers in common use in New Zealand display differing sensitivities to microtexture and macrotexture properties of road surfaces. However, their measurements of skid resistance showed significant correlations ($r^2 \geq 0.8$) with both dry and wet tyre-road coefficients of friction derived from locked-wheel emergency braking. Generally, SCRIM (Sideway-force Coefficient Routine Investigation Machine) measurements were shown to provide the most reliable estimates.

**Recommendation**

- Improved understanding of the inter-relationships between wet tyre-road friction, volumetric texture depths of tyres and road surfaces, vehicle speed, and water film depth is required before models for the reliable prediction of friction under different wet operating conditions can be developed. In the interim, IFI modelling of wet friction-speed dependencies appears adequate if the volumetric texture depth of the tyre is incorporated in the calculation of the speed number Sp.

**Field Study – Time Series GripTester Measurements**

GripTester surveys were undertaken on public roads to monitor the variation of skid resistance of road surfaces over a prolonged period of time. These surveys established that skid resistance is highest soon after a period of rain and then reduces with time if there is a prolonged dry spell. The results highlight the need to take care when interpreting skid resistance measurements to distinguish what is the inherent skid resistance of a road surface and what is the influence of previous rainfall history.

**Recommendation**

- Some evidence suggests that the rate at which skid resistance decays, as a function of days since rain, will differ with aggregate type (i.e. greywacke, basalt, andesite, etc.). Therefore, further investigation is required to quantify the rate the skid resistance of a road surface reduces with the length of time since rain as a function of skid tester device, aggregate rock type, sealing chip size, and aggregate microtexture depth. The findings will be useful for interpreting and normalising skid resistance survey results and in the selection of sealing chips to achieve a specified level of skid resistance.

**Laboratory-Based Study – Bitumen Contamination**

British Pendulum Tester (BPT) measurements were performed on pavement core and laboratory-made chipseal samples successively coated with thicker films of bitumen. This allowed the relative contributions of aggregate microtexture and surface texture profile to be quantified in terms of British Pendulum Number (BPN). These measurements showed that:

1. Aggregate microtexture contributes between 8 BPN (worn surface) and 28 BPN (new surface) to the overall skid resistance of the road surface sample, corresponding to 13% and 30% respectively.

2. The contribution of macrotexture to overall skid resistance is comparable to that of aggregate microtexture. This was an unexpected result and suggests that for chipseal surfaces, the hysteresis and adhesion components of friction are similar in magnitude.
3. The relative contribution of aggregate microtexture to the skid resistance provided by a road surface increases as the macrotexture of the surface decreases.

4. The presence of bitumen film on chipseal road surfaces can result in reductions of skid resistance of between 20% and 30% in situations where the contamination is severe (i.e. bitumen film thickness of the order of 0.1 mm). However, the resulting level of skid resistance is still significantly greater (at least three times) than that provided by a smooth, bitumen-only surface. This suggests that chipseal surfaces in a flushed condition pose a greater safety hazard to motorists in wet conditions than chipseal surfaces that have been blackened by tracked bitumen.

Recommendations

- To assist the formulation of skid resistance models, and to identify any significant anomalies, the relative contributions of aggregate microtexture and macrotexture to overall skid resistance should be investigated for alluvial-sourced and hard rock-sourced aggregates of the rock types commonly used in New Zealand as sealing chips.

- Safety management of road networks should target the elimination of flushed sections of chipseal surfaces wherever they occur at locations of high friction demand, such as mid curve, and wherever the continuous length of flushed surface in a wheelpath is 20 m or greater, to prevent potentially hazardous braking manoeuvres.

Statistical Modelling Studies – Aggregate Characteristics and Skid Resistance

A regression analysis was performed to investigate the sensitivity of in-service skid resistance performance of chipseal-surfaced sections of state highway to aggregate and texture characteristics under different traffic loading. This regression analysis was performed on a specially assembled database that comprised SCRIM-based skid resistance data from annual network surveys undertaken since 1998 and 18 different standard measures of surface texture derived from stationary laser profiler measurements made on 47 straight and level test sites located on state highways.

The regression analysis revealed that:

1. The model for relating skid resistance, aggregate PSV, and HCV traffic contained in Transit New Zealand’s TNZ T/10 specification gave predictions of skid resistance that correlated poorly ($r^2 = 0.08$) with the measured in-service skid resistance of the 47 test sites. This model tended to overestimate the level of skid resistance, which is a concern. The predicted mean summer SCRIM coefficient (MSSC) values agreed to ±0.04 of that observed for about 55% of the test sites (26 out of 47).

2. The critical determinants of in-service skid resistance performance of straight, chipseal-surfaced road sections were identified through unconstrained stepwise regression analysis to be:
   - cumulative heavy commercial vehicle (HCV) passes; and
   - the mean spacing between tips of the aggregates (the smaller the spacing, the higher the skid resistance).

3. A threshold value of cumulative HCV passes exists which, when reached, results in no further reduction in skid resistance over time due to traffic-induced wear. This threshold value is 1 million HCV passes.
4. When the stepwise regression was forced to include aggregate PSV as a model input, the following surface texture variables became important predictors of skid resistance:

\[ Rsk = \text{the skewness of the road profile about the mean line}; \]
\[ \text{delq} = \text{the root-mean-square (rms) slope of the road surface profile}; \]
\[ Rvm = \text{the mean maximum depth of the road profile from the mean line}. \]

5. In practice, the combined contribution of the surface texture variables Rsk, delq, and Rvm to overall skid resistance was found to range between –0.07 MSSC and 0.03 MSSC with a mean value of –0.03 MSSC. This result suggests that the potential for optimising aggregates with regard to shape and distribution within the surface to maximise skid resistance may be limited.

6. The regression model that displayed the best compromise between ease of application and accuracy was as follows:

\[
\text{MSSC}_{av} = 0.0013 \times \text{PSV} + 0.10 \times e^{-\text{CHCV}} - 0.007 \times \text{ALD} + 0.44
\]

where:

\[
\text{MSSC}_{av} = \text{average MSSC derived from 1998, 1999, 2000, and 2001 surveys}
\]
\[
\text{PSV} = \text{polished stone value}
\]
\[
\text{CHCV} = \text{cumulative heavy commercial vehicle traffic per lane in millions}
\]
\[
= \text{commercial vehicle traffic} > 3.5 \text{ tonnes} / \text{lane/day} \times \text{surface age (years)} \times \text{operational days per year} (=300)/10^6
\]
\[
= 0.0003 \times \text{HCV} \times \text{AGE}
\]
\[
\text{ALD} = \text{the average least dimension of the sealing chip (mm)}
\]

7. This regression model represents a significant improvement over the skid resistance model incorporated in Transit New Zealand’s T/10 specification, achieving fit statistics of \( r^2 = 0.35 \), and standard error of estimation (SE) = 0.04.

8. The average HCV exposure of two-lane rural state highways is 129 HCV/lane/day. The expected rate of change in skid resistance due to the polishing action from this volume of HCV traffic is estimated from the regression model to average out at about –0.003 MSSC/year over the expected service life of a chipseal surface. This can be regarded as being negligible, when compared to short-term variations in skid resistance brought about by spells of dry and wet weather.

9. A critical value of cumulative HCV passes exists, above which it is very difficult to satisfy investigatory levels for skid resistance specified in Transit New Zealand’s T/10 specification for the high demand site categories (i.e. 1, 2 and 3) using natural aggregates.

10. Evidence suggests that the skid resistance deterioration mechanism for alluvial aggregates is quite different to that of aggregates quarried from hard rock.

11. By grouping the 47 test sites in terms of alluvial- and hard rock-sourced aggregates and performing a separate regression analysis on each grouping, an indication of the size of differences in MSSC sensitivities to the key variables of PSV, cumulative HCV passes and aggregate size, was able to be obtained for these two aggregate types.

12. The preliminary indications are that:

- selection of “rounded” alluvial aggregates for skid resistant surfaces should be predicated on PSV as is current practice; and
selection of “angular/sharp-edged” hard rock aggregates should be predicated on size (the smaller the better) and ability to withstand tip- and edge-wear caused by HCV traffic.

Recommendations

- The statistical modelling has shown that, for a given speed, the more often there is contact between the tyre and road, the higher the skid resistance. For the vehicle speeds expected on rural state highways, a mean spacing of 5 mm to 15 mm between tips of aggregates is considered necessary to satisfy both hysteresis and drainage requirements. In comparison, the tip spacing measured in the field ranged between 8 mm and 25 mm, reflecting the dominant use of Grade 2 to Grade 5 sealing chips.

  A move to confine the construction of chipseal surfaces to Grade 3 to Grade 6 sealing chips is therefore seen as being desirable for efficient provision of skid resistant roads.

- Aggregates need to be tested for their ability to maintain their shape under the wearing action of HCV traffic. A possible candidate test is the aggregate abrasion value (AAV), which provides a measure of resistance of the aggregate to surface wear by abrasion.

- Measuring more surface texture variables than mean profile depth (MPD) during annual high speed condition surveys of the state highway network should be considered so that additional information on amplitude, spacing and shape characteristics of the road surface profile can be provided. This will lead to an improved knowledge as to how the macrotexture of a road surface wears as a result of both seasonal effects and exposure to traffic. This improved knowledge, in turn, can be used to improve design processes and laboratory test procedures utilised for prequalifying surface course aggregates on the basis of their long-term skid resistance.

- Continued investigation in the following two areas is required to refine the regression model to the stage that it can be incorporated in Transit New Zealand’s T/10 specification:
  - Effect of aggregate microtexture depth and abrasion/wear resistance to establish whether or not separate models will be needed for different types of sealing chip, i.e. for hard or soft alluvial or quarried rock.
  - Effect of horizontal tyre forces to establish whether or not the rate of skid resistance decay with cumulative HCV passes increases and/or the equilibrium value of skid resistance reduces as a function of increasing horizontal tyre forces.

- If the proposed regression based skid resistance model is to be used for seal design purposes, the constant term should be reduced by 0.08 to 0.36 to account for both short-term weather effects and the model’s precision. This will yield conservative estimates of skid resistance for straight road sections.

- The PSV test allows roading aggregates to be ranked according to their ability to resist polishing under standard conditions. However, at the present time, it has not been established whether or not the polishing action of HCV traffic is more or less abrasive than the polishing action of the PSV test, yet in modelling skid resistance, aggregate PSV is still assumed to correspond to the situation of terminal microtexture.

- As depth of microtexture has been shown to be a strong contributor to the variation of skid resistance, the development of microtexture decay relationships for different natural aggregate sources is necessary to advance skid resistance modelling, and to allow selection of aggregates on the basis of exposure to cumulative HCV passes over the expected service life of the road surface.
• There is a need to better understand how the microtexture characteristics of roading aggregates change with respect to cumulative HCV passes and how this can be reliably simulated through laboratory testing.