AUSTROADS DEVELOPMENTS IN SKID RESISTANCE

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ABSTRACT

Australia is a large land mass with an expansive road network and a small population. As with most countries, the allocation of scarce resources between competing community needs is very competitive, and skid resistance issues are not immune from this. However, Austroads has been, and continues to be, active in the area of skid resistance. To maximise results, Austroads continues to encourage partnerships to encourage solutions that meet specific Australian needs, whilst building on any appropriate global state-of-the-art.

This paper discusses recent Austroads work in developing guidance for developing procedures and practices for the management of skid resistance that are achievable and sustainable in an Australian environment. It also includes a review of factors affecting the measurement of skid resistance, a discussion on future work regarding 'calibration, correlation, harmonisation or standardisation', and questions of the PSV test and today's traffic.

INTRODUCTION

The membership of Austroads comprises the six Australian state and two territory road transport and traffic authorities, the Commonwealth Department of Infrastructure and Transport, the Australian Local Government Association, and the NZ Transport Agency.

Austroads' purpose is to contribute to improved Australian and New Zealand transport outcomes by (Austroads 2010):

- providing expert advice on road and road transport issues
- facilitating collaboration between road agencies
- promoting harmonisation, consistency and uniformity in road and related operations
- undertaking strategic research on behalf of road agencies and communicating outcomes
- promoting improved and consistent practice by road agencies.

Austroads has been, and continues to be, active in the area of skid resistance.

Recent skid-related publications include:

- Austroads (2005) Guidelines for the management of road surface skid resistance, AP-G83/05
- Austroads (2009a). Guide to Asset Management Part 5F: Skid Resistance, Austroads guide to asset management, AGAM05F/09
- Austroads (2009b). Guide to Asset Management Part 5G: Texture, Austroads guide to asset management, AGAM05G/09
- Austroads (2011) Guidance for the Development of Policy to Manage Skid Resistance, Austroads Research Report, AP-R374/11.

All of these publications can be downloaded from https://www.onlinepublications.austroads.com.au

This paper describes work that has built on this, and then concludes with the current skid resistance activities in Austroads, including: equipment harmonisation, correlation or calibration; seasonal variation in Australia; and investigating the relevance of the polished stone value (PSV) test with today's traffic.

POLICY FOR THE MANAGEMENT OF SKID RESISTANCE

The aim of this particular Austroads project was to provide practitioners with guidance on developing procedures and practices for the management of skid resistance at the network level. The report presents a targeted approach for field testing and a framework that will assist all road authorities determine appropriate monitoring programs and investigatory levels applicable to local conditions. The document does not provide specific local investigatory levels for road authorities to adopt, as a significant amount of local input data is required to devise investigatory levels that are fit for local purpose.

Skid resistance monitoring programs and investigatory limits used in Australia were based on systems developed in the UK where the climate, traffic intensity and network configuration are very different. These do not *necessarily* suit Australian conditions and can have high cost implications in terms of monitoring and maintaining surfaces at sometimes inappropriate skid resistance levels that are not readily achievable or sustainable in an Australian environment. Austroads recognised a targeted approach applicable to Australian conditions is required and initiated this research project to develop a suitable national approach to skid resistance management.

The primary focus of this project was skid resistance management in Australia. New Zealand has a range of climate, geography and traffic densities such that it could form a subset of the conditions in Australia, with one or more of the resulting zones described herein also applying to New Zealand.

Method of working

Three workshops were conducted to bring together key stakeholders in the management of skid resistance in Australian and New Zealand road agencies. These workshops had the primary objective of scoping an appropriate way forward for the management of skid resistance that would ultimately satisfy the requirements of all road authorities, regardless of differences in local conditions, environment, etc.

Representatives of the following organisations were either part of the working group or were consulted from time to time by the working group: Roads and Traffic Authority, New South Wales (RTA) (Chair); ARRB Group; Opus New Zealand; Department of Lands and Planning, Northern Territory; Department for Transport, Energy and Infrastructure, South Australia (DTEI); W.D.M. Limited; Roads Corporation, Victoria (VicRoads); Department of Infrastructure, Energy and Resources, Tasmania (DIER); NZ Transport Agency (NZTA); and Department of Transport and Main Roads, Queensland (TMR).

Different Australian regions

It is believed that the success and suitability of various standards and investigatory levels are a function of local and jurisdictional conditions. There are important differences, not only from jurisdiction to jurisdiction, but within a jurisdiction, which must be considered, and a decision reached as to their relative significance, when formulating a national skid resistance management policy. Some of these are:

- road management budgets
- construction materials
- road network characteristics
  - road use

  - road age
  - network intensity
- climate.

Assigning zones of similarities

Whilst accepting that there are significant variations between regions and localities that may challenge any harmonisation approach, it is possible to categorise regions into similar zones. Building on this philosophy of 'zones of regional similarities' and the knowledge that skid-related crashes rarely have a single contributory factor it is proposed that regional zones of skid resistance demand based on recognised contributing risk factors can be identified geographically.

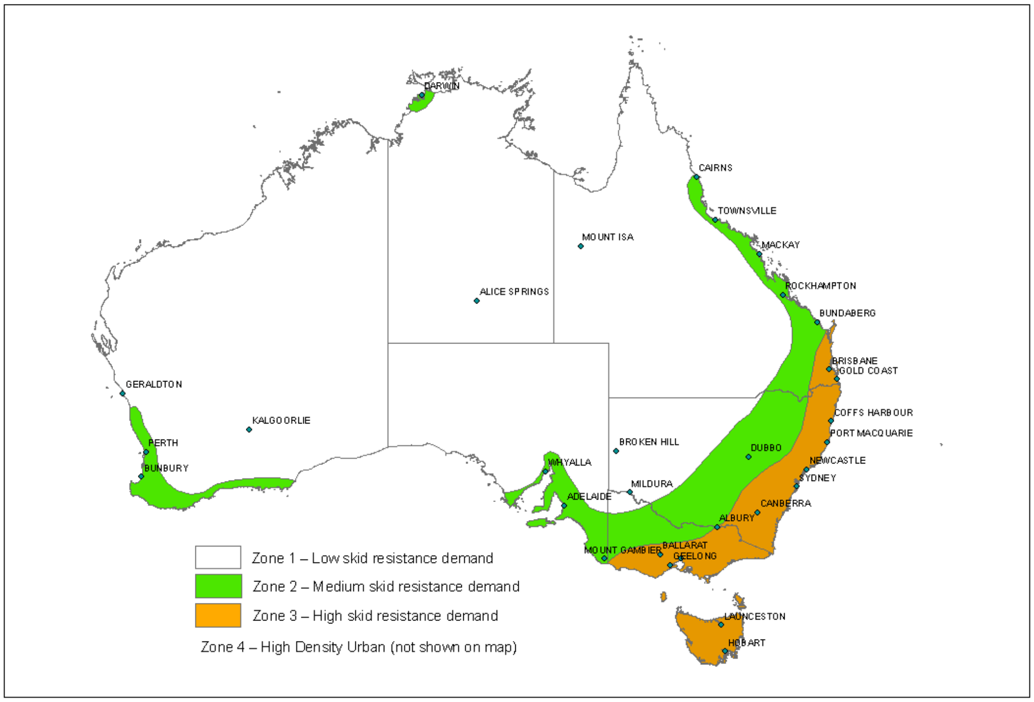
Given the difficult task of settling upon weightings and risk factors where hard factual data is either scant in one extreme or overwhelming in the other, zones of regional similarities have been devised using generalised data for climate, population, topography and traffic information, and engineering judgement. These considerations are shown in tabulated form in Table 1.

Table 1: Contributing factors to zones of regional similarities

Contributing factor	% weighting
Average annual rainfall	40
Population density	30
Topography	20
Traffic	5
Climate/seasonal rainfall	5

Source: Austroads (2011).

From this generalised consideration of elements contributing to risk, Australia can then be divided into the four generic zones with associated recommended minimum levels of testing as shown in Figure 1 and Table 2.



Source: Austroads (2011).

Figure 1: Indicative zones of skid resistance demand

Table 2: Zones of skid resistance demand

Generic zone	Recommended minimum level of testing
1. Low skid resistance demand	Process monitoring (e.g. network laser texture surveys or visual analysis as a minimum)
2. Medium skid resistance demand	Targeted testing (e.g. portable and towed devices such as British pendulum, GripTester, ROAR as a minimum)
3. High skid resistance demand	Network monitoring (e.g. SCRIM - where cost effective - portable and towed devices as a minimum)
4. High density urban	SCRIM or GripTester for inaccessible sites

Source: Austroads (2011).

Setting investigatory levels

Whilst Austroads (2005) recommends road authorities establish investigatory levels, it does not detail practical advice on an approach that authorities can use and adapt as appropriate, to set their own investigatory levels. The method now provided for calculating investigatory levels is derived from the Transport Research Laboratory/Highways Agency established principle of broadly equalising the risk of skidding accidents across a network. This is achieved by providing a level of wet road skid resistance that is appropriate to each location (Highways Agency 2007).

The 'investigation' – site review and prioritisation

A recommended uniform format for undertaking an investigation is described in detail in Appendix D of Austroads (2011). It shares many features with road safety audits of existing roads. The process outlined in Appendix D closely follows the audit process contained within the *Guide to Road Safety Part 6: Road Safety Audit* (Austroads 2009d) and draws heavily on the Austroads *Guide to Road Design Part 3: Geometric Design* (Austroads 2009c) to provide definitions.

REVIEW OF MEASUREMENT METHODS

Recent Austroads projects, carried out under management of the Asset Task Force (ATF), have identified a need for skid resistance maintenance procedures that are suitable for the local environment where a number of different measurement systems are currently used. For this maintenance procedure development task, the ATF proposed that a review of skid resistance (mainly focussed on variability in measurement) be first carried out.

Literature review – factors affecting skid measurement

Skid resistance can be affected by various testing and environmental factors. An understanding that these factors exist is important when trying to correlate or harmonise results from many different devices. Some factors affecting skid resistance measurement are reviewed in the following sub-sections.

Slip ratio

During a braking cycle, friction (represented as CoF) varies with increasing slip ratio (Figure 2). When the wheel is free rolling, the slip ratio is 0% (i.e. angular wheel speed equals the travel speed). As the brakes are applied and the wheels are slowed down, the difference between angular wheel speed and travel speed gradually increases. When the wheel is fully locked, the angular wheel speed becomes zero, and the slip ratio becomes 100% (i.e. slip speed = travel speed).

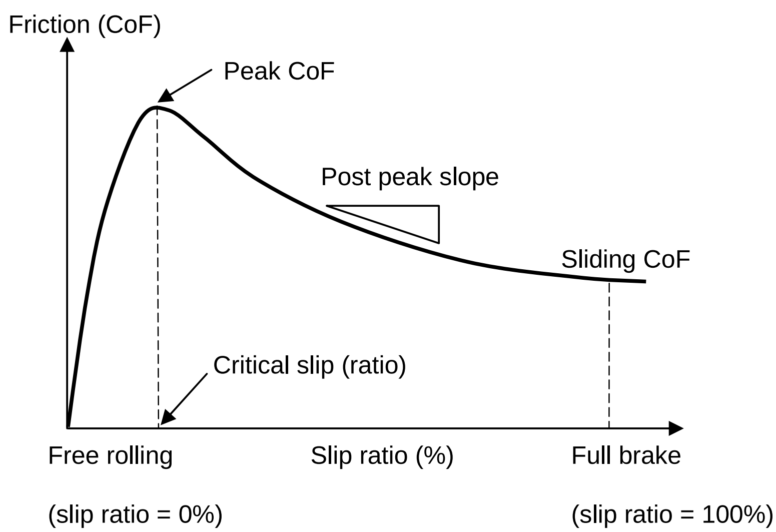


Figure 2: Illustration of varying friction during a braking cycle

The point at which a peak CoF occurs is commonly called critical slip (or critical slip ratio). After the critical slip, the CoF gradually decreases to the sliding CoF at the 100% slip (i.e. where the wheel is fully locked). The sliding CoF may be as low as 50% of the peak CoF, and the reduction is much greater on wet surfaces than dry. Vehicles with the anti-locking brake system (ABS) are designed to apply the brakes on and off repeatedly, such that the slip ratio is held near the peak CoF (AASHTO 2008).

Slip speed

The CoF generally decreases as the slip speed increases (Figure 3). An example is given in Flintsch et al. (2002) where the CoF were measured under varying slip speeds (30 ~ 90 km/h). A lock wheel trailer was used and thus the slip speed was controlled by changing the vehicle speed, while the slip ratio was fixed to 100%.

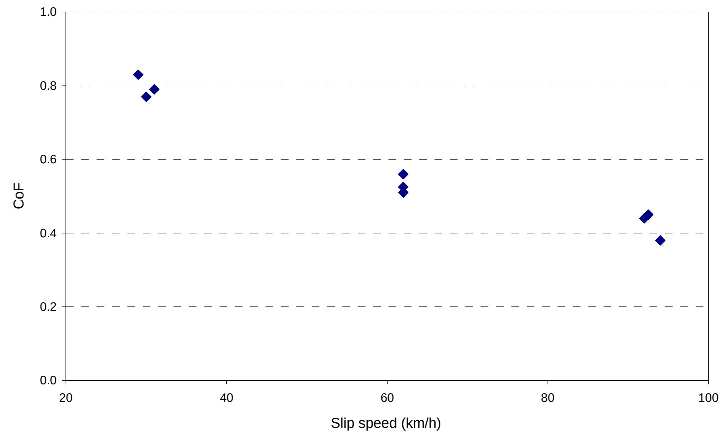


Figure 3: CoF measured under different slip speeds

Source: Data from Flintsch et al. (2002).

Friction at high speed is considered more dependent on macrotexture of the road surface. This is because hysteretic friction increases with slip speed exponentially (PIARC 1987). As the slip speed decreases, the hysteretic friction also decreases exponentially and the interaction between tyre and individual aggregate surfaces (i.e. microtexture and adhesion properties) becomes a more dominant factor (Feighan 2006).

Water film thickness

When the road surface is wet, thin water film can be formed at the tyre/road interface and can reduce the measured skid resistance significantly (and may produce a critical environment for crashes). Therefore, most skid resistance testers are equipped with a water sprayer (and water storage tank) to deliberately wet the surface for the measurement. The water spray rate is normally controlled to give a range of 'nominal' water film thickness from 0.25 mm to 1.0 mm depending on device type and settings. It was reported that this level of water film thickness can be formed under a light rainfall (Jellie 2003).

Test tyre

Research has shown that using different test tyres (e.g. size, rubber compound) and testing set-up (e.g. vertical load, inflation pressure) could result in unknown variations (Veith 1983).

Tyre tread design (i.e. type, pattern, and depth) and wear have a significant influence on draining trapped water at the tyre/road interface (AASHTO 2008). Skid resistance testers in Australia are normally equipped with smooth surfaced tyres to remove these variations. Additionally, using smooth tyres emphasises the water drainage capability of the road surface since the water escape channels are provided by the road surface (macrotexture) only.

Temperature

Research has shown that measured surface friction decreases with an increase in road surface temperature (Kummer 1966, McDonald et al. 2009). However, there is no general agreement as to exactly what the influences of temperature are or how they should be taken into account (Do and Roe 2008). Some devices are equipped to measure air temperatures and some other devices can measure road surface temperature. Other devices rely on the assumption that the temperature of the tyre is reasonably maintained to a certain degree, due to a combined effect of the spray water (i.e. cooling) and friction action (i.e. warm up). For example, SCRIM uses a natural rubber tyre but temperature correction may not always be required under current practice.

Measurement equipment: correlation and harmonisation

Pavement friction has typically been reported as a single number measured at a specific speed recommended for the particular device used in the measurement. The wide variety of testing devices (with all the different associated testing conditions) meant that a skid resistance value measured using one device is not directly comparable to that measured using another device.

There have been correlation exercises locally, such as a correlation study on New Zealand state highways by Cenek and Jamieson (2000), the Australian Runway and Roads Friction Workshop at Sydney Airport in 2003, and the Austroads Christchurch Correlation Study in 2005 (Austroads 2006), but none of these come close to the scope and the budget of those undertaken in Europe. For this reason the European trials will now be discussed.

PIARC (IFI)

The Permanent International Association of Road Congresses (PIARC) undertook substantial research work in 1992 to define an international scale of friction indices called IFI (PIARC 1995).

Forty-seven different measuring systems participated, representing 16 countries, (Austria, Belgium, Canada, Denmark, France, Germany, Great Britain, Italy, Japan, the Netherlands, Norway, Poland, Spain, Sweden, Switzerland, and United States). These systems measured 67 different parameters (33 texture parameters and 34 friction parameters).

The resulting report proposed a common scale (IFI). It provides a uniform means of reporting friction characteristics of pavements, adjusts the values provided by the traditional measurement to the common scale, and allows for the retention of those traditional values to relate to historical data and includes information on both friction and texture.

European countries have since expressed difficulty in having sufficient confidence in the precision of IFI results (Roe and Sinhal 2005).

HERMES (EFI)

These IFI precision concerns then led to a proposal for a harmonised index based on a similar principle, but focussed on the specific devices used in Europe (Descornet et al. 2006). This so-called European friction index (EFI) and means of calibrating different devices to it was evaluated in a major study, the Harmonization of European Routine and Research Measuring Equipment (HERMES) project, carried out through the Forum of European National Highway Research Laboratories (FEHRL).

This study involved 15 skid measurement devices, seven texture measurement devices, and 61 test sites across five countries (Belgium, the Netherlands, Spain, Great Britain and France). The test sites provided a wide range of surfacings representing most materials and textures available in Europe. In order to apply mathematical models to harmonise the devices, mean profile depth (MPD) was used for the texture depth measurements of the road surfaces.

The HERMES project found that (Descornet et al. 2006):

- Using the power law for the correlation of speed constant (SP) and mean profile depth (MPD) was better than the linear correlation used in the PIARC IFI model (Roa 2008).
- The procedure specified in the draft CEN standard works in the sense that it allows a common, stable scale of friction to be kept between the various devices that participated in the calibration exercises, in fully realistic conditions.
- The reproducibility of EFI has proved to be rather poor in comparison with the reproducibility between devices of a similar type, which makes the procedure as yet unsuitable for a mandatory application.
- The project has paved the way to alternative solutions by drawing up specifications for a proposed reference device and by setting up general specifications and possible designs for reference surfaces.

TYROSAFE (Standardisation)

In July 2007 a European consortium was formed to work on a project entitled Tyre and Road Surface Optimisation for Skid Resistance and Further Effects (known as the TYROSAFE project). One of the tasks of the project was to carry out a review of previous skid resistance harmonisation research projects (Vos and Groenendijk 2009).

The conclusion made from the review was that there is not yet a scale or system that can harmonise the range of devices currently used in Europe with sufficient precision to be of practical application with widespread acceptance.

TYROSAFE have therefore formulated scope for further research. The plan was to develop a set of alternative road maps, with some based on a common scale for skid resistance measurements through harmonisation and others based on standardisation. Standardisation can be seen as an ultimate case of harmonisation, achieving a common scale by using a single standard device only. Standardisation has the advantage of having the best precision in principle, but problems still exist, such as:

- maintaining consistency between the standard devices (e.g. one SCRIM to another), both within and across national boundaries
- the costs in replacing existing devices and revising current standards and policies to align with the new approach
- overcoming the commercial interests of current device manufacturers
- overcoming a possible lack of political will to adopt a single standard device.

Ultimately, standardisation may be the best approach across Europe for the purposes of new surfacing acceptance and in-service network monitoring (Vos and Groenendijk 2009). Nonetheless, various skid resistance measurement techniques will still be used in the foreseeable future.

WHAT NOW?

Calibration, correlation, harmonisation, or standardisation?

Following the review of the extensive work undertaken in Europe, it is not currently considered an efficient use of funds to correlate or harmonise the different outputs of the various skid measurement devices used in Australia. For historical and financial reasons, standardisation is not envisaged either unless by individual jurisdictional choice, or market forces.

A recommendation from Austroads (2011) is that each jurisdiction should carefully choose its most appropriate testing device, and then retain its use over a long period of time.

SCRIM

An Austroads-wide calibration of SCRIM devices is being planned with an aim of investigating whether it is possible to standardise the different ways that SCRIM data are recorded, processed (averaged) and analysed throughout Australia and NZ (e.g. it seems that the rolling average methodology has been locally adopted for Australian conditions).

It is also planned to explore possibilities of variable test speeds, which would include variable water flow rates. This would look at the effect of water film thickness, overseas practices, and adjustments for Australian conditions. The possibilities of standardising the approach to temperature correction of skid resistance data and the reference temperatures used will also be examined

GripTester

DTEI SA has two GripTesters and will undergo a monitored calibration excise.

British Pendulum Tester

An Italian-produced pendulum tester produces different results to the British BPT. A calibration trial at ARRB's Melbourne laboratory has been undertaken to correct for this.

Seasonal variation

A new Austroads working group has been formed, with representation invited for all Austroads jurisdictional members. This working group has discussed two main reasons why Austroads should be interested in seasonal variation.

The first is that when presenting or applying data, the known inaccuracies in predicting skid values that may have applied at the time of an accident, from test results produced at a different time and under different environmental conditions, need to be well explained, preferably with documented Australian evidence.

The second is the allocation of road maintenance budgets. If amounts of highly competitive funding are to be used on improving skid resistance and reducing wet weather accidents, an understanding of the degree of accuracy of the information used in making these decisions needs to be reached. The information currently available on this is questionable.

Therefore the revised aim of this project element is to measure the extent and periodicity of seasonal variation, and also to attempt to understand the effect of contributing factors (amount of rainfall, rate of change of skid after rain, materials and other environmental factors). The aim is to quantify the factors and their relative magnitudes influencing seasonal variation in Australia - but not to study them to such an extent that any hypothetical correction factor could be applied to actual field measured data.

ARRB Group is to supply a consistent British Pendulum Tester device and a consistent operator. The data collection exercise will follow a 'climatic' loop consisting of sites in Melbourne, Brisbane and Mildura, tested once per month.

THE PSV TEST AND TODAYS TRAFFIC?

The polished stone value (PSV) test was developed about 60 years ago, and remains relatively unchanged since. In contrast, there has been significant change in the amount of traffic, and the stressing experienced by surfacing aggregates (Woodward et al 2004).

A growing number of Australian jurisdictions are now questioning the correlation between the PSV test result, and the actual and measurable skid resistance performance of the road surfacings made from these aggregates.

Some European countries are investigating and adopting the German Wehner Schulze machine and its potential use to improve aggregate specification, as this test involves simulating the polishing effects in the field. An advantage of this is that it may enable the use of lower quality aggregates in specific treatment types, and yet still give the same overall skid resistance. This would assist in more use of locally available material, and in better reallocation of scarce quality resources. Also, if a better polishing procedure is formulated, an improved correlation to the crash rate might be expected.

Several American states are investigating and adopting the Micro-Deval test combined with an aggregate imaging system (AIMS) as an improvement over the PSV (amongst other tests) in correlating aggregate test properties with actual field performance (Masad et al. 2006, Massad et al. 2009, Wang et al. 2010 .

The Micro-Deval test is similar in concept to the L.A. abrasion test, except that water is added to the drum. Thus the Micro-Deval test tends to polish (smoothen) aggregate particle whereas the L.A. abrasion test tends to break them. AIMS is used to measure aggregate texture from images taken before polishing in the Micro-Deval, and again after different polishing intervals. The AIMS measurements provide information on the rate of aggregate texture loss.

Therefore, continuous review on international developments on aggregate polish resistance test methods will be maintained.

THE PAFV TEST: REFERENCE AGGREGATE

Polished aggregate friction value (PAFV) is an Australian developed aggregate characteristic devised in the 1970s as a local surrogate for the British polished stone value (PSV). The history of and distinction between PSV and PAFV is described in some detail in Neaylon (2009) but summarised below.

Although several British PSV machines were used in Australia, the accompanying British reference stone, grit and tyres were expensive to procure, and alternative Australian reference stone, grit and tyres that most closely reproduced the results of their British counterparts, were chosen.

The AS 1141 series of test methods for PAFV were developed in the 1970s and required a standard aggregate be used as part of the test. The reference aggregate adopted at that time, known as *Panmure*, was chosen because of its consistent quality, and because it was believed the quarry would still be available in 20 years time (Wylde 1977). However, the quarry has now been closed for many years. Stockpiles of the reference aggregate that were established at the time, and that were predicted to satisfy Austroads requirements for 20 years, are now virtually depleted after more than 30 years.

Austroads decided in February 2010 to adopt the United Kingdom reference stone to fast-track this project, rather than repeat the process of searching Australian quarries, selecting another reference aggregate, and then crush, sieve and store sufficient reference aggregate for projected use in the next 20 years.

Despite the discussion earlier about questions of the relevance of PSV test results, the adoption of any alternative test will still require discovery, laboratory and field trials, correlation of results and finally acceptance for implementation. In the meantime, the PSV/PAFV test will have a number of years remaining for its use - it is still the best and accepted test that we have - and the depletion of its reference stone is a problem for *today*.

Several technical aspects of the polished stone value test such as grit type, wheel type and grit feeder type, and a correlation exercise, however still need to be resolved.

CONCLUSION

By world standards, Australia is a large land mass with an expansive road network and a small population. As with most countries, the allocation of scarce resources between competing community needs is very competitive, and skid resistance issues are not immune from this.

To maximise results, Austroads continues to encourage partnerships and working groups between all members – and others - to encouraging solutions that meet specific Australian needs, whilst building on any appropriate global state-of-the-art.

REFERENCES

AASHTO 2008, *Guide for pavement friction*, no. GPVF-1, American Association of State Highway and Transportation Officials, Washington, DC, USA.

Austroads 2005, Guidelines for the management of road surface skid resistance, by P Hillier, AP-G83/05, Austroads, Sydney, NSW.

Austroads 2006, Report on skid resistance test device trials, 5 - 6 May 2005, by P Roe & P Hillier, AP-T72/06, Austroads, Sydney, NSW.

Austroads 2009a, Guide to asset management: part 5F: skid resistance, by P Hillier & W Soet, AGAM05F/09, Austroads, Sydney, NSW.

Austroads 2009b, Guide to asset management: part 5G: texture, by P Hillier & W Soet, AGAM05G/09, Austroads, Sydney, NSW.

Austroads 2009c, Guide to road design: part 3: geometric design, by D Barton, AGRD03/09, Austroads, Sydney, NSW.

Austroads 2009d, Guide to road safety: part 6: road safety audit, 3rd edn, AGRS06/09, Austroads, Sydney, NSW.

Austroads 2010, Annual report 2009-10, AP-C20/10, Austroads, Sydney, NSW.

Austroads 2011, Guidance for the development of policy to manage skid resistance, by K Neaylon, AP-R374/11, Austroads, Sydney, NSW.

Cenek, PD, Jamieson, NJ 2000, Correlation of skid resistance measuring devices under normal state highway survey conditions, report 00-529282.00, Opus International Central Laboratories, Lower Hutt, NZ.

Descornet, G, Schmidt, B, Boulet, M, Gothie, M, Do, M-T, Fafie, J, Alonso, M, Roe, P, Forest, R, Viner, H, 2006, Harmonization of European routine and research measuring equipment for skid resistance: HERMES final report, report 2006/1, Forum of National Highway Research Laboratories (FEHRL), Brussels, Belgium.

Do, M-T, Roe, PG (eds) 2008, Report on state-of-the-art of test methods, Seventh Framework Programme: Theme 7: Transport, D04, TYROSAFE, FEHRL Strategic Research Programme "SERRR IV".

Feighan, K, 2006, 'Pavement skid resistance management' in T Fwa, (ed.), The handbook of highway engineering, CRC Press, Boca Raton, FL, USA.

Flintsch, G, Al-Qadi, IL, Davis, R, McGhee, KK, 2002, 'Effect of HMA properties on pavement surface characteristics', Pavement evaluation conference, Roanoke, VA, USA, Falling Weight Deflectometer User Group & Road Profiles User Group, USA.

Highways Agency 2007, Guidance for HA service providers on implementing the skid resistance policy (HD28/04), interim advice note - IAN 98/07, Highways Agency, Department for Transport, London, UK.

Jellie, JH 2003, ' A study of factors affecting skid resistance characteristics' PhD Thesis, University of Ulster, Ireland.

Kummer, HW 1966, United theory of rubber and tire friction, Engineering research bulletin B-94, College of Engineering, Pennsylvania State University, University Park, PA, USA.

Masad, EA, Luce, A, Mahmoud, E 2006, Implementation of AIMS in measuring aggregate resistance to polishing, abrasion and breakage, technical report 5-1707-03-1, Texas Department of Transportation, Austin, Texas.

Masad, E, Rezaei, A, Chowdhury, A, Harris, P, 2009. Predicting asphalt mixture skid resistance based on aggregate characteristics. Texas Transportation Institute. College Station. FHWA/TX-09/0-5627-1.

McDonald, MP, Crowley, LG, Turochy, RE 2009, 'Determining the cause of seasonal variation in pavement friction: observational study with Datapave 3.0 database', Transportation Research Record, no. 2094, pp. 128-35.

Neaylon, KL, 2009, The PAFV test and road friction, AAPA 13th International Flexible Pavements Conference. Gold Coast.

PIARC 1987, 'Report of the Committee on Surface Characteristics', PIARC world road congress, 18th, 1987, Brussels, Belgium, technical report no.1, PIARC, Paris, France.

PIARC 1995, International Experiment to Compare and Harmonize Skid Resistance and Texture Measurements. PIARC Report 01.04.T: 430pp.

Roa, J. A. 2008, Evaluation of international friction index and high-friction surfaces. Virginia, USA. Virginia Polytechnic Institute and State University. MSc thesis.

Roe, PG, Sinhal, R. 2005, How do you compare? Correlation and calibration of skid resistance and road surface friction measurement devices. International Conference on Surface Friction. Christchurch, NZ.

Veith, AG 1983, 'Tires-roads-rainfall-vehicles: the traction connection', Frictional interaction of tire and pavement: a symposium, 1981, Akron-Fairlawn, Ohio, ASTM special technical publication 793, ASTM, Philadelphia, PA, USA, pp. 3-40.

Vos, E., Groenendijk J. 2009, Report on analysis and findings of previous skid resistance harmonisation research projects. Seventh Framework Programme: Theme 7: Transport, D05, TYROSAFE, FEHRL Strategic Research Programme "SERRR IV".

Wang, L, Druta, C, Lane, S 2010, Methods for Assessing the Polishing Characteristics of Coarse Aggregates for Use in Pavement Surface Layers. Virginia Transportation Research Council. Charlottesville, VA. VTRC 10-CR7.

Woodward, D, Woodside, A, Jellie, J, 2004, Improved Prediction of Aggregate Skid Resistance Using Modified PSV Tests. International Conference on Applications of Advanced Technologies in Transportation Engineering, 8th, 2004 China, ASCE.

Wylde, LJ 1977, The production of a potential reference stone for PSV testing from Panmure, Victoria. ARRB Internal Report. ARRB. Melbourne.

AUTHOR BIOGRAPHIES

Mr Kym Neaylon

Kym's early civil engineering career was practically focussed in quarrying, local government, road construction, and contract superintending, before specialising in bituminous road surfacings at DTEI SA. He has undertaken road surfacings research and development at both state and national levels, has chaired various Austroads technical publication committees and reference groups, and lectured in bituminous surfacings at the University of South Australia. In 2002 and 2003 he was the Australian representative for PIARC (World Road Association) International Technical Committee C1, Surface Characteristics, which dealt with the state-of-the-art in skid resistance.

Since joining ARRB, his activities have included bituminous road surfacings consulting for state road authorities throughout Australia and overseas, project leading the Austroads sprayed sealing research project, the management of skid resistance project, and the measurement of skid resistance project. He also has responsibility for the work and outcomes of ARRBs 16 person Materials Technology team.

Dr Young Choi

Young completed his PhD in April 2005 with a thesis titled 'Development of the SATS test for HMB materials', based on hot mix asphalt research. In May 2005 he started his career at the ARRB Group as a Senior Research Scientist in the Bituminous Surfacing Group. Since then, he has participated in various research projects and written many reports, including Austroads *Surface characteristics to meet road user needs*, *Review of standard methods for measuring road condition*, and *Improving skid resistance measurement*.