INTRODUCTION

A study has been undertaken by the Cement and Concrete Association of Australia to assess the skid resistance qualities of decorative concrete finishes used in residential streets, footpaths, cycleways and pedestrian areas. The study comprised a literature review of skid resistance and experimental work, both in the laboratory and in the field.

The literature review considered the following aspects:
- what statutory requirements exist at present for skid resistance;
- the major factors affecting skid resistance of various surfacing types; and
- typical skid resistance ranges for surfacing currently in use.

The experimental work was conducted in order to:
- Determine and compare the skid resistance qualities of various concrete paving types that are used for residential streets and pavements.
- Compare these results with any established skid resistance criteria.
- Determine whether particular surface finishes or concrete paving types are more appropriate for different applications.

SKID RESISTANCE OF CONCRETE SURFACES

Skid resistance is described as the ability of a surface to provide friction to a reference tyre or slider usually measured wet. Skid resistance is primarily dependent upon the surface macro and microstructure, see Figure 1.

Other parameters affecting skid resistance are:
- environmental conditions including surface contaminants and temperature;
- physical properties of the paving materials;
- age of pavement and traffic volumes;
- pavement geometry; and
- seasonal conditions, i.e. amount of rain.

SKID RESISTANCE is described as the ability of a surface to provide friction to a reference tyre or slider usually measured wet.
**DEVICES FOR MEASURING SKID RESISTANCE**

**High speed devices – SCRIM (Sideways force Coefficient Routine Investigation Machine)** is a vehicle-mounted device comprising one or two specially manufactured testing wheels and a water tank which continually tests the pavement surface for skid resistance. The measure of skid resistance from SCRIM is termed the Sideways Force Coefficient (SFC) and is expressed as a ratio of the sideways force upon a free-to-rotate test wheel which is angled to the direction of travel, and the vertical force exerted by the mass of the equipment.

ROAR is a trailer-mounted device towed by a vehicle which can operate in either a fixed degree of slip or in a variable slip mode. The basic unit comprises a precision hydraulic brake machine with a standard ASTM 1551 test tyre. ROAR is able to measure surface friction over a range of slip speeds.

**Low(er) speed devices – British Pendulum,** also known as the Portable Skid Resistance Tester, is a device primarily used in a laboratory to determine the frictional qualities of small areas of surfaces, typically sealing aggregates. The unit of measure is the Skid Resistance Value or the Skid Resistance Number and is approximately 100 times the value of the coefficient of friction (Kennedy et al)\(^2\). Details of the test are in BS 812: Part 114 and in AS 1141.42 with preparation of samples as given in AS 1141.40 and AS 1141.413.

**The Grip Tester** is a device that can be towed by a vehicle or pushed by hand and can thus test confined areas such as intersections and pedestrian walkways where devices like SCRIM and ROAR can not easily access. This device measures a wet coefficient of friction using a braked wheel aligned in the direction of travel. Drag and load are continuously measured and the quotient is displayed on a laptop computer. The force on the axle due to the surface friction is divided by the mass of the assembly and a Grip Number is derived, which is a ratio of less than unity. The value is different from but can be correlated to those of other devices.

**FACTORS AFFECTING SKID RESISTANCE OF CONCRETE SURFACES**

As previously mentioned, skid resistance is usually described as the ability of a surface to provide friction to a reference type or slider, usually measured wet. Friction is dependent upon the pavement macro and microtexture. Microtexture has greater influence on friction at the low speeds encountered in residential areas. Macrotexture becomes dominant at higher speeds, though microtexture is still important. Macrotexture supplies the paths through which water can escape from between the tyre and road surface, thereby allowing the microtexture to provide resistance to the relative movement between the tyre and the road surface.

Skid resistance is a function of many variables, some of which are independent of the pavement surfacing type, eg traffic volume, traffic speed, the presence of contaminants or lubricants and seasonal variations. These are not discussed further. Factors relating to the concrete pavement are briefly discussed below based on the literature review.

**General** Improvement of skid resistance for concrete pavements is documented by the Highway Research Board\(^4\) where the use of silica-sand mixes, non-polishing aggregates and the imparting of a suitably deep macrotexture to the plastic concrete is emphasised. Quartz, which comprises silica would be generally regarded as the hardest road-surfacing mineral, with only other silica minerals able to polish quartz.

**Abrasion resistance** Abrasion resistance of the pavement slows the rate of decrease of skid resistance with time and trafficking. A minimum compressive strength, typically specified at 32 MPa, generally ensures durability to allow the retention of texture during the design life of the pavement.

Concrete surfacing practice has been primarily directed not only to provide a surface that is naturally safe in terms of resistance offered to tyre skidding but also that the required friction is maintained throughout the life of the pavement.

**Surface texture** Surface texture is dependent upon the aggregate type and the concrete composition. For example, the difference produced by varying sand content versus coarse aggregate content; or by varying the density or porosity of the concrete. At low speeds, skid resistance is primarily provided by fine surface texture, ie the sand in the mortar.

At higher speeds on wet roads, the surface must contain in addition to fine surface texture, sufficient drainage paths for the water to be dispersed before the fine texture can come into play. Surface macrotexture can also be imparted on the pavement by longitudinal tine, transverse broom, exposing the aggregate, applying aggregate chips and by open-graded concrete. The longer the contact length of the hessian drag with the plastic concrete the greater the depth of the longitudinal striations. For traffic speeds up to 80 km/hr a ‘hessian drag’ finish provides acceptable skid resistance. For speeds greater than 80 km/hr transverse tining is required to provide greater drainage capacity. This lessens the likelihood of aquaplaning at high speeds by providing macrotexture.
A full-scale experiment involving the construction of twelve 150 m long sections of concrete pavement over a ten year period in the UK was reported by Franklin. An assessment of the skidding resistance was made for various quality limestone coarse aggregate and for various quantity of limestone or shell used in the fine aggregate. The factor having the most effect on skid-resistance was the acid-soluble content of the fine aggregate. The greater the acid-soluble content, the lower the measured skid resistance of the concrete. This concurs with studies undertaken by Colony in the USA.

A carbonate (sea shell) content of 25% of the fine aggregate (either retained on or passing the 600 µm sieve) reduced the Sideways Force Coefficient, SFC, by 0.11 when compared to a fine aggregate with no acid-soluble content.

The Roads and Traffic Authority of NSW (Nichols and Dash) requires that the sand component of concrete (less than 5 mm particle size) comprise not less than 70% quartz. Coarse aggregate durability of the coarse aggregate also can provide for and slows the rate of decrease of skid resistance. The higher the polished stone value (PSV) of the aggregate the greater the retardation of any reduction in skid resistance.

In Franklin’s study, the mineral aggregates’ Polished Stone Value (PSV) also had a significant effect on the pavement’s skid resistance, however the SFC was unlikely to change by more than 0.05 over the range of coarse aggregates normally used in concrete pavements.

Kennedy et al in citing work by others stated “Measurements of skid resistance on concrete roads have shown that the choice of fine aggregates has a major effect on the level of results. Compressive strength of the concrete and the proportion of fine aggregates also affect resistance to skidding, but the characteristics of the coarse aggregates have little effect.”

Statutory requirements The results of the literature search indicates that at present there are no statutory requirements for the skid resistance of local roads. However, based on extensive studies undertaken in the UK investigatory skid resistance levels were introduced in the UK for different site categories, Table 1. Hosking suggested minimum values of skid resistance as measured by a Portable Skid Resistance Tester (British Pendulum) as shown in Table 2.

<table>
<thead>
<tr>
<th>Category</th>
<th>Type of site</th>
<th>Minimum skid resistance (SRV) (surface wet)</th>
</tr>
</thead>
</table>
| A        | Difficult sites such as:  
1 Roundabouts  
2 Bends with radius less than 150 m on unrestricted roads  
3 Gradients 1 in 20 or steeper of lengths greater than 100 m  
4 Approaches to traffic lights on unrestricted roads  
B Motorways, trunk and class 1 roads and heavily trafficked roads in urban areas (carrying more than 2000 vehicles per day)  
C All other sites                                                                 | 65                                           |
| B        | Motorways, trunk and class 1 roads and heavily trafficked roads in urban areas (carrying more than 2000 vehicles per day) | 55                                           |
| C        | All other sites                                                              | 45                                           |
THE TEST PAVEMENT EXPERIMENT
An 8 m long section of an internal CSIRO site in Highett, Victoria was made available for the study. The road leads to a staff parking area and would be trafficked by about 20 vehicles a day, including a number of trucks making deliveries to the canteen.

The road was prepared for the construction of a concrete slab 8 m x 5 m x 180 mm thick with one layer of F82 mesh, six decorative concrete finishes and buffer zone at each end as shown below.

CONCRETE LAYOUT
Northern end of 5 m wide road (bitumen surface) leading to road network

<table>
<thead>
<tr>
<th>0.5 m of stippled concrete buffer zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m of surface 1, Stamped – slate finish</td>
</tr>
<tr>
<td>1 m of surface 2, Exposed aggregate</td>
</tr>
<tr>
<td>1 m of surface 3 Stencilled – brick paving</td>
</tr>
<tr>
<td>1 m of surface 4, Wood float</td>
</tr>
<tr>
<td>1 m of surface 5, Stamped – split-faced cobble</td>
</tr>
<tr>
<td>1 m of surface 6, Broomed</td>
</tr>
<tr>
<td>1.5 m of stippled concrete buffer zone</td>
</tr>
</tbody>
</table>

Southern end of 5 m wide road (gravel surface) leading to turning circle and car park.

The slab as shown in Figure 2 was poured in two stages with Y12 dowel bars at 400 mm centres along all construction joints. The concrete strength was 32 MPa.

Laboratory specimens were also cast as 500 x 400 x 50 mm slabs. These specimens were used to determine pedestrian slip resistance, results of which will be discussed in a separate article. The curing procedure was to cover all finishes with polythene sheet as they were finished and to secure it for seven days. The completed pavement is shown in Figure 3 and example of some of the finishes in Figure 4.

The skid resistance of the concrete finishes was determined on the basis of AS 1141.42. The surface roughness of the finishes was measured using Surtronic 10 R₆ instrument, as recommended by the UK Slip Resistance Group. It is a pocket size, electronic, stylus instrument which measures the maximum peak to trough amplitude readings over a 4 mm length of floor which is divided into 5 lengths of 0.8 mm. The average of the five values is displayed.
SKID RESISTANCE RESULTS
Two sets of results (A and B) are given for the initial skid resistance results in Table 3. This work was performed in duplicate in order to obtain a better understanding of the variability of the results, given that each of the five measurements is made on an area of the pavement that only measures 126 x 75 mm. On this scale, the profiled nature of the patterned finishes represents a heterogeneous surface. Thus, the exact positioning of the pendulum can have a significant influence on the measurements. Positioning of the pendulum in exactly the same position for each set of measurements was considered to be unachievable. The variability in the individual results has been expressed as a coefficient of variation. The coefficients of variation of the patterned finishes were high (up to 23.7%) and the difference between the two sets of mean results for the initial skid resistance results was up to 2.8 measurement units. This suggests that all of the results should be considered to have a precision of perhaps ±3 units.

The surface roughness of the decorative concrete pavements is shown in Table 4. It should be noted that a second laboratory sample of cobblestone and stencil finishes were prepared and were intentionally made rougher. The cobblestone finish was brushed and 10-mesh grit was used for the stencil finish.

Table 3 Skid resistance of the external decorative concrete finishes
Test Method: Wet Pendulum AS 1141.42 [TRRL rubber]

<table>
<thead>
<tr>
<th>Finish</th>
<th>Before trafficking</th>
<th>4 weeks</th>
<th>12 weeks</th>
<th>18 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SMV_A COV%</td>
<td>SMV_B COV%</td>
<td>SMV_A COV%</td>
<td>SMV_B COV%</td>
</tr>
<tr>
<td>Slate</td>
<td>28.5 12.21</td>
<td>26.3 23.74</td>
<td>30.5 5.99</td>
<td>40.4 11.36</td>
</tr>
<tr>
<td>Cobblestone</td>
<td>30.6 18.93</td>
<td>27.8 18.89</td>
<td>32.2 8.85</td>
<td>41.8 7.05</td>
</tr>
<tr>
<td>Stencil</td>
<td>44.6 14.76</td>
<td>42.4 18.23</td>
<td>40.0 16.52</td>
<td>53.7 6.48</td>
</tr>
<tr>
<td>Stippled</td>
<td>66.1 3.44</td>
<td>65.4 3.34</td>
<td>59.0 1.71</td>
<td>68.8 2.44</td>
</tr>
<tr>
<td>Broom</td>
<td>71.0 2.28</td>
<td>70.1 4.39</td>
<td>63.5 4.37</td>
<td>66.4 3.95</td>
</tr>
<tr>
<td>Wood float</td>
<td>69.8 3.11</td>
<td>67.9 4.17</td>
<td>66.9 2.79</td>
<td>71.5 8.82</td>
</tr>
<tr>
<td>Exp aggregate</td>
<td>74.3 6.89</td>
<td>76.9 7.29</td>
<td>72.5 1.81</td>
<td>74.0 3.77</td>
</tr>
</tbody>
</table>

SMV_: Sample mean value corrected for temperature to the nearest 0.1
COV%: Coefficient of variation = (standard deviation/mean)%

Table 4 The Rz surface roughness of the external decorative concrete pavements (using a cut-off length of 0.8 mm)

<table>
<thead>
<tr>
<th>Finish</th>
<th>Before trafficking</th>
<th>12 weeks</th>
<th>18 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(µm) COV%</td>
<td>(µm) COV%</td>
<td>(µm) COV%</td>
</tr>
<tr>
<td>Slate</td>
<td>25.2 42.07</td>
<td>32.2 21.17</td>
<td>43.7 42.29</td>
</tr>
<tr>
<td>Cobblestone*</td>
<td>28.9 35.59</td>
<td>27.2 27.80</td>
<td>33.7 29.22</td>
</tr>
<tr>
<td>Stencil*</td>
<td>39.2 34.76</td>
<td>52.9 39.87</td>
<td>55.5 37.46</td>
</tr>
<tr>
<td>Stippled</td>
<td>69.5 24.89</td>
<td>52.1 34.49</td>
<td>71.3 15.90</td>
</tr>
<tr>
<td>Broom</td>
<td>79.3 33.96</td>
<td>56.8 31.96</td>
<td>67.3 20.42</td>
</tr>
<tr>
<td>Wood float</td>
<td>64.8 26.77</td>
<td>59.5 40.35</td>
<td>58.5 42.14</td>
</tr>
<tr>
<td>Exp aggregate</td>
<td>59.9 40.11</td>
<td>67.3 37.44</td>
<td>75.9 43.24</td>
</tr>
</tbody>
</table>

* The mean Rz surface roughness of the cobblestone 2 and stencil 2 laboratory specimens were 49.9 and 61.8 microns respectively
Present there are no statutory requirements for the skid resistance of roads. Hosking suggested that a wet surface should have a minimum skid resistance value of 65 in order to provide adequate skid resistance on difficult sites (Table 2). A lower level of skid resistance may be acceptable in some residential streets depending on its geometry and traffic conditions. Assuming that some residential streets will have sharp curves, roundabouts, steep gradients and intersections where a high level of skid resistance is required, Table 5 has been based on a minimum SRV of 65 and provides a cautious conservative interpretation of the results obtained in this study.

The initial SRV of the grey finishes (stippled, broom, wood float and exposed aggregate) was in excess of 65 and this was generally maintained with trafficking, although the heterogeneous nature of the finishes resulted in high coefficients of variation.

The original patterned (somewhat smooth) finishes (stamped slate, stamped cobblestone and stencilled) had lower initial skid resistance. The skid resistance of these patterned finishes increased with trafficking. It was shown that some rougher finishes might provide suitable skid resistance. However, some accelerated wear testing should be undertaken to ensure that the finish is likely to remain sufficiently skid resistant.

<table>
<thead>
<tr>
<th>Finish</th>
<th>Suitability for residential streets</th>
<th>Suitability for public footpaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slate</td>
<td>Unsuitable</td>
<td>Unsuitable</td>
</tr>
<tr>
<td>Cobblestone (smooth)</td>
<td>Unsuitable</td>
<td>Probably unsuitable*</td>
</tr>
<tr>
<td>Rough Cobblestone</td>
<td>Suitable*</td>
<td>Probably unsuitable*</td>
</tr>
<tr>
<td>Stencilled paver (smooth)</td>
<td>Unsuitable</td>
<td>Probably suitable</td>
</tr>
<tr>
<td>Coarse stencilled paver</td>
<td>Suitable**</td>
<td>Suitable</td>
</tr>
<tr>
<td>Stippled</td>
<td>Marginal</td>
<td>Suitable</td>
</tr>
<tr>
<td>Broom</td>
<td>Appears suitable</td>
<td>Suitable</td>
</tr>
<tr>
<td>Wood float</td>
<td>Suitable</td>
<td>Suitable</td>
</tr>
<tr>
<td>Exposed aggregate</td>
<td>Suitable</td>
<td>Suitable</td>
</tr>
</tbody>
</table>

† As there is no ‘standard’ method of achieving these finishes they should be considered generic rather than specific

* Could present unacceptable difficulties for wheelchair traffic on pavements and crossing roads; poorly suitable for bicycles on residential street.

** The abrasion resistance with trafficking would determine the longevity of such a finish.

REFERENCES
For the preparation of samples refer to:


CCAA OFFICES
SYDNEY OFFICE:
Level 6, 504 Pacific Highway
St Leonards NSW Australia 2065
POSTAL ADDRESS:
Locked Bag 2010
St Leonards NSW 1590
TELEPHONE: (61 2) 9437 9711
FACSIMILE: (61 2) 9437 9470

BRISBANE OFFICE:
Suite 2, Level 2, 485 Ipswich Road
Annerley QLD 4103
TELEPHONE: (61 7) 3227 5200
FACSIMILE: (61 7) 3892 5655

MELBOURNE OFFICE:
2nd Floor, 1 Hobson Street
South Yarra VIC 3141
TELEPHONE: (61 3) 9825 0200
FACSIMILE: (61 3) 9825 0222

PERTH OFFICE:
45 Ventnor Avenue
West Perth WA 6005
TELEPHONE: (61 8) 9389 4452
FACSIMILE: (61 8) 9389 4451

ADELAIDE OFFICE:
PO Box 229
Fullarton SA 5063
TELEPHONE: (61 8) 8274 3758

TASMANIAN OFFICE:
PO Box 246
Sheffield TAS 7306
TELEPHONE: (61 3) 6491 1509
FACSIMILE: (61 3) 6491 2529

WEBSITE: www.ccaa.com.au
EMAIL: info@ccaa.com.au

LAYOUT: Helen Rix Design

Disclaimer: Cement Concrete & Aggregates Australia is a not for profit organisation sponsored by the cement, concrete and aggregate industries in Australia to provide information on the many uses of cement, concrete and aggregates. This publication is produced by CCAA for that purpose. Since the information provided is intended for general guidance only and in no way replaces the services of professional consultants on particular projects, no legal liability can be accepted by CCAA for its use.

CCAA respects your privacy. Your details have been collected to provide you with information on our activities, publications and services. From time to time your details may be made available to third party organisations who comply with the Privacy Act such as affiliated associations, sponsors of events and other reputable organisations whose services we think you may find of interest. If you do not wish to receive information from CCAA or wish to be taken off the database please write to the Privacy Officer, CCAA, Locked Bag 2010, St Leonards, NSW, 1590.