DATAsheet

JULY 2003

SLIP RESISTANCE of Residential Concrete Paving Surfaces

INTRODUCTION

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

The literature review considered the following aspects:

- what statutory requirements exist at present for slip resistance,
- the major factors affecting slip resistance of each surfacing type; and
- typical slip resistance ranges for surfacing currently in use.

The experimental work was conducted in order to:

a Determine and compare the slip resistance qualities of various concrete paving types that are used for residential streets and pavements.

b Compare these results with any established slip resistance criteria.

c Determine whether particular surface finishes or concrete paving types are more appropriate for different applications.

SLIP RESISTANCE is described as the ability of a surface to substantially reduce or prevent the risk of a person slipping.

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SLIP RESISTANCE OF SURFACES

Slip resistance is described as the ability of a surface to substantially reduce or prevent the risk of a person slipping. It is used generally to refer to those textured flooring materials that perform well in preventing slipping in both wet and dry conditions.

Pedestrian slip resistance is a complex subject where the likelihood of a slip is a function of the pedestrian surface, the environmental conditions, the individual and their physical condition, footwear, etc. There is an expectation that surfaces will provide sufficient slip resistance and this is being increasingly enshrined in legislation. Slip resistance is a highly complex area due to its multifactorial nature. The reasons for accidental falls on concrete surfaces can be divided into four categories:

- **External factors** these are essentially hazards such as lipped footpath cracks and slippery floor surfaces. These can be minimised through improved design and installation practices, better cleaning maintenance practices, safety audits, remedial policies, and mandatory legislation. Footwear may be an extrinsic factor, since inappropriate or excessively worn footwear may be the prime cause of an accident.
- **Internal factors** these would include voluntary and involuntary responses of people to environmental factors such as distractions. Such responses are also influenced by stress, fatigue medicinal and recreational drugs, and also by mood and degree of preoccupation (which may be influenced by the nature of the activity being undertaken (carrying, pushing, rushing), and whether it imposes a temporary functional limitation, eg obscured vision, impaired balance.
- **Environmental factors** include lighting conditions, contamination and slopes. The risks can be minimised by better design practices (lower gradients, less glare) and staff training (response to spills, replacement of light bulbs).
- **Pathologies** include ageing, impaired vision, instantaneous health conditions (eg stroke, heart attack, lower limb amputee), and diseases (eg Parkinson's disease).

MEASURES OF SLIP RESISTANCE

Wet Pendulum Test – Portable instrument that is used in the laboratory for classifying the wet slip resistance of new flooring (pedestrian surfaces) materials **Figure 1**. It is also used on site to assess the slip resistance of existing floors and pavings. A rubber slider is attached to a spring loaded foot at the end of a pendulum arm (leg). The pendulum arm is released, allowing it to swing so that the slider contacts the wet pedestrian surface over a set distance of 126 mm. The extent to which the pendulum fails to reach its release height on the overswing is used as a measurement of the slip resistance. The AS 4586 classifications are given in **Table 1**. **Table 2** gives the interpretation that the UK Slip Resistance Group (2000) has developed for pendulum results, where due consideration is also given to surface roughness results.

Figure 1: Wet pendulum test apparatus

Ramp Tester – Uses human subjects to subjectively assess the slip resistance of floorings under closely controlled conditions. The operator walks forwards and backwards on the ramp, progressively increasing the angle of inclination, until he/she reaches the 'zone of insecurity' where he/she either experiences slipping or senses that he/she will fall if the angle is further increased **Figure 2**. There are two principal test methods: the wet barefoot test and the oil wet test. The ramp tester is accepted as the best means of testing the slip resistance of floorings for the use in barefoot areas, such as showers and swimming pools.

Table 1 **Classification of Pedestrian Surface Materials According to the AS/NZS 4586 Wet Pendulum Test using Four S Rubber**

	Four S rubber		**Contribution of the floor surface to the risk of slipping when wet**
Class	Mean pendulum (BPN)	Coefficient of friction	
V	>54	>0.59	Very low
W	45–54	0.47–0.59	Low
X	35–44	0.36–0.46	Moderate
Y	25–34	0.25–0.34	High
Z	<25	<0.25	Very high

Table 2 **UK Slip Resistance Group Interpretation of Pendulum Test Results**

Four S pendulum value	**Potential for slip**	**TRRL pendulum value**
25 and below	High	19 and below
25 to 35	Moderate	20 to 39
35 to 65	Low	40 to 74
Above 65	Extremely low	Above 75

Oil Wet Test – Two test persons wearing standard test shoes, are used to determine the angle of inclination at which safe walking no longer occurs, after the pedestrian surface material being tested has been coated with engine lubricating oil. The test persons, each in turn, facing downhill and with an upright posture, move backwards and forwards over the test surface, as they increase their angle of inclination, until the safe limit of walking is reached. Subjective influences on the acceptance angle are limited by means of a calibration procedure.

Surface Roughness Roughness measurements are often used as a secondary indication of slip resistance potential. Harris and Shaw (1998) concluded that "The actual roughness (R_z) required to avoid slipping problems in the wet appears to be in the region of 8–10 µm". The significance of this finding lies in the implication that safer flooring can be obtained by introducing surface roughness at level small enough not to detract from the floors appearance. For an indication of the scale of roughness involved, the average diameter of a humans hair is approximately 60 µm. The (British) Health and Safety Executive now recommends a minimum R_z 20 µm for catering establishments, and has stated a preference for surfaces with a roughness of 30 µm. Research has shown that R_{pm} (the mean of several separate maximum peak height measurements) provides a better correlation than R_z with subjective human-based (ramp) assessments of slip resistance. While the use of R_z

Figure 2: The Ramp Tester uses human subjects to assess the slip resistance of surfaces under controlled conditions

surface roughness parameter is the subject of potential criticism, it is significantly easier to measure than R_{pm} and is thus more widely used.

Table 3 gives the interpretation that the UK Slip Resistance Group (2000) has developed for surface roughness results. This interpretation is always used as an adjunct to the interpretation that is derived in **Table 2**.

Table 3 UK Slip Resistance Group Interpretation of Surface Roughness Results

R_z	Potential for slip
Below 10	High
10 to 20	Moderate
Above 20 and up to 30	Low
Above 30	Extremely low

THE EXPERIMENT

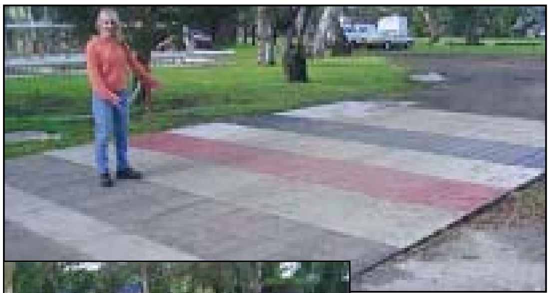
An 8 m long section of an internal road at the CSIRO site in Highett, Victoria was made available for the study. The road leads to a staff parking area and would be trafficked by about 20 vehicles a day, including a number of trucks making deliveries to the canteen.

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
0.5 m of stippled concrete buffer zone
1 m of surface 1, Stamped – slate finish
1 m of surface 2, Exposed aggregate
1 m of surface 3 Stencilled – brick paving
1 m of surface 4, Wood float
1 m of surface 5, Stamped – split-faced cobble
1 m of surface 6, Broomed
1.5 m of stippled concrete buffer zone
Southern end of 5 m wide road (gravel surface) leading to turning circle and car park.

Figure 3: The concrete pavement was placed in two stages with dowel bars along all construction joints



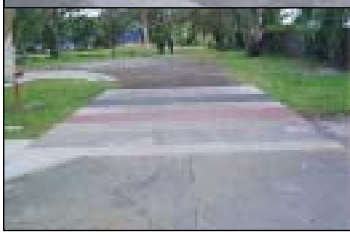


Figure 4: Completed section of the road after it was opened to traffic

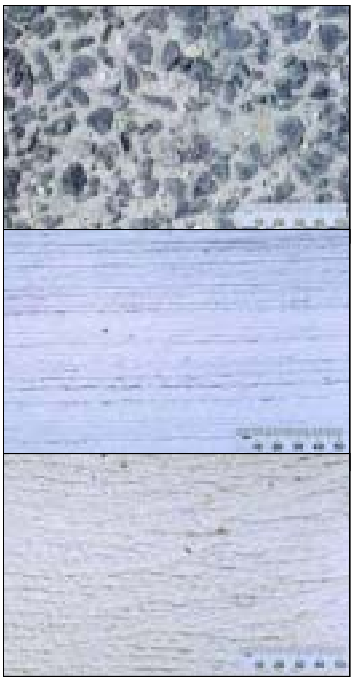


Figure 5: The exposed aggregate (top), broomed (middle) and wood floated (bottom) finishes, shown with a 50 mm scale.

The slab as shown in **Figure 3** was poured in two stages with Y12 dowel bars at 400 mm centres along all construction joints. Laboratory specimens of reinforced concrete were also cast as 500 x 400 x 50 mm slabs. The concrete strength was 32 MPa with a 60–80 mm slump.

The curing procedure was to cover all finishes with polythene sheet as they were finished and to secure it for 7 days. The completed pavement is shown in **Figure 4** and example of some of the finishes in **Figure 5**.

The slip resistance of the external concrete finishes was determined according to Appendix A of AS/NZS 3661.1:1993 *Slip resistance of pedestrian surfaces – Part 1: Requirements*. The initial tests were undertaken commencing approximately 14 days after the concrete had been poured. Further tests were undertaken after periods of 4, 12, 16 and 18 weeks.

AS/NZS 3661.1:1993 covers the Wet Pendulum, Wet/Barefoot Ramp and Oil-Wet Ramp test methods for these specimens. When testing according to Appendix A, both the Four S and TRRL rubbers were used. The RAPRA CH0001 ramp test was also conducted where the walkers wear shoes clad with untreaded Four S rubber, and running water is used as a lubricant. The above tests were conducted a month after the concrete had been poured.

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.

The surface roughness of the finishes was measured using Surtronic 10 R_z 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.

SLIP RESISTANCE RESULTS

Results for the slip resistance of the external decorative concrete finishes and for the laboratory specimens are given in **Tables 4 and 5** respectively.

It should be noted that the exact positioning of the pendulum can have a significant influence on the measurements. The variability of the individual results have been expressed as a coefficient of variation.

The surface roughness of the decorative pavements is shown in **Table 6**.

DISCUSSION AND RECOMMENDATION

There are a number of standards that provide general guidance as to what constitutes acceptable slip resistance, AS 4226—1994, *Guidelines for safe housing design*, requires external paths with slopes of greater than 1 in 20 to have a textured slip resistant finish, with rough textured concrete being a preferred material. In wet conditions, steel trowelled concrete is assessed as being very poor; wood floated as poor; and ground and broomed finishes are assessed as fair to poor. However, the marked improvement in the slip resistance of the rougher cobblestone and stencilled paver finishes highlights the difficulties in the use of generic descriptions.

AS 3661.1 was the current standard at the time of determining the in-situ slip resistance of existing surfaces. It had a wet slip resistance requirement that the coefficient of friction is 0.4 or more, using the pendulum test. AS 3661.1 has now been replaced by the standard AS 4663, which does not have any compliance criteria. Standards Australia Handbook 197 recommends that new external walkways have a wet pendulum classification of at least class W, which effectively means a minimum coefficient of 0.47. If one anticipates that some surfaces will be polished by traffic and that they might lose up to 10 BPN units, this would reduce the minimum mean slip resistance to 0.36. It is, however, quite possible that the mean 0.4 coefficient of friction requirement (a BPN of 39) will be retained for public footpaths.

In this study, the grey (stippled, broom, wood float and exposed aggregate) finishes all achieved a V classification when tested in the laboratory. However, the stippled finish only achieved a W classification when tested on the roadway using the TRRL rubber. The slip resistance of some laboratory specimens differed from that of the external pavement finishes, although this is not surprising given the high coefficients of variation. All of the finishes greatly exceeded the AS 3661.1 wet compliance requirement for a coefficient of friction of 0.4 or greater (using Four S rubber).

The ramp results suggest that where water is a contaminant, there is relatively little difference between the finishes when wearing shoes shod with Four S rubber (RAPRA test). However, there is a large difference between the grey and the initial patterned finishes for the wet barefoot tests. This highlights the potential influence of different types of footwear. The wet barefoot results indicate that the initial patterned finishes are unsuitable as swimming pool surrounds. While the original stencilled finish just failed to obtain the necessary B rating, the rougher patterned finishes achieved a

Table 4 The Slip Resistance of the External Decorative Concrete Finishes Test Method: Wet Pendulum AS 4586, Appendix A [Four S Rubber] (before trafficking) and AS 3661.1 (after trafficking) although the results have been reported in BPN with AS 4586 classifications

	Before trafficking			**4 Weeks**			**12 Weeks**			**18 Weeks**		
Finish	BPN	COV%	Class	BPN	COV%	Class	BPN	COV%	Class	BPN	COV%	Class
Slate	43	17.34	X	47	9.96	W	50	4.52	W	50	7.18	W
Cobblestone	46	7.88	W	50	11.49	W	50	11.81	W	48	12.49	W
Stencil	58	2.88	V	58	4.73	V	61	4.34	V	63	3.95	V
Stippled	51	2.48	W	55	7.31	V	60	2.87	V	59	4.67	V
Broom	55	2.2	V	63	1.81	V	65	3.82	V	65	2.92	V
Wood float	62	6.22	V	64	3.79	V	67	3.16	V	66	2.03	V
Exp aggregate	64	6.11	V	68	3.03	V	70	9.19	V	73	6.77	V

COV%: Coefficient of variation = (standard deviation/mean)%

Table 5 The Slip Resistance of the Internal Decorative Concrete Laboratory Specimens Tested According to AS/NZS 4586

	Wet Pendulum Four S			**Wet Pendulum TRRL**			**Wet Barefoot Ramp**		**Oil Wet Ramp**		**RAPRA**
Finish	BPN	COV%	Class	BPN	COV%	Class	Angle	Class	Angle	Class	Angle
Slate	49	12.28	W	27	26.19	†	16	A	8.3	R9	31.0
Cobblestone	45	3.18	W	31	10.94	†	18*	A	14.7	R10	33.0
Stencil	57	4.89	V	38	8.51	†	19*	A	19.7	R11	35.3
Stippled	61	4.94	V	69	3.12	V	40	C	38.6	R13	39.1
Broom	61	2.00	V	66	3.02	V	40	C	37.5	R13	39.4
Wood float	57	4.63	V	69	0.88	V	42	C	39.2	R13	39.4
Exp aggregate	75	5.72	V	81	3.22	V	43	C	40.7	R13	40.6
Cobblestone 2	61	5.79	V	70	9.01	V	37	C	30.1	R12	39.2
Stencil 2	63	3.00	V	79	7.16	V	36	C	35.6	R13	41.6

† *Surfaces with BPN of 39 or less do not receive a classification when the TRRL rubber is used.*
* *These finishes did not achieve a B rating because the angles achieved were slightly lower than that obtained for the B calibration board.*

Table 6 The R_z Surface Roughness of the External Decorative Concrete Pavements (using a cut-off length of 0.8 mm)

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

* *The mean R_z surface roughness of the cobblestone 2 and stencil 2 laboratory specimens were 49.9 and 61.8 microns respectively*

Table 7 **Interpretative Summary of the Experimental Results**

Finish†	Suitability for residential streets	Suitability for public footpaths
Slate	Unsuitable	Unsuitable
Cobblestone (smooth)	Unsuitable	Probably unsuitable*
Rough cobblestone	Suitable*	Probably unsuitable*
Stencilled paver (smooth)	Unsuitable	Probably suitable
Coarse stencilled paver	Suitable**	Suitable
Stippled	Marginal	Suitable
Broom	Appears suitable	Suitable
Wood float	Suitable	Suitable
Exposed aggregate	Suitable	Suitable

† *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.*

much higher C rating, although the finishes were so rough as to the point of being painful. There is obviously an intermediate range where the finishes would provide adequate wet barefoot slip resistance.

SA HB 197 recommends that external walkways should have ramp rating of R10. The slate finish failed to achieve this, and was thus rated unsuitable. SA HB 197 also recommends that external ramps should have a rating of R11. This recommendation would also be applicable to some sloping footpaths, particularly where the slopes are severe. The initial cobblestone finish failed to achieve an R11 rating, while the initial stencilled finish just achieved it.

ROUGHNESS measurements are often used as a secondary indication of slip resistance potential.

CONCLUSION

Caution should be exercised in using generic classification when determining whether or not products are suitable for a specific purpose.

The heterogeneous nature of decorative concrete surface finishes could lead to high coefficient of variation in slip resistance measurements.

The stippled, broom, wood float and exposed aggregate finishes generally provided excellent pedestrian slip resistance according to all interpretive criteria. The original patterned finishes (stamped slate, stamped cobblestone and stencilled brick paver) were less resistant than the grey finishes. The coarser stamped cobblestone and stencilled brick paver surfaces gave results that were close to those obtained for the stippled, broom and wood float finishes.

The wet barefoot ramp testing indicated that the original patterned finishes were not suitable for swimming pool surrounds.

The oil-wet testing indicated that the slate finish was not suitable for external walkways and that the stamped cobblestone finish was not suitable for external ramps and sloping walkways.

The stencilled finish was found to be the most suitable patterned finish for pedestrian applications.

The slip resistance of the decorative concrete finishes were measured approximately 56 weeks after the concrete was laid. It was concluded that the slip resistance (measured in accordance with AS 4663) has either improved or remained unchanged for all the surfaces tested.

REFERENCES

Harris, G W and Shaw, S R (1998) *Slip resistance of floors: User's opinions, Tortus Instrument readings and roughness measurements.* J. Occupational Accidents, 9 (1998) 287–298.

Standards Australia (1993) AS/NZS 3661.1—1993 *Slip resistance of pedestrian surfaces – Requirements.*

Standards Australia (1994) AS 4226—1994 *Guidelines for safe housing design.*

Standards Australia (1999) AS/NZS 4586—1999 *Slip resistance classification of new pedestrian surface materials.*

Standards Australia (1999) Standards Australia Handbook 197:1999, *An introductory guide to the slip resistance of pedestrian surface materials.*

Standards Australia (2002) ASNZS 4663—2002 *Slip resistance measurement of existing pedestrian surfaces.*

Abbreviations

Four S	Simulated Standard Shoe Sole
TRRL	Transport Road Research Laboratories
RAPRA	Rubber and Plastic Research Association in the UK. Now it is RAPRA Technologies Pty Ltd

IMPORTANT SAFETY INFORMATION

When handling and using cement or fresh concrete, avoid skin contact. Wear suitable protective clothing.

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