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SLIP RESISTANCE of Polished Concrete Surfaces

INTRODUCTION

Slip resistance of floors and pavements is a measure of the ability of a surface to resist accidental slipping by pedestrians – in dry or wet conditions. There is an expectation that surfaces will provide adequate slip resistance and this is increasingly being incorporated into regulations.

Polished concrete floors[1] is a generic term that describes a variety of exposed decorative concrete flooring options often having a highly polished or gloss surface finish. With the increasing popularity of these types of finishes the issue of providing adequate slip resistance has become an important consideration.

This data sheet examines the factors influencing the slip resistance of a surface and methods of measuring, specifying, achieving, maintaining and improving slip resistance. It focuses on the factors related to the concrete floor or pavement surface that impact on the risk of slipping, which include the surface finish, texture and applied sealer (if present) that combine to produce a final surface roughness.

A number of case studies have been examined to determine the factors contributing to whether or not the specified slip resistance was achieved.

Information on the slip resistance of other decorative residential concrete paving surfaces has already been published[2].

Slip resistance of floors and pavements is a measure of the ability of a surface to resist accidental slipping by pedestrians – in dry or wet conditions.

FACTORS INFLUENCING SLIP RESISTANCE

Pedestrian slip resistance is a complex subject, where the likelihood of a slip is a function of a variety of factors such as the surface (type and texture), the environmental conditions, and the individual users (their physical condition and footwear). The reasons for accidental falls on concrete surfaces can be divided into four categories:

- **External factors.** These are essentially hazards such as stepping (vertical displacement) at footpath cracks and other slab joints, slippery floor surfaces and slopes. These can be minimised through good design and installation practices, good cleaning and maintenance practices, safety audits, remedial policies, and mandatory legislation. Footwear may be considered an external factor, since inappropriate or excessively worn footwear may be the prime cause of an accident.

- **Internal factors**. These include voluntary and involuntary responses of people to environmental factors such as distractions. Responses may also be influenced by stress, fatigue, medicinal and recreational drugs, and also by the person's mood and the 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 or impaired balance**.**

- **Environmental factors**. These include lighting conditions, contamination of the surface (by water or other materials) and slopes. The risks can be minimised by good design practices (lower gradients, less glare) and staff training (response to spills, replacement of light bulbs).

- **Pathological factors**. These include ageing, impaired vision, physical disabilities, instantaneous health conditions (eg stroke, heart attack), and diseases (eg Parkinson's disease).

Sufficient micro-roughness is necessary to provide the frictional force or 'grip' required to prevent footwear (and bare feet) from slipping. Micro-roughness is the irregularities in a walking surface, often invisible to the naked eye, with a surface roughness (R_z) typically between 10 μm and 100 μm as measured by a surface roughness meter. The coarser the surface roughness, the greater will be the slip resistance, especially when contaminated by water or a range of other substances. This is dealt with in more detail in the section on improving slip resistance.

MEASURING SLIP RESISTANCE

While the surface roughness can be measured, the two common methods used to assess wet slip resistance are the wet pendulum test, which measures the frictional force offered by simulating a foot moving over a water-contaminated surface, and the ramp test, which determines the maximum gradient at which a person can just traverse the surface, either barefoot (wet barefoot test) or in shoes (oil-wet test). AS/NZS 4586[3] also includes a friction test method for dry floors. Since most floors will provide adequate slip resistance when clean and dry, this test is not commonly specified.

Wet Pendulum Test This test (AS/NZS 4586) is generally used in the laboratory for classifying the wet slip resistance of new flooring (pedestrian surface) materials. However, as the test instrument is portable **Figure 1**, it can also be used on site to assess the slip resistance of existing floors and pavements (AS/NZS 4663[4]).

The instrument has a rubber slider attached to a spring-loaded foot at the end of a pendulum arm (leg). The pendulum arm is released from a horizontal position, 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 reading on the scale is the British Pendulum Number (BPN).

The AS/NZS 4586 classifications for slip resistance based on this test using a Four S (simulated standard shoe sole) rubber are given in **Table 1**. Note that a TRL (Transport Research Laboratory) rubber can also be used (listed in Table 2 of AS/NZS 4586) but the results are sensitive to temperature and a correction must be applied. A Four S rubber is typically specified as it is generally considered to best differentiate between the slip resistance of smoother surfaces. The TRL rubber is sometimes used when considering wet barefoot slip resistance.

Figure 1 Wet pendulum test apparatus

TABLE 1 Classification of Pedestrian Surface Materials according to AS/NZS 4586 *Wet Pendulum Test using Four S Rubber* (after AS/NZS 4586)

Class	Mean BPN	Coefficient of friction
V	>54	>0.59
W	45–54	0.47–0.59
X	35–44	0.36–0.46
Y	25–34	0.25–0.34
Z	<25	<0.25

Ramp Tests These tests use human subjects to subjectively assess the slip resistance of pedestrian surfaces under closely controlled conditions. The subjects walk forwards and backwards on a ramp **Figure 2** while the operator progressively increases the angle of inclination, until the subjects reach the 'zone of insecurity' where they either experience slipping or sense that they will fall if the angle is further increased. The angles of inclination reached are used to assess the friction characteristics of the test surface. The test is not intended to provide guidance on the angle of ramps for which a particular classification is suitable.

There are two principal test methods: the wet barefoot test and the oil-wet test.

- **Wet Barefoot Test** For the test procedure described above, the subjects are barefoot and water is applied to the surface being tested. This method is accepted as the best means for assessing the slip resistance of materials that are intended for use in barefoot areas, such as showers and swimming pools.
- **Oil-Wet Test** This involves coating the material surface with engine lubricating oil, and having two test subjects wearing standard test shoes, walking forwards and backwards on the ramp to determine the inclination at which safe walking is no longer possible. Facing downhill and with an upright posture, each subject in turn moves backwards and forwards over the test surface as the angle of inclination is gradually increased, until the safe limit of walking is reached. Subjective influences on the acceptance angle are limited by means of a calibration procedure. This test method is accepted as the best means for assessing the slip resistance of materials that are intended for use in industrial premises, where the nature and extent of the contamination can be predicted, and staff can be compelled to wear appropriate footwear.

Figure 2 A ramp test being conducted

SPECIFYING SLIP RESISTANCE

General Slip resistance is typically specified by nominating an appropriate class from those listed in AS/NZS 4586 test methods. To assist with this decision, HB 197 Table 3[5] gives guidance on the appropriate classes of slip resistance for a variety of applications. The relevant classification and test method for various end uses is given below.

Since the wet pendulum test will always be used for conducting slip resistance audits (and accident investigations) it is recommended that the slip resistance of polished concrete be specified in terms of the AS/NZS 4586 wet pendulum classifications.

Sloping surfaces and ramps should be given special consideration. The Building Code of Australia[6] requires that ramps must have a non-slip finish, and limits the maximum gradient of accessible ramps for disabled access to 1 in 14. In any other case, the maximum gradient is 1 in 8.

AS 1428.1[7] requires that the gradients and crossfalls of the surface area within a landing or circulation space shall not exceed 1:40.

Slopes of 1 in 100 to 1 in 40 are typically provided in surfaces, both internal and external. Surfaces with slopes of 1 in 20 (about 3°) to 1 in 8 are regarded as accessible ramps and require safety features such as handrails and tactile ground surface indicators[8]. Some surfaces with slopes between these two ranges (ie 1 in 40 to 1 in 20) may warrant particular attention since they present a higher slip hazard but without the safety features associated with ramps, eg handrails.

General Pedestrian Areas These include areas such as courtyards, paths, walkways, driveways and the entrances to and circulation areas within publicly accessible buildings. When specifying polished concrete floors in general pedestrian areas, the guidance in HB 197 should be considered before specifying that the concrete have the appropriate Class V, W, X, Y or Z slip resistance in accordance with the wet pendulum test, Four S rubber **Table 1**. As the risk of slipping depends on many factors, the designer must consider to what extent various other design decisions will influence the overall risk of slipping when the concrete is wet (or contaminated).

External public areas and walkways generally require a Class W slip resistant surface, in order to ensure that the floor does not make a high contribution to the risk of slipping when wet. Class W surfaces were specified for all the external case studies examined in this Data Sheet (see *Achieving Slip Resistance*) and is recommended in HB 197. For entrance areas and other interior situations, such as bars/taverns and food court areas, where occasional contamination may occur, HB 197 recommends Class X surfaces. This is appropriate where the risk of slipping when wet is mitigated by promptly cleaning up spills and rainwater. For interior floors such as hotel foyers, offices, supermarket aisles and other public buildings/areas that are maintained in a clean and dry condition, the risk of contamination is very low and HB 197 recommends Class Z as an appropriate level of slip resistance.

Similarly, for polished concrete floors in residential applications where any spills are generally spot cleaned immediately to maintain the surface in a dry condition, Class Z would also be appropriate. Bathrooms and other 'wet' areas would generally require a Class X slip resistance.

While the wet pendulum test classifications are suitable for surfaces that have a maximum 1 in 20 slope, HB 197 recommends the use of Class V for external ramps (ie steeper than 1 in 20). HB 197 also has an appendix that details a method for calculating the slip resistance class required for ramps. The procedure is as follows:

1. Convert the required BPN value of the 'level' surface to a coefficient of friction, μ equal to 3P / (330 – P), where P is the recommended BPN value for the level surface
2. To allow for the slope, increase the value of μ by an amount equal to the slope (expressed as a percentage) multiplied by 0.0125.
3. Convert the resulting coefficient of friction back to a BPN value equal to 330μ / (3 + μ)
4. Select the appropriate slip resistance class.

EXAMPLE 1

If a floor is required to have a Class X slip resistance and part of the area has a 1 in 20 slope, is it appropriate to specify Class X for the entire floor?

Step 1 Class X has a minimum required BPN of 35.
μ = 3 x 35 / (330 – 35) = 0.356

Step 2 For a slope of 1 in 20 or 5% calculate the increased coefficient of friction required
μ = 0.356 + 5 x 0.0125 = 0.419

Step 3 Required BPN for sloping section
= 330 x 0.419 / (3 + 0.419) = 40.4.

Step 4 As the BPN is still within the range for Class X slip resistance (35 to 44), a higher class may not be required for the part of the floor with a slope of 1 in 20. Note that this is consistent with the wet pendulum test being satisfactory for surfaces having a maximum 1 in 20 slope.

EXAMPLE 2

Class W slip resistance is recommended for external accessible paths of travel. If a path of travel contains a ramp with a 1 in 14 slope, is Class W appropriate for both the level areas and the ramp?

Step 1 Class W has a minimum required BPN of 45
μ = 3 x 45 / (330 – 45) = 0.474

Step 2 For a slope of 1 in 14 or 7.14% calculate the increased coefficient of friction required
μ = 0.474 + 7.14 x 0.0125 = 0.563

Step 3 Required BPN for sloping section
= 330 x 0.563 / (3 + 0.563) = 52.2.

Step 4 As the required BPN of 52.2 is still within the range for Class W (45 to 54 BPN), the area containing the ramp could be specified as Class W, with a minimum of 53 BPN. However, as BPN 53 is close to the upper limit of the range, it is probably easier to specify the next Class up (Class V) to ensure the minimum 53BPN is achieved. This is consistent with HB 197 (Table 3) recommendation of Class V.

EXAMPLE 3

If part of an external footpath has a 1 in 8 slope, is Class W appropriate for the entire footpath?

Step 1 μ = 0.474 (as in Example 2)

Step 2 For a slope of 1 in 8 or 12.5% calculate the increased coefficient of friction required
μ = 0.474 + 12.5 x 0.0125 = 0.630

Step 3 Required BPN for sloping section
= 330 x 0.630 / (3 + 0.630) = 57.3.

Step 4 As the required BPN of 57.3 is outside the range for Class W (45 to 54), the steeply sloping portion of the footpath should be specified as Class V.

Note that for Class Z where no range of BPNs is given, any increase in the slope will require a minimum Class Y slip resistance. Also, the same procedure can be used to modify the dry floor friction values to account for sloping areas.

The wet pendulum test may be used within a range of ±10° from level (slope of about 1 in 5.7). When assessing whether or not a sloping surface has adequate slip resistance, use the same procedure as in the examples above, and compare the obtained result with the required BPN. The AS/NZS 4586 wet pendulum test can be used to check the compliance of new surfaces, while the AS/NZS 4663 wet pendulum test can be used to monitor changes in the slip resistance over time. For measuring the slip resistance of slopes steeper than 10°, a flatter area either at the top or bottom of the ramp (having the same surface texture and roughness as the slope) may need to be used for the test.

An alternate approach for ramps is to specify a Class R10 for dry internal ramps, or an R11 or R12 for external ramps **Table 2**. However, since the oil wet ramp test can only be conducted in the laboratory, compliance can only be assessed by secondary means such as wet pendulum tests and R_z surface roughness measurements. HB 197 contains recommendations for specific locations in terms of the R9 to R13 classifications. **The angles do not relate to the steepness of the ramp that can be safely traversed.**

TABLE 2 Classification of Pedestrian Surface Materials According to the Oil-Wet Ramp Test *(after AS/NZS 4586)*

Classification	**Angle** (degrees)
R9	≥6 <10
R10	≥10 <19
R11	≥19 <27
R12	≥27 <35
R13	≥35

TABLE 3 Classification of Pedestrian Surface Materials According to the Wet/Barefoot Ramp Test *(from AS/NZS 4586)*

Classification	**Angle*** (degrees)
A	≥12 <18
B	≥18 <24
C	≥24

**Note that these are the nominal angles for the calibration boards on which finishes are applied. The classification of a sample is based on the results that the walkers obtained for the calibration boards.*

Surfaces Intended Specifically for Barefoot Use

These should be specified as having a slip resistance Class A, B or C in accordance with AS/NZS 4586, wet/barefoot ramp test **Table 3**.

HB 197 contains recommendations for specific locations in terms of the A, B and C classifications. As with the oil-wet test, this test is used merely to assess the relative slip resistance of level surfaces. A higher classification may be appropriate in the case of sloping surfaces. Table 4 in HB 197 provides guidance on classifications required for particular applications. Examples include:

Class A Barefoot passages (mostly dry), changing and locker rooms, swimming pool floors where water depth >800 mm.

Class B Barefoot passages not covered by Class A, shower rooms, pool surrounds, swimming pool floors where water depth <800 mm, toddlers' paddling pools, some stairs leading into the water

Class C Walk-through wading pools, sloping pool edges

Commercial and Industrial Applications As floors in many businesses and industrial applications can be subjected to a wide range of contaminants, their slip resistance is normally specified in accordance with the oil-wet ramp test **Table 2**. This test is used merely to assess the relative slip resistance of surfaces and the classifications are applicable to level surfaces. (Note: Oil-wet ramp test can only be conducted in the laboratory and compliance can only be assessed by secondary means such as the wet pendulum test). The wet pendulum test is the most appropriate means of specifying the slip resistance of concrete surfaces.

Table 5 in HB 197 gives guidance on suitable classifications for various commercial and industrial applications. HB 197 often recommends that surfaces should have a minimum displacement volume determined in accordance with AS 4568 Appendix E. Where it recommends a profiled surface, such as an R11 and V4 finish for car wash areas, it is best to go to a higher classification, in this case R12.

Examples include:

Class R9 Dining rooms, shops, operating theatres, hairdressing salons, classrooms.

Class R10 Entrance areas in public buildings where moisture can enter from the outside. Social facilities (toilets, washrooms), some kitchens, most bathrooms and wash facilities, garages, and covered areas of multi-storey carparks.

Class R11 Laundry areas, florist shops, vehicle repair workshops, aircraft hangers.

Class R12 Most food processing/production facilities and large commercial kitchens.

Class R13 Slaughtering, processing of meat, fish and vegetables.

ACHIEVING THE DESIRED SLIP RESISTANCE

When specifying the slip resistance of polished concrete surfaces, an optimization of appearance and required slip resistance needs to be made. For example, high gloss finishes may not achieve the required slip resistance for some applications. It is therefore important to consider the slip resistance offered by the combination of finish, texture and sealer (if present) so that the slip resistance and finish requirements can be realistically specified and achieved. The advice of a hard-flooring specialist may be sought regarding the appropriate combination of finish, texture and sealer for the slip resistance performance required.

To provide some guidance, numerous case studies have been carried out to determine what effect variations in the finish, texture and sealer have on the slip resistance. A summary of these case studies is presented in **Table 4.** The studies highlighted the following specific points, which should be considered when specifying and constructing slip resistant concrete finishes.

- For external pavements, wet pendulum Class W finishes were consistently specified. A honed finish at 80–100 grit with a penetrating sealer applied gave satisfactory slip resistance. Honed finishes and penetrating sealers give consistent results due to the uniform texture provided.
- Concrete finishes that are honed with a finer grit provide lower slip resistance and therefore increased risk of slipping when the floor is wet.
- Honed finishes generally provide satisfactory results in accordance with the recommendations in HB 197, but may be rendered inadequate by the application of a surface coating.
- Unsealed surface. The case studies revealed BPNs typically greater than 54 where appropriately honed surfaces remained unsealed. However, increased wear over time and resultant polishing of the surface, or loss of texture-providing aggregates should be considered.
- Surface coatings or other products that form a film on the surface generally give unsatisfactory results.
- For large areas, the sealer should be applied to a sample spot and slip resistance tested prior to the application of the sealer to the entire area. This is especially true for coating type sealers as they generally provide much lower slip resistance.
- Penetrating sealers provide better results than those that form a coating or film on the surface. They also assist in maintaining slip resistance by maintaining the surface roughness.
- Rougher textures generally provide higher slip resistance results, but may be harder to clean.
- Uniform application of sealer is important as this will give consistent slip resistance results over the surface. Note that variable slip resistance is considered to be a hazard.
- Applied coating with aggregate broadcast into the coating must have the aggregate distributed uniformly to avoid variable slip resistance.
- Surface wear may decrease slip resistance by either polishing the surface or removing texture-providing aggregate from the surface. Basic concrete quality issues must therefore be addressed to ensure durability of the surface (refer to *Further Information*)
- Polished surfaces used in foyer areas should have matting at all entries to try and remove water and dirt walked in by the public. Spot cleanup with clean mops or cloths should also be undertaken as required.
- Use of colour pigments in the concrete does not affect the slip resistance.
- Broom finishes provide greater slip resistance across the grain than along it. This finish should therefore be provided normal to the direction of pedestrian movement if possible.
- Stamped and broom finishes give similar slip resistance results as only the micro-roughness of the surface contributes to slip resistance.
- Abrasive blasted finishes can provide variable results due to uneven removal of surface mortar. They are generally suitable only for external use due to the aggressiveness of the finished surface and difficulty in maintaining these types of finishes internally.
- Finishes must suit the application. Rough finishes should be used only where constant contamination with water or other liquids/solids is present.
- Ramps may require increased roughness.

TABLE 4 Slip Resistance Achieved in Various Applications (tested at completion of construction)

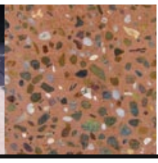
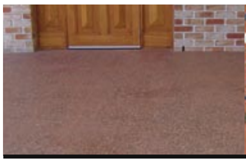
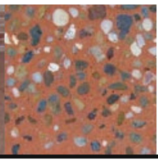
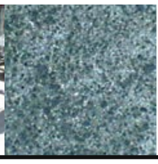
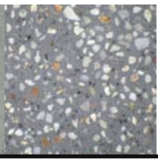
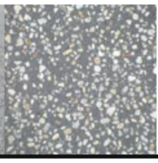
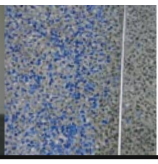
Concrete			Slip Resistance		
Finish	**Sealer**	**Recommended Maintenance**	**Specified** Mean BPN	**Achieved** BPN (Mean BPN)	**Comments**
Honed at 80–100 grit External path  	Penetrating type	High-pressure clean when required	45–54	64–67 (65)	Satisfactory. Coarser grit provides better results
Honed at 300 grit Covered patio  	Penetrating type	High-pressure clean when required	45–54	47–57 (52)	Satisfactory
Honed External shopping centre walkway  	Surface coating with aggregate broadcast over surface	Sweep daily High-pressure clean every 3 months or when required	45–54	15 tests done (65–66)	Very consistent results achieved. Areas with coating but no aggregate were unsatisfactory
Honed at 80–100 grit External path at university campus  	Unsealed	High-pressure clean when required	45–54	Plain concrete 62–64 (63)	Very good slip resistance
				Colour pigments used 62–65	Use of colour pigments does not affect results
Honed at 80–100 grit External path at university campus  	Penetrating type	Follow sealer manufacturer's recommendation for cleaning	45–54	67–72 (69)	Clean surface gives better results
Honed at 200 grit Public area exposed to weather  	Surface coating type	High-pressure clean when required	45–54	Test area 1 35–45 (41)	Unsatisfactory Honed too fine for exterior area, wrong sealant used and better cleaning procedure required
				Test area 2 30–34 (32)	Very unsatisfactory

Table 4 continues

TABLE 4 Slip Resistance Achieved in Various Applications (tested at completion of construction) *continued*

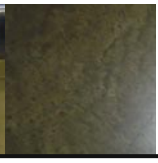
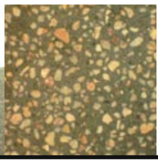
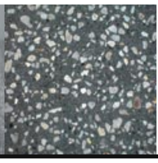
Concrete: Finish	Concrete: Sealer	Recommended Maintenance	Slip Resistance: Specified Mean BPN	Slip Resistance: Achieved BPN (Mean BPN)	Comments
Steel trowelled (polished) Covered carpark 	Unsealed (vehicle ramps) 	Carpark sweeper at maximum 3 month intervals. Annual degreaser scrub	R10	2 tests done 50 and 57	Underground carpark. Drainage should ensure that parking areas stay dry. Should consider abrasive blasting designated walkways within the carpark, with use of a penetrating type sealer
	Surface coating type (parking areas) 	As above	As above	5 tests done 21–36	Unsatisfactory. Remediation required unless the parking areas remain dry on rainy days
Honed Interior surface at university campus 	Surface coating type 	Auto scrub nightly	35–44	36–40 (39)	Satisfactory Suggest matting at doors to remove water on wet days
Honed External path 	Penetrating type 	High-pressure clean when required	45–54	61–63 (62)	Very good slip resistance
Honed Domestic driveway at 25.4% grade 	Unsealed 	High-pressure clean when required	>54 specified. Note that this equates to 76 on a 25.4% gradient	Tests on flat surface at top of driveway 63–67 (65)	While this concrete offers significant slip resistance on flat surfaces, it is probably just satisfactory for the slope. Could consider abrasive blasting to increase roughness or use of a non-slip coating. Ensure inserts in the concrete also have an adequate slip resistance
Honed Grit unknown	Unsealed	High-pressure clean when required	45–54	54–67	Honed finish satisfactory
Polished	Surface coating type	Hose down nightly. Mechanically scrub weekly. High-pressure clean monthly	45–54	35	Surface coating type sealer gives unacceptable results.
	Penetrating type	As above	As above	68	Penetrating type sealer gives much better results.

Table 4 continues

TABLE 4 Slip Resistance Achieved in Various Applications (tested at completion of construction) *continued*

Concrete			Slip Resistance		
Finish	**Sealer**	**Recommended Maintenance**	**Specified** Mean BPN	**Achieved** BPN (Mean BPN)	**Comments**
Polished Entry foyer	Surface coating type	Auto scrub nightly	35–44	26–46 (34)	Large range of results with mean less than specified range. May cause a high contribution to the risk of slipping when wet. Provide matting at entry foyer to remove water.
Wooden float Loading bay at shopping centre	Unsealed	High-pressure clean every 3 months or when required	45–54	55–62 (60)	Very good slip resistance. Rougher texture provided better results
Honed External shopping centre walkway	Surface coating type	High-pressure clean every 3 months or when required	45–54	23–33 (26)	Most unsatisfactory. Remove coating, regrind at 80–100 and use penetrating type sealer.
Honed at 120 grit Public tavern	Sealed (type unknown)	Mechanically scrub each night. Spot clean with mop as required during trading	35–44	33–41 (38)	Marginal. Needs to be well maintained and audited.
Honed Internal walkway to community centre	Surface coating containing aggregate	Auto scrubber with cylindrical head (to remove contamin-ants from between the aggregate)	35–44	64–71 (66)	Very good slip resistance. Aggregate in sealer gives good results and prevents polishing of surface.
Polished Concrete in change rooms	Epoxy paint coating	Mop during hours of operation if becomes wet. Hose after hours of operation	35–44	43–59 (50)	Variability due to application of epoxy paint. Poorest result still satisfactory.
Honed Coloured concrete to public external walkway	Surface coating with aggregate broadcast over surface	High-pressure clean every 3 months or when required	45–54	(47)	Marginal. Results were variable due to uneven coating of aggregates.
Stamped finish with light acid etch External	Matt finish surface coating	EXTERNALLY: Regular hosing High-pressure clean every 3 months INTERNALLY: Auto scrub nightly Spot clean with mop during day	Sample only	52–56 (54)	Results were consistent due to uniform application of sealer.
Stamped finish External	Penetrating type	High-pressure clean every 3 months or when required	Sample only	60–65 (63)	Good slip resistance due to use of penetrating type sealer.
Broom finish External	Penetrating type	As above	Sample only	59–65 (61)	Better results (65) achieved across the grain rather than along the grain.
Abrasive blast finish External	Penetrating type	As above	Sample only	60–66 (62)	Results varied due to depth of removal of surface.
Exposed aggregate finish by water washing External	Penetrating type	As above	Sample only	61–74 (65)	Results varied due to varying degrees of aggregate exposure.

MAINTAINING FLOORS AND SLIP RESISTANCE

Floor surfaces need appropriate maintenance to ensure that the required slip resistance is not reduced by contamination or wear. As most level polished concrete floors will have adequate slip resistance if clean and dry, preventing contamination and, if it occurs, limiting its spread and effects should be considered.

The selection of appropriate cleaning procedures will depend on the surface roughness, likely contaminants and the size of the areas to be cleaned. The recommendations of product manufacturers in relation to the type of surface to be cleaned should be followed.

The following points should be considered when establishing a cleaning and maintenance programme:

- **Cleaning procedure.** This should not increase the risk of slipping, eg by leaving areas wet. Cleaning of public areas is thus best carried out after trading; if small cleanups are required during trading hours, the surface should be left dry.
- **Surface roughness**. As the ability to clean gross contamination from a floor is not linked to the surface finish, both smooth and rougher textures can be effectively cleaned. Thus in food preparation areas subject to regular spills, rougher textures which provide greater slip resistance can still be adequately cleaned.
- **Microbial cleaning.** Research reported by CIRIA[9] indicates that there are two stages of cleaning: removal of visible gross soiling (the main source of physical contamination and slip hazards and a barrier to subsequent disinfection), and removal of microbial contamination. Microbial cleaning was also found to be a function of the contamination rather than the finish, and can not be assessed by measurement of the surface roughness. The conclusion reached is that 'it is possible to select a floor that possesses good slip resistance while also having good hygiene characteristics in terms of cleanability'. While normal sealers may not be suitable for such applications, the use of a sealed epoxy finish could be considered.
- **Floor polish.** The regular application of floor polish will tend to fill surface roughness and reduce slip resistance. For polished finishes with low surface roughness, even a few layers of polish can significantly reduce the slip resistance. The reduced slip resistance may be satisfactory for dry floors, but in other situations it is recommended that the surface simply be coated with a durable sealer and maintained with regular sweeping and cleaning. When re-coating is required, the existing sealer should be removed and the new one applied to avoid a buildup on the surface. Note that penetrating sealers are largely protected by the abrasion resistance of the concrete itself and therefore tend to have a good service life.
- **Avoid contamination.** The use of tools such as entrance matting to reduce the ingress of contamination and packing products in containers that will not break if dropped are all simple techniques to reduce the risk of slipping.

Generally, food preparation areas will require a daily wet scrub or wash with hot water and neutral detergent. Disinfectant may also be required. Other areas may require only a damp mop and spot clean daily, more extensive cleaning weekly with a mop and water/detergent solution, and periodic machine cleaning at intervals of one to three months – depending on the nature of the contamination.

The main methods of cleaning floors include:

- **Spot cleaning.** Paper towel or rag used to clean up minor water-based contamination and prevent spreading.
- **Mop.** Generally suitable only for smooth floors having surface roughness <20 μm. Smooth floors must be left dry, dirty mops must themselves be cleaned regularly and simple mopping may not remove all greasy/oily deposits.
- **Machine.** Scrubber-driers come in three main categories: rotary action, contra-rotating (two brushes in opposite directions) and cylindrical. They are an effective way to clean large areas but the type of cleaner must suit the floor surface and design, and all areas must be accessible. The squeegee must be able to recover all water, so their suitability for rough or highly profiled surfaces should be confirmed. Contra-rotating machines suit areas having recessed joints, small amounts of debris, high levels of dust and irregular features, while cylindrical machines are best for very smooth and flat surfaces having no debris. With the variety of materials available for brushes and designs of machines, final selection may depend on actual field trials.
- **Hose cleaning.** High-pressure water is suitable for dusty or 'doughy' contaminants, with detergents added for greasy/oily contamination. Note that the slip resistance of the surface must be adequate to cope with a wet surface. Where products fall far short of the specified wet slip resistance, extreme care should be taken in hosing down surfaces. Alternative cleaning procedures may need to be identified in order to comply with water restrictions.
- **Wet vacuum.** While suitable for liquid spills, drying of the surface may also be required.
- **Dry vacuum.** Suitable for dusty contaminants, especially on rough surfaces.
- **Sweeping.** May spread contaminants and be ineffective on rougher floors and is generally not recommended, especially in areas where airborne dust may cause health problems. May be used effectively to remove some solid contaminants prior to washing.

- **Scouring pad.** May increase removal of contaminant but cause wearing of any surface coatings or sealers.
- **Squeegee.** May spread greasy/oily contaminants and leave rough surfaces wet.
- **Detergent.** Used for removal of greasy/oily contaminants. Should be selected in accordance with the expected contamination and manufacturer's recommendations should be followed.

While each application will require its own cleaning procedure, case studies of various pavements **Table 4** indicate that a suitable procedure for public areas that may give acceptable slip resistance is as follows:

- Spot cleaning using mops. Note that mops are not recommended for general cleaning as they tend to spread contaminants over the surface.
- Clean daily (typically by hosing at night after trading) and high-pressure clean every one to three months depending on level of contamination. More-regular hosing may be required depending on frequency of contamination during the day. For carparks a yearly degreaser scrub may also be needed.
- Preferred method of cleaning is with an auto scrubber fitted with squeegee and vacuum system in order to pick up contaminants from the surface. For applications such as shopping centres this should be done nightly, with other floors/pavements such as building foyers on a weekly basis if possible.
- Use of manufacturer's recommended chemical cleaners will generally provide more efficient removal of contaminants and better slip performance.

REINSTATING AND IMPROVING SLIP RESISTANCE

There may be a number of reasons why new or existing surfaces fail to comply with a specified slip resistance. Generally it involves the lack of adequate surface texture/roughness caused by such factors as inappropriate specification of the concrete finish and/or sealer, contamination of the surface, or wear over time causing either polishing of the surface or removal of surface aggregates that contribute to the roughness of the finish.

As there is a direct link between the texture or roughness of the surface and the slip resistance **Table 5**, most remedial measures basically involve increasing the surface roughness, and thereby surface friction and slip resistance. Research has found that the actual roughness of the surface required to avoid a high slip potential when wet appears to be about 10 µm (0.01 mm), with CIRIA suggesting that under normal walking conditions a minimum value of 20 µm delivers a low (noted as a risk of one in a million) potential for slip when wet. Whilst this guidance[9] is valid for many floor surfaces, some floor surfaces can give very good wet slip resistance even though their R_z surface roughness is less than 10 µm. Similarly floor surfaces can have a high slip potential even though their measured R_z roughness is greater than 20 µm. This is because the nature of the surface roughness (eg sharpness, spacing etc.) will influence the coefficient of friction. It is therefore imperative that surface roughness measurements should not be relied upon of themselves to judge the likely slip resistance of the floor[10]. Putting these roughness values into perspective, the diameter of a human hair is approximately 60 µm. The significance of this finding lies in the implication that safer surfaces can be obtained by a surface roughness fine enough not to detract from the appearance.

TABLE 5 British interpretation of wet pendulum and R_z surface roughness test results for water wet conditions

Four S Rubber (Mean BPN)	**Surface roughness, R_z** (µm)	**Potential for slip**
≤25	≤10	high
25 to 35	10 to 20	moderate
35 to 65	20 to 30	low
>65	>30	extremely low

As some burnished concrete and ground and polished terrazzo finishes may have roughness values of only 3 to 5 µm, the floor surface may make a high contribution to the risk of slipping when water wet, or contaminated by a range of other substances. They are thus generally suitable only for internal dry applications, and any spills or other contamination should be cleaned up immediately. If polished concrete surfaces fail to comply with the specified slip resistance requirements, or the requirements change during the life of the floor or pavement, there are a number of options to either increase the surface roughness and therefore improve the slip resistance, or deal with the increased risk of slipping when the existing floor is wet:

- **Regular maintenance to ensure surface is clean.** Contamination of the surface will reduce its roughness and slip resistance. Cleaning procedures that suit each particular application should be included in the documentation. Note that it is often the tenacity of the contaminant rather than the roughness of the surface that prevents thorough cleaning of the floor, and this is where the use of appropriate cleaning products can be most beneficial. Oil, grease, dirt or other contaminants on the surface will affect the slip resistance, particularly as these contaminants can easily fill a surface roughness of less than 20 µm. In fact a surface roughness of approximately 60 µm is required in areas contaminated by cooking stock, 70 µm for motor oil and olive oil, and more than 70 µm for gear oils and margarine.

- **Non-slip clear sealer/coating.** There are many coatings/sealers available that contain fine silica or other aggregates that provide sufficient surface texture/roughness to meet the required slip resistance properties. Such products may also improve the stain resistance. Aggregates may also be broadcast into a coating or sealer, but the application method must ensure a uniform coverage as variations in the slip resistance of a surface will increase the risk of slipping. The case studies showed that these types of finishes achieved BPN values in the range of 64 to 71, easily complying with the requirements of a Class V finish **Table 1**, offering a very low contribution of the floor surface to the risk of slipping when wet.
- **For external surfaces.** Re-grinding the surface at 80–100 grit and use of a penetrating sealer should satisfy the slip resistance requirements. The case studies showed that such finishes consistently achieved BPN values in the range of 62 to 72, easily complying with the requirements of a class V finish, offering a very low contribution of the floor surface to the risk of slipping when wet. For internal surfaces, honing to a finer grit may be possible, depending on the likely contamination. Note that ramps require special consideration.
- **Maintain dry conditions.** For internal (and possibly other covered) areas the surfaces should always be kept dry. This may be a requirement if film-forming coatings/sealers are required for their gloss appearance. Spot cleaning with mops, cloths or disposable rags to remove any water or spillages should be specified in the cleaning procedures. Providing suitable drainage and entrance matting to intercept water and other contaminants are also effective measures to assist in keeping the floor dry. CIRIA reports that ground and polished terrazzo finishes may have BPN values of 63 when dry but just 9 when wet. Similarly the BPN results for steel trowelled finishes may reduce from 65–75 when dry to 10–35 when wet, depending on the degree of surface texture.
- **Abrasive blast or acid etch surface.** A light abrasive blast or acid etch may achieve sufficient surface roughness to provide satisfactory slip resistance. A penetrating type sealer should be used. Note that such treatments will usually provide a slightly matt rather than gloss finish, and that an acid etch (typically using 1 part hydrochloric acid to 20 parts water) may affect the appearance of coloured concrete surfaces. Most proprietary acid etchants contain hydrogen fluoride, a dangerous chemical that requires careful handling. Ensuring a consistent finish to avoid varying levels of slip resistance across the surface will also assist in reducing the risk of slipping. Note that tests on an acid-etched surface (**Table 4**) indicated a mean BPN of 54, again delivering a Class V finish.
- **Penetrating sealers.** Sealers that penetrate into the concrete surface and leave the natural texture/roughness of the surface should be used in situations where improved slip resistance is required. The case studies indicated that where penetrating type sealers were used on honed or polished surfaces, the mean BPN was typically in the range of 62 to 68, whereas film-forming sealants or coatings delivered variable results ranging from 21 to 41. If increased slip resistance is required, the film formed on the surface by some sealers could be stripped off to reveal more of the surface roughness of the concrete surface. Caution: Removal of products must be uniform to avoid variable slip resistance over the floor surface.
- **Tapes, inserts and sheets.** The use of various slip resistant tapes, inserts and slip resistant sheets and floor coverings are common in applications such as stair treads and building entries where there is an increased risk of the surface wearing and/or becoming wet, kitchen areas where heavy build up of oils and grease may occur and change areas subject to continuous water contamination. Products applied to the surface may need intermittent replacement and may not provide a permanent solution.
- **Unsealed surfaces.** Slip resistance may be improved by leaving the surface unsealed or removing surface coating type sealers to expose the concrete surface. The case studies showed good slip resistance for unsealed surfaces.

REFERENCES

1 Briefing 5, *Polished Concrete Floors*, Cement Concrete and Aggregates Australia, 2006.

2 Road Note 64, *Slip Resistance of Residential Concrete Paving Surfaces*, Cement & Concrete Association of Australia, February 2003, pp 17–23.

3 AS/NZS 4586 *Slip resistance classification of new pedestrian surface materials*, Standards Australia 2004

4 AS/NZS 4663 *Slip resistance measurement of existing pedestrian surfaces*, Standards Australia 2004

5 *An Introductory Guide to the Slip Resistance of Pedestrian Surface Materials*, HB 197, Standards Australia 1999

6 *Building Code of Australia 2006*, Volume 2, Australian Building Codes Board.

7 AS 1428.1, *Design for access and mobility, Part 1: General requirements for access – New building work*, Standards Australia 2001

8 AS 1428.4, *Design for access and mobility, Part 4: Tactile indicators*, Standards Australia 2002

9 Carpenter J, Lazarus D, Perkins C, *Safer surfaces to walk on reducing the risk of slipping*, Construction Industry Research and Information Association (CIRIA) C652 2006

10 *The Assessment of Floor Slip resistance: The UK Slip Resistance Group Guidelines*, Issue 3, UK Slip Resistance Group, 2005

FURTHER INFORMATION

- *Guide to Concrete Construction* C&CAA T41/ SAA HB64 Cement & Concrete Association of Australia/Standards Australia 2002.
- Cement Concrete & Aggregates Australia web site at **www.concrete.net.au**.

TECHNICAL REVIEW

This data sheet has been technically reviewed by Richard Bowman of Intertile Research Pty Ltd.

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