

# **FLOOR SLIPS**

## **A TECHNICAL REVIEW**

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# FLOOR SLIPS: A TECHNICAL REVIEW

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# FLOOR SLIPS: A TECHNICAL REVIEW <sup>1</sup>

## 1. Introduction

- 1.1. A slip occurs when a foot, having made contact with a surface, slides backwards, forward or sideways. Slipping, or rather resistance to slipping, is measured by the "Coefficient of Friction". ( $C_f$ )
- 1.2. The Coefficient of Friction is defined as the ratio of the horizontal force (H) necessary to move an object across a surface, to the weight of the object (V). Thus  $C_f = H / V$ .
- 1.3. The Static Coefficient of Friction ( $C_{fs}$ ) is defined as the ratio of the horizontal force necessary to initiate movement of a stationary object across a surface, to the weight of the object. It is the tangent of the angle of an inclined surface when a body at rest on that surface just begins to slip.
- 1.4. The Dynamic Coefficient of Friction ( $C_{fd}$ ) is defined as the ratio of the minimum horizontal force necessary to maintain steady movement of an object across a surface, to the weight of the object. It is the tangent of the angle of an inclined surface when a body in motion on that surface just continues to move at a constant rate.
- 1.5. The Effective Coefficient of Friction of a body on an inclined surface is the actual Coefficient of Friction less the tangent of the angle of inclination of that surface.
- 1.6. A pedestrian walking on a level surface exerts a horizontal force on that surface that is about 20% of his weight<sup>2</sup>. It follows that if the coefficient of friction between the pedestrian's shoes and the surface is less than 0.2 he will "slip". This will only happen when walking at a normal pace if either both the soles of the shoes and the floor surface are very smooth or a liquid film is present on the floor. Slipping most frequently occurs in wet conditions and the ability of a surface to disperse a water film is of utmost importance. If this does not happen the floor will feel slippery to the pedestrian.

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<sup>1</sup> This is an evolving document and additional data will be added as it comes to the author's attention.

<sup>2</sup> National Building Studies Research Paper No 32: Part 1. This Paper is summarised in section 3.27 of this Review.

## 2. Measurement of Friction

Methods for measuring the resistance of surfaces to sliding and the Coefficient of Friction have been developed using various items of equipment and methods that have gained acceptance are considered below.

### 2.1. The Pendulum: the Portable Skid Resistance Tester<sup>3</sup>

2.1.1. This device was originally developed to assess the slipperiness of road surfaces.

2.1.2. A pad of rubber is mounted at the end of the pendulum arm and slides over the surface on which the machine is placed. The difference in height of the centre of gravity of the slider head between the horizontal release position and the highest point of the swing after the slider has passed over the surface, is a measure of the loss of energy arising from friction. The machine is calibrated so that a "Skid Resistance Value" (srv), dependent on the difference in height, can be read on a scale. The rubber pad is usually either "TRRL" rubber, 55° International Rubber Hardness (IRHD) or Four S (Standard Simulated Shoe Sole) rubber, 96 °IRHD.

2.1.3. The srv is related to the Coefficient of Friction<sup>4</sup> and research has established acceptable "safe values" for various floor surfaces under differing conditions.

### 2.2. The Tortus

2.2.1. The British Ceramic Research Association developed this device. The Tortus comprises a box, which is electrically driven at a constant speed of 17 mm per second (a little over three foot per minute) over the surface of the floor. A 9 mm diameter slider is maintained in contact with the floor by a load of 200 g (0.44 lb). The results can be produced on a paper trace or on a scale. This machine is not normally used for in situ tests since very minor changes in the surface profile, for example, the joints in tiles and local dust and debris, result in wild fluctuations of the results.

2.2.2. The slider of the Tortus is cut from a test material, such as Four S rubber sheet, which is placed on 400 grit silicon carbide paper and gently sanded until the sheen is removed. Then a 12 ° angle is formed from the horizontal at one end and the holder is held vertically. At

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<sup>3</sup> This apparatus is described in detail in Road Research Technical Paper No 66: "Development and Performance of the Portable Skid-Resistance Tester"

<sup>4</sup> The coefficient of friction between the material used on the slider and the surface tested is approximately 1% of the skid resistance value obtained. This relationship is reasonably accurate until the coefficient of friction exceeds a value of 0.5. The more accurate relationship is calculated as:  $C_{fd} = 3 \times (srv) / \{330 - (srv)\}$ . This can be re-arranged to give:  $(srv) = 330 \times C_{fd} / \{3 + C_{fd}\}$

least half of the area of the slider is horizontal; the remaining area is angled to give a maximum height of 1 mm at one side.

### **2.3. Trailing shoe**

2.3.1. Elrond Consulting/Torr Forensic Partnership, in common with a large number of workers in the field, uses a trailing shoe device.

2.3.2. This device, incorporating various materials commonly used to form the soles of shoes, is placed on the surface to be tested and subjected to a horizontal force by means of an electronic force-measuring device. The meter records the force under which the shoe first moves and then the lesser force required to maintain slow steady movement.

2.3.3. It is generally accepted that although there is no standard equipment for measuring the Coefficient of Friction, apparatus of this kind, which can be loaded with varying weights, closely replicates the human foot in slip conditions. It does give a parameter of horizontal force/vertical force approximating to the Coefficient of Friction.

### **2.4. SATRA test**

The Shoe and Allied Trades Research Association, SATRA, has a laboratory apparatus in which shoes, set at an angle of five degrees, are subjected to a vertical load force of 400 Newtons (89.9 lb). The horizontal force is measured as the shoe is slipped at a speed of 100 mm per second over a test surface. When used to test a particular floor covering Four S Rubber is used as the sole of the shoe. This apparatus is used to measure very large number of test shoes as they come into the market, amongst others, shoes for postmen.

### **2.5. The Floor Slide Control Machine: FSC 2000 print**

2.5.1. A German manufacturer has developed this machine. It has a total weight of 7.5 kg, is motorised and has a four-wheel chassis, travelling at a speed of 200 mm per second. (About 0.5 mph.)

2.5.2. When the machine is activated a slider automatically lowers onto the floor to measure the Dynamic Coefficient of Friction. The slider is loaded with a force of 24 Newtons (2.45 kg or 5.4lbs force)

2.5.3. The slider is about 25 mm square and has a slightly curved surface in the direction of travel. Sliders are surfaced with various materials used to form the soles of shoes.

## 2.6. Shuffle ramp

A platform, surfaced with the material being tested, is trafficked by a person either barefoot or wearing test shoes. The surface is covered with either water based wetting solution or oil. The angle of inclination of the platform is steadily increased and the angle at which the person begins to slip is recorded and averaged over a number of tests.

## 2.7. The Surtronic Roughness Meter

2.7.1. This electronic device automatically records the variation in the profile of a material by moving a stylus with a 5 µm radius tip across a 4 mm length of the surface. Ten readings are taken in varying directions within an area 75 mm square and an average value recorded.

2.7.2. It is recognised that measurement of the surface roughness, that is to say the measurement between peaks and troughs on the actual surface of the floor covering material and indeed the shoe surface, is related to the Coefficient of Friction.

## 2.8. Displacement volume

2.8.1. This criterion is used in Australia to measure the size of the displacement space of pedestrian surface materials that have a severely profiled or structured surface, as are commonly used in industrial work areas.

2.8.2. The volume of the displacement space is determined by filling the open cavities beneath the true surface of the surface material with a paste of known density. The volume is calculated from the mass difference before and after filling the cavities.

## 3. Design criteria

Relevant Standards giving advice are:

3.1. **BS 812 Part 3**, 1975, refers to the use of the pendulum but with a contract length of 76 mm and a rubber slider of 55 ° IHRD. There is no recommended srv.

3.2. **BS 5385 Part 4**, 1992: Wall & Floor Tiling.

3.2.1. Paragraph 5.5, addresses slipperiness and recognises that it is dependent not only on the nature of the surface (for example, whether

it is rough or smooth, level or inclined), but also on the properties of footwear, conditions of heat, wetness and cleanliness.

3.2.2. Paragraph 7.2.2 on Floor Tiling for Pool Surrounds, gives the required dynamic coefficient of friction,  $C_{fd}$ , as  $0.4 \pm 0.05$ : in wet conditions measured on a horizontal surface before use. Thus, for pool surrounds, one of the most sensitive of areas, a minimum dynamic coefficient of friction of 0.395<sup>5</sup> is required.

### 3.3. **BS 5395, 2000 Part I: Code of Practice for the Design of Straight Stairs.**

3.3.1. The Standard gives helpful guidance on slip resistance requirements for floors. It states that slip resistance values obtained using a Pendulum together with roughness measurements using a stylus-type instrument can be used as a basis for an assessment of floor surfaces.

3.3.2. It says that research has shown that a surface roughness greater than  $10 \mu\text{m}$  is required "to provide a reasonable slip resistance" for surfaces contaminated with pure water. However, in Table 2- "*Minimum levels of Rz (din) roughness necessary to provide reasonable slip resistance in the presence of various contaminants*", it gives a value of  $20 \mu\text{m}$  with clean water as the contaminant.

3.3.3. In "*Table 4 - Potential for slip of floor and tread finishes*" it states that wet ceramic tiles (matt) have a "Moderate to low" potential for slip and it is remarked that "*Wet slip potential is dependent on surface roughness. An Rz. (din) value of greater than  $10 \mu\text{m}$  is recommended for clean water wet areas.*"

3.3.4. The previous edition of this Standard, issued in 1977, utilised the research work of the GLC and referred to the research work of the Department of Scientific & Industrial Research. (DSIR) It adopted the following classifications: -

"Very good": a surface suitable for areas where special care is required;  $C_{fd} > 0.75$ .

"Good": a surface satisfactory for normal use;  $C_{fd} = 0.4$  to  $0.75$ .

"Poor to fair": a surface below acceptable safety limits;  $C_{fd} = 0.2$  to  $0.4$ .

"Very poor": an unsafe surface;  $C_{fd} < 0.2$ .

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<sup>5</sup> This is equivalent to a Pendulum (Four R) value of 38

- 3.4. **BS 7044**, Special Activities and Sports Halls, uses the Pendulum, specifying high levels for sport.
- 3.5. **BS 8203**, 1987 Code of Practice for Installation of Sheet and Tiled Flooring.
- 3.5.1. At paragraph 9.8 this refers to slip resistance: -
- "Most floorings provide adequate slip resistance under normal conditions, providing they are kept dry and properly maintained. On ramps or wet areas where slipping is likely to be a problem, consideration should be given to the use of floorings specifically designed for the purpose... a special surface... containing cork granules or mineral aggregate... textured."*
- 3.5.2. The classification of surface regularity of screeds and direct finished concrete to normal standards has a maximum permissible departure from the underside of a 3m straight edge resting in contact with the floor of 5mm. It also advocates the use of the BRE Screed Tester as an impact device for the quality of screed.
- 3.5.3. The 1996 version of BS 8203 makes no reference whatsoever to slip resistance, other than that a matwell will reduce the risk of slipping in service and the materials covered need a slip resistant nosing on stairs in a contrasting colour. The test for surface regularity does not indicate a criterion.
- 3.6. **BS 8204 Part 1**, 1987: Code of Practice for Concrete Bases & Screeds to receive Insitu Flooring makes reference to the acceptable limits of surface regularity.
- 3.7. **BS 8204 Part 2**: Code of Practice for Concrete Wearing Surfaces, at paragraph 5.10 says: -
- 3.7.1. *"A reasonable slip resistance ...categories of slip resistance cannot be defined with any degree of certainty."*
- 3.7.2. Any suitable method: trowelling, grinding, mechanical roughening, slip resistant granules, slip resistant inserts and correct cleaning.
- 3.8. **BS 8204 Part 3**, 1993: Code of Practice for Polymer Modified Cementitious Materials uses the pendulum with an IRHD 55° slider and gives a recommended srv of 39.

- 3.9. **BS 8204 Part 4**, 1993: Code of Practice for Terrazzo Wearing Surfaces, at paragraphs 6.10 and 8.5, recommends the pendulum with a 55° IRHD rubber slider and specifies an *srv* of 39 as a minimum.
- 3.10. **BS 8204 Part 5**, 1994: Code of Practice for Mastic Asphalt Underlays & Wearing Surface. This recommends use of the Pendulum, with a 55° ± 5° IRHD rubber slider over a contact length of 76mm, as distinct from the normal contact length of 127mm. An *srv* >39 is required for a wet floor. Five successive readings should be recorded within three units. Temperature correct the *srv*, which should be greater than 39 in both wet and dry state. Mastic asphalt is not inherently slippery.

### 3.11. BS EN European Standards

- 3.11.1. BS EN 649, 1997: Resilient Floor Coverings, homogenous and heterogeneous polyvinyl fluoride floor coverings;
- 3.11.2. BS EN 651, 1997: Resilient Floor Coverings polyvinyl chloride coverings with foam layer;
- 3.11.3. BS EN 654, 1997: Resilient Floor Coverings semi flexible polyvinyl chloride tiles;
- 3.11.4. This Suite of codes gives detailed specifications for manufacture and provides details of determination tests on chair castors, flatness, straightness, squareness, thickness thickness of layers, mass, indentation under static loading, curling, flexibility, density, seam strength, classification, colour and fastness to light. However, no reference to slip resistance is made. The effect of stains, movement of furniture, peel resistance, shear force, spreading of water, curling on exposure to moisture, pattern depth, volatile loss, exudation of plasticisers, gelling, mass per unit area of reinforcement, electrical resistance and static electrical propensity are all included. The methods of test are informative.

### 3.12. ISO/DIS [Draft International Standard] 10545/17 - Ceramic Tiles, Part 17: Determination of Coefficient of friction.

- 3.12.1. This document defines at paragraph 2 the Coefficient of Friction as the ratio of the tangential force to the vertical load on the slider. For some methods this is the equivalent to the tangent of the angle between the inclined platform and the horizontal. The critical angle is where slipping of the test subject occurs while walking on a lubricated inclined platform.

- 3.12.2. Method A. The dynamic coefficient of friction is measured by means of a slider moving at constant speed over a horizontal surface by any portable self powered mobile apparatus traversing tiles with a friction foot of Four S Rubber under a fixed load to measure the dry and wet dynamic coefficients of friction. One example, as shown in their Appendix A, is the Tortus. This method is effectively identical to the ELROND Trailing Shoe.
- 3.12.3. Method B. The static coefficient is measured by the force required to move a slider from a static position on a horizontal surface. The static slider has a weight upon it of 4.5Kg. It uses Four S rubber, 75mm x 75mm x 3mm, gently sanded on the 400 grit silicone carbide paper until the sheen is completely removed. The heel assembly after calibration is placed on a test surface so that the measuring spring balance is at the same level as the test surface shoe or heel, as it is described. Then with 4 pulls, each perpendicular to the previous pull, on each of 3 surface areas or 3 test specimens, so as to give 12 necessary readings to determine the force required to set the test assembly in motion. This is also effectively identical to the ELROND Shoe.
- 3.12.4. Specified coefficients of friction are: using a static slider with a 4.5 Kg load applied, Class 1 > 0.4 and Class 2 equal to or < 0.4.
- 3.12.5. Shuffle Ramp Test classification A: 0.32, B: 0.44, C: 0.44.
- 3.12.6. The UK has voted against this Draft due to the inclusion of the Tortus and similar methods including the American James Machine, similar to the Trailing Shoe as described by ASTM.

**3.13. ISO 13006** - Ceramic Tiles Definitions, classifications, Characteristics and Marking.

- 3.13.1. This gives a definition of tiles, how they should be co-ordinated, sized, classified, sampled and marked. The requirements for testing are in length, width, thickness, straightness, rectangularity, surface flatness, water absorption, breaking strength, modulus of rupture, abrasion resistance, thermal expansion, thermal shock resistance, crazing resistance, frost resistance, coefficient of friction.
- 3.13.2. Coefficient of friction measurements, using the dynamic test method with a Four S rubber slider, to be carried out on new tiles in both dry and wet conditions.
- 3.13.3. Class 1: Less than 0.2 dynamic C of F: Mostly smooth glazed tiles recording this low value when wet. Should only be used in dry situations.

Greater than or equal to 0.2 but < 0.4 C of F: glazed tiles showing these values only when wet. Besides domestic bathrooms, where the use of a slip resistant bath mat is essential, may be considered for dry domestic areas.

- 3.13.4. Class 2: Greater than or equal to 0.4 but < 0.7 C of F: includes some glazed tiles and most un-glazed tiles. Tiles having this minimum value, dry and wet, considered safe for bathrooms, kitchens, porches, halls, cloakrooms and living rooms. May also be used for public areas that are subject to wetting.

Greater or equal to 0.7 C of F: tiles where more enhanced slip resistance is required.

- 3.13.5. *"The coefficient of friction of tiles varies depending on the nature of the surface of the tile, whether the surface is dry or wet and results differ for different types of shoe material and barefoot applications."*

- 3.13.6. *"Requirements also vary depending on the nature of the flooring application, the size of the floor area, its intended use. A coefficient of friction higher than those needed for many types of domestic application may be desirable for large flooring areas, industrial and commercial applications, ramps, especially those connected immediately to the outside and for many types of domestic situations."*

- 3.13.7. *"Tests are performed on tiles prior to installation. The coefficient of friction of any floor covering in use including tiles can be adversely effected by inadequate or improper maintenance, such as the use of unsuitable cleaning materials."*

### **3.14. Australian/New Zealand Standard 4586: 1999: "Slip resistance classification of new pedestrians surface materials".**

- 3.14.1. The Standard sets out *"... to provide users and specifiers of pedestrians surface materials... with means for classifying such surfaces according to their pedestrian slip resistance for use in the selection of surfaces."*

- 3.14.2. *"These classifications are based on an assessment of the contribution of a pedestrian surface to the risk of slipping and they will assist in the specification of a surface material suitable for most pedestrian applications."*

3.14.3. The Standard provides detailed guidance on the testing of floor surfaces using the Pendulum, a Floor Friction Tester<sup>6</sup> and a Ramp.

3.14.4. Surface classifications are tabulated against test results achieved using each of the three testing methods. These classifications are reproduced from the Standard in the following tables.

### AS/NZS 4586: 1999

**TABLE 1: TEST AND CLASSIFICATION COMBINATIONS**

Test conditions	Classification table to be used
Wet Pendulum	Table 2
Wet Pendulum and dry floor friction	Tables 2 and 3
Dry floor friction	Table 3
Wet/barefoot ramp	Table 4
Oil wet ramp	Table 5

**TABLE 2: CLASSIFICATION OF PEDESTRIAN SURFACE MATERIALS ACCORDING TO THE WET PENDULUM TEST**

Class	Pendulum Mean sr <sub>v</sub>		Contribution of the floor surface to the risk of slipping when wet
	Four S rubber	TRRL rubber	
V	> 54	> 44	very low
W	45 - 54	40 - 44	low
X	35 - 44	-	moderate
Y	25 - 34	-	high
Z	less than 25	-	very high

**TABLE 3: CLASSIFICATION OF PEDESTRIAN SURFACE MATERIALS ACCORDING TO THE DRY FLOOR FRICTION TEST**

Classification	Floor Friction Tester mean value
F	≥ 0.4
G	< 0.4

<sup>6</sup> This is a portable self powered mobile apparatus similar in concept to the FSC 2000 Print. It determines the dynamic friction between the surface and a 9mm diameter disc cut from Four S. rubber.

**TABLE 4: CLASSIFICATION OF PEDESTRIAN SURFACE MATERIALS ACCORDING TO THE WET/BAREFOOT RAMP TEST**

Classification	Angle (degrees)
A	$\geq 12 < 18$
B	$\geq 18 < 24$
C	$\geq 24$

**TABLE 5: CLASSIFICATION OF PEDESTRIAN SURFACE MATERIALS ACCORDING TO THE OIL WET RAMP TEST**

Classification	Angle (degrees)
R9	$\geq 3 < 10$
R10	$\geq 10 < 19$
R11	$\geq 19 < 17$
R12	$\geq 27 < 35$
R13	$\geq 35$

**3.15. CSIRO and Standards Australia: An Introductory Guide to the Slip Resistance of Pedestrian Surface Materials. HB 197: 1999**

- 3.15.1. This is an interim publication that will be withdrawn when Standards Australia publishes the "Slip Resistance Handbook".
- 3.15.2. The publication is intended to be read with AS/NZS 4586: 1999 and establishes a basis for specifying pedestrian surfaces.
- 3.15.3. The Handbook contains a pedestrian flooring selection guide (Table 3) that is based on the wet Pendulum and ramp test methods. It also contains the German requirements for slip resistance in public barefoot areas (Table 4) and for commercial and industrial areas (Table 5). The German regulations include requirements for volumetric displacements in some industrial areas. It does not provide any interpretation of dry slip resistance test results. It contains guidance on how the various test results can be used to design sloping surfaces.
- 3.15.4. The guidance given on the selection of flooring is comprehensive and covers most public, commercial and industrial situations. However, it is interesting to note that: *"No guidance is provided in the case of domestic, hotel and institutional bathroom suites. There is a reasonable probability that a laundry or bathroom floor may be wet, and it can be assumed that most people are conditioned to exercise some caution when using such facilities."*

3.15.5. Minimum recommended slip resistance values for a selection of new floor surfacing can be interpreted from the relevant tables:-

Location	Pendulum <sup>7</sup>		Ramp (wet)	
	srv	C <sub>fd</sub> <sup>8</sup>	∅ <sup>9</sup>	C <sub>fd</sub> <sup>9</sup>
Entry foyers hotel, office, public buildings - wet	35 - 44	0.36 - 0.46	10 - 19	0.18 - 0.34
Fast food outlets, buffet food servery areas	35 - 44	0.36 - 0.46	10 - 19	0.18 - 0.34
Supermarket fruit and vegetable areas	35 - 44	0.36 - 0.46	10 - 19	0.18 - 0.34
Swimming pool surrounds and shower rooms	45 - 54	0.47 - 0.59	18 - 24	0.32 - 0.45
Toilet facilities in offices, hotels and shops	35 - 44	0.36 - 0.46	10 - 19	0.18 - 0.34
External stair nosings	45 - 54	0.47 - 0.59	19 - 27	0.34 - 0.51
Commercial and Industrial toilets/washrooms			10 - 19	0.18 - 0.34
Hotel and restaurant kitchens (<100 meals/day) <sup>10</sup>			19 - 27	0.34 - 0.51
Dish washing areas (<100 meals/day) <sup>11</sup>			27 - 35	0.51 - 0.70

3.16. **The Workplace (Health, Safety and Welfare) Regulations 1992** requires at Regulation 12:

3.16.1. *Workplace floors and traffic route surfaces must be suitably constructed for their intended uses, and so far as is reasonably practicable, kept free from obstructions, articles or substances likely to cause slips, trips or falls. Floors must be provided with adequate drainage where necessary. In particular, floors and the surfaces of traffic routes must not have any holes or unnecessary slopes, be uneven or slippery.*

3.16.2. The Approved Code of Practice, at paragraph 93 says that traffic route and floor surfaces that get wet should be of a type that does not become unduly slippery.

### 3.17. The Health and Safety Executive

The HSE produces a wide range of publications giving both general and specific guidance to both private and commercial organisations. This advice covers causative and environmental factors and provides recommendations for good work practice; choice of floor coverings and shoes, cleaning procedures and good housekeeping etc.

<sup>7</sup> Four S Rubber

<sup>8</sup> Calculated using the relationship:  $C_{fd} = 3 \times (srv) / \{330 - (srv)\}$

<sup>9</sup>  $C_{fd} = \tan \emptyset$

<sup>10</sup> Minimum displacement volume of profiled surface = 4cm<sup>3</sup>/dm<sup>2</sup>. Ramp – oil wet.

<sup>11</sup> Minimum displacement volume of profiled surface = 4cm<sup>3</sup>/dm<sup>2</sup>. Ramp – oil wet.

**3.17.1. Slips and Trips: Guidance for employers on identifying hazards and controlling risks. May 1996**

3.17.1.1. This publication gives detailed guidance on the selection and maintenance of floor coverings. However, it contains no criterion for the allowable Coefficient of Friction.

3.17.1.2. In the section on "Footwear" it says: *"On wet surfaces the sole should have a well defined pattern (tread) as more edges will give a firmer grip. The tread will cut through surface liquid and break-up the slippery layer under foot."* And *"On dry surfaces it is better to have as much of the sole as possible in contact with the ground so the pattern on the sole is less important."*

3.17.1.3. A table: *"Shoe sole material and floor types"*, shows that *"Microcellular urethane and rubbers"* provide the best slip resistance for water wet floors.

**3.17.2. Slips and Trips: Guidance for the food processing industry. May 1996**

3.17.2.1. This publication provides comprehensive advice on practical measures for controlling slip risks.

3.17.2.2. It contains many tables that provide employers with checklists for ensuring that the correct precautions are in place and the recommended procedures are observed.

3.17.2.3. No criteria are given for recommended coefficients of friction of floor surfaces. However, advice is given on sufficient surface roughness. *"For level, water-wet surfaces at least 30  $\mu$  m roughness is necessary"*. And: *"Floors with a maximum peak to trough distance of the granular surface, of less than 10  $\mu$  m, have been shown to be hazardous in wet conditions."*

3.17.2.4. Advice is given on "sensible shoes" and the choice of shoe sole material for varying floor types. PVC and leather are "Most slippery", Urethane and rubber are "Less slippery" and Micro-cellular urethane and rubber are "Least slippery".

**3.17.3. Watch Your Step: Prevention of the slipping, tripping and falling accidents at work. 1984**

3.17.3.1. This booklet was written as a guide for preventing accidents in the workplace.

3.17.3.2. It contains a brief review on "measuring slipperiness".

3.17.3.3. It states that "... values of coefficient of friction between floor and footwear surfaces greater than 0.5 may generally be acceptable, values below 0.2 generally unacceptable. Again, there can be no hard and fast rules." On footwear it says: "... the sole pattern is not very important in dry conditions where it is more important to have as much of the sole as possible in contact with the ground. But in the wet the tread is important as the more wiping edges the better. (These cut through the surface water and break up the lubricating layer of water under the boot.)"

#### **3.17.4. Food Sheet No 22: "Preventing slips in the food and drink industries - technical update on floor specifications"**

3.17.4.1. This leaflet, published in May 1999, contains recommended values for slip resistance measured with the pendulum and the roughness meter. It refers to the Guidelines recommended by **The UK Slip Resistance Group**.<sup>12</sup>

3.17.4.2. Pendulum values of 36 or more, measured on a dry or wet surface, are "... currently accepted to indicate satisfactory slip resistance."

3.17.4.3. Minimum values of roughness are quoted for various lubricants. These range from a value of 20  $\mu$  m for clean water to greater than 70  $\mu$  m for margarine.

3.17.4.4. A floor surface roughness of 30  $\mu$  m is stated to be "... required to enhance the slip resistance of hard floor materials (e.g. ceramics, concrete) in water-wet conditions. This figure may be reduced slightly when considering soft flooring materials (e.g. vinyl, linoleum)."

#### **3.18. The European Tiling Industry: Use Group Classification for tiles:**

Use groups for industrial work places.

3.18.1. R9: [ $3^\circ$ ( $C_{fs} = 0.052$ ) to  $10^\circ$ ] is the minimum classification for tiles used in public areas.

3.18.2. R10: [ $10^\circ$ (  $C_{fs} = 0.17$  ) to  $19^\circ$ ]is for floors in areas facing a small slip risk from grease, oil, water food or dust, wet storage cellars,

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<sup>12</sup> See section 3.19 of this Review.

defrosting and warming kitchens, coffee and tea kitchens in hotels or hospitals, serviceway for meat and sausage packed goods, sterilisation rooms in a hospital, sanitary service rooms, rooms with de-fleshing machines.

- 3.18.3. R11: [19° ( $C_{fs} = 0.34$ ) to 27°], a greater increase in slip risk cheese production, milk storage and packing, chocolate raw material production, dough preparation, sterilising room in vegetable processing, beverage filling, fruit juice production, kitchens with up to 100 covers a day in joint care in homes, schools or sanatoria, cold storage rooms for packed goods, sales outlets for receiving meat and fish, serviceway for meat and sausage, hospital sanitary service room disinfection, wet faeces room and pathologies, hotel laundry rooms, dry feed production areas and concentrated feed production with fat or water being used, dye works for textiles, wet grinders for ceramic materials, stone saw shops, glass grinding shop, concrete washing places, glass etching and acid polishing, repair and maintenance workshops, wash halls for vehicle repair, aircraft halls;
- 3.18.4. R12: [27° ( $C_{fs} = 0.51$ ) to 35°] cooking fat and salad oil production and packing, margarine, fresh milk process including butter, ice cream production, sugar, cocoa, fat or liquid mass processes, washing up areas in bread and cake industries, sausage drying room, smoking room, pickling room, sliced meat packing department, kitchens with over 100 covers a day, kitchens for joint care in clinics hospitals, canteen, fast food kitchens and snack bars, washing up areas, cold storage room for unpacked goods, serviceway for fish and meat, preparatory room, fat rooms for sealing leather production, glazing area, pickling hardening rooms for chemical treatments, galvanising rooms, work and test pits for vehicle repair, washing places for vehicles, pump rooms, sludge draining plants in waste water treatment, fire brigade tender bays and rooms for hose maintenance care;
- 3.18.5. R13: [over 35° ( $C_{fs} = 0.70$ )] the highest category is only specified for tinned vegetable production and water workshops in tanneries.

**3.19. The UK Slip Resistance Group: Guidelines for the measurement of floor slip resistance. June 2000.**

- 3.19.1. This publication recommends the use of the Pendulum, with Four S and TRRL rubber sliders, and the Surtronic 10 or Duo Rz Roughness Meters. Detailed procedures for laboratory and site testing are stated.
- 3.19.2. Test criteria for the categorisation of the "*... Slip Resistance of the floor for able-bodied pedestrians, when tested with the Pendulum and Four S rubber... with due consideration of roughness...*" are given as: -

Surface Slip Potential	Pendulum		Surface Roughness
	Four S slider	TRRL slider	
High	25 and below	19 and below	Below 10 $\mu\text{m}$
Moderate	25 to 35	20 to 39	Between 10 and 20 $\mu\text{m}$
Low	35 to 65	40 to 74	Between 20 and 30 $\mu\text{m}$
Extremely Low	65 and above	75 and above	Above 30 $\mu\text{m}$

3.19.3. The recommended values are "as found" conditions, to include dry and wet surfaces.

3.19.4. TRRL rubber is more applicable on rough surfaces, say above 30 $\mu\text{m}$  Rz roughness.

3.19.5. Elrond Consulting/Torr Forensic Partnership follow the site testing procedures advised in this publication.

### 3.20. British Ceramic Research Ltd (CERAM)

3.20.1. CERAM published a report in February 1997 summarising their research into slip resistance measurements of ceramic floor tiles. The most common methods for measuring slip resistance are compared and evaluated.

3.20.2. The German ramp test is considered to most closely mirror reality. However, it is not a test that can be readily executed, especially on-site!

3.20.3. The report concludes that both the Pendulum and Tortus are acceptable devices for measuring slip resistance and give results that correlate well in wet conditions. A Pendulum reading of 35, using a Four S Rubber slider, correlates to a Tortus reading of 0.55  $\mu$  and a reading of 25 to 0.4  $\mu$ .

### 3.21. RAPRA

3.21.1. The Rubber and Plastics Research Association was established in 1999 and is now, as Rapra Technology, an independence plastics and rubber consultancy.

3.21.2. Rapra developed the "Four S Rubber", now accepted internationally as the standard material for use in the Pendulum and other devices for measuring the slip resistance of floor surfaces.

3.21.3. Rapra has published research into the testing of many different floor-surfacing materials over the years and a paragraph, from a paper<sup>13</sup> dated 1989, is still relevant today.

*"It cannot be emphasised too strongly, however, that no slip resistance test gives answers which can be guaranteed to correlate under all circumstances with users experience, and test figures must be used with some sensitivity. In real life people wear different footwear and their expectations of a floor vary considerably. Some people are used to shoes with large heels and rather soft patterned soles, whereas others take for granted shoes with extremely small, hard, heels and smooth unpatterned soles."*

3.21.4. Rapra has noted that for some wet floor surfaces a high coefficient of friction is obtained by using the Ramp test, whilst a "marginal" slip resistance is determined by the Pendulum. This phenomenon is attributed to the speed at which the Pendulum operates, which is much higher than that of a heel slip.

### **3.22. SATRA**

3.22.1. SATRA is concerned with the slip resistance of footwear and has carried out research since 1974.

3.22.2. The aim has been to produce a sole material that provides both a satisfactory slip resistance and a reasonable life expectancy. This is a compromise between hardness, softness and sole pattern.

3.22.3. SATRA has adopted a value of 0.30 as the "arbitrary pass level" for the dynamic coefficient of friction, this being the ratio of H/V quoted in American research for walking at medium speed.

### **3.23. H & R Johnson Ceramics International Ltd**

3.23.1. Johnson publishes test values for the slip resistance of their tiles and "Guidelines Requirements". In summary these values are:-

#### **Tortus**

Dry and Wet:	0.2 to 0.4	Fair
	0.4 to 0.75	Good

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<sup>13</sup> "A Standard Slider for Slip Measurements" by D. I. James.

### **Pendulum (Four S Rubber slider)**

Dry and Wet:	24 and below	Unsatisfactory
	25 to 34	Marginal
	35 to 64	Satisfactory
	65 and above	Excellent

### **3.24. Marley Floors Ltd**

3.24.1. Marley produce three thermo-plastic "slip resistance" floor coverings. The properties of the tiles are described in their catalogue as: "*Slip resistance (Pendulum 4 S.): High level of wet and dry slip resistance as evaluated using the TRRL Pendulum.*"

3.24.2. I am grateful to Marley for providing information on tests carried out on these floor coverings. The results are summarised below.

#### **Pendulum (Four S)**

Condition of Tile	Condition of surface			Roughness
	Dry	Dusty	Wet	
As manufactured	49	28	27	5.2µm
Sanded/abraded	64		35	3.9µm

#### **Tortus (Four S: Dusty slider)**

Condition of Tile	Condition of Surface	Coefficient of Friction (Average)
Unsanded	Dry	0.48
Sanded	Dry	0.42
Burnished/Polished	Dry	0.22

### **3.25. Pilkington's Tiles Limited**

3.25.1. Pilkington publish test data on their ceramic tiles and give recommendations for use in various environments.

3.25.2. The test methods used are:-

- DIN 51097: Barefoot walking on a ramp.

- DIN 51130: short foot traffic on a ramp in the presence of a surface lubricant.
- Tortus
- Pendulum, using Four S rubber slider.

3.25.3. The criteria for recommended usage appears to be based on a combination of experience and compliance with the relevant DIN classification and a minimum Pendulum srv of 35.

### 3.26. ELROND

3.26.1. ELROND has investigated cases involving "slips" since 1980 and tested many surfaces using the Pendulum, the Elrond Trailing Shoe and, since 2000, the FSC 2000 Print.

3.26.2. A series of tests, carried out for a client in 1997, provides valuable information on the Dynamic Coefficient of Friction for a shoe with leather and composite soles and also the human, bare foot. The surface tested was a patent, "slip resistant", bath bottom. The averaged results were:-

Material	Condition of surface	Coefficient of Friction
Leather	Dry	0.57
Composition	Dry	0.8
Leather	Wet (distilled water)	0.52
Leather	Wet (soapy tap water)	0.63
Composition	Wet (distilled water)	0.52
Composition	Wet (soapy tap water)	0.56
Barefoot	Dry	0.71
Barefoot	Wet (distilled water)	0.64 to 0.77
Barefoot	Wet (soapy tap water)	0.44 to 0.55

3.26.3. Another series of tests in 2001, using a Pendulum, ELROND Trailing Shoe and a bare foot, on a tiled floor produced the following averaged results:-

Surface Condition	Pendulum		ELROND Trailing Shoe (Four S)		Barefoot (Static)	Surtronic
	Four S	TRRL	Static	Dynamic		
Dry	65	123	0.62	0.57	0.79	11.94
Damp			0.61	0.60	0.88	
Wet	32	26	0.58	0.60	0.83	

3.26.4. ELROND commissioned a series of laboratory tests on ice in April 2001. The ice was made with distilled water and tests were carried out using the Pendulum and the FSC 2000 Print Machine. The test results are summarised below.

Machine	Slider (Rubber)	Ice Surface	SRV <sup>14</sup>	Dynamic Coefficient of Friction		
				Max	Av	Min
Pendulum	Four S	Dry	13		0.12 <sup>15</sup>	
		Wet	10		0.09	
	TRRL	Dry	25			
		Wet	17.5			
FSC 2000	Four S	Dry		0.32	0.13	0.04
		Wet		0.18	0.12	0.05

3.26.5. ELROND has assembled a collection of Sample Tiles to demonstrate the relationship between Surface Texture, Oil and Water Wet Ramp Tests, Pendulum (Four S Rubber) tests and Roughness. The tile manufacturers provided the ramp test results. Owen William Laboratory Services under the direction of the Author, who measured the surface roughness, carried out the pendulum tests. The results of the tests and a description of the tiles is contained in the table: "Sample Tiles: Comparative Slip Resistance Tests."

<sup>14</sup> Values given are for sliders at ambient temperature. The values corrected to 0° C, in accordance with Road Note 27, are respectively: 6, 3, 18 and 10.5.

<sup>15</sup> Calculated using the Standards Australia Handbook relationship:  $C_d = 3 \times (srv) / \{330 - (srv)\}$

Ref	Manufacturer's Description	Manufacturer's Classification		Pendulum Test (Four S Rubber) Mean SRV		Roughness $\mu\text{m}$	UK SRG Potential for Slip		Surface
		Shod: Oil Wet Ramp DIN 51130	Barefoot: Water Wet Ramp DIN 51097	Dry	Wet		Dry	Wet	
0	Monogres: Mono-Color	R9		65	32	11.9	Low	Moderate	Matt glazed
1	Langley: V & B Series Unit 1			69.5	15	6.5	Extremely low	High	Smooth glazed
2	Langley: V & B Series Unit 1	R10	A	65	46	17.4	Low	Low	Matt glazed
3	Langley: V & B Series Unit 1		B	73	66.5	27.8	Extremely low	Extremely low	Matt glazed
4	Langley: V & B Maxi-Floor Commercial	R10	B	64	40	32.4	Low	Low	Matt unglazed
5	Langley: V & B Maxi-Floor Commercial	R12/V4		70	53	32	Extremely low	Low	Textured pattern unglazed
6	Pilkingtons Pin Head	R11	C	61	44.5	19.4	Low	Low	Raised dot pattern glazed
7	Langley: V & B Maxi-Floor Commercial	R10	A	60	35	20.8	Low	Low	Semi-matt unglazed

**SAMPLE TILES: COMPARATIVE SLIP RESISTANCE TESTS**

### 3.27. Building Research Station

3.27.1. Extensive research work was done in the 1960s covering persons walking normally on flat and sloping surfaces of floors and climbing and descending stairs of different pitches. The National Building Studies Research Paper No. 32: Part 1. The Stationery Office published "Walking on a level surface" in 1961. Part 11. "Walking on a slope" and Part 111. "Walking on stairs" were published in 1967.

3.27.2. What was tested was the actual vertical force and the actual horizontal force required by candidates whilst they walked across the relevant surface.

3.27.3. The results, expressed as the ratios of horizontal force divided by vertical force, are summarised below.

<b>Straight Walking</b>		Highest	Lowest	Average
Male	Right Foot	0.26	0.08	0.17
Male	Left Foot	0.25	0.11	0.17
Female	Right Foot	0.21	0.12	0.16
Female	Left Foot	0.21	0.11	0.15

<b>Turning</b>		Highest	Lowest	Average
Male	Right Foot	0.30	0.16	0.22
Male	Left Foot	0.26	0.15	0.19
Female	Right Foot	0.22	0.18	0.20
Female	Left Foot	0.19	0.16	0.17

<b>Ascending Stair</b>		Highest	Lowest	Average
Male	Right Foot	0.10	0.06	0.08
Male	Left Foot	0.11	0.06	0.09
Female	Right Foot	0.09	0.05	0.07
Female	Left Foot	0.10	0.05	0.08

<b>Descending Stair</b>		Highest	Lowest	Average
Male	Right Foot	0.15	0.04	0.10
Male	Left Foot	0.13	0.04	0.08
Female	Right Foot	0.14	0.07	0.10
Female	Left Foot	0.09	0.07	0.08

<b>Ascending Steep Stair</b>		Highest	Lowest	Average
Male	Right Foot	0.29	0.05	0.10
Male	Left Foot	0.13	0.03	0.08
Female	Right Foot	0.24	0.05	0.09
Female	Left Foot	0.09	0.06	0.08

<b>Descending Steep Stair</b>		Highest	Lowest	Average
Male	Right Foot	0.16	0.06	0.09
Male	Left Foot	0.13	0.05	0.10
Female	Right Foot	0.22	0.05	0.08
Female	Left Foot	0.11	0.06	0.09

### 3.28. The Greater London Council

3.28.1. Research carried out by the GLC in the 1960 is, in which they correlated readings taken by the TRRL Pendulum with the known slipping history of floor surfaces, formed the basis of later design guidance. The results of this Research were published in: *"Bulletin No. 43 (2nd Series) Item No. 5 'Slip Resistance of Floors, Stairs and Pavings'. The GLC Department of Architecture and Civil Design: March 1971."*

3.28.2. Tests were carried out using a TRRL slider on the Pendulum and four categories of floor surfacing were defined. These are:-

*"'Dangerous': 19 or below. This condition is quite unsafe and, where it exists immediate action should be taken to replace or treat the surface to an acceptable standard.*

*'Marginal': 20 to 39. The surface is below the recommended safe level and methods of improving the condition should be considered and carried out as soon as reasonably possible. Some remedial treatments have only temporary effect and will need to be repeated at regular intervals; in the long-term, the substitution of an alternative finish may be more economic. In the meantime, warnings should be given to all using the building that care must be observed.*

*'Satisfactory': 40 to 74.*

*'Excellent': 75 and above. This condition, though desirable in many situations, is required in certain special cases, such as railway platform edges and crowded public stairs."*

3.28.3. The Bulletin discusses the results obtained by using different rubber slider is on the Pendulum. It says: *"In the dry 4S' gives results comparable to a typical men's rubber heel while the TRRL is a softer rubber more akin to crepe soles. In the wet the readings they give are similar but not identical. One reason for this is that if the surface is only very slightly convex or concave the hard '4S' rubber 'rides' on the edge or centre of the swept area and the lubricating film is not fully developed. The TRRL rubber, like a 'normal' rubber is more conformable, and unless the surface is markedly convex or concave the lubricating film will be fully developed."*

3.28.4. Another interesting comment is that: *"Sole slip is generally not likely to lead to a fall; it takes place as a person pushes off with their trailing foot. Heel slip on the other hand is dangerous because it takes place at a very critical part of the walking process. However sole slip can be a problem in food halls when pushing heavily laden trolleys."*

## 4. DISCUSSION

### 4.1. Introduction

The extensive range of published information on the subject of slips is often contradictory and rarely definitive. It is clear that no one method of measuring the slip resistance of floor surfaces is universally applicable. The normal use of the floor is of paramount importance as is the footwear most likely to be worn, or not, in the area.

### 4.2. Test Apparatus

ELROND Consulting, having investigated slips over a period of some 20 years, has evolved standard test procedures using the Pendulum, the ELROND trailing shoe, the FSC 2000 and the Surtronic 10.

4.2.1. **The Pendulum** where it can be used in available space, using the Four S Rubber slider.

This uses a copious quantity of distilled water for the wet test, taking groups of 5 results, no more than 3 units apart.

Where the investigation includes a situation where a floor may have been washed before an accident the test is continuous, with the slider striking the water away leading from a wet to a damp condition. The time and number of readings needed, to reach back or near to the dry test readings, is made.

4.2.2. **The Trailing Shoe** to measure both static and dynamic friction:

With a Four S Rubber "sole";

Where feasible using a "sole" of the type on a specific shoe being worn at the time;

Using water or other relevant liquids.

4.2.3. **FSC 2000 Print** with a Four S Rubber slider, since it gives a paper trace showing details of changes in measured dynamic friction in dry and wet conditions.

4.2.4. **Surtronic 10 Roughness Meter** giving a reading in  $\mu\text{m}$ .

### 4.3. The acceptability of Floor Surfacing

4.3.1. The most comprehensive advice currently available is contained within Standards Australia Handbook 197: 1999, read with AS/NZS 4586: 1999. The Handbook gives detailed recommendations for floor surfacing criteria covering a wide range of usages. The criteria are Pendulum readings, ramp values and, mainly for commercial/industrial processes, displacement volumes for profiled surfaces.

4.3.2. United Kingdom sources of guidance, such as British Standards, HSE booklets, the UK Slip Resistance Group and floor surfacing manufacturers, rarely give specific test criteria. They rather advise which surfaces, when tested in various ways, have differing degrees of "potential for slip".

4.3.3. The evaluation of a surface for a given location, purpose or use, is dependent on a careful consideration of relevant criteria.

4.3.4. A designer specifying a floor surfacing or an Expert giving an opinion on the suitability of a floor surfacing must be aware of these criteria and the expectation of pedestrians traversing the particular surface.

4.3.5. The specification of universally acceptable slip resistance values for floor surfacings is not possible. The decision as to the suitability of a floor surfacing material must be based on a rigorous evaluation of the circumstances obtaining in the location, the use of the floor and the probable cleaning regime.

**James Torr**

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