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Evaluation of the Kirchberg Rolling Slider and SlipAlert Slip Resistance Meters

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EXECUTIVE SUMMARY

Introduction

The Health and Safety Laboratory (HSL) use the Pendulum skid resistance tester to determine the dynamic coefficient of friction (CoF) of a floor surface. This test correctly models the interaction between the pedestrian heel and the floor during normal pedestrian gait. Sled-type tests do not simulate these conditions correctly and are often unable to distinguish between contaminated and uncontaminated surfaces. For this reason HSL/HSE strongly recommends that sled tests are not used in wet conditions. Roller coaster-type tests could potentially overcome the limitations of the more traditional tests. They utilize a ramp to bring the slider into contact with the floor whilst in motion. In wet conditions this generates a squeeze film of contamination, in a similar fashion to the Pendulum or pedestrian heel, and this may allow them to correctly determine CoF values for contaminated surfaces.

Objectives

- To evaluate the ability of roller coaster type tests to accurately measure the slip resistance of contaminated floor surfaces.

- To evaluate the Kirchberg Rolling Slider and SlipAlert to ascertain whether data generated compares closely with current United Kingdom Slip Resistance Group (UKSRG) test methods.

Main Findings

Both the Kirchberg Rolling Slider and the SlipAlert tests are able to distinguish between dry floors and contaminated floors. The tests are able to generate a squeeze film of contaminant comparable with that generated by pedestrian gait. This is a significant advantage over sled tests that often produce misleading results.

Of the two new tests evaluated, SlipAlert is the more portable and is also more readily accessible, being a commercially available product. The extended testing of SlipAlert showed a good correlation with the Pendulum test when both instruments were fitted with the same slider material (Four-S rubber) and the sliders were prepared in the same manner (conditioning with P400 & pink lapping film). The results show that, in wet conditions, SlipAlert is at least as dependable as Rz surface microroughness when compared with the Pendulum. SlipAlert offers the ability to measure the friction of contaminated floors.

It was previously noted (Hallas 2005) that the SlipAlert tends to give fail-safe readings, underestimating the friction available. In this study, there are several floors where SlipAlert has overestimated the available friction.

On inhomogeneous surfaces and floors with a mixture of tiles, SlipAlert gives an average friction reading and surface microroughness data should be used to supplement SlipAlert data in order to make a better assessment of the pedestrian slip potential.

It is suggested that SlipAlert should be regarded as a good indication of available friction, lending itself to risk assessment, monitoring of floor surfaces and evaluating & monitoring cleaning regimes.

Recommendations

Address the weaknesses of the SlipAlert test by improving manufacture, calibration, checking and preparation procedures and adopting Four-S rubber as standard specification. SlipAlert needs to be supplied with comprehensive information detailing testing procedures for specific situations such as evaluating spills and limitations such as averaging effect on mixed surfaces.

Consider the role of each of the tests to address HSE's demand for slip testing of floors in-situ. A combination of tests is likely to provide a robust method with clearly defined boundaries for each test according to their strengths and weaknesses.

It is recommended that when friction measurements are critical (e.g. for a forensic investigation, product specification, etc) the Pendulum test should be used.

Consider undertaking further development of the Kirchberg Rolling Slider to optimise squeeze film and calibrate against established test methods.

CONTENTS

1 INTRODUCTION

In a typical year, slips, trips and falls account for about 33% of all reported major workplace injuries, 20% of over-3-day workplace injuries and 50% of all reported accidents to members of the public. The majority of slip accidents occur in wet contaminated conditions. Amongst other things, the properties of floor surfaces can make a significant contribution to the cause or prevention of these accidents, but how is slip resistance measured?

The Health and Safety Laboratory (HSL) use the Pendulum skid resistance tester to determine the dynamic coefficient of friction (CoF) of a floor surface. This test correctly models the interaction between the pedestrian heel and the floor during normal pedestrian gait. The Pendulum test is the only portable slip resistance measurement method used by HSL on behalf of HSE (HSE, 2004). The pendulum data are routinely supplemented by Rz microroughness measurements, which give an indication of slip resistance in contaminated conditions.

Sled-type tests do not simulate the conditions of pedestrian gait correctly and are often unable to distinguish between contaminated and uncontaminated surfaces, producing misleading data. For this reason HSL/HSE strongly recommends that sled tests are not used in wet conditions (HSE 2004).

Roller coaster-type tests could potentially overcome the limitations of the more traditional tests. They utilize a ramp to bring the slider into contact with the floor whilst in motion. In wet conditions this generates a squeeze film of contamination, in a similar fashion to the pendulum or pedestrian heel, and this may allow them to correctly determine CoF values for contaminated surfaces.

The aim of this project was to evaluate the performance of two dynamic roller coaster-type tests; the Kirchberg Rolling Slider (Fig. 2.3) and SlipAlert (Fig. 2.4) and to compare their performance to the standard test methods employed by HSL/HSE and the UK Slip Resistance Group (UKSRG). The experimental work was completed prior to the release of Issue 3 of the UKSRG Guidelines in October 2005, therefore the work is reported in relation to Issue 2, 2000.

The Kirchberg Rolling Slider was constructed by HSL according to the design described by Kirchberg *et al* (1997). The SlipAlert instrument was designed by Malcolm Bailey, the secretary of the UK Slip Resistance Group, and was supplied by SlipAlert LLP.

2 METHOD

2.1 SURFACE MICROROUGHNESS

Two surface microroughness transducers were used; the Surtronic Duo (Fig. 2.1a) and the Mitutoyo Surftest SJ201P (Fig. 2.1b). Both are hand-held, electronic stylus-based instruments originally designed to assess the microroughness of metallic components in the engineering industry. Both instruments use a 5µm radius, 90˚ diamond-tipped stylus (Fig. 2.1c), which is traversed across a 5mm section of the material under study. During measurement, the vertical movement of the stylus is monitored, and a mean of five separate maximum peak to valley height measurements is calculated and presented as a single figure, termed “Rz”.

[a] [b] [c]

Figure 2.1: [a] The Surtronic Duo Rz surface microroughness transducer,
[b] The Mitutoyo Surftest SJ201P,
[c] Stylus detail

All testing was carried out using a standardised three-direction methodology to account for surface directional inhomogeneity. The Rz measurement was recorded throughout this study to form a benchmark for comparison of the new instruments.

2.2 DYNAMIC COEFFICIENT OF FRICTION – THE TRL PENDULUM

The TRL Pendulum (Fig. 2.2) is currently the preferred method of slipperiness assessment of HSL/HSE and the UK Slip Resistance Group. The apparatus consists of a spring-loaded rubber test slider, which is set to traverse a 126mm +/-1mm section of the flooring under study. The slider (a carefully specified and prepared sample of simulated footwear soling material) is mounted at the end of a weighted pendulum arm, which is released from a raised, horizontal position to the right of the test area. The energy lost by the slider / arm assembly during the floor traverse limits the height of the upward pendulum swing to the left of the test area; the extent of this energy loss is represented on a simple Slip Resistance Value (SRV) scale. As a general rule, SRV values (also known as British Pendulum Numbers (BPN)) may be converted to Coefficient of Friction (CoF) by simple division by 100, though this simple relationship is not accurate above a slip resistance value of 40. The pendulum results in this report have been converted to coefficient of friction (CoF) using the following equation (from BSI 96/104915 [B/208]):

$$CoF = (3 \times SRV) / (330 - SRV)$$

In 2002, a sub-committee of British Standards Committee B/556 (The Pedestrian Slip Resistance Coordinating Committee) produced three British Standards (BS 7976, Parts 1-3, 2002), which formally describe the specification, operation and calibration of the pendulum respectively. All testing was carried out in line with the methodologies outlined in BS 7976-2, where appropriate.

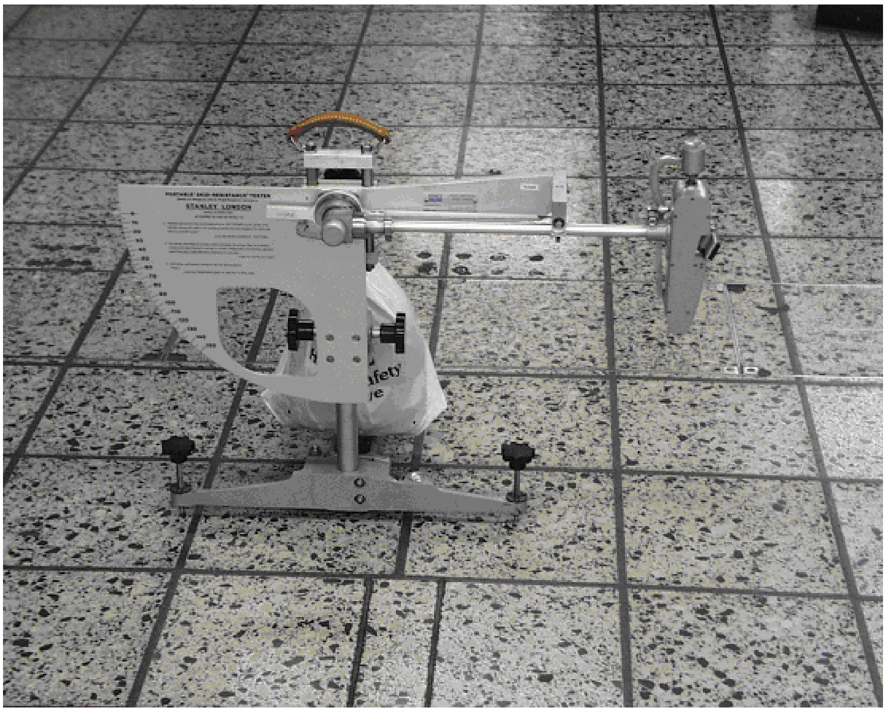

Figure 2.2: The TRL Pendulum dynamic coefficient of friction test

A *Four-S* (standard simulated shoe sole) test slider was used during the study; this material was developed by RAPRA (Rubber and Plastics Research Association) to represent footwear heel materials of moderate slip resistance. Sliders were conditioned using the methodology jointly developed by the UK Slip Resistance Group and HSE/HSL (UKSRG, 2000). Sliders were prepared / conditioned fully before testing and between sets of tests in order to both ensure a consistent finish to the slider face, and to prevent cross-contamination between test areas. The pendulum was calibrated by the British Standards Institute prior to use, and was visually inspected *in situ* before use according to BS 7976-3 (Informative Annex B).

Pendulum SRV (or BPN) data were generated in the as-found condition before and after the application of potable water by hand spray.

2.3 KIRCHBERG ROLLING SLIDER TESTS

The Kirchberg Rolling Slider (Fig. 2.3) was constructed by HSL according to the design described by Kirchberg *et al* (1997) and has three rubber sliders arranged in a similar pattern to those on a GMG100 sled test. The ramp has three different height (and therefore speed) settings, and the distance travelled by the trolley after initial contact with the floor is used to determine the level of dynamic friction available. The distance travelled is determined by tape measure from the point of contact of the rear of the trolley with the floor to the rear of the trolley at rest after testing.

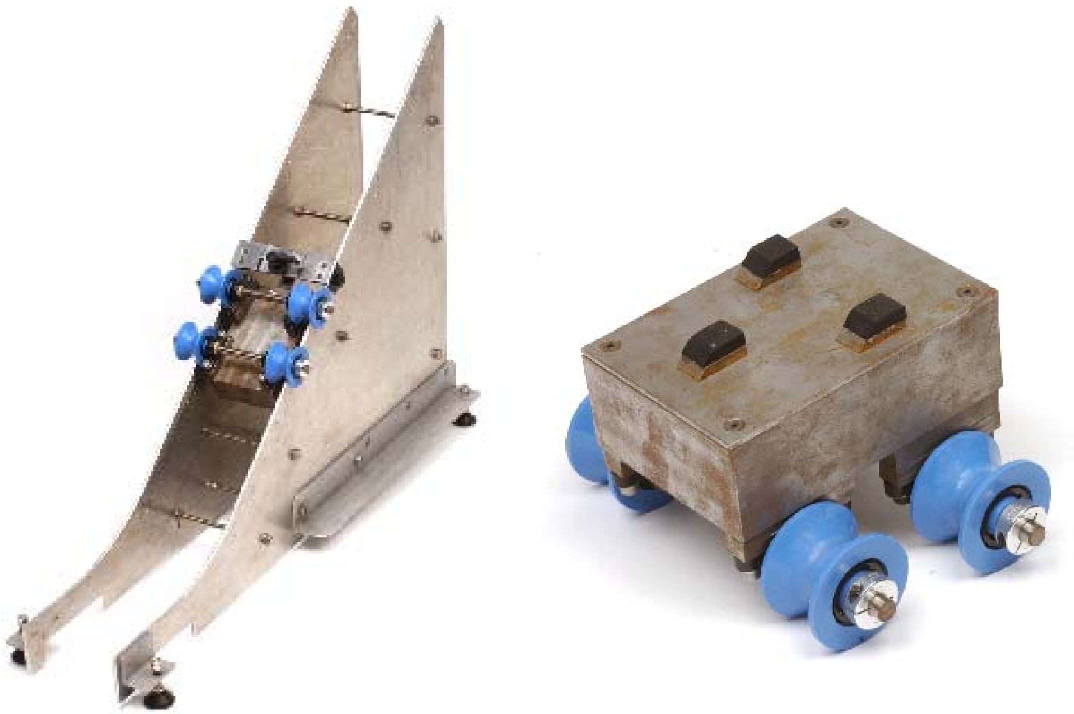

Figure 2.3: [a] The Kirchberg Rolling Slider, [b] Underside showing slider arrangement.

In order to condition the rubber sliders used on the Rolling Slider, the distance travelled by the pendulum slider during each conditioning step was calculated, and the procedure adapted as outlined below:

- For a new slider the Rolling Slider was pulled 5 times over an A4 sheet of P400 grit paper and 9 times over an A4 sheet of pink lapping film.
- For a used slider the Rolling Slider was pulled 1.5 times over an A4 sheet of P400 grit paper and 9 times over an A4 sheet of pink lapping film.

As with the pendulum eight measurements were taken with the Rolling Slider test and the final 5 used to determine the coefficient of friction.

After initial measurements were taken, readings were repeated with smaller sized sliders to assess how varying the available slider area affected the results. The standard slider arrangement on the trolley uses three sliders, each measuring 15mm x 16mm. In order to reduce the thickness of the squeeze film generated by the sliders, an alternative set were made, each measuring 10mm x 13mm. This also has the effect of reducing the contact area for dry measurements, which should increase the distance travelled, potentially improving differentiation between dry surfaces.

2.4 SLIPALERT

The SlipAlert instrument (Fig. 2.4) is a gravity-powered trolley, which rolls down a specially made ramp before making contact with the floor surface under examination (note that this evaluation used the wooden ramp and corresponding conversion chart photographed in figure 2.4a). Once in contact with the floor, the SlipAlert rolls on two front wheels and a single rubber slider towards the rear, mounted at the same angle as the Pendulum slider relative to the ground on impact. It features an inbuilt digital display from which the number is converted to coefficient of friction using the chart attached to the ramp. During the initial trials it was discovered that the SlipAlert had been supplied with a non-standardised rubber compound (referred to in the results section as "Three-S", i.e. simulated shoe sole). All readings were repeated with a Four-S slider.

Figure 2.4: [a] SlipAlert, [b] Underside showing slider detail.

In order to condition the rubber sliders used on the SlipAlert, the distance travelled by the pendulum slider during each conditioning step was calculated, and the procedure adapted as outlined below:

- For a new slider the SlipAlert was pulled 5 times over an A4 sheet of P400 grit paper and 9 times over an A4 sheet of pink lapping film.
- For a used slider the SlipAlert was pulled 1.5 times over an A4 sheet of P400 grit paper and 9 times over an A4 sheet of pink lapping film.

The initial study showed that the choice of slider material was critical to the readings obtained using SlipAlert. Where the SlipAlert was evaluated further the slider used was Four-S rubber (Standard Simulated Shoe Sole) supplied by RAPRA.

The instrument was evaluated by testing installed flooring materials in dry and water wet contaminated conditions during site visits. Pendulum and microroughness measurements were taken on each floor for comparison. Further testing was carried out with other contaminants, notably mayonnaise, sugar and sawdust.

A series of tests were undertaken using three runs of SlipAlert as per the instructions.

Further tests were undertaken using the median of the last five of eight runs as per the UKSRG guidelines for the Pendulum test.

The results are reported here as coefficient of friction, and the Pendulum data have been converted to allow direct comparison.

All friction measurements were conducted in either “as found dry” or “as found water-wet” conditions. Floors were not subjected to any cleaning prior to the tests, other than the normal scheduled cleaning for the areas tested. Where cleaning was investigated, further measurements were taken after cleaning in order to evaluate the effectiveness of the cleaning, and the ability of the instruments to distinguish between clean and unclean floors.

2.5 TEST MATERIALS

For the initial comparative work using both roller coaster instruments the following installed floors (see Figure 2.5) were assessed during the site visits:

- Terrazzo 1
- Natural Stone
- Linoleum
- Vinyl Tiles
- Smooth Interior Concrete
- Ceramic tiles
- Mosaic
- Parquet
- Terrazzo 2
- Vinyl Floor
- Profiled Safety Vinyl

Figure 2.5: Installed Floors.

Terrazzo 1

Natural Stone

Linoleum

Vinyl Tile

Figure 2.5: Installed Floors.

Ceramic

Mosaic

Smooth Interior Concrete

Terrazzo 2

Vinyl floor

Parquet

Figure 2.5: Installed Floors.

Safety Vinyl

3 RESULTS

The surface microroughness of each flooring surface was measured. The mean values of each set of ten measurements are presented in Tables 3.1, 3.2, 3.3 and 3.4. The roughness values are useful in distinguishing between floors of the same generic type.

The Slip Resistance Values (SRV) were generated using the Stanley Pendulum fitted with Four-S rubber sliders. The median slip resistance value of each installed floor was converted to CoF and the results are presented in Tables 3.1, 3.2, 3.3 and 3.4.

The CoF results for the Kirchberg Rolling Slider were obtained from the last five of eight distance measurements, using the chart on page 28 of the paper by Kirchberg *et al* (1997). The Kirchberg Rolling Slider results are presented as low speed (LS), medium speed (MS) and high speed (HS) in Table 3.1.

CoF values for SlipAlert were determined using the chart supplied with the instrument. The results are presented in Tables 3.2, 3.3 and 3.4.

Chart 3.1 shows a comparison between CoF values obtained with the Kirchberg Rolling Slider and those obtained with the Pendulum.

Chart 3.2 shows a comparison between CoF values obtained with the SlipAlert and those obtained with the Pendulum in the initial phase of the study.

Chart 3.3 shows a comparison between CoF values obtained with the SlipAlert CoF values (calculated from mean of three runs) and those obtained with the Pendulum in the later phase of the study.

Chart 3.4 shows a comparison between CoF values obtained with the SlipAlert CoF values (calculated from median of last five of eight runs) and those obtained with the Pendulum in the later phase of the study.

Chart 3.5 shows a comparison between CoF values obtained with the Pendulum and the Rz Surface Microroughness values.

Flooring	Mean Rz (μm)	Pendulum Tests (μ)		Kirchberg Rolling Slider (μ)							
		Four-S Rubber Slider		Four-S Rubber Slider (3 x 15mm x 16mm)				Four-S Rubber Slider (3 x 10mm x 13mm)			
		Dry	Wet	MS Dry	LS Wet	MS Wet	HS Wet	LS Wet	MS Wet	HS Wet	
Terrazzo 2	2.1	0.71	0.08	0.28	0.13	0.10	0.08	0.10	0.10	0.09	
Vinyl Tiles	2.5	0.64	0.21	0.26	0.17	0.14	0.13	0.19	0.18	0.18	
Parquet	3.0	0.61	0.18	0.35	0.24	0.19	0.18	0.21	0.23	0.22	
Terrazzo 1	3.1	0.72	0.15	0.39	0.16	0.13	0.12	0.19	0.18	0.16	
Linoleum	6.4	0.52	0.30	0.27	0.17	0.15	0.14	0.19	0.18	0.18	
Ceramic Tile	11.9	0.65	0.09	0.45	0.10	0.07	-	0.09	0.08	-	
Vinyl Floor (Blue)	13.1	0.75	0.14	0.44	0.18	0.12	0.10	0.15	0.12	0.10	
Vinyl Safety Floor	13.5	0.72	0.54	-	0.28	0.28	0.22	0.26	0.24	0.23	
Mosaic	15.2	0.63	0.25	0.30	0.22	0.15	0.14	0.19	0.18	0.18	
Smooth Internal Concrete	18.2	0.64	0.43	0.50	0.22	0.20	0.20	0.28	0.28	0.25	
Natural Stone	19.0	0.67	0.50	0.38	0.26	0.25	0.25	0.28	0.28	0.28	

Table 3.1: Mean surface roughness measurements, Pendulum CoF Values and Kirchberg Rolling Slider CoF values.

Colour coding: Red indicates High Slip Potential, Amber indicates Moderate Slip Potential, Green indicates Low Slip Potential, according to the boundaries set in the UKSRG Guidelines for Surface Microroughness and Pendulum tests.

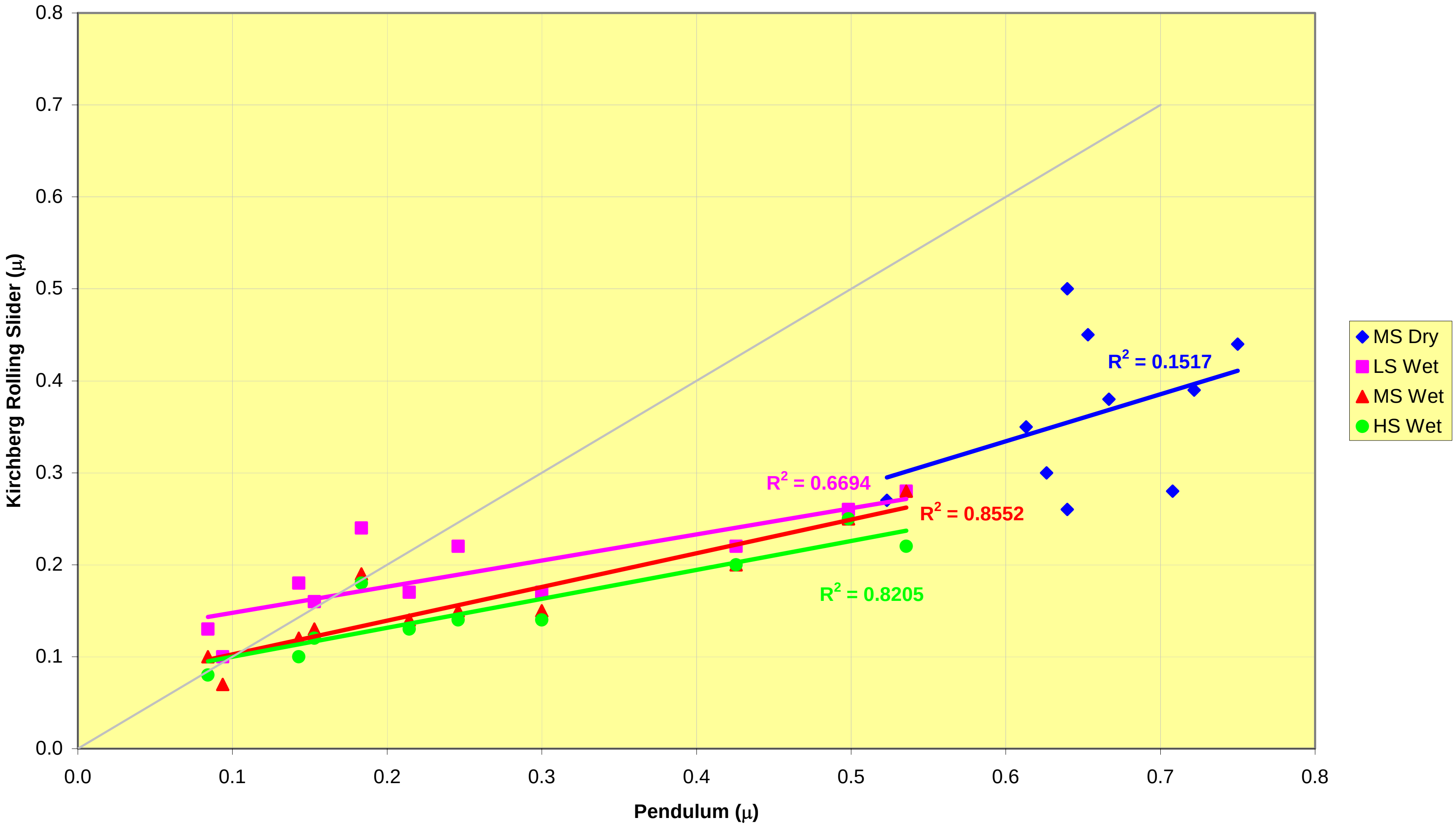

Chart 3.1: Pendulum CoF values and Kirchberg Rolling Slider (3 x 15mm x 16mm) CoF values.

Flooring	Mean Rz (μm)	Pendulum Tests (μ)		SlipAlert (μ)		
		Four-S Rubber Slider		Four-S Rubber Slider		"Three-S" Rubber Slider
		Dry	Wet	Dry	Wet	Wet
Terrazzo 2	2.1	0.71	0.08	0.23	0.14	0.15
Vinyl Tiles	2.5	0.64	0.21	0.45	0.21	0.21
Parquet	3.0	0.61	0.18	0.41	0.27	0.23
Terrazzo 1	3.1	0.72	0.15	0.55	0.20	0.29
Linoleum	6.4	0.52	0.30	0.41	0.28	0.24
Ceramic Tile	11.9	0.65	0.09	0.59	0.10	0.11
Vinyl Floor (Blue)	13.1	0.75	0.14	0.53	0.15	0.15
Vinyl Safety Floor	13.5	0.72	0.54	0.53	0.37	0.36
Mosaic	15.2	0.63	0.25	0.49	0.28	0.24
Smooth Internal Concrete	18.2	0.64	0.43	0.55	0.35	0.38
Natural Stone	19.0	0.67	0.50	0.60	0.37	0.42

Table 3.2: Mean surface roughness measurements, Pendulum CoF Values and SlipAlert CoF values.

Colour coding: Red indicates High Slip Potential, Amber indicates Moderate Slip Potential, Green indicates Low Slip Potential, according to the boundaries set in the UKSRG Guidelines for Surface Microroughness and Pendulum tests.

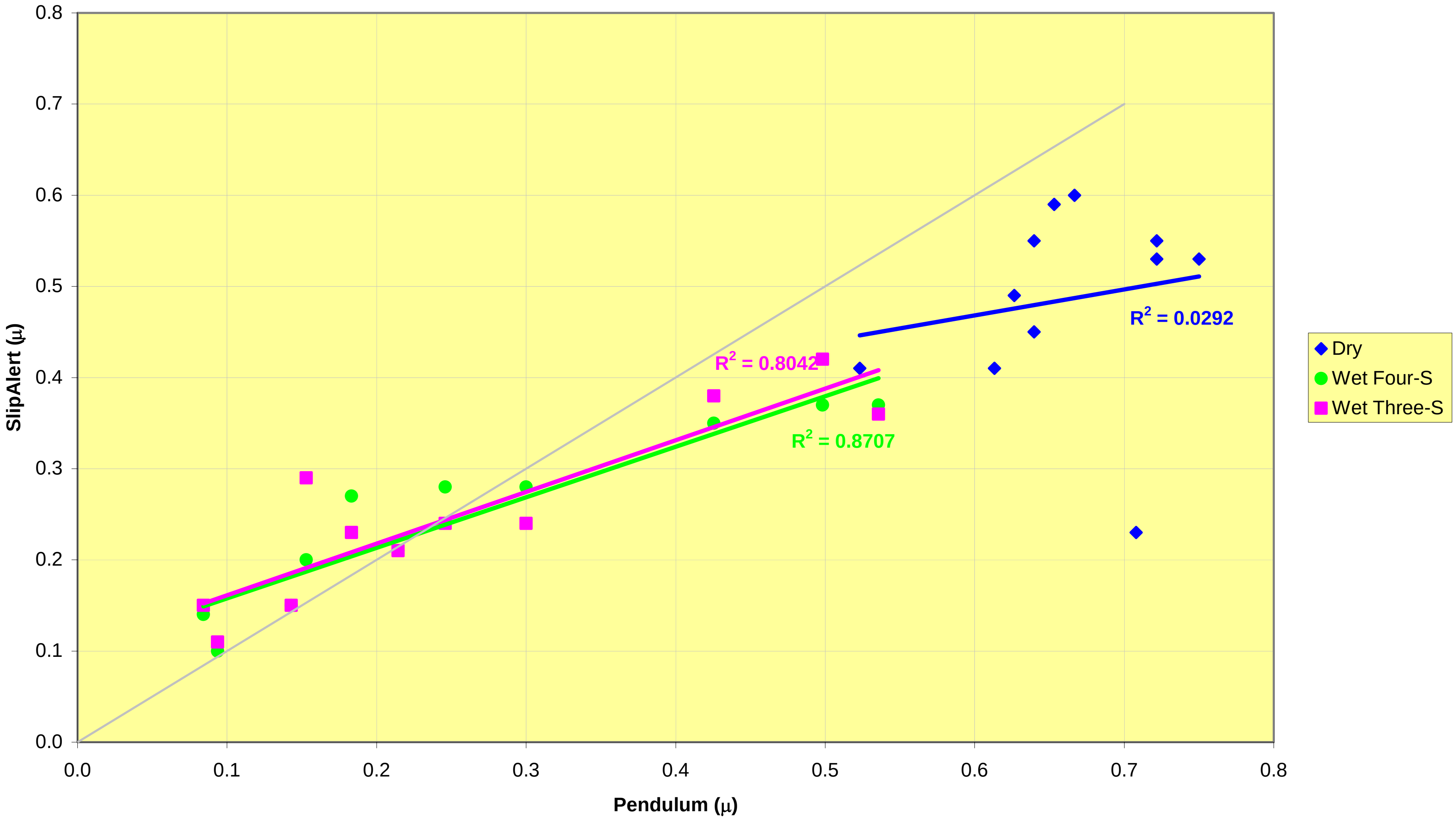

Chart 3.2: Pendulum CoF values and SlipAlert CoF values.

Flooring	Mean Rz (μm)	Pendulum (CoF)		Slip Alert (CoF)	
		Dry	Wet	Dry	Wet
Terrazzo	3.60	0.59	0.09	0.54	0.12
Vinyl	4.30	0.74	0.15	0.60	0.14
Vinyl	10.46	0.69	0.15	0.60	0.18
Ceramic Tile	10.80	0.31	0.07	0.19	0.09
Ceramic Tile with Carborundum	11.40	0.64	0.27	0.50	0.21
Vinyl Tile	14.61	0.60	0.32	0.35	0.22
Ceramic tile	14.80	0.64	0.33	0.54	0.27
Ceramic Tile	16.02	0.60	0.30	0.54	0.33
Safety Vinyl	24.50	0.65	0.50	0.60	0.41
Safety Vinyl	30.19	0.64	0.44	0.54	0.33
Safety Vinyl	37.10	0.49	0.30	0.32	0.28
Metal Blister Profile D1	-	0.69	0.37	0.46	0.27
Metal Blister Profile D2	-	0.63	0.34	0.54	0.27
Metal Blister Profile D3	-	0.75	0.36	0.54	0.39

Table 3.3: Mean surface roughness measurements, Pendulum CoF Values and SlipAlert CoF values (Sliders conditioned to UKSRG, SlipAlert average of 3 runs).

Colour coding: Red indicates High Slip Potential, Amber indicates Moderate Slip Potential, Green indicates Low Slip Potential, according to the boundaries set in the UKSRG Guidelines for Surface Microroughness and Pendulum tests.

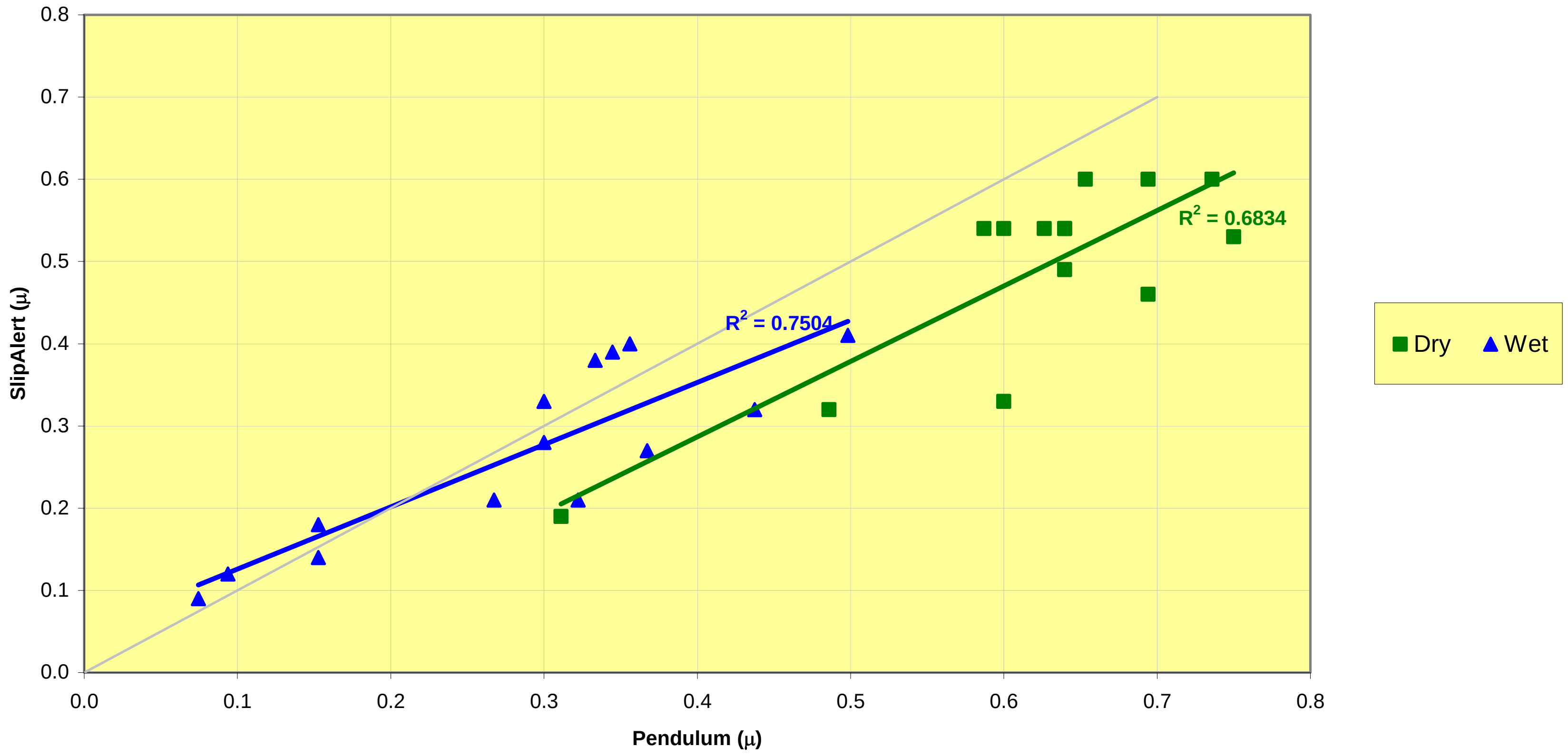

Chart 3.3: Pendulum CoF values and SlipAlert CoF values (calculated from mean of three runs).

Flooring	Mean Rz (µm)	Pendulum (CoF)		SlipAlert (CoF)	
		Dry	Wet	Dry	Wet
Vinyl	1.6	0.76	0.11	0.78	0.18
Studded Rubber	2.1	0.71	0.13	0.77	0.21
Vinyl Tiles	2.5	0.64	0.21	0.45	0.21
Parquet	3.0	0.61	0.18	0.41	0.27
Terrazzo	3.1	0.72	0.15	0.55	0.20
Linoleum	4.4	0.72	0.15	0.49	0.21
Linoleum	6.4	0.52	0.30	0.41	0.28
Wood	8.1	0.75	0.19	0.61	0.34
Slate	8.3	0.61	0.30	0.50	0.29
Parquet	8.4	0.67	0.19	0.62	0.32
Terrazzo	10.0	0.61	0.15	0.33	0.21
Ceramic Tile	11.9	0.65	0.09	0.59	0.10
Quarry Tile	12.8	0.67	0.19	0.70	0.18
Vinyl	13.1	0.75	0.14	0.53	0.15
Safety Vinyl	13.5	0.72	0.54	0.53	0.37
Quarry Tiles	14.8	0.72	0.12	0.69	0.11
Mosaic	15.2	0.63	0.25	0.49	0.28
Vinyl	15.6	0.50	0.28	0.42	0.40
Wood	15.9	0.74	0.18	0.63	0.28
Concrete	18.2	0.64	0.43	0.55	0.35
Natural Stone	19.0	0.67	0.50	0.60	0.37
Slate	23.4	0.68	0.33	0.63	0.41
Natural Stone	23.5	0.60	0.41	0.60	0.49
Epoxy / Aggregate	27.0	0.72	0.43	0.77	0.43
Parquet	-	0.69	0.18	0.78	0.14

Table 3.4: Mean surface roughness measurements, Pendulum CoF Values and SlipAlert CoF values (Sliders conditioned to UKSRG, CoF median of last 5 of 8 runs).

Colour coding: Red indicates High Slip Potential, Amber indicates Moderate Slip Potential, Green indicates Low Slip Potential, according to the boundaries set in the UKSRG Guidelines for Surface Microroughness and Pendulum tests.

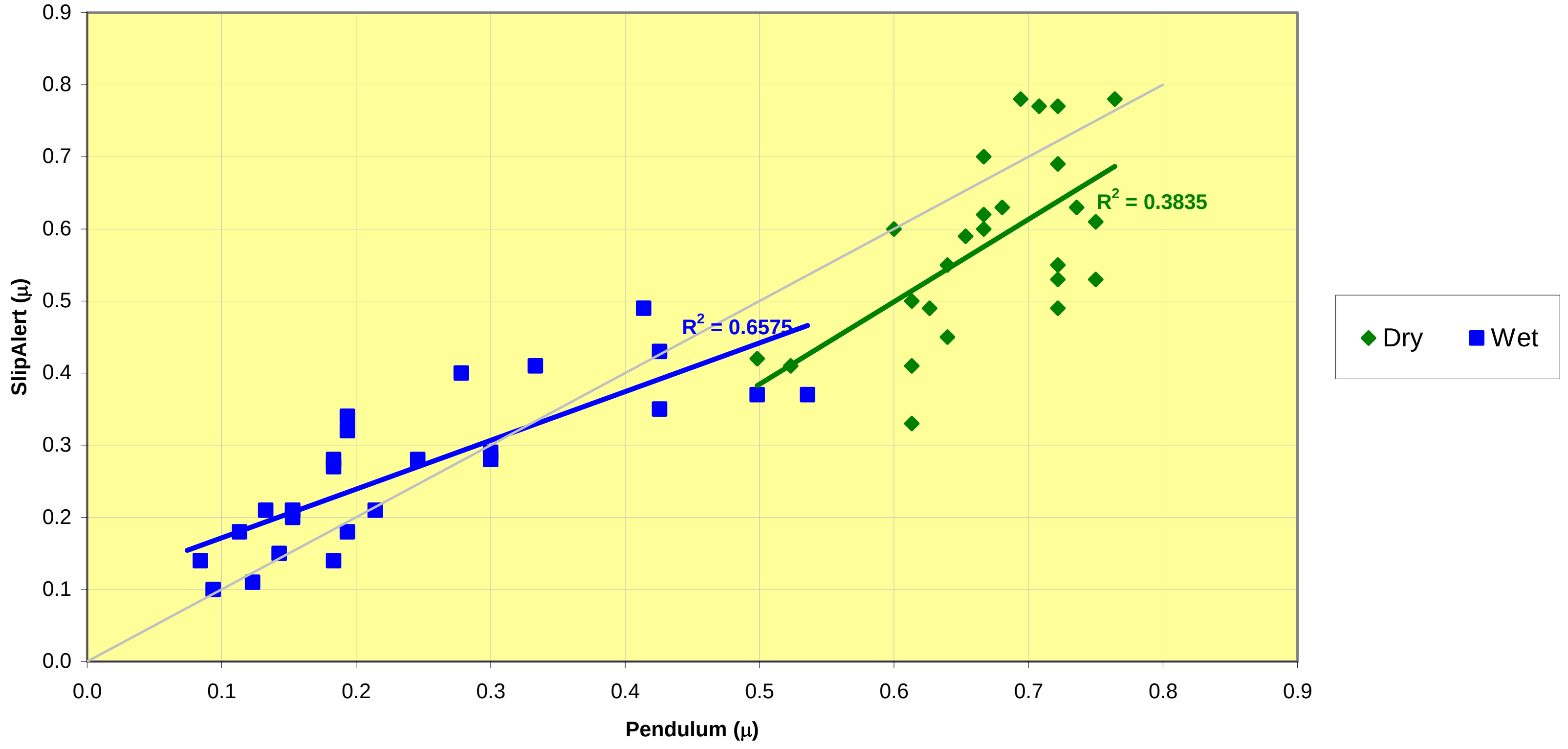

Chart 3.4: Pendulum CoF values and SlipAlert CoF values (calculated from median of last five of eight runs).

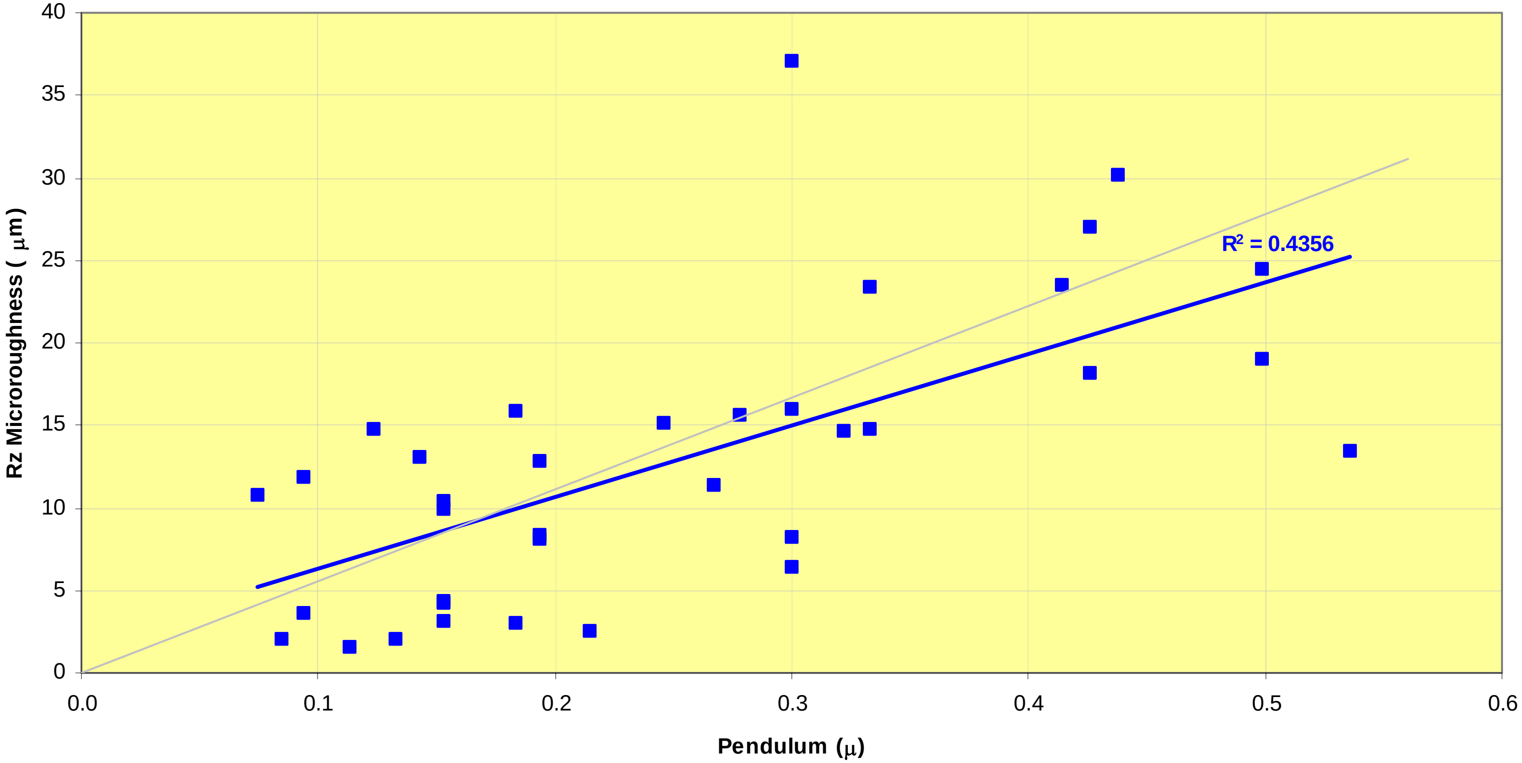

Chart 3.5: Pendulum CoF values and Mean Rz Surface Microroughness values.

4 DISCUSSION

4.1 KIRCHBERG ROLLING SLIDER VS PENDULUM

4.1.1 Operation

In order to take readings on a floor, the ramp needs to be set up carefully. The critical aspect to this is the height, as the Rolling Slider should move smoothly from the ramp to the floor. If the ramp is too high, the Slider drops from the end of the ramp onto the floor, too low and the Slider makes a heavy impact with the floor before reaching the end of the ramp.

The Rolling Slider can be released from three height positions on the ramp, giving three speeds as the Slider leaves the ramp. At the lowest height, and therefore low speed (LS) the distance travelled by the Rolling Slider is very small and errors in human judgment when measuring the distance may have a large effect on the final result. At high speed (HS) in contaminated conditions the slider can travel up to two meters. This distance can be difficult to measure accurately by tape measure, especially for a single operator. At medium speed the slider travels an acceptable distance to allow ease of measuring and minimisation of potential operator error. The medium speed giving the best compromise between distances travelled in the dry compared with distance travelled in the wet.

When the small rubber sliders were used, it was difficult to fix them strongly using double-sided sticky tape (as used on the large sliders) due to the reduced surface area. This was overcome by use of a new mounting plate with a lug to resist the shear force applied to the slider during testing.

4.1.2 Results

From Chart 3.1 it can be seen that in wet conditions the operation of the Kirchberg Rolling Slider at the medium speed (MS) gives the closest correlation with the corresponding Pendulum measurements. The gradient of the line of best-fit shows that the Kirchberg Rolling Slider tends to under-read at higher levels of friction, as compared to the results from the Pendulum test.

Chart 3.1 also highlights the lack of correlation between the Kirchberg Rolling Slider and the Pendulum in dry conditions. The Kirchberg instrument does not rank the floors in the same order as the Pendulum and does not appear to be able to differentiate clearly between them. Results suggest that half of the floors tested would present a moderate slip potential in the as-found dry condition. This result is not supported by the pendulum (or by workplace experience), which classifies all the floors as presenting a low slip potential in the dry.

In the wet condition the Kirchberg Rolling Slider agrees much more closely with the Pendulum on more slippery surfaces. Although the roller coaster ranks the floors in a similar order as the Pendulum on less slippery surfaces, it does not seem able to attain high CoF values and consistently and dramatically underestimates the level of available friction.

The conversion from distance travelled by the trolley to CoF is by use of a chart in Kirchberg et al (1997). Given the relatively good correlation coefficient of 0.86 at the medium speed, it may be possible to plot a calibration curve for the Kirchberg instrument to allow a Pendulum reading to be obtained, at least in wet conditions.

Adjusting the size of the sliders to reduce the squeeze film thickness gave the anticipated effect on the results of the tests. The CoF values obtained are slightly higher for all floors (except the vinyl safety floor) suggesting the thinner squeeze film is allowing more contact with the floor surface. The exception on the vinyl safety floor may be due to the flexibility of the flooring, which can cause the roller coaster trolley to bounce on impact. The Rolling Slider is still unable to achieve high CoF values with smaller sliders.

The ability to adjust the squeeze film thickness by simply altering the dimensions of the sliders and the possibility of plotting a calibration curve to give readings similar to the Pendulum in wet conditions suggest the test could be useful with further development.

4.2 SLIPALERT VS PENDULUM

4.2.1 Operation

In terms of operation, the SlipAlert is very simple and user friendly. The instrument is compact and can be packed away into a small toolbox making it easily portable. The visual impact of observing the distance travelled by the slider can demonstrate the relative slipperiness of surfaces without understanding the science behind the test. As such, the SlipAlert test is particularly suited to training events, where non-experts can easily see the effect on slip resistance of a wet floor. However, the logistics of using the device in such a way may be a problem, as a 2m length of smooth flooring material would be required. It is also difficult to demonstrate the effect of a very small quantity of water, as the whole area needs to be wet for accurate readings to be obtained.

The trolley is also prone to veer off to one side where there are imperfections in the flooring being tested, which can produce misleading results. In heavily contaminated conditions, the wheels of the trolley become contaminated and this can make the operation more difficult. When the contaminant present was changed from water to mayonnaise, the wheels became contaminated and this hindered the subsequent operation of the instrument until a thorough clean was possible. It also allowed the trolley to slide off the ramp sideways, before reaching the end of the ramp. SlipAlert LLP has since introduced a new aluminium ramp to reduce this effect and also issued revised instructions (Jul 2005).

The instrument has an LCD display that shows the distance travelled, which is then converted to CoF using a chart. A direct reading on the instrument would be a significant improvement in terms of simplicity and reduced potential for errors. The authors are aware of other SlipAlert users simply comparing the values obtained from the readout and not converting to CoF. Since the conversion of the readout to CoF is an inverse relationship, this created confusion as to which floor was the most slippery. The same operators of the SlipAlert were also unaware of the difference between Three-S and Four-S rubber, leading to further confusion.

On certain floor surfaces, particularly uneven and profiled surfaces, the slider fitted to SlipAlert tends to rotate around its fixing screw. This rotation during a measurement run was seen to shift the reading by as much as 20 points on counter. This was overcome by the use of double-sided adhesive tape under the slider, to supplement the screw fixing. SlipAlert LLP has since modified the instrument to prevent this.

A certain amount of bouncing has been observed on softer flooring materials, notably the vinyl and safety vinyl. Attempts to use TRRL rubber for the slider were thwarted by the tendency to bounce, as the rubber is much softer than the more commonly used Four-S rubber. TRRL rubber is used by HSL and the UKSRG to test areas for barefoot pedestrian traffic in wet conditions.

4.2.2 Results

In wet conditions, SlipAlert appears to be capable of distinguishing between floors and agrees reasonably closely with the Pendulum results (Table 3.2 & Chart 3.2). The correlation between the Pendulum and the SlipAlert, above a CoF of about 0.3, is not as close as on more slippery surfaces. This may in part be due to a slight error in the chart used for conversion from the reading on the instrument to the CoF value. The chart was revised when the new aluminium ramp was introduced.

When using the “Three-S” slider the SlipAlert misclassifies floors more often when compared with the pendulum, including overestimating the available friction on Terrazzo 1. Terrazzo is a very common flooring type across many sectors including supermarkets, shopping centres etc. The “Three-S” slider is non standardised and therefore could not be used for direct comparison with the Pendulum values. As the correlation coefficient on Chart 3.2 shows, there is a slight improvement when Four-S is used. The use of Three-S rubber also introduces confusion to an already confused arena.

In the dry condition, the correlation between SlipAlert and the Pendulum is not so good. The two instruments measure slightly different conditions, skewing some of the data presented. For example, the obvious outlier on Chart 3.2 where the Pendulum result is 0.71 and the SlipAlert result is 0.23 is thought to be due to low levels of dust contamination. Where a small amount of dust is present on a smooth floor, the SlipAlert exaggerates the effect of the dust. In this situation, the SlipAlert does not run over exactly the same path on each test, so there is a tendency for dust to accumulate on the slider. The Pendulum measures exactly the same area of floor on each swing, so the amount of contamination does not increase from one swing to the next. The different data from the two tests is probably useful in understanding slips in dusty situations, and in this case, this could be an advantage of the SlipAlert test. When the outlier is removed, the R^2 correlation coefficient is 0.38 compared with 0.03 when included.

4.3 KIRCHBERG ROLLING SLIDER VS SLIPALERT

During the initial phase of this study, both roller coaster tests were compared with pendulum on a variety of installed floors with Rz surface roughness ranging from 2.1μm to 19.0μm. This gives a good basis for comparison of the two tests with the Pendulum and with each other in wet and dry conditions.

4.3.1 Operation

One factor that must be taken into consideration is the amount of space required to operate the roller coaster slip tests as opposed to the Pendulum. When the level of available friction is very low the trolleys can travel up to two metres. In many areas there will not be sufficient floor space to correctly use these tests. The Kirchberg Rolling Slider does offer the possibility of a lower speed test, and therefore short test distance, which may be of use in restricted spaces.

4.3.2 Results

Where an accident has occurred on a small spill, the effect of the spill on the availale friction is easy to assess with the Pendulum, as the small tests area is often comparable with the contaminated area. When testing the effect of spills with the roller-coaster tests, the whole length of the path travelled by the slider must be contaminated to get a representative reading.

Both roller coaster-type tests have shown the ability to distinguish between wet and dry floors, which standard sled tests are unable to do reliably. Although the narrower range of both the Kirchberg Rolling Slider and SlipAlert can result in misclassification of dry floors, their main application is likely to be in assessing contaminated surfaces (the conditions in which most slip accidents occur) and therefore the wet results are of more importance. Dry reading can have significance in understanding unusual situations. For example, when a very high CoF reading is obtained in the dry with the Pendulum, the CoF in the wet condition would be expected to be low on the same surface. When CoF in both the wet and dry conditions are similar, this usually indicates a surface either with high microroughness or dry / greasy contamination. The experienced operator would use the relative magnitude of the dry and wet tests to understand the surface and perhaps investigate further. With the compressed range of readings from the roller coaster tests, this extra information may be missed.

Of the two tests, SlipAlert appears to be able to generate a wider range of results and for this reason produces results which better reflect the Pendulum values. Only the parquet floor was misclassified by the SlipAlert when compared to the Pendulum values. Although it still lacks the ability of the Pendulum to record very high values, it is able to distinguish between wet and dry floors and correctly classify floors. Where there is a difference between the CoF values generated by SlipAlert and the Pendulum CoF values, the test generally errs on the side of caution by underestimating the level of available slip resistance. It is therefore unlikely that an unsafe floor would be erroneously classified as safe by SlipAlert.

4.4 FURTHER TESTING OF SLIPALERT VS PENDULUM

4.4.1 Results

The initial phase of this study showed that the use of Four-S rather than Three-S rubber sliders gave a better correlation with the Pendulum test. It was therefore decided to look further at the SlipAlert test fitted with a Four-S rubber slider. The rubber was conditioned in a standard manner, giving the best possible comparison with the Pendulum test.

The agreement between the measurements made using the Pendulum and SlipAlert is generally good (Table 3.4 & Chart 3.4). It was previously noted in section 4.2.1 (and Hallas 2005) that the SlipAlert tends to give fail-safe readings, underestimating the friction available. In this extended section of the study, there are several floors where SlipAlert has overestimated the available friction.

When measuring slippery surfaces, where the instrument can travel up to 2m, the instrument can turn, causing difficulties. The effect on the distance counter readings can be quite significant, with readings of 185 where the spinning is observed, and readings 210 in the same conditions when no turning occurs. Once converted to CoF these differences are less significant, as both would lead to a high slip potential classification.

When testing floors contaminated with dry materials, the agreement between the two tests remains good, for example, contamination of a kitchen floor with sugar gave Pendulum CoF of 0.13 and SlipAlert CoF of 0.18. In a butchers shop, where sawdust is used to control greasy contamination from meat, the Pendulum CoF was 0.30 compared with a SlipAlert CoF of 0.29.

The SlipAlert often needs a large area of flooring to carry out wet and dry evaluations, compared with that necessary for the Pendulum. The instrument is ideal for testing large areas of flooring and survey work. For accident investigation, several limitations would inhibit its use. It is not possible to measure a small spill, for which the Pendulum test is ideal. The effect of a small spill can be seen, by wetting the whole path travelled by the trolley. The Pendulum test is usually carried out in three directions to account for floor surface directionality. This is often not possible with SlipAlert, in corridors for instance, where the area is too small for a measurement perpendicular to the pedestrian traffic flow.

Floors with variability within a small area are difficult to accurately assess, for example floors consisting of a resin matrix and a fine aggregate or where a mixture of tiles is used. On these surfaces, SlipAlert will only give a mean CoF, whereas the Pendulum is able to evaluate much smaller areas within the floor surface, such as individual tiles. It should be considered that if the variability in the floor were overlooked, an inaccurate conclusion could be reached regarding the slip potential of an area. This is particularly significant when inexperienced operators use SlipAlert. For example, when visiting premises to assess slip resistance of flooring in an area, it is not uncommon to find a whole variety of tiles that had not previously been noted as being different. Large areas of tiles often suffer from defects over time, with tiles cracking and so necessitating replacement. If the same tile is no longer available, the replacement tiles often differ from the originals. Complementary surface microroughness measurements would be useful to overcome this limitation.

Below is a table of strengths and weaknesses of the SlipAlert test method.

Strengths	**Weaknesses**	**Solution**
Easy to use	Limited experience	Time
Visual	Poor calibration procedure	Clearly define procedure (see Instructions Jul 2005)
Relatively inexpensive	No checking procedure	Adapt Pendulum procedure?
Monitoring	Three S or Four S	Adopt Four-S
Portable	Dry values	
Recognises contamination	Spills	Explanation / Training
Robust	Turning	
Use on slopes / ramps	Large sample length	
Measures friction	Slider movement	Improved fixing
	Wheels contaminated (& cross contamination)	
	Convert to μ	Direct reading
	Averaging (inhomogeneous & mixed surfaces)	Combine with Surface microroughness (see Instructions Jul 2005)
	Limited on some surface (profiles, stairs)	Combine with Surface microroughness

Table 4.1: Strengths and Weaknesses of SlipAlert.

Many of the weaknesses are relatively easy to overcome, and others could be addressed by combination with other tests, as discussed in section 4.6.

Below is a table of strengths and weaknesses of the Pendulum test method.

Strengths	Weaknesses	Solution
Established	Expensive	Use other tests where possible
Developed protocol	Difficult to use	
In HSE guidance	Delicate	
In BS7976	Limited portability	
Spills	Limited on some surfaces, stairs	Combine with other tests
Mopped floors		
UKSRG		
Good calibration procedure		
Good checking procedure		
Recognises contamination		
Use on slopes and ramps		

Table 4.2: Strengths and Weaknesses of Pendulum.

Weaknesses may be relatively difficult to overcome, but may be addressed by combination with other tests, as discussed in section 4.6.

4.5 RZ SURFACE ROUGHNESS VS PENDULUM

4.5.1 Results

Rz surface microroughness is used by HSE as a simple and accessible method of assessing slip potential in contaminated conditions. Surface microroughness meters are very portable and easy to use. The first impression from Chart 3.4 may be that the correlation of the Rz roughness data and water wet Pendulum test data in this study is not as good as might be expected. However, in this study, real floors were used, which were not necessarily clean when the Pendulum tests were undertaken. Surface roughness is not significantly affected by contamination on a floor. Other work has studied the relationship between Rz roughness and wet slip resistance, showing a good correlation. Previous studies have tended to use laboratory samples in a clean condition. When surface microroughness and Pendulum data are gathered both data sets are useful in understanding the slip resistance of the surface. In this example, the different results from the two test methods point the investigator to the possibility of contamination.

It is not recommended that surface microroughness data be used in isolation. HSE/HSL have produced a computer program, the Slips Assessment Tool (SAT), designed to take Rz microroughness information and subjective environmental factors to assist with risk assessments relating to slip potential. Research is ongoing to understand how other roughness parameters relate to slip resistance in order to make this software tool more robust.

Below is a table of strengths and weaknesses of the surface microroughness test method.

Strengths	Weaknesses	Solution
Easy	Only one measure	Develop understanding of other parameters
Understand limits	Doesn't recognise contamination	Use with SAT
Relatively inexpensive	5µm radius stylus	Investigate other stylus
Monitoring	Could mislead on certain surfaces	Use other parameters / CoF test
Portable	Doesn't recognise certain surface modifications	Use other parameters / CoF test
Change in Rz = Change in CoF		
HSE Guidance		
Good calibration		
Good checks		
SAT		
Use on Profiles		
Use on Stairs		

Table 4.3: Strengths and Weaknesses of Surface Microroughness.

Many of the weaknesses are relatively easy to overcome, and others could be addressed by combination with other tests, as discussed in section 4.6.

4.6 COMBINING RZ ROUGHNESS & SLIPALERT RESULTS

4.6.1 Results

SlipAlert and the surface microroughness meter could become useful complementary tools. SlipAlert is quicker and easier to set up and operate and more portable than the Pendulum, however it is not necessarily accurate enough to be the sole determining factor in assessing the slip resistance of a surface. Where a surface may present a non-uniform level of friction in contaminated conditions, such as where a mixture of tiles are present, or where an inhomogeneous surface is installed, the combination of SlipAlert data with surface microroughness data may be useful. Surface microroughness data would highlight differences between tiles and non-uniformity in continuous surfaces, allowing some interpretation of the mean value of CoF that would be obtained with the SlipAlert test.

SlipAlert is able to distinguish between a given floor surface in clean condition and in a contaminated condition. This is a the key advantage of SlipAlert compared with using surface microroughness and makes it ideal for use in commonly contaminated areas, such as kitchens, and for monitoring the effectiveness of cleaning for example.

The Slips Assessment Tool (SAT) is used to improve the reliability of surface microroughness data, and it is possible that such a system could use the data from SlipAlert and surface microroughness data to provide a more comprehensive assessment. The computer package could easily be made to use the direct reading from SlipAlert rather than requiring the user to convert to CoF for example. The system could also prompt the user to gather microroughness data along the path of SlipAlert, to assess the uniformity. Alternatively, the SAT could continue to be based on the microroughness measurement, and a methodology could be developed for using the SAT with the Pendulum or SlipAlert as a complementary technique.

5 CONCLUSION

Both the Kirchberg Rolling Slider and the SlipAlert tests are able to distinguish between dry floors and contaminated floors. The tests are able to generate a squeeze film of contaminant comparable with that generated by pedestrian gait. This is a significant advantage over sled tests that often produce misleading results.

Of the two new tests evaluated, SlipAlert is the more portable and is also more readily accessible, being a commercially available product. The extended testing of SlipAlert showed a good correlation with the Pendulum test when both instruments were fitted with the same slider material (Four-S rubber) and the sliders were prepared in the same manner (conditioning with P400 & pink lapping film). The results show that, in wet conditions, SlipAlert is at least as dependable as Rz surface microroughness when compared with the Pendulum. SlipAlert offers the ability to measure the friction of contaminated floors.

It was previously noted (Hallas 2005) that the SlipAlert tends to give fail-safe readings, underestimating the friction available. In this study, there are several floors where SlipAlert has overestimated the available friction.

On inhomogeneous surfaces and floors with a mixture of tiles, SlipAlert gives an average friction reading and roughness data should be used to supplement SlipAlert data in order to make a better assessment of the pedestrian slip potential.

It is suggested that SlipAlert should be regarded as a good indication of available friction, lending itself to risk assessment, monitoring of floor surfaces and evaluating & monitoring cleaning regimes.

6 RECOMMENDATIONS

Address the weaknesses of the SlipAlert test by improving manufacture, calibration, checking and preparation procedures and adopting Four-S rubber as standard specification. SlipAlert needs to be supplied with comprehensive information detailing testing procedures for specific situations such as evaluating spills and limitations such as averaging effect on mixed surfaces.

Consider the role of each of the tests to address HSE's demand for slip testing of floors in-situ. A combination of tests is likely to provide a robust method with clearly defined boundaries for each test according to their strengths and weaknesses.

It is recommended that when friction measurements are critical (e.g. for a forensic investigation, product specification, etc) the Pendulum test should be used.

Consider undertaking further development of the Kirchberg Rolling Slider to optimise squeeze film and calibrate against established test methods.

7 APPENDICES

7.1 EXCERPTS FROM THE UKSRG GUIDELINES

Please Note:

The United Kingdom Slip Resistance Group is a non profit making body which is partly sustained via sales of the UKSRG Guidelines (see references). Relevant information is reproduced below to allow interpretation of the results presented.

Reproduced from "The Measurement of Floor Slip Resistance

Guidelines Recommended by the UK Slip Resistance Group"

Issue 2, June 2000

"These Guidelines outline standard procedures for the assessment of the slip resistance characteristics of flooring materials. Confusion has arisen when attempts have been made to use them to specify a floor. The Guidelines should not be used in this way; it is recommended that the manufacturer or his agent be consulted before a product is specified for a particular application".

"IMPORTANT NOTE: Research in the UK by the Health and Safety Executive (HSE) has identified that more than 90% of slipping accidents occur on wet floors, most usually on relatively smooth surfaces. Evaluation of the slip resistance of floors is not an exact science. In addition to selected measuring instruments, it demands the relevant expertise and methodical procedures. In this context these guidelines offer advisory information in respect of measuring the slip resistance of flooring materials under water wet conditions.

The information within this document, which may be revised as knowledge and understanding of pedestrian slipping increase, does not define the 'safety status' of any floor or flooring material at any stage of its service life."

Four-S Pendulum Value	**Potential for Slip**
25 and below	High
25 to 35	Moderate
35 to 65	Low
Above 65	Extremely Low

TRRL Pendulum Value	**Potential for Slip**
19 and below	High
20 to 39	Moderate
40 to 74	Low
Above 75	Extremely Low

Rz (Rtm) Surface Roughness*	**Potential for Slip**
Below 10	High
Between 10 and 20	Moderate
Above 20 and up to 30	Low
Above 30	Extremely Low

*Roughness values applicable for water-wet, low activity pedestrian areas.

8 REFERENCES

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