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HEALTH & SAFETY LABORATORY

The Role Of Towels As A Control To Reduce Slip Potential

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EXECUTIVE SUMMARY

Introduction

Following various on-site investigations, the need for a technique to evaluate towels as a control for slip potential in bathrooms has been identified. The techniques currently used for the assessment of pedestrian slip potential do not include a method to assess the effects of towels laid on floors in areas that are foreseeably wet, such as bathrooms. For this research the standard operating procedure for the pendulum test, HSL-PS-SOP10, is adapted to enable a piece of towel to be introduced between the test surface and pendulum slider. Also, the standard operating procedure for the ramp test, HSL-PS-SOP12, is adapted to enable a piece of towel to be laid between the test surface and operators feet.

Objectives

The aim of this study is to find:

- A suitable technique for the assessment of slip potential for pedestrians walking on towel.
- Whether laying a towel on a bathroom floor is a sufficient control to reduce the potential for pedestrian slip.

Main Findings

The results suggest that:

- For the assessment of pedestrian slip risk on towel in wet conditions, the results of the ramp test method and the towel on surface pendulum method described appear to correlate well.
- Towel may be considered suitable as a measure for the control of pedestrian slip accidents in wet areas.

It is uncertain whether wet or dry towel is a better control measure.

Recommendations

Unfortunately the testing carried out here is insufficient to draw significant conclusions, but the trends suggest that it may be considered a suitable control measure to lay towel as anti-slip control in wet areas. This topic requires much more thorough investigation and testing to establish whether the test methods described are accurate and reliable.

1 INTRODUCTION

A large number of slip accidents occur in bathrooms. HSL have been involved in several accident investigations involving slips in bathrooms in both hotels and hospitals. As predictably wet areas, bathrooms are an area likely to present a significant slip potential to pedestrians, and therefore an area where effort to reduce the slip potential would have the potential to significantly reduce slip accidents.

Existing test methods, such as pendulum skid resistance testing, or surface microroughness, are suitable for measuring the slip potential of the floor surface in both dry and wet conditions. Two slider materials can be used in order to simulate both shod and barefoot conditions. Other bathroom activities may further increase the friction demanded from the floor surface, such as stepping down out of the bath. Where the slip resistance in wet conditions is poor, it is common to provide a towel to place on the floor to help control the slip risk. However, the effectiveness of the towel in reducing the slip potential has not been established. This study aims to explore the effectiveness of a towel as a control measure, and establish a test methodology for use on site.

2 EXPERIMENTAL

The slip resistance of each of the surfaces used was assessed using standard test methods as outlined in the United Kingdom Slip Resistance Group (UKSRG) guidelines using a Surtronic Duo microroughness transducer, see Figure 2.1, and a Pendulum Coefficient of Dynamic Friction (CoF) Test, see Figure 2.2. Both test methods are used routinely by HSL during on-site slipperiness assessments and during contract research for HSE. The slip resistance of some floors was further characterised using the HSL ramp test. These procedures were adapted to enable towel to be placed between the test surface and the ramp operator / pendulum slider.

A single towel material was used for all testing. White towels were selected to minimise the effects of any colour dyes on the results. Several identical towels were purchased from a local supermarket.

When applying fluid squeeze film theory to slip resistance, the surface roughness of the floor is a useful indicator of the likely performance (Lemon & Griffiths, 1997). When a pedestrian heel comes into contact with a contaminated floor surface, it is essential that the floor surface micro-roughness is sufficient to break through the fluid squeeze film formed, which allows solid contact to be made and reduces the chance of slipping.

However, when the two surfaces are of uneven nature, the fluid squeeze film generated is altered. The effect of putting towel between the floor surface and pedestrian heel is to place an uneven material between the contact surfaces, disrupting the fluid squeeze film and so altering the chances of slipping. What this study aims to clarify is the effect that towel has on pedestrian slip potential by disrupting the fluid squeeze film between pedestrian heel and floor surface.

2.1 SURFACE ROUGHNESS

During the routine slipperiness assessment of a flooring material, 10 Rz measurements are taken in a standardised three directional methodology to account for surface directional inhomogeneity. The Surtronic Duo surface roughness transducer was calibrated against a UKAS roughness standard and checked prior to use against a calibrated roughness plate. Interpretations of surface roughness data are based on the UKSRG Guidelines, 2005.

Figure 2.1. The Surtronic Duo microroughness transducer

Surface microroughness will be measured for all the floor surfaces used. However, it is not possible to measure the surface of the towel material.

2.2 PENDULUM TEST

A Slider 96 (also known as Standard Simulated Shoe Sole, or Four-S) rubber slider was used. Four-S rubber is the standard material used for the assessment of pedestrian slip potential, and represents shoe soles of a moderate slip resistance. A second slider material, Slider 55 (also known as TRRL) used to represent barefoot conditions was also used.

Slider preparation was carried out as per the UKSRG Guidelines. The pendulum was calibrated by the British Standards Institution. Interpretations of pendulum data are based on the UKSRG Guidelines, 2005.

Figure 2.2. Slipperiness assessment test methods; the "Stanley" Pendulum CoF test.

Four-S is the more commonly used test material, so was used to assess each sample floor surface used for these tests in a way which could be easily related to test data recorded from other lab and on-site investigations. As this study is investigating slips in bathrooms, barefoot pedestrians are to be expected. As such, Slider 55 was also used. Slider 55 was also selected as the slider for the tests using towels.

The standard slider was modified to allow attachment of a piece of towel material. A 5cm x 5cm sample of the towel was attached to the slider assembly using strong double-sided adhesive tape.

The main modification which had to be made was lightening the slider assembly. BS 7976-1:2002 Pendulum testers, Part 1 – Specification, Section 5.4 states that "The mass of the slider assembly (the pad with its backing plate) shall be 35±5g". The addition of the towel would increase the overall mass of the slider assembly, especially when wet, so lightening the assembly is necessary. The piece of towel used weighed approximately 1.5g, and gained approximately 7.5g when wet compared to dry.

Slider 55 + Backing plate = 35.5g
Slider 55 + Backing plate + 5cm x 5cm dry towel = 36.7g
Slider 55 + Backing plate + 5cm x 5cm wet towel = 44.3g

To bring the total mass of the slider assembly into line with the specifications, 2 slider assemblies were used; one for dry towel, the other for wet. For the dry towel slider, a standard slider can be used, as the total mass is still within the specifications of the standard. For the wet towel, the rubber slider was cut down to reduce the weight by 5g so that the wet weight would be below 40g, and within the specification. Rubber was removed from the trailing edge of the slider to minimise interference with the working edge, which could be conditioned in line with the guidelines. The mass of the slider assembly was measured as 30.8g, and with the added dry towel the total mass was 33.2g.

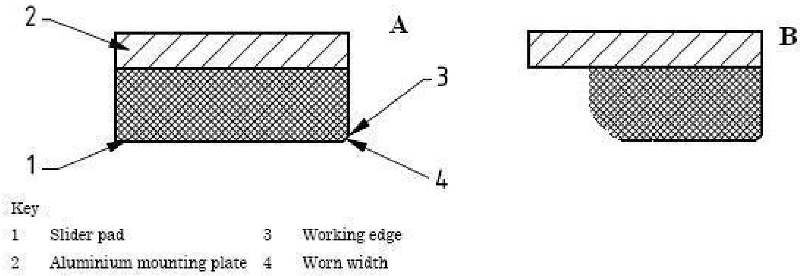

Figure 2.3. Diagram of pendulum slider in normal use condition (A) and the modified slider for the towel-attached method

BS 7976-1:2002 specifies that the dimensions of the slider pad shall be:

76.0mm ±1mm wide;
25.4mm ±1mm long;
6.35mm ±0.5mm thick.

The modified slider measures:

76mm wide;
20mm long;
6.3mm thick.

These modifications therefore put the slider assembly outside the specification for the size of the rubber pad. However, they are necessary to ensure the mass of the slider assembly is within the specification. To check that the modifications to the slider to reduce its mass did not adversely affect the test results, the modified slider was subjected to the normal conditioning and checking regime as specified in the UKSRG guidelines using P400 grit paper and standardised 3μm lapping film. The certified test value for Slider 55 at the time of testing was PTV 49 ±2. The modified slider achieved PTV 51, suggesting that the modification does not affect the validity of the results.

The procedure was further modified as PTV was only measured in 1 direction, rather than the 3 directions specified. Surfaces are tested in 3 directions to account for directionality of a surface. With this work we are concerned with comparing the PTV for a selection of surfaces to assess the contribution made by towel material to pedestrian slip potential. Measurement in 3 directions was considered unnecessary for the purpose of this work, as all tests were carried out in the same direction.

A second phase of pendulum testing involved laying a loose piece of towel approximately 7cm x 7cm onto the surface at the point where the slider impact occurs, rather than having the towel attached to the slider itself. For these tests a standard slider conditioned in the normal way could be used. Separate towel pieces were used as dry and wet to allow multiple tests to be carried out in one session without having to either repeatedly change the test surface or dry the towel between tests.

Although outside the HSL standard operating procedure HSL-PS-SOP10, and the specifications of BS 7976-1:2002, these modifications are considered suitable for the work and are accepted as limitations of the modified procedure.

2.3 RAMP TEST

Information on the slip-resistance performance of specific flooring / footwear / contamination combinations can be obtained using the DIN ramp coefficient of friction test. A version of the DIN:51130 test method has been developed by the Health & Safety Laboratory (HSL), HSL–PS–SOP12, also known as the UKSRG Ramp Test, see Figure 2.4.

Figure 2.4. The 'HSL-PS-SOP12' ramp-type CoF test.

Ramp tests conducted according to HSL–PS–SOP12 use potable water at a flow rate of 6 litres per minute as a contaminant. The operator increases the inclination of the ramp in approximately 1° increments until an unrecoverable slip is initiated and the angle of the ramp is recorded. Twelve angles are determined, with the highest and lowest values being discarded. The mean of the 10 remaining values give the critical angle. The coefficient of friction for level walking is then determined by taking the tangent of the critical angle. The results are generated by two operators who achieve critical angles within 2° of each other.

For this investigation, the SOP12 barefoot test method was modified slightly to allow a piece of towel to be laid loose over the test surface. For initial testing a standard sheet steel surface was used, as a standardised smooth surface of low surface roughness. Once the procedure had been tested using the steel surface the same procedure could then be tried on other surfaces. Various vinyl surfaces were selected as representative of the type of floors commonly found in bathrooms. It is recognised that tile surfaces are also common in bathrooms, yet vinyl's were selected to allow a more direct comparison between smooth and safety surfaces.

HSL-PS-SOP12 specifies a constant flow of water at 6 litres/min. However, for these tests the water was added in much smaller quantities. The towel was first tested in the dry condition, then gradually soaked using hand spray to give even coverage over the towel. The hand spray was measured as releasing approximately 30ml of water in 10 seconds. This allows an approximation for the levels of contaminant used for each test. The flow rate was checked before each set of tests was undertaken. The ramp operator's feet were soaked for 10 minutes before wet barefoot testing as described in SOP12.

The test conditions were as follows:

Towel	**Feet**
Dry	Dry
Dry	Soaked
15ml	Soaked
30ml	Soaked
60ml	Soaked
90ml	Soaked
150ml	Soaked
Saturated	Soaked

To keep the level of contamination as consistent as possible each test was carried out consecutively. For an operator to carry out a set of 12 walks as described in HSL-PS-SOP12 normally takes about 15 to 20 minutes. To carry out all 8 of these tests consecutively would therefore require about 2 hours of constant testing. It was decided that 6 walks for each test would be a suitable substitute method to give an indication of the slip resistance. It was therefore decided that only 6 walks would be carried out for each test rather than 12, to reduce the time required to a more manageable level.

After the 150ml test the towel was thoroughly soaked by allowing the 6l/min sprays normally used for ramp testing to run for about 1 min. The towel was saturated, and much of the water applied had run off to drain. The dry and fully saturated tests were later repeated to check consistency and repeatability of the tests.

3 RESULTS AND DISCUSSION

3.1 SURFACE ROUGHNESS MEASUREMENT

The Rz parameter, highlighted in Table 3.1, is routinely measured during slipperiness assessments and is a useful parameter in predicting the likely slip resistance of a flooring material under water contamination. The UKSRG guidelines on the interpretation of surface roughness data is summarised in Table 3.1.

Rz Surface Roughness (µm)	Potential for Slip
Below 10	High
Between 10 and 20	Moderate
Above 20	Low

Table 3.1 Summary table of UKSRG guidelines (issue 3) on the interpretation of surface roughness data. Roughness values applicable for water-wet, low activity pedestrian areas.

Various floor surfaces were selected for testing with the pendulum. The flooring samples included new, old and modified surfaces, as well as the standard float glass used for pendulum calibration and training checks. Each surface was characterised using the Surtronic Duo surface microroughness transducer. The surfaces were separated into generic types; hard, e.g. tiles and soft, e.g. vinyl. The surface microroughness results are presented in Figure 3.2 below.

Hard Surfaces

ID	Sample Name	Sample No	Rz
L	FLOAT GLASS	PS/PL/16	0.3
A	PHILKERAM-JOHNSON SA "C" POLISHED TILE	x	2.6
B	SOMERFIELD TILE 14	x	2.8
C	DOMUS CREAM TILE	PS/03/57	4.6
H	"NATURAL" FINISH TILE	PED/06/20	9.4
D	IN SITU FIORI URBAN	x	12.5
E	PLATT NATURAL TERRACOTTA CLAY TILE	x	18.5
K	ROUGH FINISHED CREAM TILE	PED/04/165(B)	25.4
I	DOMUS BLACK	PED/05/164	27.6
J	GRES BURELLA WHITE / GREY TILE	PED/06/126	31
G	GRES PURELLA GREY TILE	PED/06/127	35.4

Soft Surfaces

ID	Sample Name	Sample No	Rz
GG	BLUE NORAMENT SV WITH BLACK/YELLOW	PED/06/198	7.8
AA	BROWN SV WITH BLUE/GREY DETAIL (worn)	x	14.4
BB	BLUE SAFETY VINYL	PS/03/59	18.8
CC	GREEN SV WITH BLUE DETAIL	PED/05/51	21
DD	PROFILED WHITE SV WITH BLUE/GREY DETAIL	PED/05/20	26.2
EE	GREEN SV WITH GREEN DETAIL	PED/05/50	31.1
FF	"SAFETRED AQUA" SV WITH CORK DETAIL	x	46.3

Figure 3.2. List of samples tested and surface microroughness. ID is assigned for this work only. Sample number is indicated for registered samples. Results ordered by Rz roughness.

3.2 PENDULUM TESTING

A summary of the pendulum results for the flooring samples used in this study is given in Figure 3.3. PTV results for Direction I only are given for each of the slider materials used; Slider 96, Slider 55 and Towel attached to Slider 55. Results are ordered by Rz from smoothest to roughest. Results are colour coded to show the slip potential classification as described by the UKSRG guidelines. Green indicates a low slip potential, orange a moderate slip potential and red indicates a high slip potential.

Tile

ID	Sample Name	Rz	Slider 96		Slider 55		Towel Slider	
			Dry	Wet	Dry	Wet	Dry	Wet
L	FLOAT GLASS	0.3	95	5	134	8	88	24
A	PHILKERAM-JOHNSON SA "C" POLISHED TILE	2.6	79	7	109	11	34	24
B	SOMERFIELD TILE 14	2.8	80	8	117	8	28	30
C	DOMUS CREAM TILE	4.6	97	5	123	10	41	21
H	"NATURAL" FINISH TILE	9.4	60	18	137	14	41	27
D	IN SITU FIORI URBAN	12.5	62	36	138	19	39	34
E	PLATT NATURAL TERRACOTTA CLAY TILE	18.5	60	50	119	44	50	44
K	ROUGH FINISHED CREAM TILE	25.4	55	25	124	27	35	32
I	DOMUS BLACK (TS-2 B60/10)	27.6	60	24	125	19	31	30
J	GRES BURELLA WHITE / GREY TILE	31.0	71	65	107	47	59	47
G	GRES PURELLA GREY TILE (RICHMOND POOL)	35.4	67	56	118	35	60	43

Vinyl

ID	Sample Name	Rz	Slider 96		Slider 55		Towel Slider	
			Dry	Wet	Dry	Wet	Dry	Wet
GG	BLUE NORAMENT SV WITH BLACK/YELLOW	7.8	73	16	105	24	43	30
AA	BROWN SV WITH BLUE/GREY DETAIL (worn)	14.4	75	23	134	18	31	24
BB	BLUE SAFETY VINYL	18.8	65	33	137	23	39	25
CC	GREEN SV WITH BLUE DETAIL	21.0	61	36	130	28	41	28
DD	PROFILED WHITE SV WITH BLUE/GREY DETAIL	26.2	54	32	124	35	48	34
EE	GREEN SV WITH GREEN DETAIL	31.1	54	30	120	29	44	29
FF	"SAFETRED AQUA" SV WITH CORK DETAIL	46.3	62	36	108	41	50	31

Figure 3.3. Summary of pendulum slip resistance testing results for Slider 96, Slider 55 and towel attached to Slider 55. Results ordered by Rz roughness.

Much variation can be seen between the different floor surfaces. Some of the patterns shown in these results are as would be expected. For both slider 96 and slider 55, the dry PTV suggests a low slip potential for all surfaces tested in the clean dry condition. Wet surfaces show a reduction in PTV compared to the dry surface, and that a decrease in PTV corresponds with a decreased Rz surface microroughness.

The towel slider shows a similar set of trends in that the dry PTV are generally in the low slip potential classification. However, the values are significantly lower than those given by the rubber sliders in the dry condition. This would suggest that in the dry condition the towel actually increases the slip potential of the test surface compared to that indicated by the rubber sliders. For the wet tests the towel shows a mixture of results. To try to clarify comparison, the following table indicates whether the towel PTV is better, similar or worse than each slider material in water wet condition.

If the towel slider PTV is greater than the rubber slider for that test parameter, the result is "better" and is coloured green. If the towel slider PTV is less than the rubber slider, the result is "worse" and is coloured red. If the values are within 10% they are "similar" and coloured orange.

Tile

ID	Rz	Slider 96		Slider 55		Towel Slider		DRY TOWEL VS WET 96	WET TOWEL VS WET 96	DRY TOWEL VS WET 55	WET TOWEL VS WET 55
		Dry	Wet	Dry	Wet	Dry	Wet				
L	0.3	95	5	134	8	88	24	BETTER	BETTER	BETTER	BETTER
A	2.6	79	7	109	11	34	24	BETTER	BETTER	BETTER	BETTER
B	2.8	80	8	117	8	28	30	BETTER	BETTER	BETTER	BETTER
C	4.6	97	5	123	10	41	21	BETTER	BETTER	BETTER	BETTER
H	9.4	60	18	137	14	41	27	BETTER	BETTER	BETTER	BETTER
D	12.5	62	36	138	19	39	34	SIMILAR	SIMILAR	BETTER	BETTER
E	18.5	60	50	119	44	50	44	SIMILAR	WORSE	BETTER	SIMILAR
K	25.4	55	25	124	27	35	32	BETTER	BETTER	BETTER	BETTER
I	27.6	60	24	125	19	31	30	BETTER	BETTER	BETTER	BETTER
J	31.0	71	65	107	47	59	47	SIMILAR	WORSE	BETTER	SIMILAR
G	35.4	67	56	118	35	60	43	SIMILAR	WORSE	BETTER	BETTER

Average - split into high, moderate and low slip potential as indicated by Rz.

HIGH	3.94	82.2	8.6	124.0	10.2	46.4	25.2	BETTER	BETTER	BETTER	BETTER
MOD	15.5	61.0	43.0	128.5	31.5	44.5	39.0	SIMILAR	SIMILAR	BETTER	BETTER
LOW	29.85	63.3	42.5	118.5	32.0	46.3	38.0	SIMILAR	WORSE	BETTER	BETTER

Figure 3.4. Comparison of slip potential of tile surfaces measured using the different pendulum slider materials.

Vinyl

ID	Rz	Slider 96		Slider 55		Towel Slider		DRY TOWEL VS WET 96	WET TOWEL VS WET 96	DRY TOWEL VS WET 55	WET TOWEL VS WET 55
		Dry	Wet	Dry	Wet	Dry	Wet				
GG	7.8	73	16	105	24	43	30	BETTER	BETTER	BETTER	BETTER
AA	14.4	75	23	134	18	31	24	BETTER	SIMILAR	BETTER	BETTER
BB	18.8	65	33	137	23	39	25	BETTER	SIMILAR	BETTER	SIMILAR
CC	21.0	61	36	130	28	41	28	BETTER	WORSE	BETTER	SIMILAR
DD	26.2	54	32	124	35	48	34	BETTER	SIMILAR	BETTER	SIMILAR
EE	31.1	54	30	120	29	44	29	BETTER	SIMILAR	BETTER	SIMILAR
FF	46.3	62	36	108	41	50	31	BETTER	SIMILAR	BETTER	WORSE

Average - split into high, moderate and low slip potential as indicated by Rz.

HIGH	7.8	73	16	105	24	43	30	BETTER	BETTER	BETTER	BETTER
MOD	16.6	70.0	28.0	135.5	20.5	35.0	24.5	BETTER	WORSE	BETTER	BETTER
LOW	31.15	57.8	33.5	120.5	33.3	45.8	30.5	BETTER	SIMILAR	BETTER	SIMILAR

Figure 3.5. Comparison of slip potential of vinyl surfaces measured using the different pendulum slider materials.

The data suggests:

- Dry towel improves the slip resistance of wet floors in most cases.
- Wet towel seems to offer more slip resistance in most cases; wet towel is beneficial for barefoot pedestrians, not so much of an improvement for shod pedestrians
- Wet towel seems to offer a greater degree of improvement to slip resistance on smoother surfaces than rougher surfaces, suggesting that the Rz surface microroughness of the floor surface may influence the degree to which pedestrian slip potential is changed by addition of towel to a floor.
- Towel seems to offer a greater level of improvement to vinyl floors than to tile floors.

As previously discussed, the floor in a bathroom environment would be expected to have to deal with both shod and barefoot pedestrians. Towels are often put down as a control to aid barefoot pedestrians, and the results in the above table suggest that this may be a suitable measure for shod and barefoot pedestrians as long as the towel is dry. When wet the towel offers varying levels of slip resistance, but in many cases this is less than the flooring material alone, and so the towel would be a hazard rather than a safety aid. It should also be noted that a couple of floors presented a moderate slip potential with the dry towel, increasing the likelihood of a slip compared with the dry floor alone.

For the second phase of pendulum testing, the surfaces were tested by swinging an unmodified slider onto a loose piece of towel material laid onto the test surface at the point of slider impact. To allow comparison of the pendulum test results the following tables list surfaces that were tested by all methods in order of increasing roughness.

Tile

Rz	**Slider 96**		**Slider 55**		**Towel On Surface**		**Towel Slider**	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
0.3	**95.0**	**5.0**	**134.0**	**8.0**	**64.0**	**35.0**	**88.0**	**24.0**
4.6	**97.0**	**5.0**	**123.0**	**10.0**	**42.0**	**30.0**	**41.0**	**21.0**
12.5	**62.0**	**36.0**	**138.0**	**19.0**	**41.0**	**46.0**	**39.0**	**34.0**
18.5	**60.0**	**50.0**	**119.0**	**44.0**	**59.0**	**61.0**	**50.0**	**44.0**
25.4	**55.0**	**25.0**	**124.0**	**27.0**	**41.0**	**49.0**	**35.0**	**32.0**
31.0	**71.0**	**65.0**	**107.0**	**47.0**	**79.0**	**72.0**	**59.0**	**47.0**

Figure 3.6. Comparison of slip potential of tile surfaces measured using the different pendulum slider materials.

Vinyl

Rz	Slider 96		Slider 55		Towel On Surface		Towel Slider	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
7.8	73.0	16.0	105.0	24.0	45.0	39.0	43.0	30.0
14.4	75.0	23.0	134.0	18.0	40.0	36.0	31.0	24.0
18.8	65.0	33.0	137.0	23.0	51.0	39.0	39.0	25.0
26.2	54.0	32.0	124.0	35.0	64.0	51.0	48.0	34.0
31.1	54.0	30.0	120.0	29.0	58.0	47.0	44.0	29.0

Figure 3.7. Comparison of slip potential of vinyl surfaces measured using the different pendulum slider materials.

These tables clearly show that the towel laid on the floor surface method suggests a greater level of slip resistance than the towel slider method. What also remains evident is the differences between tiled and vinyl surfaces, not only in their inherent slip resistance for a given roughness, but the degree to which the towel test methods change the PTV of the wet floor.

These tables show that if the towel on floor surface method is used as described then a consistent improvement is shown in the slip resistance of a flooring surface when compared to the wet PTV for the rubber sliders. The towel on surface method almost always brought about an increase in PTV to a level which would be classified as a low slip risk in water wet conditions. This test method would therefore seem to suggest that laying towel onto a bathroom floor could be considered a suitable anti-slip control measure. The data from the towel on surface consistently show increased PTV when wet towel is used as well as dry towel. This is a fundamental difference, regardless of other factors and variables which may influence the results, which may be pivotal to the decision to use towels as a control measure. If it is shown that both dry and wet towels reduce the risk of pedestrian slipping compared to wet floors then it can be considered that towels are a suitable control measure.

The pendulum results indicate that either method could be argued to be the better to use for investigations, but both methods give an increased PTV, and so suggest that towel could be used as a control measure for reducing barefoot pedestrian slip accidents in bathroom situations. It could also be suggested that each method is showing something different, and given the differences in the results, this would seem a valid point. However, at this early stage in the investigation of these factors we cannot fully explain the reasons for these differences, or which of these methods gives the more accurate assessment of slip potential.

In order to identify and validate the appropriate pendulum test method, ramp tests were carried out on a selection of the floor samples tested.

3.3 RAMP TESTING

Previously it has been reported that there is generally good agreement between Slider 96 pendulum results generated in water-wet conditions and ramp results generated using footwear soled with Slider 96 rubber (Loo-Morrey 2006). PTV data can be converted into Coefficient of Friction (CoF) using the following equation taken from BSI 96/104915 [B/208].

$$\mu = \left(\frac{110}{PTV} - \frac{1}{3} \right)^{-1}$$

This existing method for comparison of pendulum and ramp data will be slightly modified to suit the needs of this study. Rather than comparing Four-S pendulum slider and Four-S ramp footwear, comparison is drawn between Slider 55 and towel slider methods, as previously described, and barefoot ramp tests.

HSL-PS-SOP12 allows for ramp testing by barefoot operators. Slider 55 pendulum sliders are intended to assess barefoot pedestrian slip potential. We should therefore be able to compare Slider 55 pendulum results with standard barefoot ramp results and expect to achieve correlation.

As described in section 2.3, HSL-PS-SOP12 has been modified for these tests to allow multiple testing at different levels of water contamination, starting from none, progressing to wet feet only then with increasing levels of water sprayed onto the surface until saturation level is achieved.

Due to the limited time available for testing, few floors could be tested on the ramp. The standard steel board was selected as a benchmark hard surface test, which should give a worst case scenario. The steel board is used by HSL for training and calibration purposes, and causes barefoot slips at angles of approximately 9^{o}, which equates to a CoF of 0.16, has Rz microroughness of approximately 2μm and water-wet PTV 8, so is classed as a high slip risk.

Two samples of vinyl flooring were selected; one safety vinyl of fairly smooth finish (Rz microroughness of 26μm and water-wet PTV 40, so is classed as a low slip risk), and a safety vinyl with cork inclusions (sample FF, low slip risk by other test methods) which is sold specifically as a flooring material for wet barefoot areas.

A brief summary of the results is presented below. 500ml of water is used to represent fully soaked towel to allow a graph scale that should enable patterns to be seen easily at the lower values. The orange line (CoF 0.25) indicates the CoF value below which classification as a high slip potential is applied and above which classification as a moderate slip potential is applied. The bright green line (CoF 0.36) indicates the CoF value above which classification as a low slip potential is applied.

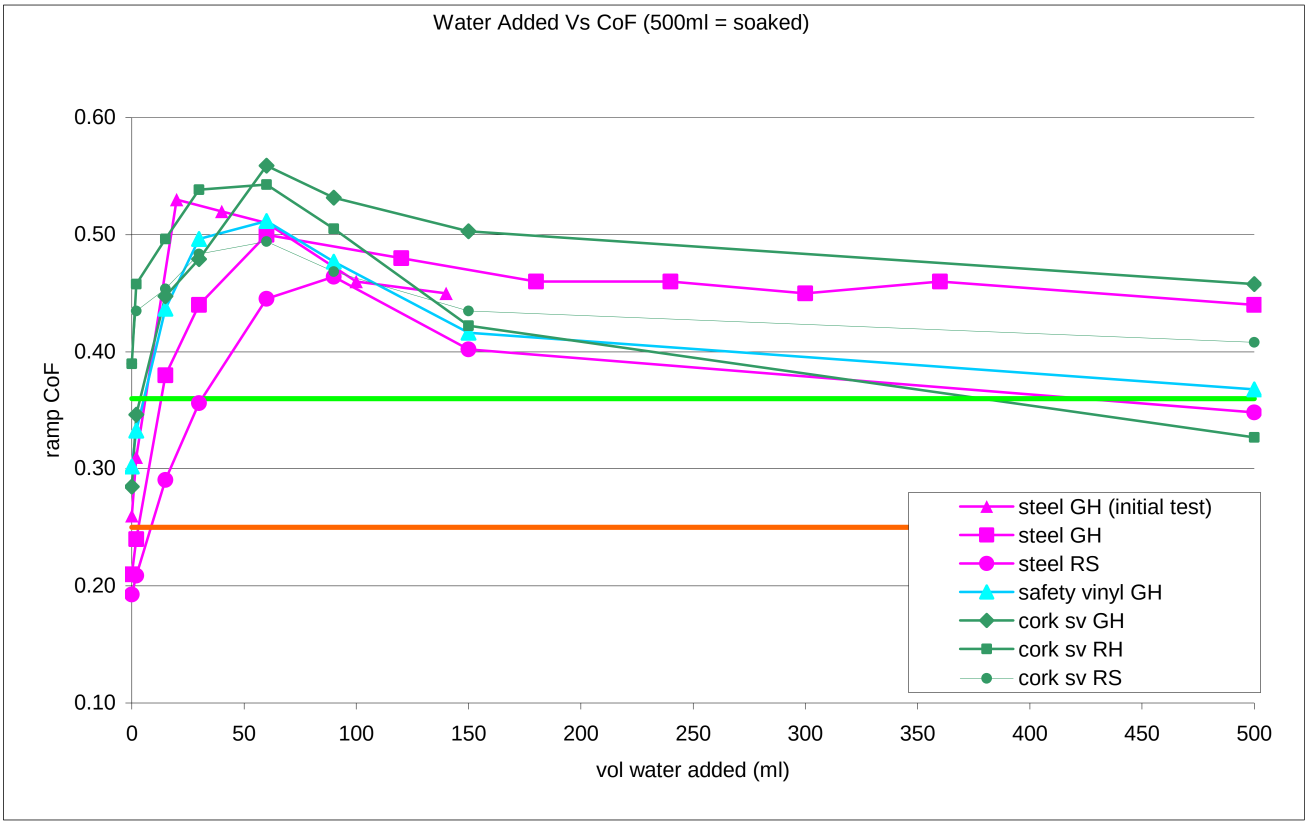

Figure. 3.8. Graphical display of ramp CoF achieved by operators GH, RH and RS

The graph shows a very similar pattern for all the surfaces tested. With no added water the CoF measured on the ramp varies from 0.19 to 0.26 for the steel, and 0.28 to 0.39 for the vinyls. The second set of results, designated as water added = 2ml on the graph, are for wet feet on dry towel. These data points range from 0.21 to 0.46 and are higher than the dry feet on dry towel tests for each surface. This small change to the test method gives appreciably different results.

With only a very small amount of water added to the towel the slip resistance increases appreciably. Just 15ml of water applied by spray bottle raises the CoF to between 0.29 0.50. Only one of the steel floor tests remains a moderate slip potential at this level of contamination, both the vinyl floors are into the low slip potential classification. This level of slip resistance is reasonably well maintained throughout the range of water added through to saturation.

The first tests with steel board showed a levelling off of the values after about 100ml, so for the other tests the 150ml test was followed by compete saturation. This allowed us to reduce the number of walks the operator had to complete for each set of tests, so reducing operator fatigue, and allowing us to take greater confidence in the values.

With 150ml of water added the towel was thoroughly soaked, although not saturated, and residual water would be left on the test surface after the operator slipped. Just as at the lower levels of soaking we saw that about 50ml was sufficient to reach the optimal slip resistance, 150ml may represent a critical level of saturation above which the test towels slip properties do not change. It would be reasonable to assume that these levels will be different for each different type of mat.

Limitations Of The Modified Ramp Test Method

Although "soaked" towel is defined as 500ml it is likely to be more than this, say 1000-1500ml. As not much change was noticed in the angle at which the operator slipped above about 150ml water added, 500ml was merely assigned to allow a suitable scale on the graph to see the patterns below 150ml. For different towels the amount of water absorbed to achieve saturation will vary, and so measuring the actual saturation point may be worthwhile if testing multiple materials. For this test it was decided to be unnecessary.

For the very first test of the ramp method, which was dry towel laid over dry steel sheet, the operators feet slid over the towel, rather than the towel sliding over the test floor surface. This never occurred in any of the following tests when the steel test set was repeated. This anomaly was probably because it was the first time the operator had experimented with the new method, and was adapting to the unusual test surface. For this reason, the very first set of tests has not been reported, and the steel board test set was repeated and the repeat values reported. It should be noted that the actual results were very similar, but it was considered to be a fairer method to repeat these values. This also gives us a degree of confidence in the test method and its repeatability. However it does lead to the possibility of further study in this area including measuring the slip resistance between the foot and the towel itself as a possible hazard.

The main limitation of the ramp-based work is the limited number of surfaces which could be tested. The standard steel board is not necessarily representative of flooring which would be expected in a bathroom, however as a hard smooth surface with similar roughness to many tiled surfaces it is a useful substitute. The lack of any tile surface tested on the ramp was a result of the time constraints faced. Far more surfaces were tested with the pendulum to assess the modified pendulum techniques on a wider selection of surfaces, as the pendulum is considered to be the primary test method.

3.4 COMPARISON OF PENDULUM AND RAMP SLIP RESISTANCE DATA

To compare the different pendulum methods and the ramp a summary of the results are presented in table 3.9 below. Results are highlighted in colours to show slip potential according to UKSRG guidelines. For the wet ramp results, the result for 150ml water added is used to give a fair estimation of "wet".

		STEEL	SAFETY VINYL	CORK VINYL
DRY	Barefoot Ramp	0.73	0.71	
	Barefoot Ramp With Towel	0.20	0.30	0.28
	96 Pend.	1.00	0.74	0.74
	55 Pend	1.00	1.00	1.00
	55 Pend Towel On Slider	0.32	0.40	0.45
	55 Pend Towel On Surface	0.47	0.47	0.69
Wet	Barefoot Ramp	0.16		
	Barefoot Ramp With Towel	0.39	0.42	0.50
	96 Pend	0.08	0.40	0.32
	55 Pend	0.07	0.28	0.41
	55 Pend Towel On Slider	0.29	0.30	0.34
	55 Pend Towel On Surface	0.41	0.40	0.52

Table 3.9. Summary of ramp and pendulum results for each surface

The important numbers for comparison are wet results from the ramp and towel pendulum methods. The standard steel board was used as an extreme test, as the low surface roughness would give a fair representation of a worst-case scenario.

For each board, the barefoot ramp CoF on wet towel is greater than that on dry towel. This would suggest that in the dry condition the towel is less effective than in the wet condition, and may actually increase the slip potential of the test surface when compared to the rubber slider PTV, as stated in section 3.2. This would lead to the conclusion that in dry conditions placing a towel on the floor may be more of a hazard than a safety aid.

This data set, although small, gives an indication of which test methods give complementary results. For dry tests it is difficult to see any patterns, but the towel slider values seem closer than the towel on surface values to the ramp results. However, for each of the surfaces there is a strong correlation between the CoF recorded by the barefoot towel on ramp method and the towel on surface pendulum method in water-wet condition. On the graph below the data for ramp CoF is plotted against pendulum CoF for the each towel method. Note that dry PTV is plotted against dry towel ramp data, and wet PTV against wet towel ramp data.

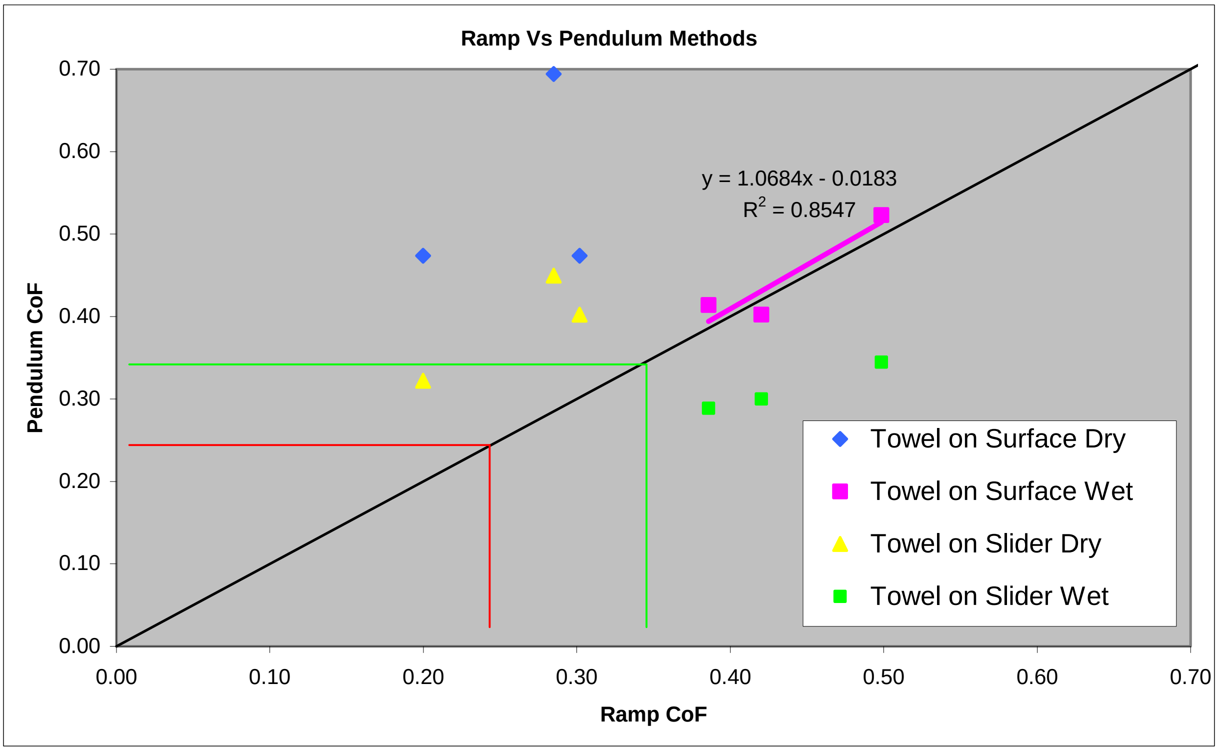

Fig 3.10. Graphical presentation of relationships between the various pendulum and ramp test methods

The table gives the values for the two methods which show the closest correlation.

	STEEL	SAFETY VINYL	CORK VINYL
Barefoot Ramp With Towel	**0.39**	**0.42**	**0.50**
55 Pend Towel On Surface	**0.41**	**0.40**	**0.52**

Table 3.11. Apparent agreement between towel on surface pendulum method and ramp in water-wet condition.

The fine black line marked on the graph is independent of the results, and shows the 1:1 correlation. The "towel on surface wet" (pink) data points lie very close to this line, and the trend line of these results is close to the 1:1 line, with an R^2 value of 0.85. However, due to the small number of data points and the close proximity of each of these points to each other, the line should not be considered significant.

This does give us an idea of which methods correlate closely to each other. On the basis that correlation between complementary methods gives confidence to those methods, we can suggest that the best pendulum method of the two investigated here is the towel on surface method, as this method correlates well with the ramp for wet tests.

It would appear that the dry towel slider method (yellow) correlates more closely with the dry towel ramp results than the dry towel on surface method (blue). This gives us a second method which may provide correlation to the ramp method for assessing the slipperiness of floors on site.

When applying squeeze film theory to slip resistance, the surface roughness of the floors studied are of primary importance. When a pedestrian heel comes into contact with a contaminated floor surface, it is essential that the floor roughness is high enough to break through the squeeze film of water formed. This allows solid contact to be made and reduces the chance of slipping. The introduction of a towel between the two surfaces changes the situation and requires further work to study its effects.

4 CONCLUSIONS

With such a small data set it is difficult to draw conclusions. It is however possible to see patterns in the results that give us an indication to the effectiveness of towels as mats to control slips.

PENDULUM

Pendulum test results showed that in most cases a towel would be a suitable control measure to reduce the risk of pedestrian slip, especially for barefoot pedestrians.

Pendulum testing suggested that a dry towel would offer better slip resistance than a wet towel. It should be considered that the dry towel might increase the slip potential when the floor is dry (i.e. getting into the bath).

RAMP

The modified ramp method gives a close relationship between barefoot ramp operators on loose towel laid over the test surface to the towel on surface pendulum method. This correlation would suggest that the towel on surface method might be the more reliable method to use.

The modified ramp method appears to be robust and repeatable. Repeat testing gave fairly consistent results.

Ramp testing suggested that wet towel would offer better slip resistance than dry towel, although damp towel offered the most slip resistance. This is in contrast with the pendulum test results, which suggest that dry towel is better

SUMMARY

The results suggest that

- The towel on surface method would be the better of the two pendulum methods to use for the assessment of pedestrian slip risk on towel in wet conditions.
- The towel on slider method may be the better of the two pendulum methods to use for the assessment of pedestrian slip risk on towel in dry conditions.
- Towel may be considered suitable as a measure for the control of pedestrian slip accidents in wet areas.
- Whether wet or dry towel is a better control measure is uncertain.

5 FURTHER WORK

Further study to expand the work presented here would allow the controlled variables, such as towel type, floor type, contaminant, to be investigated further, and give a fuller picture of the effects described. The main constraint faced here was the restricted time and therefore the amount of testing it was possible to complete. It is suggested that more work to establish the reliability of the procedures undertaken here be carried out before any action is taken to trial or implement such procedures for routine investigations.

More ramp based testing to cover a wider range of surfaces which may be expected to be installed in bathrooms, specifically tiles but also vinyl and wooden floors, would be valuable to expand the study and determine any changes to the patterns found here. The test could be further modified to allow testing with footwear, or different contaminants, such as soap.

Although one of the pendulum methods correlated closely with the ramp in water-wet conditions, neither of the pendulum methods trialled here would be considered suitable for forensic testing. Different pendulum techniques could be tried, again giving opportunity to adapt the many variables which were kept constant, i.e., different sizes of towel sample, different sliders, different contaminants, different levels of contamination.

Different types of towel should be used to expand the findings presented here to include different towel types, i.e., thicker weave, material type etc, as well as rubber-backed mats. Previous investigations show that rubber backed mats can adhere to the floor surface very well, especially on very smooth surfaces. In such situations, and in contrast to the work presented, the slip resistance between the foot and the towel can be less than between the towel and the floor, leading to a situation where rather than the towel slide over the floor the operator slips across the towel. Also, work could include rubber and plastic bath mats to see how they compare with towel materials.

The methodology tested here may also be applicable to pedestrians wearing socks, which is relevant to many changing areas in addition to the bathroom environment considered above.

6 REFERENCES

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7 APPENDIX

1.1 INTERPRETATION OF SURFACE ROUGHNESS RESULTS USING UKSRG GUIDELINES

Rz Surface Roughness (µm)	Water-Wet Slip Potential
Below 10 µm	High Slip Potential
10 - 20 µm	Moderate Slip Potential
20 + µm	Low Slip Potential

1.2 INTERPRETATION OF PENDULUM RESULTS USING UKSRG GUIDELINES

Pendulum Test Value	Slip Potential
0 - 24	High Slip Potential
25 - 35	Moderate Slip Potential
36 +	Low Slip Potential

1.3 INTERPRETATION OF RAMP RESULTS USING UKSRG GUIDELINES

Ramp Coefficient of Friction	Slip Potential
0 – 0.25	High Slip Potential
0.26 – 0.35	Moderate Slip Potential
0.36 +	Low Slip Potential