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HEALTH & SAFETY LABORATORY

Ramp Testing Natural and Man Made Stone Floors – Final Report

HSL/2006/47

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EXECUTIVE SUMMARY

Objectives

The aim of this project was to thoroughly characterise a range of natural and man made stone flooring materials, by both the portable test methods routinely used during forensic site investigations, i.e. Rz surface roughness and pendulum tests, and the HSL ramp test which is a purely laboratory based test method.

Main Findings

Portable Test Methods

Rz data collected from the ramp boards resulted in the slip potential in wet conditions presented by the flooring materials being classified as follows:

High Slip Potential:	Polished Marble Agglomerate Polished Granite Terrazzo Natural Finish Terrazzo Gloss Finish Unfilled Travertine Gloss Finish Honed Limestone
Moderate Slip Potential:	Polished Limestone Unfilled Travertine Natural Finish
Low Slip Potential:	Riven Slate Gloss Finish Pebble Mosaic Riven Slate Natural Finish Artificial Slate Natural Stone.

Rz surface roughness data indicates that seven of the floors should be classified as presenting a high potential for slip in water-wet conditions, two floors should be expected to present a moderate potential for slip and five floors might reasonably be expected to pose a low potential for slip when wet.

The pendulum test resulted in the slip potential in wet conditions presented by the flooring materials being classified as follows:

High Slip Potential:	Polished Marble Agglomerate Polished Granite Honed Limestone Terrazzo Natural Finish
High / Moderate Slip Potential:	Terrazzo Gloss Finish
Moderate Slip Potential:	Polished Limestone Unfilled Travertine Natural Finish Unfilled Travertine Gloss Finish Artificial Slate Smooth Finish

Low Slip Potential: Pebble Mosaic
Rivan Slate Natural Finish
Rivan Slate Gloss Finish
Natural Stone

Pendulum data indicates that five of the floors should be classified as presenting a high potential for slip in water-wet conditions, one floor should be considered to have a high to moderate potential for slip in the wet, four floors should be expected to present a moderate potential for slip and four floors might reasonably be expected to pose a low potential for slip when wet.

For the flooring investigated in the current study the agreement in slip potential classifications obtained from surface roughness data and pendulum results was very good:

- For 11 out 14 floors the slip potential classifications based on surface roughness and pendulum data were the same.
- For 2 out of 14 floors the surface roughness data under estimated the slip potential of the flooring materials as determined by the pendulum i.e. the flooring was less slippery than might have been expected from roughness alone.
- In only 1 case did the surface roughness data under estimate the level of slip potential of the floor as determined by the pendulum i.e. the flooring was more slippery than might have been expected.

Comparison of the surface roughness and pendulum data indicates that the relationship between pendulum data and surface roughness can be described by the following equation:

$$Y = 1.4821X + 9.0357, R^2 = 0.7939$$

The relationship between pendulum values and surface roughness appears to be linear in nature and the R^2 values for the best-fit predictive line indicates that approximately 79% of the total variability of the Slip Resistance Values (SRV) can be explained in terms of its relationship to Rz surface roughness.

Overall the findings reported here support HSL / HSE's stance that while Rz is a useful indictor of the slip resistance of flooring materials it is not recommended that it be used as the sole selection criteria on which to base the choice of a new floor. **Wherever possible** surface roughness should be considered in *conjunction with pendulum measurements* in both wet and dry conditions before specification decisions are made.

Ramp Test Results

Ramp test results when the operators used shoes that had been soled with Four-S rubber indicated that the slip potential of the floors be classified as follows:

High Slip Potential: Polished Marble
Agglomerate
Polished Granite
Terrazzo Natural Finish
Terrazzo Gloss Finish
Unfilled Travertine Gloss Finish
Honed Limestone
Polished Limestone
Unfilled Travertine Natural Finish

Low Slip Potential: Pebble Mosaic
Artificial Slate
Rivan Slate Natural Finish
Rivan Slate Gloss Finish
Natural Stone

Ramp test results generated using Four-S soled footwear indicated that nine floors should be classified as posing a high potential for slip in the water-wet condition and five floors might reasonably be expected to present a low potential for slip when wet.

All of the floors used in the study appear to present a lower potential for slip when the commercially available men's shoes were worn rather than Four-S soled footwear.

Comparison of ramp and pendulum test methods

It has been previously reported that there is generally good agreement between pendulum results and ramp results when both tests are undertaken using Four-S rubber under water-wet contamination.

Initial comparisons showed that the slip potential classifications obtained from ramp and pendulum test methods for agreed for ten out of fourteen floors used in the study. Simplistic analysis of coefficient of friction data obtained from the ramp and pendulum tests showed that the relationship maybe described by the following equation:

$$Y = 0.5357X - 2.2028, R^2 = 0.7939$$

Where Y= Ramp CoF, X= Pendulum CoF.

The relationship between the results of the two test methods appears to be linear in nature and the R^2 value for the best-fit predictive line indicates that 82% of the total variability in the CoF as measured by the ramp test method can be explained in terms of its relationship to CoF as measured by the pendulum test method.

Of the fourteen floors investigated in the current study there is only one case that is a potential cause for concern. From the surface roughness, pendulum and ramp data it is somewhat ambiguous as to whether or not the artificial slate flooring is suitable for use in for use in foreseeably wet areas or not. The potential exists for a duty holder to specify this floor for use in wet areas in good faith based on surface roughness and ramp data, but in the event of HSE / HSL investigation of an incident, pendulum data would suggest that the floor was unsuitable for wet areas.

While a potential cause for concern the discrepancies in slip potential classification observed for the artificial slate flooring should be put in context with the overall findings of this project. When considered as a whole the data generated in the course of this project strongly supports the opinion that there is good agreement between Four-S results produced by the pendulum and ramp test methods.

1 INTRODUCTION

The work detailed in this report was carried out at the request of Mr. Stephen Taylor (Construction Division Technology Unit, HSE).

The aim of the current study was to assess the slip resistance of a range of natural and man made stone flooring materials. These types of floors are commonly found in a variety of commercial and retails premises where high end prestige finishes are required, however to date there has not been a systematic study of the slip characteristics of these floors. A better understanding of the anti-slip performance of these flooring materials would better inform the advice given to duty holders considering the installation of this type of flooring.

All the floors studied was assessed using a range of test methods:

- Surface roughness
- The pendulum test
- The standard HSL-PS-SOP 12 ramp test

2 EXPERIMENTAL

Fourteen floors have been selected for study in the current work (see Table 1). The floors chosen have been selected to be representative of the different types stone flooring available in the marketplace and commonly installed. They range from natural stones such as marble, granite and limestone to man made agglomerates and terrazzo type floors. Their surface finishes ranged from highly polished, to honed, to cleaved riven surfaces.

Flooring	Type
Polished Granite	Natural Stone
Honed Limestone	Natural Stone
Natural Stone	Natural Stone
Polished Marble	Natural Stone
Pebble Mosaic	Natural Stone
Riven Slate Natural Finish	Natural Stone
Riven Slate Gloss Finish	Natural Stone
Polished Limestone	Natural Stone
Unfilled Traventine Natural Finish	Natural Stone
Unfilled Traventine Gloss Finish	Natural Stone
Terrazzo Gloss Finish	Man Made
Terrazzo Gloss Finish	Man Made
Agglomerate	Man Made
Artificial Slate Smooth Finish	Man Made

Table 2.1 Floors used in the current investigation.

Each of the floors was laid onto the ramp boards professionally in accordance with the manufactures instructions.

The slip resistance of each of the ramp boards used in the current work was assessed using standard test methods as outlined in the United Kingdom Slip Resistance Group (UKSRG) Guidelines[1] using a Pendulum Coefficient of Dynamic Friction (CoF) Test, see Figure 2.2, and a Mitutoyo SJ-201P microroughness transducer, see Figure 2.1. Both test methods are used routinely by HSL during on-site slipperiness assessments and during contract research for HSE. The slip resistance of each floor was further characterized using the HSL ramp test.

2.1 SURFACE ROUGHNESS

During the routine slipperiness assessment of a flooring material 10 R_z measurements are taken in a standardised three directional methodology to account for surface directional inhomogeneity. Given that is the aim of the current work to characterise the stone floors as completely as possible, the opportunity was take to collect a much wider range of surface roughness parameters (R_a, R_z, R_q, R_t, R_p, R_{mr}, R_s) than would routinely be collected during a site investigation. The Mitutoyo surface roughness transducer was calibrated against a UKAS roughness standard and checked prior to use against a calibrated roughness plate.

[1] Issue 2 which was current at the time of testing.

Figure 2.1 The Mitutoyo SJ-201P microroughness transducer

2.2 PENDULUM TEST

A Four-S rubber slider was used throughout. 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, 2000[2]. Interpretations of surface roughness data are based on existing HSE Guidance, Food Information Sheet 22 [HSE] and the UKSRG Guidelines.

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

2.3 RAMP TEST

Reliable 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 this test method has been developed by the Health & Safety Laboratory (HSL), HSL – PS – SOP 12, see Figure 2.3.

[2] Issue 2 which was current at the time of testing.

Figure 2.3 The 'HSL-PS-SOP-12' ramp-type CoF test.

The ramp tests were conducted according to HSL – PS SOP 12, using potable water at a flow rate of 6 litres a minute as a contaminant. The operator increased the inclination of the ramp in approximately 1° increments until an unrecoverable slip was initiated and the angle of the ramp was recorded. Twelve angles were determined, with the highest and lowest values being discarded. The 10 remaining values were then averaged to give the critical angle. The coefficient of friction for level walking was then determined by taking the tangent of the critical angle. The results presented here, were generated by two operators who achieved critical angles within 2° of each other.

The flooring surfaces under investigation in the work presented are typically installed and used within a wide range of commercial and retail premises; it is unlikely that duty holders have any control of the type of footwear being worn in such premises. In order to reflect this typical lack of footwear control, three pieces of footwear were used during this study that reflect the wide range of slip characteristics of typical footwear, as shown in Table 2.2 (see Figure 2.4). All footwear was prepared with a fresh piece of P400 grit abrasive paper prior to testing.

Shoe	**Type of Shoe**
Four-S	Calibration Footwear
Megane Trekker	Men's Fashion Shoe
Salindas Classic	Men's Dress Shoe

Table 2.2: Shoes used in the current investigation.

(a) Four-S Shoes

(b) Megan Trekkers

(c) Salindas Classic

Figure 2.4: The three different types of footwear used in the study.

3 RESULTS AND DISCUSSION

3.1 SURFACE ROUGHNESS RESULTS

Surface roughness results for the ramp boards used in this work are given in Table 3.1.

Ramp Board	Average Surface Roughness (μm)						
	Ra	Rz	Rq	Rt	Rp	Rmr	Rs
Polished Marble	0.07	0.87	0.12	1.81	0.23	17.9%	52.8(8)
Agglomerate	0.19	2.39	0.32	5.15	0.50	24.8%	46.3
Polished Granite	0.37	3.39	0.64	11.98	0.92	14.1%	43.3(5)
Terrazzo Natural Finish	0.80	4.32	1.01	11.95	1.96	13.1%	81.3(9)
Terrazzo Gloss Finish	0.69	4.79	1.03	12.95	2.87	0.3%	97.5(6)
Unfilled Travertine Gloss Finish	0.81	5.90	1.11	12.5	2.42	1.2%	75.7
Honed Limestone	1.32	8.39	1.72	15.07	2.79	4.7%	59.7
Polished Limestone	1.62	10.43	2.10	16.39	4.30	4.1%	58.8
Unfilled Travertine Natural Finish	1.64	10.90	2.29	23.65	3.44	5.1%	67.0
Riven Slate Gloss Finish	4.43	20.84	538	29.71	10.46	2.4%	194.1(9)
Pebble Mosaic	4.75	21.18	5.82	34.10	10.50	2.3%	83.1
Riven Slate Natural Finish	4.62	22.51	5.60	29.67	10.99	2.1%	117.1
Artificial Slate Smooth Finish	4.62	23.04	5.74	32.59	13.20	1.4%	238.0(7)
Natural Stone	8.50	40.19	10.46	60.31	20.19	2.7%	140.0

Table 3.1 Table giving average values for the surface roughness results for the fourteen ramp boards used in the current study. R_z (μm) values are given in the highlighted column.

Definitions of the different roughness parameters are given in Appendix 1.

The Rz parameter, highlighted in Table 3.1, is routinely measured during HSL slipperiness assessments and is a key parameter in predicting the likely slip resistance of a flooring material under water contamination. The Slip Resistance Group (UKSRG) guidelines on the interpretation of surface roughness data is summarised in Table 3.2.

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

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

Table 3.2 Summary table of UKSRG guidelines (issue 3) on the interpretation of surface roughness data.

Previous work [Richardson and Griffiths, Lemon and Griffiths] has shown that higher viscosity contaminants require greater levels of surface roughness to provide equivalent levels of anti-slip performance because the thickness of the squeeze film formed between the floor and a pedestrian's shoe increases as the viscosity of the contaminant increases. The level of surface roughness required to provide satisfactory slip resistance therefore also higher, see Table 3.3.

Contaminant Viscosity (cPS)	Workplace Analogue	Minimum Rtm (Rz) Floor Roughness
<1	Clean Water	20 μm
1-5	Milk	45 μm
5-30	Stock	60 μm
30-50	Olive Oil	70 μm
>50	Margarine	> 70 μm

Table 3.3 Table giving minimum levels of Rtm (Rz) roughness required to allow satisfactory levels of CoF [HSE].

Comparison of the Rz data for ramp boards used in this study with the information in Table 3.2 results in the floors being classified as follows in wet conditions:

High Slip Potential:
- Polished Marble
- Agglomerate
- Polished Granite
- Terrazzo Natural Finish
- Terrazzo Gloss Finish
- Unfilled Travertine Gloss Finish
- Honed Limestone

Moderate Slip Potential:
- Polished Limestone
- Unfilled Travertine Natural Finish

Low Slip Potential:
- Riven Slate Gloss Finish
- Pebble Mosaic
- Riven Slate Natural Finish
- Artificial Slate
- Natural Stone.

Rz surface roughness data indicates that seven of the floors should be classified as presenting a high potential for slip in water-wet conditions, two floors should be expected to present a moderate potential for slip and five floors might reasonably be expected to pose a low potential for slip when wet. Based on surface roughness information alone the majority of the floors used in the study would be considered to pose a high or moderate slip risk in water-wet conditions and therefore unsuitable for use in foreseeably wet areas such as entrances, bathrooms and cafeterias.

3.2 PENDULUM MEASUREMENTS

Pendulum results for the ramp boards used in this study are given in Table 3.4. Note, pendulum test results maybe known by a variety of terms, Slip Resistance Value (SRV, which is used in this report), Pendulum Test Value (PTV), and British Pendulum Number (BPN).

Ramp Board	Direction	Dry (SRV)	Wet (SRV)	Slip Potential in wet
Polished Marble	Direction I	99	6	**High**
	Direction II	86	6	**High**
	Direction III	90	6	**High**
Agglomerate	Direction I	72	7	**High**
	Direction II	76	11	**High**
	Direction III	73	9	**High**
Polished Granite	Direction I	113	6	**High**
	Direction II	95	9	**High**
	Direction III	95	11	**High**
Terrazzo Natural Finish	Direction I	89	5	**High**
	Direction II	81	8	**High**
	Direction III	85	6	**High**
Terrazzo Gloss Finish	Direction I	65	24	**High**
	Direction II	67	24	**High**
	Direction III	72	26	**Moderate/High**
Unfilled Travertine Gloss Finish	Direction I	65	28	**Moderate**
	Direction II	67	31	**Moderate**
	Direction III	72	35	**Moderate**
Honed Limestone	Direction I	71	21	**High**
	Direction II	76	22	**High**
	Direction III	66	22	**High**
Polished Limestone	Direction I	71	26	**Moderate/High**
	Direction II	71	41	**Low**
	Direction III	66	25	**Moderate/High**
Unfilled Travertine Natural Finish	Direction I	66	31	**Moderate**
	Direction II	65	31	**Moderate**
	Direction III	63	31	**Moderate**
Rivan Slate Gloss Finish	Direction I	61	40	**Low**
	Direction II	62	43	**Low**
	Direction III	61	45	**Low**
Pebble Mosaic	Direction I	71	56	**Low**
	Direction II	71	64	**Low**
	Direction III	70	60	**Low**
Rivan Slate Natural Finish	Direction I	64	50	**Low**
	Direction II	60	50	**Low**
	Direction III	62	52	**Low**
Artificial Slate Smooth Finish	Direction I	58	31	**Moderate**
	Direction II	56	29	**Moderate**
	Direction III	56	30	**Moderate**
Natural Stone	Direction I	72	61	**Low**
	Direction II	69	66	**Low**
	Direction III	70	66	**Low**

Table 3.4. Table giving 4S pendulum results in dry and wet conditions for each of the ramp boards used in the current work.

The pendulum test resulted in the slip potential in wet conditions presented by the flooring materials being classified as follows:

High Slip Potential:	Polished Marble Agglomerate Polished Granite Honed Limestone Terrazzo Natural Finish
High / Moderate Slip Potential:	Terrazzo Gloss Finish
Moderate Slip Potential:	Polished Limestone Unfilled Travertine Natural Finish Unfilled Travertine Gloss Finish Artificial Slate Smooth Finish
Low Slip Potential:	Pebble Mosaic Rivan Slate Natural Finish Rivan Slate Gloss Finish Natural Stone

Pendulum data indicates that four of the floors should be classified as presenting a high potential for slip in water-wet conditions, one floor should be classified as having a high to moderate potential for slip in the wet, four floors should be expected to present a moderate potential for slip and four floors might reasonably be expected to pose a low potential for slip when wet. Based on pendulum data the majority of the floors used in the study would be considered to pose a high or moderate slip risk in water-wet conditions and therefore unsuitable for use in foreseeably wet areas such as entrances, bathrooms and cafeterias.

3.3 COMPARISON OF SURFACE ROUGHNESS AND PENDULUM RESULTS

The effect of surface micro-roughness on the pendulum data generated for the water-wet condition during pendulum testing of the flooring used in the current work is shown graphically in Figure 3.1.

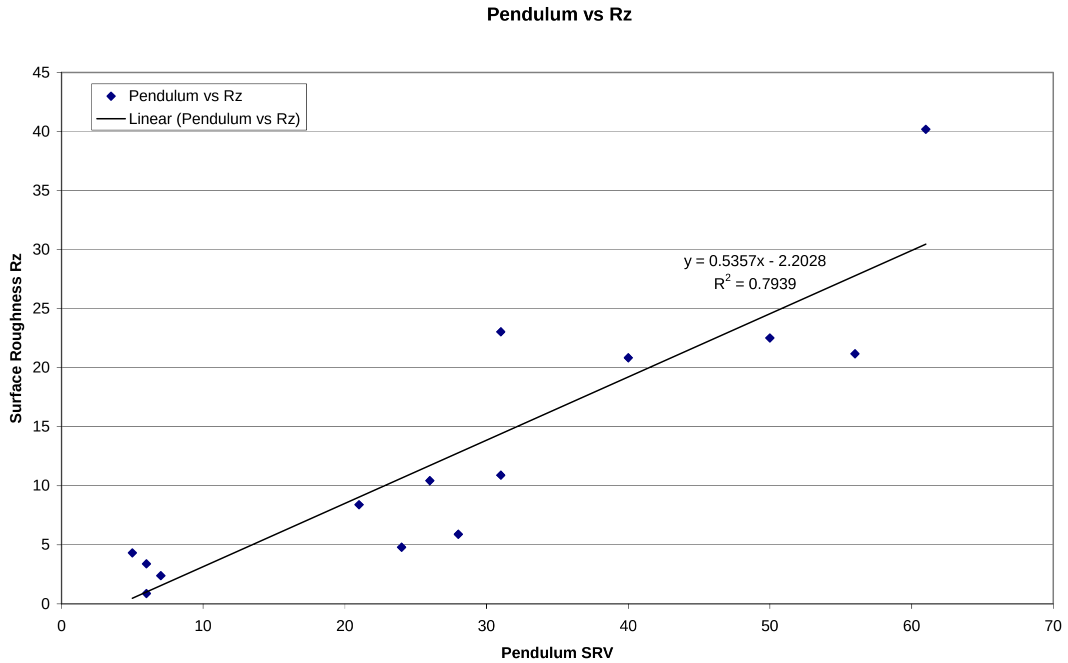

Figure 3.1 Graph showing wet pendulum values plotted against Rz surface roughness.

It can be seen from Figure 3.1 that as a general trend the water-wet SRV measurements increase as the Rz surface roughness of the natural or man-made stones increases. This is in line with previous work on pedestrian slipping, which has shown that the anti-slip performance of a flooring material is related to the level of surface micro-roughness. Previous studies have shown that for a flooring to exhibit satisfactory levels of anti-slip performance the surface roughness needs to be sufficient to break through the squeeze film formed between the floor and a pedestrian's shoe [Richardson and Griffiths, Lemon and Griffiths].

A best-fit trend line fitted through the data in Figure 3.1 indicates that the relationship between pendulum data and surface roughness can be described by the following equation:

$$Y = 0.5357X - 2.2028, R^2 = 0.7939$$

The relationship between pendulum values and surface roughness appears to be linear in nature and the R^2 values for the best-fit predictive line indicates that approximately 79% of the total variability of the pendulum SRV data can be explained in terms of its relationship to Rz surface roughness.

The overall slip potential classifications obtained from surface roughness data and pendulum tests for the natural and man made stone floors are compared below in Table 3.5.

Flooring	Slip Potential in Wet from Surface Roughness Rz (μm)	Slip Potential in Wet from Pendulum Data (SRV)	Agreement
Polished Marble	High	High	Yes
Agglomerate	High	High	Yes
Polished Granite	High	High	Yes
Terrazzo Natural Finish	High	High	Yes
Terrazzo Gloss Finish	High	High / Moderate	No
Unfilled Travertine Gloss Finish	High	Moderate	No
Honed Limestone	High	High	Yes
Polished Limestone	Moderate	Moderate	Yes
Unfilled Travertine Natural Finish	Moderate	Moderate	Yes
Riven Slate Gloss Finish	Low	Low	Yes
Pebble Mosaic	Low	Low	Yes
Riven Slate Natural Finish	Low	Low	Yes
Artificial Slate Smooth Finish	Low	Moderate	No
Natural Stone	Low	Low	Yes

Table 3.5 Summary table comparing the slip potential classifications of the ramp boards obtained using surface roughness and pendulum data generated in the water-wet condition.

In 11 out of 14 cases (79%) the slip potential classifications of the flooring materials obtained using surface roughness measurements and pendulum data are the same. For the remaining three cases:

Unfilled Travertine Gloss – Surface roughness data indicated this floor is likely to pose a high potential for slip in water-wet conditions. Pendulum data suggests that this floor should be considered a moderate slip potential in the wet. Given the comparatively low level of surface roughness of this material the pendulum results are a little higher than might have been expected. Any specification decision based on surface roughness for this material would result in conservative choice, as the slip resistance of the material in wet conditions appears to be better than could have been predicted from surface roughness alone, i.e choices based on Rz surface roughness alone would fail safe.

Terrazzo Gloss Finish – Surface roughness data indicated this floor is likely to pose a high potential for slip in water-wet conditions. Pendulum data suggests that this floor should be considered a high to moderate slip potential in the wet. Given the low level of surface roughness of this material the pendulum results are a little higher than might have been expected. Any specification decision based on surface roughness for this material would result in conservative choice, as the slip resistance of the material in wet conditions appears to be better than could have been predicted from surface roughness alone, i.e choices based on Rz surface roughness alone would fail safe.

Artificial Slate Smooth Finish – Surface roughness data indicates that this floor is likely to present a low potential for slip in water-wet conditions. Pendulum data however, suggests that this floor should be considered a moderate potential for slip in the wet. Of all the flooring materials investigated in this study this is the only case where selection of flooring on the basis of surface roughness would have resulted in a floor whose slip resistance in the wet that was worse than might have been expected. A possible explanation for the disagreement in slip potential classifications resulting from surface roughness and pendulum data for this floor may be found in the surface roughness data. The Rs value, the distance between adjacent peaks, is very high for this particular floor. Consideration of the Rz and Rs surface roughness parameters together would therefore imply that although the peaks are capable for breaking through the fluid film formed by water, there are comparatively few peaks to do so. It is therefore not unreasonable for the slip potential of this flooring, as measured using the pendulum method to be higher than Rz surface roughness alone may suggest.

For the flooring investigated in the current study the agreement in slip potential classifications obtained from surface roughness data and pendulum results was very good:

- For 11 out 14 floors the slip potential classifications based on surface roughness and pendulum data were the same.
- For 2 out of 14 floors the surface roughness data under estimated the slip potential of the flooring materials as determined by the pendulum.
- In only 1 case did the surface roughness data over estimate the level of slip resistance determined by the pendulum.
- 79% of the total variability of the SRV data can be explained in terms of its relationship with Rz surface roughness.

3.4 RAMP RESULTS

Ramp results for each of the natural and man-made stone floors used in the study are given in Table 3.6.

Ramp Board	Footwear		
	Four-S	Megane Trekker	Salindas
Polished Marble	0.09	0.17	0.20
Agglomerate	0.09	0.25	0.29
Polished Granite	0.04	0.16	0.12
Terrazzo Natural Finish	0.08	0.19	0.18
Terrazzo Gloss Finish	0.23	0.27	0.36
Unfilled Travertine Gloss Finish	0.20	0.84+	0.60
Honed Limestone	0.21	0.38	0.38
Polished Limestone	0.17	0.56	0.42
Unfilled Travertine Natural Finish	0.11	0.43	0.32
Rivan Slate Gloss Finish	0.69	0.84+	0.73
Pebble Mosaic	0.62	0.84+	0.63
Rivan Slate Natural Finish	0.63	0.77	0.66
Artificial Slate Smooth Finish	0.48	0.64	0.65
Natural Stone	0.77	0.84+	0.72

Table 3.6 Table giving ramp results for each of the floors under investigation with Four-S, Megane Trekker, and Salindas Classic footwear. Red indicates floors that pose a high slip potential, yellow indicates floors that pose a moderate slip potential and green indicates those floors that present a low slip potential.

Ramp test results when the operators used shoes that had been soled with Four-S rubber of the floors indicated that the slip potential of the floors be classified as follows:

High Slip Potential:	Polished Marble Agglomerate Polished Granite Terrazzo Natural Finish Terrazzo Gloss Finish Unfilled Travertine Gloss Finish Honed Limestone Polished Limestone Unfilled Travertine Natural Finish
Low Slip Potential:	Pebble Mosaic Artificial Slate Rivan Slate Natural Finish Rivan Slate Gloss Finish Natural Stone

Ramp test results generated using Four-S soled footwear indicated that nine floors should be classified as posing a high potential for slip in the water-wet condition and five floors might reasonably be expected to present a low potential for slip when wet.

The slip resistance experienced by a pedestrian when they walk on a given floor is dependent on a number of factors including the type of flooring, the type of footwear, the presence of a contaminant and the viscosity of the contaminant. During the current work slip resistance of the floors was assessed with three different pieces of footwear. All of the floors used in the study appear to present a lower potential for slip when the commercially available men’s shoes were worn rather than Four-S soled footwear. Four-S rubber was deliberately designed to represent a soling material of moderate slip resistance, i.e. there is footwear with soles with worse slip resistance available in the marketplace and footwear with soles with better slip resistance available. It is therefore not unreasonable that both the commercially available pieces of footwear used in the study demonstrated better levels of slip resistance than the Four-S soled shoes.

3.5 COMPARISON OF RAMP AND PENDULUM DATA

Previously it has been reported that there is generally reasonably good agreement between Four-S pendulum results generated in water-wet conditions and ramp results generated using footwear soled with Four-S rubber [Loo-Morrey]. The slip potential classifications for the floors generated by the different test methods are compared in Table 3.7.

Ramp Board	Rz Surface Roughness (µm)	Four-S SRV (Direction I water-wet)	Pendulum Coefficient of Friction (Direction I water-wet)	Four-S Ramp Results Coefficient of Friction	Agreement Between Pendulum and Ramp
Polished Marble	0.87	6	0.06	0.09	Yes
Agglomerate	2.39	7	0.07	0.09	Yes
Polished Granite	3.39	6	0.06	0.04	Yes
Terrazzo Natural Finish	4.32	5	0.05	0.08	Yes
Terrazzo Gloss Finish	4.79	24	0.24	0.23	Yes
Unfilled Travertine Gloss Finish	5.90	28	0.28	0.2	No
Honed Limestone	8.39	21	0.20	0.21	Yes
Polished Limestone	10.43	26	0.26	0.16	No
Unfilled Travertine Natural Finish	10.90	31	0.31	0.11	No
Riven Slate Gloss Finish	20.84	40	0.41	0.69	Yes
Pebble Mosaic	21.18	56	0.61	0.62	Yes
Riven Slate Natural Finish	22.51	50	0.54	0.63	Yes
Artificial Slate Smooth Finish	23.04	31	0.31	0.47	No
Natural Stone	40.19	61	0.68	0.77	Yes

Table 3.7 Table ranking the flooring used in the study in terms of surface roughness, and comparing the results obtained by the pendulum (direction I, along the board) and ramp test methods and pendulum SRV data converted into coefficient of friction.

When considered in the broadest terms it can be seen from the pendulum and ramp data presented in Table 3.7 that in the majority of cases (10 out of 14) the slip potential classification obtained from the two test methods agreed.

SRV data generated using the pendulum can be converted into Coefficient of Friction (CoF) using the following equation taken form BSI 96/104915 [B/208].

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

From the coefficient of friction data given in Table 3.7 it can be seen that for the natural and man made stone flooring used in the current study there appears to be good or reasonable agreement between the results of the two test methods in the majority of cases.

Pendulum and ramp CoF data are compared graphically in Figure 3.2.

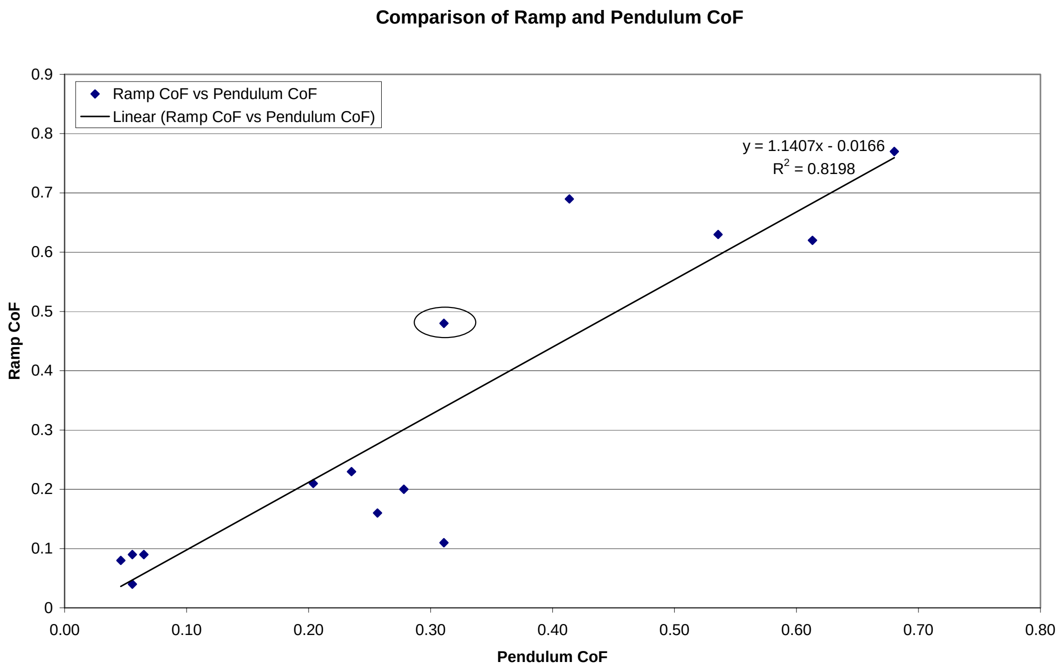

Figure 3.2 Graph comparing the coefficient of friction results obtained in water wet conditions using the ramp and pendulum test methods.

From Figure 3.2 it can be seen that the ramp CoF increases as the pendulum CoF increases, and there is generally good agreement between the data generated by the different testing methods.

A best-fit trend line fitted through the data indicates that the relationship between ramp and pendulum data maybe described by the following equation:

$$Y = 1.1407X – 0.0166, R^2 = 0.8198$$

Where Y= Ramp CoF, X= Pendulum CoF.

The relationship between the results of the two test methods appears to be linear in nature and the R^2 value for the best-fit predictive line indicates that 82% of the total variability in the CoF as measured by the ramp test method can be explained in terms of its relationship to CoF as measured by the pendulum test method.

HSE/HSL have a high degree of confidence in the pendulum test method for assessing the slip potential of floors under fluid contaminated conditions. HSL have previously conducted rigorous research on the pendulum test methodology to determine its suitability for assessing pedestrian slip risk in contaminated conditions [Richardson and Griffiths, Lemon and Griffiths] prior to HSE adopting the test method as its preferred method for assessing the slip risk posed by floors for use during enforcement and prosecution.

From HSE’s point of view it is acceptable if the ramp test underestimates the CoF of a water-wet floor compared to data generated by the pendulum test. A floor specified on the basis of the ramp results would “fail safe” and is likely to demonstrate higher levels of slip resistance when installed than might be expected based on the ramp results. This would not be problematic for HSE.

Of the fourteen floors investigated in the current study there is only one case that is a potential cause for concern, see Figure 3.2, circled data point. This data point represents the CoF values measured for the artificial slate flooring. Data for this floor generated with all three test methods used in this work is summarised in Table 3.8 below.

Ramp Board	Rz Surface Roughness (μm)	Four-S SRV (Direction I Dry)	Four-S SRV (Direction I water-wet)	Pendulum Coefficient of Friction in the wet	Four-S Ramp Results Coefficient of Friction
Artificial Slate Smooth Finish	23.04	56	31	0.31	0.47

Table 3.8 Table summarising test data for artificial slate.

From Table 3.8 it can be seen that the surface roughness data and the Four-S ramp results both indicate the floor to present a low potential for slip in water-wet conditions, while the pendulum test indicates the flooring to present a moderate slip potential when wet. It is therefore somewhat ambiguous whether this floor would or would not be suitable for use in foreseeably wet areas.

Previous work on pre-engineered wood flooring [Loo-Morrey 2006 (1)] indicated that macroscopic texture can influence the level of agreement between the two test methods, and result in appreciably lower CoF results from the pendulum test method than from the ramp. This appears to be consistent with the findings of the current work, there were two cases where the ramp results were significantly higher than the pendulum data:

1. **Artificial Slate**
2. **Rivan Slate Gloss finish**

Both of these floors have significant macroscopic texture in addition to their surface microroughness. The discrepancies between pendulum and HSL ramp test method would not be problematic in the case of the gloss finish rivan slate as both test methods classify this floor as having a low potential for slip in the wet. It could potentially be problematic for the artificial slate floor as the potential exists for a duty holder to specify this floor for use in wet areas in good faith based on surface roughness and ramp data, but in the event of HSE / HSL investigation of an incident pendulum data would suggest that the floor was unsuitable for wet areas.

It has previously been suggested [Loo-Morrey 2006(1)] that macroscopic surface texture is likely to promote the formation of a fluid squeeze film on the peaks during testing. Given the difference in the results generated by the two test methods it would seem reasonable to suspect that the surface texture of these particular floors may result in the fluid films being formed during pendulum and ramp testing being different.

Test results from this type textured flooring should be interpreted with caution. It is currently unclear whether the slip potential classification obtained from the pendulum test or the slip potential classification obtained from the HSL ramp test would be most representative the level of slip resistance experienced a pedestrian walking on these floors in wet conditions.

While a potential cause for concern the discrepancies in slip potential classification observed for the artificial slate flooring should be put in context with the overall findings of this project. When considered as a whole the data generated in the course of this project strongly supports the opinion that there is good agreement between Four-S results produced by the pendulum and HSL ramp test methods.

4 CONCLUSIONS

4.1 PORTABLE TEST METHODS

Rz Surface Roughness

Surface roughness measurements and pendulum tests were carried out on 14 ramp boards used in the study. Rz data for the ramp boards resulted in the slip potential in wet conditions presented by the flooring materials being classified as follows:

High Slip Potential:	Polished Marble Agglomerate Polished Granite Terrazzo Natural Finish Terrazzo Gloss Finish Unfilled Travertine Gloss Finish Honed Limestone
Moderate Slip Potential:	Polished Limestone Unfilled Travertine Natural Finish
Low Slip Potential:	Riven Slate Gloss Finish Pebble Mosaic Riven Slate Natural Finish Natural Stone.

Rz surface roughness data indicates that seven of the floors should be classified as presenting a high potential for slip in water-wet conditions, two floors should be expected to present a moderate potential for slip and five floors might reasonably be expected to pose a low potential for slip when wet.

Pendulum Results

The pendulum test resulted in the slip potential in wet conditions presented by the flooring materials being classified as follows:

High Slip Potential:	Polished Marble Agglomerate Polished Granite Honed Limestone Terrazzo Natural Finish
High / Moderate Slip Potential:	Terrazzo Gloss Finish
Moderate Slip Potential:	Polished Limestone Unfilled Travertine Natural Finish Unfilled Travertine Gloss Finish Artificial Slate Smooth Finish

Low Slip Potential: Pebble Mosaic
Rivan Slate Natural Finish
Rivan Slate Gloss Finish
Artificial Slate
Natural Stone

Pendulum data indicates that four of the floors should be classified as presenting a high potential for slip in water-wet conditions, one floor should be classified as having a high to moderate potential for slip in the wet, four floors should be expected to present a moderate potential for slip and four floors might reasonably be expected to pose a low potential for slip when wet.

For the flooring investigated in the current study the agreement in slip potential classifications obtained from surface roughness data and pendulum results was very good:

- For 11 out 14 floors the slip potential classifications based on surface roughness and pendulum data were the same.
- For 2 out of 14 floors the surface roughness data under estimated the slip potential of the flooring materials as determined by the pendulum i.e. the flooring was less slippery than might have been expected from roughness alone.
- In only 1 case did the surface roughness data under estimate the level of slip potential of the floor as determined by the pendulum i.e. the flooring was more slippery than might have been expected.
- 79% of the total variability of the SRV data can be explained in terms of its relationship with Rz surface roughness.

While Rz surface roughness is a very useful key indicator for the anti-slip performance of flooring materials, some of the data generated for this study suggests that considering a combination of surface roughness parameters such Rz and Rs together may give a more informed indication of the slip potential of a floor. A more detailed analysis of the relationship between surface parameters and slip potential is currently being undertaken for HSE.

Overall the findings reported here support HSL / HSE's stance that while Rz is a useful indicator of the slip resistance of flooring materials it is not recommended that it be used as the sole selection criteria on which to base the choice of a new floor. **Wherever possible** surface roughness should be considered in *conjunction with pendulum measurements* in both wet and dry conditions before specification decisions are made.

4.2 RAMP RESULTS

Ramp test results when the operators wore shoes that had been soled with Four-S rubber indicated that the slip potential of the floors should be classified as follows:

High Slip Potential: Polished Marble
Agglomerate
Polished Granite
Terrazzo Natural Finish
Terrazzo Gloss Finish
Unfilled Travertine Gloss Finish
Honed Limestone
Polished Limestone
Unfilled Travertine Natural Finish

Low Slip Potential: Pebble Mosaic
Artificial Slate
Rivan Slate Natural Finish
Rivan Slate Gloss Finish
Natural Stone

Ramp test results generated using Four-S soled footwear indicated that nine floors should be classified as posing a high potential for slip in the water-wet condition and five floors might reasonably be expected to present a low potential for slip when wet.

All of the floors used in the study appear to present a lower potential for slip when the commercially available men's shoes were worn rather than Four-S soled footwear.

4.2.1 Comparison of ramp and pendulum test methods

Previously it has been reported that there is generally reasonably good agreement between Four-S pendulum results generated in water-wet conditions and ramp results generated using footwear soled with Four-S rubber.

Initial comparisons showed that the slip potential classifications obtained from ramp and pendulum test methods for agreed for ten out of fourteen floors used in the study. Simplistic analysis of coefficient of friction data obtained from the ramp and pendulum tests showed that the relationship maybe described by the following equation:

$$Y = 1.1407X - 0.0166, R^2 = 0.8198$$

Where Y= Ramp CoF, X= Pendulum CoF.

The relationship between the results of the two test methods appears to be linear in nature and the R^2 value for the best-fit predictive line indicates that 82% of the total variability in the CoF as measured by the ramp test method can be explained in terms of its relationship to CoF as measured by the pendulum test method.

Of the fourteen floors investigated in the current study there is only one case that is a potential cause for concern. From the surface roughness, pendulum and ramp data it is somewhat ambiguous as to whether or not the artificial slate flooring is suitable for use in for use in foreseeably wet areas or not. The potential exists for a duty holder to specify this floor for use in wet areas in good faith based on surface roughness and ramp data, but in the event of HSE / HSL investigation of an incident pendulum data would suggest that the floor was unsuitable for wet areas.

While a potential cause for concern the discrepancies in slip potential classification observed for the artificial slate flooring should be put in context with the overall findings of this project. When considered as a whole the data generated in the course of this project strongly supports the opinion that there is good agreement between Four-S results produced by the pendulum and ramp test methods.

5 REFERENCES

HSE, “HSE information sheet, Preventing slips in the food and drink industries – technical update on floor specifications.” Food Sheet No. 22, HSE.

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APPENDIX 1

Definitions of Surface Roughness Parameters.

This Appendix gives definitions (calculation methods) of the roughness parameters investigated in this study.

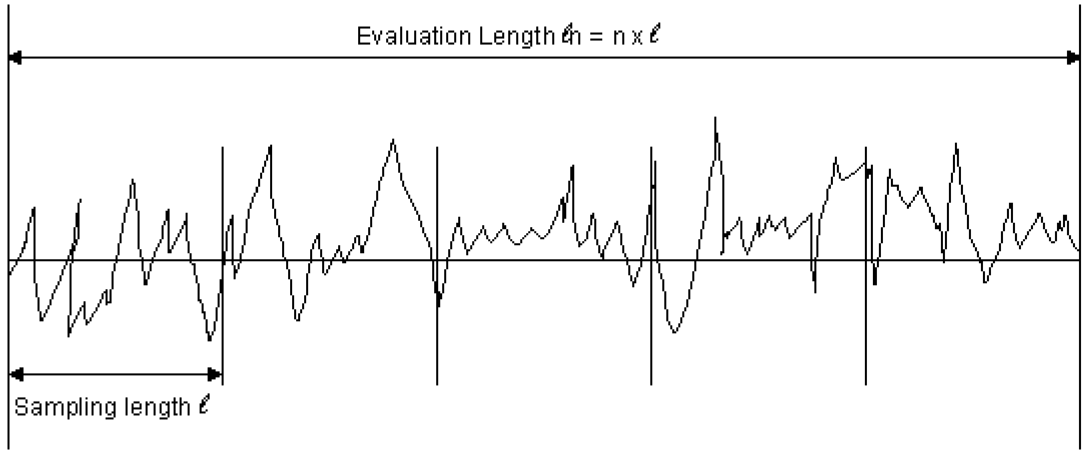


Diagram showing schematic representation of surface roughness trace.

Each of the surface roughness parameters explained in this section is calculates within a sampling length. Specific parameters to be obtained over the evaluation length will be denoted as required.

ARITHMETIC MEAN DEVIATION OF THE PROFILE - R_A

Ra is the arithmetic mean of the absolute values of the profile deviations (Y_i) from the mean line.

$$Ra = \frac{1}{N}\sum_{i=1}^{N}\left|Y_i\right|$$

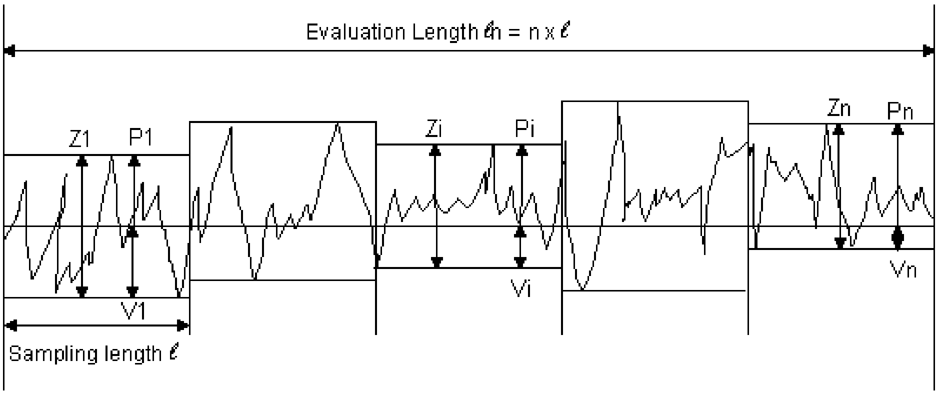
For ANSI, Ra is defined over the entire evaluation length.

ROOT-MEAN-SQUARE DEVIATION OF THE PROFILE, R_Q

Rq is the square root of the arithmetic mean of the squares of the profile deviations (Y_i) from the mean line.

$$Rq = \left(\frac{1}{N}\sum_{i=1}^{N}Y_i^2\right)^{1/2}$$

MAXIMUM HEIGHT OF THE PROFILE, RZ(DIN, ISO, ANSI)



The Rz surface roughness parameter is defined as the mean of the sum of Zi within each sampling length over the entire evaluation length.

$$Rz(DIN) = \frac{Z_1 + Z_2 + Z_3 + Z_4 + Z_5}{5}$$

Where the number of sampling lengths n = 5

MAXIMUM TWO POINT HEIGHT OF THE PROFILE, R_Y(DIN, ANSI)

The maximum value of all the Zi's used to calculate Rz over the evaluation length is defined as R_y (DIN, ISO, ANSI).

MAXIMUM PROFILE PEAK HEIGHT, R_P (DIN, ISO, NEW JIS)

R_p is defined as the mean value of the R_{pi} over the entire evaluation length, where R_{pi} is the profile peak height within each sampling length.

$$R_p = \frac{R_{p1} + R_{p2} + R_{p3} + R_{p4} + R_{p5}}{5}$$

Where the number of sampling lengths n =5.

TOTAL HEIGHT OF THE PROFILE R_T

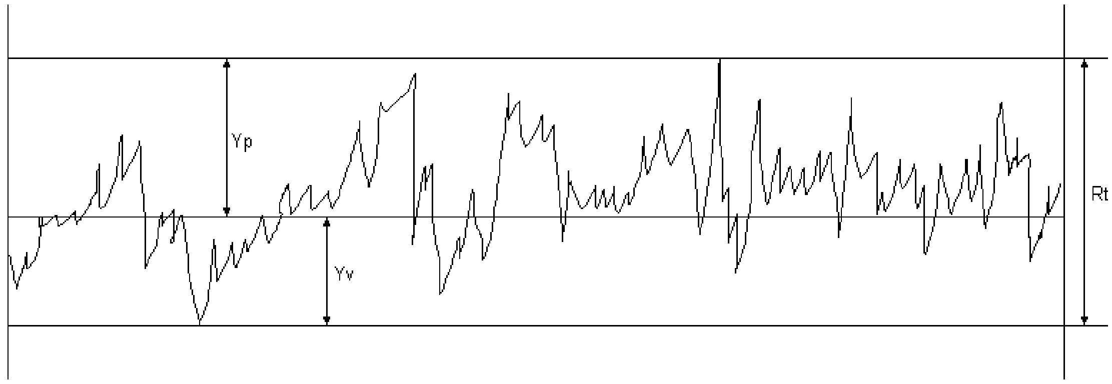
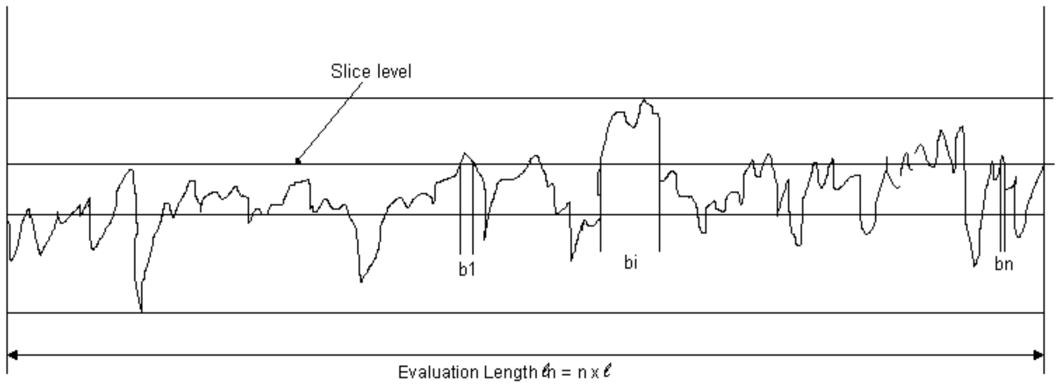


Diagram showing a schematic representation of how Rt is calculated.

R_t is defined as the height of the highest peak and the depth of the deepest valley over the evaluation length.

$$R_t = Y_p + Y_v$$

MATERIAL RATIO OF THE PROFILE, R_{MR}



Schematic diagram showing how R_{mr} is calculated

R_{mr} is defined as the ratio (%) of the material length of the profile elements at a given level (slice Level) to the evaluation length. Here the slice level is defined as the depth from the highest peak, and is called a “peak reference”. The slice level is represented by a ratio of the depth (0 to 100%) to the R_t value.

$$Rmr = \frac{\eta p}{\ln} \times 100(\%) \qquad \eta p = \sum_{i=1}^{n} bi$$

MEAN SPACING OF LOCAL PEAKS OF THE PROFILE, R_S

R_s is the mean spacing of adjacent local. For ANSI, this parameter is defined over the evaluation length.

$$R_s = \frac{1}{n}\sum_{i=1}^{n} S_i$$

Where n = number of peaks.