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Ramp testing pre-engineered wood floors

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Ramp testing pre-engineered wood floors

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The aim of the work presented here was to assess the slip resistance of a wide range of pre-engineered wooden floors; such materials have become increasingly popular in both domestic and commercial premises over recent years. Despite their current widespread use, little is understood about the slip characteristics of these floors.

All of the flooring materials studied were assessed using a range of test methods:

- Surface microroughness analysis
- The pendulum test
- The standard HSL ramp test (HSL-PS-SOP-12)

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EXECUTIVE SUMMARY

Objectives

The aim of this project was to characterise a range of pre-engineered wooden flooring materials using the HSL Ramp Test. Both of the portable test methods routinely utilised during HSL/HSE forensic site investigations (Rz surface roughness and pendulum tests) were also used.

Main Findings

Portable Test Methods

Rz surface microroughness data was collected from each of the surfaces under study. This data was used to classify the slip potential presented by these surfaces in wet conditions as follows:

High Slip Potential:	Kahrs Flooring Oak Bamboo Flooring Coastal Woodlands Swissclick Floor – Beech Pergo Kitchen Planks
High / Moderate Slip Potential	Quick Step 700 – Mirabow Domino Flash Flooring
Moderate / High Slip Potential	Richard Burbage Pine
Moderate Slip Potential:	Quick Step 950

Pendulum data generated in wet conditions was used to classify the slip potential presented by the test surfaces as follows:

High Slip Potential:	Richard Burbage Pine Quick Step 700 – Mirabow Quick Step 950
High / Moderate Slip Potential	Domino Flash Flooring Kahrs Flooring Oak Pergo Kitchen Planks
Moderate / High Slip Potential	Bamboo Flooring
Moderate Slip Potential:	Swissclick Floor – Beech Coastal Woodlands

Comparison of Rz surface micro-roughness data with pendulum SRV values appears to indicate that levels of Rz roughness may not always have an overriding influence on the slip resistance of pre-engineered wood floors in water-wet conditions. On occasions where there was disagreement between surface roughness and pendulum results the Rz data tended to an underestimate of the slip resistance of the pre-engineered wood flooring. From a safety point of view this would result in the floors “failing safe” and this would not be problematic for HSE.

The findings reported here indicate that the relationship between surface micro-roughness and slip resistance may indeed be considerably more complicated than previously suggested. It may

be possible to achieve a better correlation between slip resistance and surface roughness if a combination of surface roughness parameters was used.

These results give general support to HSL / HSE's view that Rz is a useful indictor of the slip resistance of flooring materials. However, further support is given to the view that Rz surface microroughness should not, wherever possible, be used as the sole criteria during the selection or specification of flooring materials. In such circumstances, surface roughness information should be considered in *conjunction with pendulum measurements* in both wet and dry conditions.

Ramp Test Results

Ramp test results generated using Four-S rubber-soled footwear classified the slip potential of the floors studied as follows:

High / Moderate Slip Potential:	Quick Step 700 – Mirabow Coastal Woodlands
Moderate / High Slip Potential:	Swissclick Floor – Beech
Moderate Slip Potential:	Domino Flash Flooring Kahrs Flooring Oak Quick Step 950 Bamboo Flooring
Low Slip Potential:	Richard Burbage Pine Pergo Kitchen Planks

All of the floors studied present a low slip potential when tested using the commercially available men's fashion shoes.

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 data produced during this study showed a good agreement between ramp and pendulum test methods for approximately half the floors studied.

The differences in the classifications produced by the two methods (pendulum and ramp) may be explained by considering the subtly different preparation methods used for each test. Four-S rubber used in the ramp test was prepared using rough (P400) abrasive paper, whilst Four-S pendulum test sliders were generally prepared using very smooth lapping film. This was hypothesised to result in the majority of the differences observed.

The above hypothesis was tested by repeating pendulum measurements on all of the surfaces studied, after the use of a *rough* (P400) conditioning regime under wet contamination. This appreciably increased the agreement between ramp-test and pendulum data.

Good Agreement: Quick Step 750 – Mirabow, Domino Flash Flooring, Bamboo Flooring, Swissclik Flooring – Beech, Coastal Woodlands.

Reasonable Agreement: Kahrs Flooring Oak.

The results of the work presented would therefore appear to confirm that there is generally good agreement between the ramp and pendulum test methods. However, it should be noted that:

- The preparation regime used on the Four-S rubber effects the level agreement between the two test methods.
- A lowest level of agreement exists between the ramp and pendulum test methods occurred for the more textured laminates.

Highly textured floors are known to be more difficult to test for slip resistance. Surface roughness data from these floors can be misleading and pendulum data should be interpreted with the appropriate level of caution. It may be, that no one single test method alone is able to characterise the slip resistance of textured floors. Data from all three test methods, surface roughness, pendulum and ramp can provide some useful information about the slip resistance properties of the flooring, but the results of all three test methods should be considered in concert to give a more holistic understanding of the anti-slip behaviour of these types of textured floors.

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 work presented here was to assess the slip resistance of a wide range of pre-engineered wooden floors; such materials have become increasingly popular in both domestic and commercial premises over recent years. Despite their current widespread use, little is understood about the slip characteristics of these floors.

All of the flooring materials studied were assessed using a range of test methods:

- Surface microroughness analysis
- The pendulum test
- The standard HSL ramp test (HSL-PS-SOP-12)

2 EXPERIMENTAL

Nine floors were selected for study in the current work (see Table 2.1). The floors chosen were selected to be representative of the extensive rage of pre-engineered floors available in the marketplace.

Flooring	Type
Domino Flash Flooring	Laminate
Richard Burbage Pine	Laminate
Kahrs Flooring Oak	Oak veneer laid on pre-engineered wood substrate
Quick Step 950	Laminate
Pergo Kitchen Plank	Laminate
Quick Step 700 - Mirabow	Laminate
Swissclick Floor - Beech	Laminate
Coastal Woodlands	Wood veneer laid on pre-engineered wood substrate
Bamboo Flooring	Natural Bamboo laid on ply wood substrate

Table 2.1: Floors used in the current investigation.

Each flooring studied was laid onto a ramp board by a professional joiner in accordance with the manufacturer’s instructions. Any recommended additional surface treatments were subsequently applied.

The slip resistance of each of the test surfaces used in the current work was assessed using the standard test methodology outlined in the United Kingdom Slip Resistance Group Guidelines using a Pendulum Coefficient of Dynamic Friction (CoF) Test (Figure 2.2) and a Mitutoyo SJ-201P microroughness transducer (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 test surface was further characterized using the DIN ramp test.

2.1 SURFACE ROUGHNESS

The surface microroughness analysis of flooring materials routinely involves the generation of ten R_z measurements. These are generated using a standardised three directional methodology in order to account for surface inhomogeneity. As the aim of the current work was to characterise the pre-engineered wooden floors as completely as possible, the opportunity was taken 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 normally be generated 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.

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, Version 2, 2000[1]. Interpretations of surface roughness data are based on existing HSE Guidance and the UKSRG Guidelines.

Figure 2.2: The "Stanley" Pendulum CoF test.

2.3 RAMP TEST

Reliable information regarding the slip-resistance 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–PS–SOP-12), shown in Figure 2.3.

[1] Guidelines current at the time of testing.

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

Ramp testing was conducted in accordance with HSL–PS-SOP-12 using potable water applied at a flow rate 6 litres per minute as a contaminant. The inclination of the ramp was increased by the operator in approximately 1° increments until an unrecoverable slip was initiated; the angle of the ramp at the time of the slip was then recorded. Twelve angles were determined, with the highest and lowest values being discarded. The 10 remaining values were then averaged to give a critical angle. The coefficient of friction for level walking was determined by calculating the tangent of the critical angle. All results presented here were generated by two ramp operators; the results generated by these operators were consistently 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 over 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 flooring surfaces under study are given in Table 3.1.

Ramp Board	Average Surface Roughness (μm)						
	Ra	Rz	Rq	Rt	Rp	Rmr	Rs
Kahrs Flooring Oak	1.32		1.59	7.57	3.62	11%	184.1 (8)
Bamboo Flooring	1.16		1.49	8.73	4.32	5.8%	185.3
Coastal Woodlands	1.25		1.54	8.79	4.2	5.9%	146.5
Swissclick Floor - Beech	1.14		1.45	9.44	3.12	22.6%	75.4
Pergo Kitchen Planks	1.61		1.96	10.28	4.10	17.9%	98.1
Domino Flash Flooring	2.02		2.46	12.93	4.97	14.2%	202.6 (9)
Quick Step 700 - Mirabow	1.88		2.38	14.22	3.95	43.4%	166.7 (7)
Richard Burbage Pine	2.42		2.85	13.93	5.04	30.6%	170.1
Quick Step 950	3.34		4.05	18.06	6.05	33.8%	224.7 (6)

Table 3.1: Mean average values of a range of surface roughness parameters for the nine ramp boards used in the current study. R_z (μm) results are highlighted.

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

The Rz parameter, highlighted in Table 3.1, is routinely measured during HSL slipperiness assessments and is a useful parameter for the prediction of the likely slip resistance of a flooring material under water (and other fluid) contamination. The 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 and up to 30	Low
Above 30	Extremely Low

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

Table 3.2: Interpretation of surface roughness data; UKSRG Guidelines.

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].

A strict comparison of the Rz data for ramp boards used in this study (Table 3.1) with the information in Table 3.2 resulted in classification of two of the floors tested as *moderate potential for slip* and seven as *high potential for slip* (in wet conditions). However Rz data for several of the ramp boards investigated were very close to the classification threshold given in Table 3.2. As such, the slip potential predicted by Rz microroughness analysis for wet conditions were classified as follows:

High Slip Potential:	Kahrs Flooring Oak Bamboo Flooring Coastal Woodlands Swissclick Floor – Beech Pergo Kitchen Planks
High / Moderate Slip potential	Quick Step 700 – Mirabow Domino Flash Flooring
Moderate / High Slip Potential	Richard Burbage Pine
Moderate Slip Potential:	Quick Step 950

When Rz surface roughness is considered in isolation, none of the laminate and pre-engineered wood floors selected for this project would be expected to present a *low potential for slip* in wet conditions. Rz data therefore indicates that none of these floors are appropriate for use in foreseeably wet areas.

3.2 PENDULUM MEASUREMENTS

Pendulum results generated from the flooring surfaces under study are given in Table 3.4.

Ramp Board	Direction	Dry (SRV)	Wet (SRV)	Slip Potential in Wet
Kahrs Flooring Oak	Direction I	64	23	
	Direction II	70	24	
	Direction III	70	26	
Bamboo Flooring	Direction I	70	24	
	Direction II	75	25	
	Direction III	74	25	
Coastal Woodlands	Direction I	60	32	
	Direction II	64	30	
	Direction III	65	30	
Swissclick Floor - Beech	Direction I	66	27	
	Direction II	69	29	
	Direction III	64	27	
Pergo Kitchen Planks	Direction I	62	24	
	Direction II	65	24	
	Direction III	63	20	
Domino Flash Flooring	Direction I	66	22	
	Direction II	66	25	
	Direction III	63	24	
Quick Step 700 - Mirabow	Direction I	70	19	
	Direction II	67	22	
	Direction III	67	21	
Richard Burbage Pine	Direction I	64	20	
	Direction II	69	20	
	Direction III	71	20	
Quick Step 950	Direction I	70	20	
	Direction II	73	19	
	Direction III	69	19	

Table 3.4: Four-S pendulum results in dry and wet conditions for each of the flooring surfaces under study.

Natural timber products are known to often be directional; slip resistance in the direction of the grain may differ from that across the grain. Although all of the floors in the current study were pre-engineered and had either ply wood or medium density fibreboard (MDR) substrates, a number of the number of the products (Karhs oak flooring, Bamboo flooring, Coastal Woodlands) had nature wood or bamboo veneers applied over these substrates. It was therefore hypothesised that these “natural” products might display the same type of directionality in their slip resistance that is frequently observed in solid wood flooring. These expectations were shown to be unfounded as there was little evidence of directionality in the pendulum data generated from the flooring products under study (this may be largely due to [a] the presence of sealant on the wooden products, and [b] the low-level “grain” embossed/printed onto the laminate products).

Pendulum results showed that the wet slip potential of the flooring products studied may be classified as follows:

High Slip Potential:	Richard Burbage Pine Quick Step 700 – Mirabow Quick Step 950
High / Moderate Slip potential:	Domino Flash Flooring
Moderate / High Slip Potential:	Bamboo Flooring Kahrs Flooring Oak Pergo Kitchen Planks
Moderate Slip Potential:	Swissclick Floor – Beech Coastal Woodlands

For the laminate and wood flooring materials used in this work, the results of the pendulum tests are somewhat at odds with expectations based solely on surface roughness data. From Rz measurements, the Richard Burbage pine laminate and the Quickstep 950 laminate might be expected to present a moderate or moderate to high slip potential when wet, the pendulum test, however, showed both of these floors to present a high slip potential in wet conditions.

Similarly from surface roughness alone the Swissclick Floor – Beech, Coastal Woodlands and Bamboo flooring would all be expected to present a high slip potential when wet, but the pendulum test showed them to present a moderate or moderate to high slip potential.

While it is not unknown for there to be disagreement between classifications resulting from surface roughness data and pendulum test results, level of disagreement is higher than might be expected and certainly a cause for closer examination.

It has generally been observed that the slip resistance of flooring materials in wet conditions increases as the surface roughness of the material increases [HSE]. However, the relationship between surface roughness and slip resistance appears to be more complicated for pre-engineered wood floors used in the current study. A plot of pendulum SRV (slip resistance value) against a range of surface roughness parameters is shown in Figure 3.1.

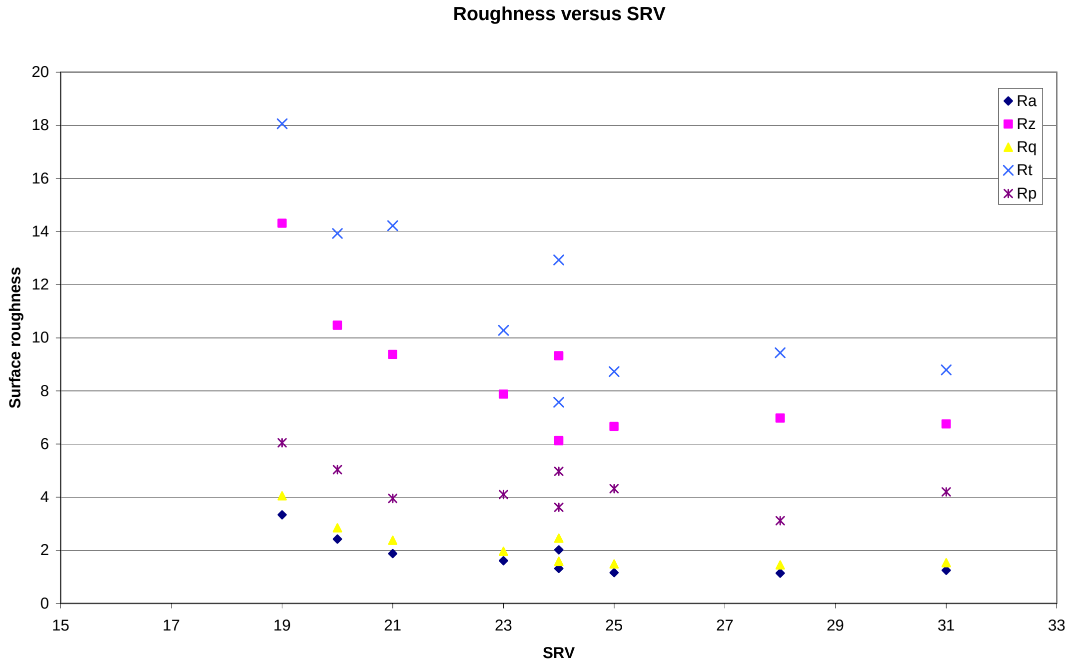

Figure 3.1 Graph showing a range of surface roughness parameters (all measured in μm) plotted against SRV data for wet conditions.

From Figure 3.1, it can be seen that the laminate floor with the highest Rz actually had the lowest slip resistance value in wet conditions, not one of the highest as might have been reasonably expected. Similarly there is a difference in Rz of only 0.3 μm between the Swissclick beech, Costal Woodlands and Bamboo floorings, it would therefore be reasonable to expect their slip resistance in wet conditions to be very similar. Pendulum tests however showed the SRV values for these floors to vary between 25 and 31, which is a somewhat wider spread than might have been expected given the very similar levels of surface roughness presented by these materials. These findings appear to indicate that the Rz surface micro-roughness alone of these materials may not be the overriding influence on their slip resistance in water-wet conditions.

Comparisons of the slip potential classifications of these floors based on surface roughness and pendulum data show that surface roughness data generally indicates lower levels of slip resistance than were subsequently measured with the pendulum. Selection of flooring based on surface roughness alone in these cases would therefore lead to a conservative flooring selection with installed flooring likely to exhibit better slip resistance than anticipated. While such discrepancies are of academic interest they do not raise major health and safety concerns.

Unfortunately in two cases the Rz surface roughness information appears to overestimate the slip potential of the floors in wet conditions. This implies that it would be possible to choose a laminate floor based on surface roughness and end up with an installed floor, which posed a higher slip potential in wet conditions than might have been expected. Unlike the other discrepancies discussed these cases are a cause for concern, however it should be stressed that this occurred in a small proportion of instances.

Comparing the surface roughness and pendulum data as a whole for the pre-engineered floors the data would appear to indicate that the Rz surface roughness parameter alone might not be the best predictive indicator of the anti-slip performance of pre-engineered wood and laminate floors. It has long been accepted that Rz surface roughness should be used an indicator only for the expected anti-slip performance of a flooring material in water-wet conditions.

The findings reported here is further confirmation that the relationship between surface micro-roughness and slip resistance considerably more complicated than previously suggested. It may be possible to achieve a better correlation between slip resistance and surface roughness if a combination of surface roughness parameters such as Rs and Rz were used as opposed to simply Rz.

A plot of pendulum SRV (slip resistance value) against the Rs surface roughness parameters is shown in Figure 3.2.

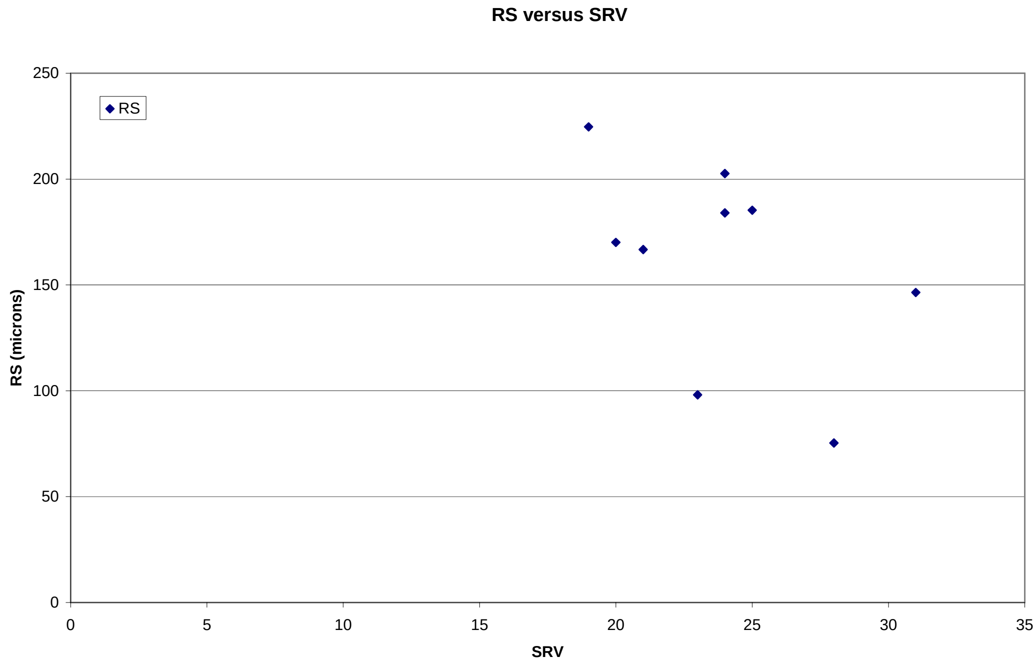

Figure 3.2 Graph showing the RS surface roughness parameters (measured in μm) plotted against SRV data for wet conditions.

It can be seen for Figure 3.2 that as a general trend wet SRV values increased as Rs decreased, i.e. the spacing between adjacent peaks decreases. This would seem to be intuitively sensible, as the peak spacing decreases the peak density increases, increasing the proportion of the flooring surface area capable of breaking through the fluid film formed by the water and having solid to solid contact with the pendulum slider. This observation provides further confirmation that Rs is a surface roughness parameter of interest in furthering our understanding of the relationship between the surface roughness and slip resistance of flooring materials.

A detailed investigation of the relationships of the wider range of surface roughness parameters with pendulum slip resistance values is beyond the scope of the current research, however surface roughness and pendulum data generated during this project has been used to feed into more detailed work on surface roughness currently being conducted by HSL for HSE.

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 data from other test methods such as pendulum measurements in both wet and dry conditions, or ramp data before specification decisions are made.

3.3 RAMP RESULTS

Ramp results for each of the pre-engineered wood floors used in the study are given in Table 3.5.

Ramp Board	Footwear		
	Four-S	Megane Trekker	Salindas
Coastal Woodlands			
Quick Step 700 - Mirabow			
Swissclick Floor - Beech			
Domino Flash Flooring			
Bamboo Flooring			
Kahrs Flooring Oak			
Quick Step 950			
Richard Burbage Pine			
Pergo Kitchen Planks			

Table 3.5 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 risk, yellow indicates floors that pose a moderate slip risk and green indicates those floors that presents a low slip risk.

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 follow:

High / Moderate Slip Potential: Quick Step 700 – Mirabow
Coastal Woodlands

Moderate / High Slip Potential: Swissclick Floor – Beech.

Moderate Slip Potential: Domino Flash Flooring
Kahrs Flooring Oak
Quick Step 950
Bamboo Flooring

Low Slip Potential: Richard Burbage Pine
Pergo Kitchen Planks

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 soling compound of moderate anti-slip performance, i.e. there are soling materials with worse anti-slip performance available in the marketplace and soling materials with better anti-slip performance available. It is therefore not unreasonable that both the commercially available pieces of footwear used in the study demonstrated better levels of anti-slip performance than the Four-S soled shoes.

All of the floors appear to present a low slip risk when commercially available men's fashion shoes were worn. This was a somewhat unexpected result as there is anecdotal evidence implicating laminate flooring in slip accidents, and during everyday experience people often perceive wet laminate flooring as being "slippery" underfoot.

3.4 COMPARISON OF PENDULUM AND RAMP SLIP RESISTANCE 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. The slip potential classifications for the floors generated by the different test methods are compared in Table 3.6.

Ramp Board	Rz Surface Roughness (μm)	Four-S SRV (Direction I water-wet)	Four-S Ramp Results Coefficient of Friction
Quick Step 950			
Richard Burbage Pine			
Quick Step 700 – Mirabow			
Domino Flash Flooring			
Pergo Kitchen Planks			
Kahrs Flooring Oak			
Bamboo Flooring			
Swissclick Floor – Beech			
Coastal Woodlands			

Table 3.6 Table ranking the flooring used in the study from least slip resistant to most slip resistant, and comparing the results obtained by the pendulum (direction I, along the board) and ramp test method.

Pendulum data in the range of the water-wet results produced in this study may be converted into coefficient of friction values be simply dividing by approximately 100. If that is done, it can be seen that for some floors such as Quick Step 700 and the Swissclick Beech flooring there is excellent agreement between the results generated by the pendulum and ramp test methods. However at first glance there would appear to be appreciable differences in the results generated for the other floors. In some cases these differences are so pronounced that flooring that the pendulum would classify as having a high potential for slip in the wet are indicated to present a low slip potential by the ramp results.

Both pendulum and ramp results are subject to a degree of variation, it is commonly accepted for example that pendulum results may vary by 2/3 points between operators and instruments.

The coefficient of friction values obtained from the ramp tests are the result of taking the average of the mean critical angles achieved by two ramp operators whose mean angles were within 2° of each other. Hypothetically, if the lowest of those two critical angles had been generated first, a second angle up to 2° lower would have been accepted and the coefficient of friction would have been calculated from those angles. Similarly, if the highest angle had been generated first, a critical angle of up to 2° higher would have been accepted.

If good agreement between the pendulum and ramp results is defined as the wet pendulum coefficient of friction ((wet SRV ± 2)/100) being within the hypothetical upper and lower bounds for the ramp results described above, then for 3 of the nine floors studied there is good agreement between the results generated by the pendulum and ramp test methods.

If we define reasonable agreement as (wet SRV ± 6 /100) being within the hypothetical ramp limits, it can be seen that there is reasonable agreement between the test methods for a further 2 flooring materials.

There would appear to good or reasonable agreement between the ramp and pendulum results for approximately half of the floors investigated. The level of agreement between the two test methods would therefore appear to be lower than might have been expected.

3.4.1 Effect of conditioning regimes

A possible explanation of the differences in measured slip potential is the different ways in which the Four-S rubber was prepared prior to testing, either in line with the UKSRG guidelines or the procedure outlined in HSL-SOP-12. The different preparation methods are compared in Table 3.6.

Test Method	P400 Silicon Carbide Paper	Pink Lapping Film
Pendulum	3 swings	20 swings
Ramp	Some	None

Table 3.6 Comparison of the preparation routes used for Four-S rubber prior to testing.

The preparation method used for pendulum testing is more controlled and reproducible than that used before ramp testing, and includes the use of two different grades of abrasive as opposed to one. It is known from previous work on the pendulum test that the inclusion or omission of the pink lapping stage of slider preparation can result in measurable differences in the SRV values obtained from floors. It is therefore possible that some of the differences between pendulum data and ramp data that have been observed during this work are a result of the different preparation methods being used.

To test this hypothesis further it was decided to generate additional pendulum data on the ramp boards after testing. For these additional tests pendulum data was generated in only a single direction along the ramp board, parallel to the direction in which the ramp operators walked, and the Four-S pendulum slider was prepared using P400 only. Results of the additional testing are given in Table 3.7.

Ramp Board	Four-S Wet SRV (Direction I) After ramp Testing	Four-S Wet SRV (Direction I – P400 only) After ramp Testing	Four-S Ramp Results
Quick Step 950	16		
Richard Burbage Pine	15		
Quick Step 700 – Mirabow	18		
Domino Flash Flooring	22		
Pergo Kitchen Planks	20		
Kahrs Flooring Oak	19		
Bamboo Flooring	25		
Swissclick Floor – Beech	27		
Coastal Woodlands	25		

Table 3.7 Comparison of pendulum results generated after testing with ramp data.

Pendulum and ramp results for the nine laminate boards used in the study are compared graphically in Figure 3.2.

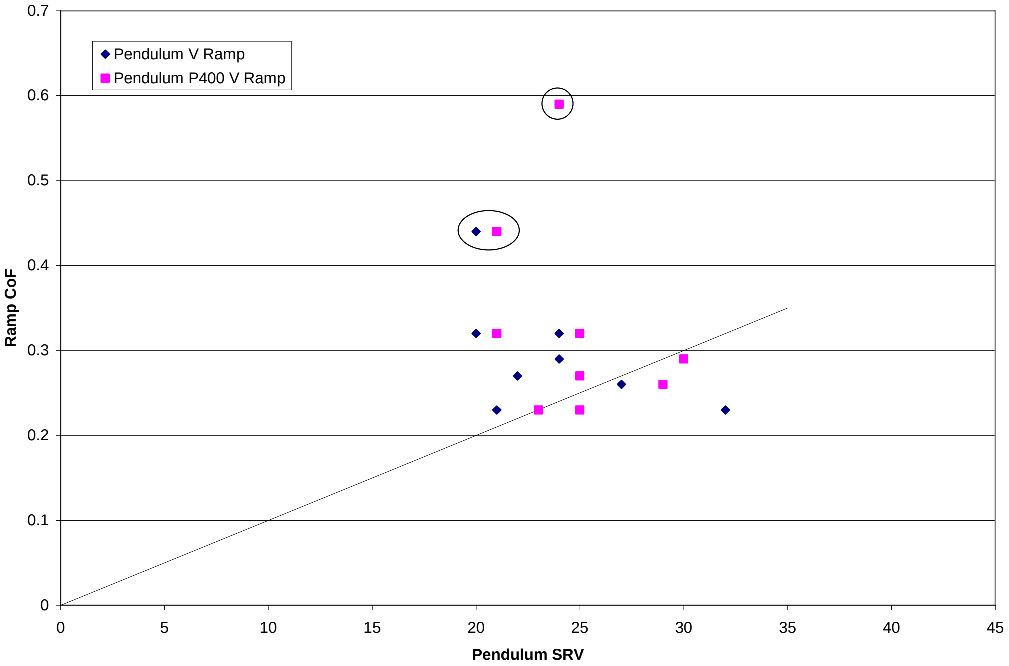

Figure 3.2 Graph showing coefficient of friction data generated on the ramp plotted against SRV data for wet conditions for the two conditioning regimes.

Conditioning the slider with P400 only, does appear to improve the agreement between the results generated using the ramp and pendulum test methods. If the same criteria as above are used, there is good agreement between the pendulum and ramp results for five of the floors and reasonable agreement for a further one floor.

Good Agreement: Quick Step 750 – Mirabow, Domino Flash Flooring, Bamboo Flooring, Swissclik Flooring – Beech, Coastal Woodlands.

Reasonable Agreement: Kahrs Flooring Oak.

The proportion of the floors for which there is good or reasonable agreement between the ramp and the pendulum has been increased from approximately half to two thirds by changing the conditioning regime of the pendulum slider.

There are three remaining floors for which there is not reasonable or good agreement between the pendulum and the ramp. Of these three floors, one the Quick Step 950 lies just outside the criteria for reasonable agreement.

For the other two outstanding floors, Pergo Kitchen Planks and Richard Burbage Pine, the ramp results are significantly higher than the equivalent results generated by the pendulum test method, see Table 3.7. The differences between the two test methods are so dramatic that the pendulum results for these floors indicate that they should be considered the present a high potential for slip in the water-wet conditions, while the ramp results appear to indicate that both floors present a low potential for slip in the wet.

It is generally argued that for a slip resistance test to be considered valid in water-wet conditions it must to reproduce the same squeeze film as a pedestrian during level walking. It is generally agreed that both the pendulum test and the HSL ramp test do produce the correct squeeze film at contact, and this would appear to be bourn out by the generally good agreement between the two test methods observed during this study. The very different results obtained from the ramp and pendulum tests for the Pergo Kitchen Planks and the Richard Burbage Pine flooring suggest that in the case of these particular floors something may be happening to affect the squeeze film being formed during testing.

On closer inspection, the Pergo Kitchen Planks and Richard Burbage Pine are atypical of the flooring selected for use in this work as they both have distinctive "pseudo wood grain" textures embossed into the laminate. This texture may tend to promote the formation of a fluid squeeze film on the peaks during testing. It would certainly 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.

The atypical behaviour observed for the Pergo Kitchen Planks and Richard Burbage Pine flooring in this study is further evidence that characterising the slip resistance behaviour of textured flooring is a non-trivial matter. Test results from this type of flooring should be interpreted with caution. It is currently unclear whether the high slip potential classification obtained from the pendulum test or the low 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.

It would therefore seem prudent to recommend that textured flooring should not be specified on the strength of results from any single test method. Data from all three test methods, surface roughness, pendulum and ramp can provide some useful information about the slip resistance properties of the flooring, but the results of all three test methods should be considered in concert to give a more holistic understanding of the anti-slip behaviour of these types of textured floors. Further work to more fully understand the effect of surface texture on squeeze film formation is needed.

Given that it is possible to explain the different behaviour observed for these two laminate materials in terms of their textured surfaces, it is therefore reasonable to disregard the data for these floors when considering the level agreement between the ramp and pendulum test methods. If the circled data points in Figure 3.2 are ignored there appears to be reasonable agreement between the results generated by the pendulum and ramp test methods. The agreement between the test methods is appreciably better when the same preparation regime (P400 only) is used in both cases.

It should be borne in mind that the floors represent a small sample of the laminate and pre-engineered floors available in the market place, and that they represent a narrow range of anti-slip performance. When these constraints are taken into consideration the results of the current work would appear to confirm that there is generally reasonable agreement between the ramp and pendulum test methods, but it should be noted that:

- The preparation regime used on the Four-S rubber effects the level agreement between the test methods.
- There are higher levels of disagreement between the test methods for more textured laminates.

4 CONCLUSIONS

4.1 PORTABLE TEST METHODS

Surface roughness measurements and pendulum tests were carried out on 9 ramp boards used. 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:	Kahrs Flooring Oak, Bamboo Flooring Coastal Woodlands Swissclick Floor – Beech Pergo Kitchen Planks
High / Moderate Slip potential	Quick Step 700 – Mirabow Domino Flash Flooring
Moderate / High Slip Potential	Richard Burbage Pine
Moderate Slip Potential:	Quick Step 950

The pendulum test resulted in 3 floors being classified as having a moderate slip potential and 6 were considered to present a high slip potential in wet conditions:

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

High Slip Potential:	Richard Burbage Pine Quick Step 700 – Mirabow Quick Step 950
High / Moderate Slip potential	Domino Flash Flooring Kahrs Flooring Oak Pergo Kitchen Planks
Moderate / High Slip Potential	Bamboo Flooring
Moderate Slip Potential:	Swissclick Floor – Beech Coastal Woodlands

Comparison of Rz surface micro-roughness values with pendulum SRV values appear to indicate that the Rz surface micro-roughness of the flooring may not always be the overriding influence on the slip resistance of pre-engineered wood floors in water-wet conditions.

The findings reported here indicate that the relationship between surface micro-roughness and slip resistance considerably more complicated than previously suggested. It may be possible to achieve a better correlation between slip resistance and surface roughness if a combination of surface roughness parameters was used.

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.

4.2 RAMP TEST 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 / Moderate Slip Potential:	Quick Step 700 – Mirabow Coastal Woodlands
Moderate / High Slip Potential:	Swissclick Floor – Beech.
Moderate Slip Potential:	Domino Flash Flooring Kahrs Flooring Oak Quick Step 950 Bamboo Flooring
Low Slip Potential:	Richard Burbage Pine Pergo Kitchen Planks

All of the floors appear to present a low slip risk when commercially available men's fashion shoes were worn. This was a somewhat unexpected result as there is anecdotal evidence implicating laminate flooring in slip accidents, and during everyday experience people often perceive wet laminate flooring as being "slippery" underfoot.

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 there was good agreement between the ramp and pendulum test methods for approximately half the floors used in the study.

A possible explanation of the differences in slip potential measured by the two test methods is the different ways in which the Four-S rubber was prepared prior to testing, either in line with the UKSRG guidelines or the procedure outlined in HSL-SOP-12. This hypothesis was tested by measuring the slip potential of all the ramp boards in the water wet condition using a pendulum slider conditioned with P400 only.

The proportion of the floors for which there is good or reasonable agreement between the ramp and the pendulum was increased from approximately half to two thirds by changing the conditioning regime of the pendulum slider.

Good Agreement: Quick Step 750 – Mirabow, Domino Flash Flooring, Bamboo Flooring, Swissclik Flooring – Beech, Coastal Woodlands.

Reasonable Agreement: Kahrs Flooring Oak.

Overall the results of the current work would appear to confirm that there is generally reasonable agreement between the ramp and pendulum test methods, but it should be noted that:

- The preparation regime used on the Four-S rubber effects the level agreement between the test methods.

- There are higher levels of disagreement between the test methods for more textured laminates.

The atypical behaviour observed for the more textured flooring in this study is further evidence that characterising the slip resistance behaviour of textured flooring is a non-trivial matter. Test results from this type of flooring should be interpreted with caution. It is currently unclear whether the high slip potential classification obtained from the pendulum test or the low 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.

It would therefore seem prudent to recommend that textured flooring should not be specified on the strength of results from any single test method. Data from all three test methods, surface roughness, pendulum and ramp can provide some useful information about the slip resistance properties of the flooring, but the results of all three test methods should be considered in concert to give a more holistic understanding of the anti-slip behaviour of these types of textured floors. Further work to more fully understand the effect of surface texture on squeeze film formation is needed.

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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.

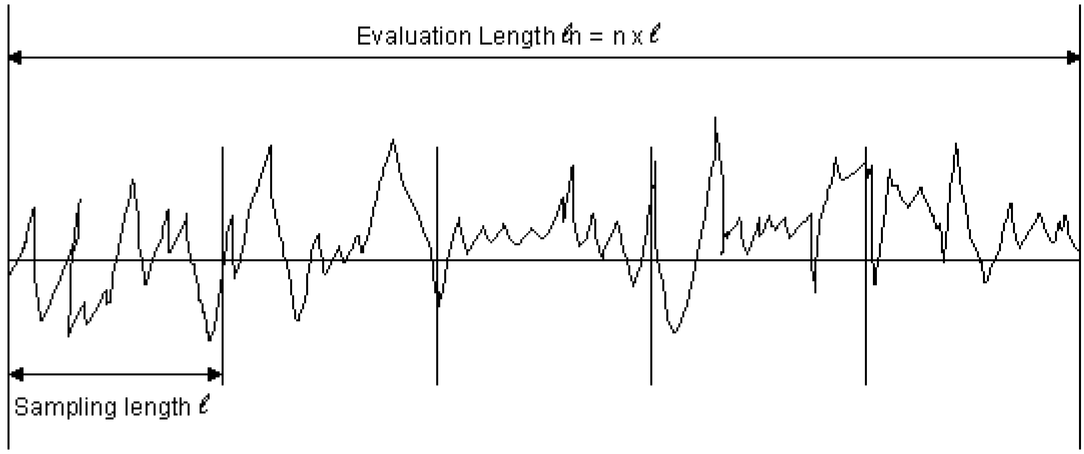


Diagram showing schematic representation of surface roughness trace.

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.

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

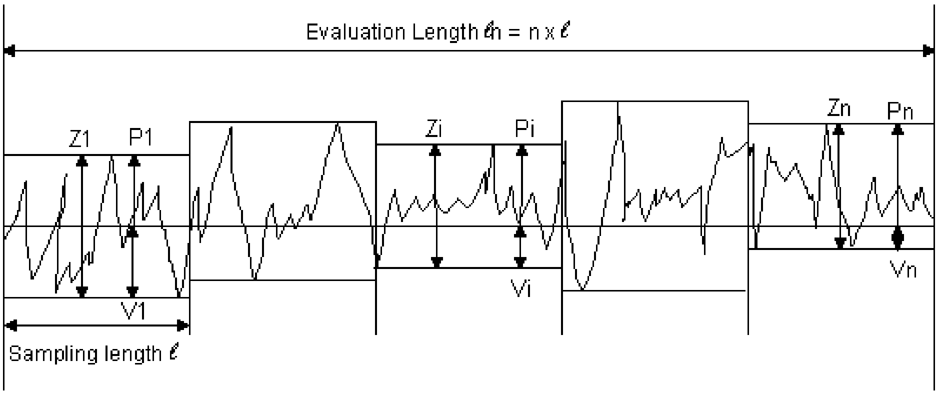
For ANSI, Ra is defined over the entire evaluation length.

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

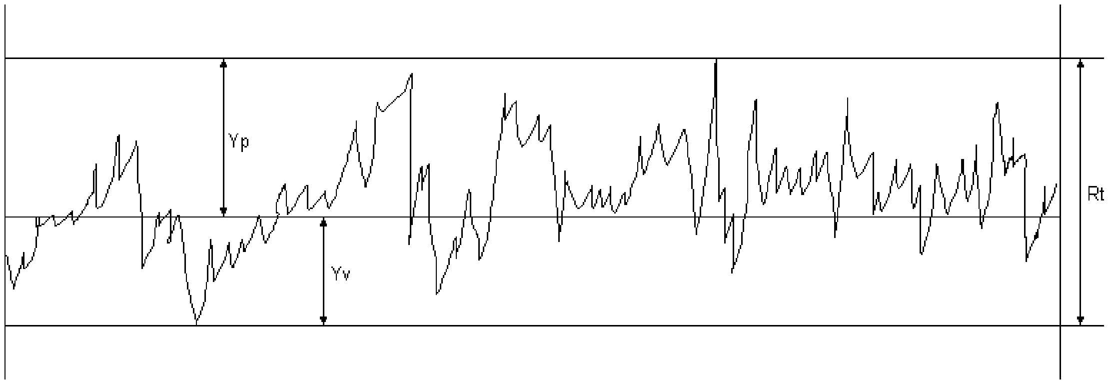
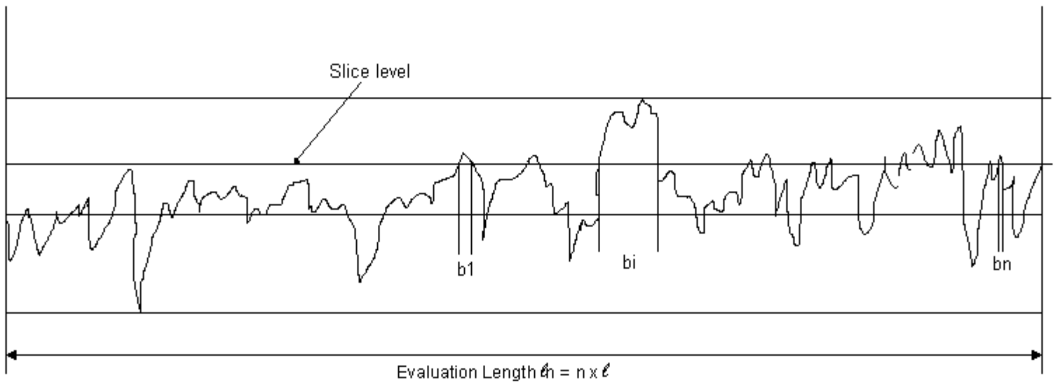


Diagram showing a schematic representation of how Rt is calculated.

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.

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Ramp testing pre-engineered wood floors

The aim of the work presented here was to assess the slip resistance of a wide range of pre-engineered wooden floors; such materials have become increasingly popular in both domestic and commercial premises over recent years. Despite their current widespread use, little is understood about the slip characteristics of these floors.

All of the flooring materials studied were assessed using a range of test methods:

- Surface microroughness analysis
- The pendulum test
- The standard HSL ramp test (HSL-PS-SOP-12)

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