HSE

Health and Safety Executive

Development of a more accurate assessment of roughness parameters for flooring

Prepared by the **Health and Safety Laboratory** for the Health and Safety Executive 2009

RR732
Research Report

HSE

Health and Safety Executive

Development of a more accurate assessment of roughness parameters for flooring

Mr Rob Shaw
Dr Paul Lemon
Dr Steve Thorpe

Health and Safety Laboratory
Harpur Hill
Buxton
Derbyshire
SK17 9JN

Slips and trips are the most common cause of major injuries at work and they occur in all workplaces; 95% of reportable major slips result in broken bones. In a typical year, slips and trips account for over 33% of all reported major injuries and approximately 20% of over-3-day injuries to employees. There is rarely a single cause of a slipping accident, and a holistic approach is required when assessing slip potential. A major contributing factor in any slip accident is the interaction of the pedestrian's heel, the floor surface and any contaminants present. It is therefore important to characterise the slip resistance of a floor surface when assessing the potential for a slip accident.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

HSE Books

First published 2009

EXECUTIVE SUMMARY

The Health and Safety Executive (HSE) and Health and Safety Laboratory (HSL) use two primary measurements to assess the slip resistance of floor surfaces, coefficient of friction (CoF) using the pendulum test, and Rz surface microroughness. Rz surface microroughness can be measured simply using a range of portable roughness meters. Measurement is a quick and easy process, provides an indication of slip resistance in most situations and can be used to monitor changes in surface properties.

Several affordable, portable microroughness instruments are now available which can easily measure a much larger range of parameters on site. The purpose of the work detailed in this report was to expand on previous work and to investigate the use of commonly available roughness parameters for characterising slip resistance.

Objectives

The aims of this work are to:

- Investigate the relationship between commonly available roughness parameters and wet Pendulum Test Values (PTV)
- Examine any differences in the relationships between roughness parameters and wet PTV for hard (e.g. ceramic) and soft (e.g. vinyl) floors
- Study the relationship between surface microroughness and wet PTV for more complex surfaces (e.g. safety vinyl, acid etched floors)

Main Findings

Rz remains a valid parameter for providing an indication of slip resistance on most floors, especially when used in conjunction with the HSE Slips Assessment Tool.

Using Rp/RS, where possible, to characterise hard floors is a logical progression from traditional Rz measurement, and allows the effects of acid-etching to be taken into account.

Use of the Rp parameter has been shown to be favourable to Rz. However, the roughness classification system used both in HSE Guidance and in the SAT are not currently compatible with Rp data.

Traditional surface microroughness measurements using a 0.8mm cut off length are not ideally suited to the assessment of safety vinyl surfaces.

Recommendations for Further Work

- Further work is required on soft floors, specifically examining the use of a longer (2.5mm) cut off length on safety vinyl and other resilient floors.
- Work should be undertaken to improve the likelihood of reliably obtaining R3z data or finding an alternative method for describing the distribution of peaks within a sample length.

- The possibility of developing a method of routinely characterising peak shape using a portable roughness meter should be investigated.
- The data generated during this study should be compared with site-based data to confirm that the same relationships are still seen on installed floors.

CONTENTS

1 INTRODUCTION

Slips and trips are the most common cause of major injuries at work and they occur in all workplaces; 95% of reportable major slips result in broken bones. In a typical year, slips and trips account for over 33% of all reported major injuries and approximately 20% of over-3-day injuries to employees. There is rarely a single cause of a slipping accident, and a holistic approach is required when assessing slip potential. A major contributing factor in any slip accident is the interaction of the pedestrian's heel, the floor surface and any contaminants present. It is therefore important to characterise the slip resistance of a floor surface when assessing the potential for a slip accident.

The Health and Safety Executive (HSE) and Health and Safety Laboratory (HSL) use two primary measurements to help assess the slip resistance of floor surfaces, coefficient of friction (CoF) using the pendulum test, and Rz surface microroughness. Rz surface microroughness can be measured simply (Harris and Shaw, 1988) using a range of portable roughness meters.

Measurement of Rz surface microroughness:

- is a quick and easy
- provides a good complementary measurement to the pendulum test
- gives an indication of slip resistance in most situations
- can be used to study local variation in a floor
- can be used to monitor changes in surface properties

For these reasons Rz forms the basis of the HSE Slips Assessment Tool (SAT), a risk assessment tool which uses Rz as an important factor in determining the slip potential of floor surfaces.

Several affordable, portable microroughness instruments are now available which can easily measure a large range of parameters on site. A study was undertaken to look at the relationship between these newly available roughness parameters and wet pendulum data. This study (documented in HSE report RR549, available on the HSE website at *http://www.hse.gov.uk/research/rrpdf/rr549.pdf*) found a strong relationship between a particular combination of parameters (Rp/RS) and wet pendulum values, however this relationship was based on a small sample of data from a range of different floor surfaces.

The purpose of the work detailed in this report was to expand on the initial study by collecting a larger sample of data. The data was separated by floor type, to look at any differences in the relationships between hard (e.g. ceramic) and soft (e.g. vinyl) floors, and more complex surfaces (e.g. safety vinyl, acid etched floors). It was decided that profiled surfaces would not be studied as part of this project; they are being studied separately.

2 EXPERIMENTAL

Over 100 flooring samples were studied under laboratory conditions, using the standard HSL/HSE techniques described below, in accordance with “The Measurement of Floor Slip Resistance - Guidelines Recommended by the UK Slip Resistance Group, (Issue 3, 2005)” where applicable. Due regard was also given to the protocols outlined in BS 7976-2:2000.

2.1 SURFACE ROUGHNESS

A set of 10 surface microroughness measurements was made using a Mitutoyo SJ201P (Fig. 2.1) surface microroughness transducer set for a 0.8mm x 5 cut off length (i.e. across the assessment length five separate samples lengths of 0.8mm are measured). Readings were taken in three directions to account for any surface directionality, reported values are an average of these 10 test results. The surface roughness transducer was calibrated against a UKAS roughness standard and checked prior to use against a calibrated roughness plate. The following 11 roughness parameters were recorded:

Ra, Ry, Rz, Rq, Rt, Rp, RPc, Rmr, R3z, RS and RSm.

Definitions of these parameters can be found in Appendix 1.

Figure 2.1 The Mitutoyo SJ-201P microroughness transducer

2.2 PENDULUM TEST

Measurements of floor surface “Pendulum Test Value” (PTV, closely related to Coefficient of Dynamic Friction) were made using a pendulum tester (Fig. 2.2) calibrated by the British Standards Institution. Data was generated in the as-found condition after the application of low volumes of potable water to the flooring by hand-spray. Two test slider materials are commonly used: Slider 96, also known as Four-S rubber (Standard Simulated Shoe Sole, developed by the UKSRG to represent a footwear material of moderate performance), and Slider 55 (a softer slider also known as ‘TRRL’ rubber, often used to simulate barefoot pedestrians). Both sliders were used during this work. Data was generated using a standardised three directional methodology, where possible, to account for surface directionality. Reported values are a mean of these three test results.

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

3 RESULTS AND DISCUSSION

The results are presented in graphical form. Due to the large number of graphs produced during the analysis of the data, this section will contain selected, pertinent graphs and discussion. All of the graphs produced during data analysis can be found in Appendix 2.

3.1 RZ

The Rz data was analysed to see how often a floor classified as a high slip potential with the pendulum was classified as a low slip potential using an Rz measurement. This is shown in the graph below.

Slider 96

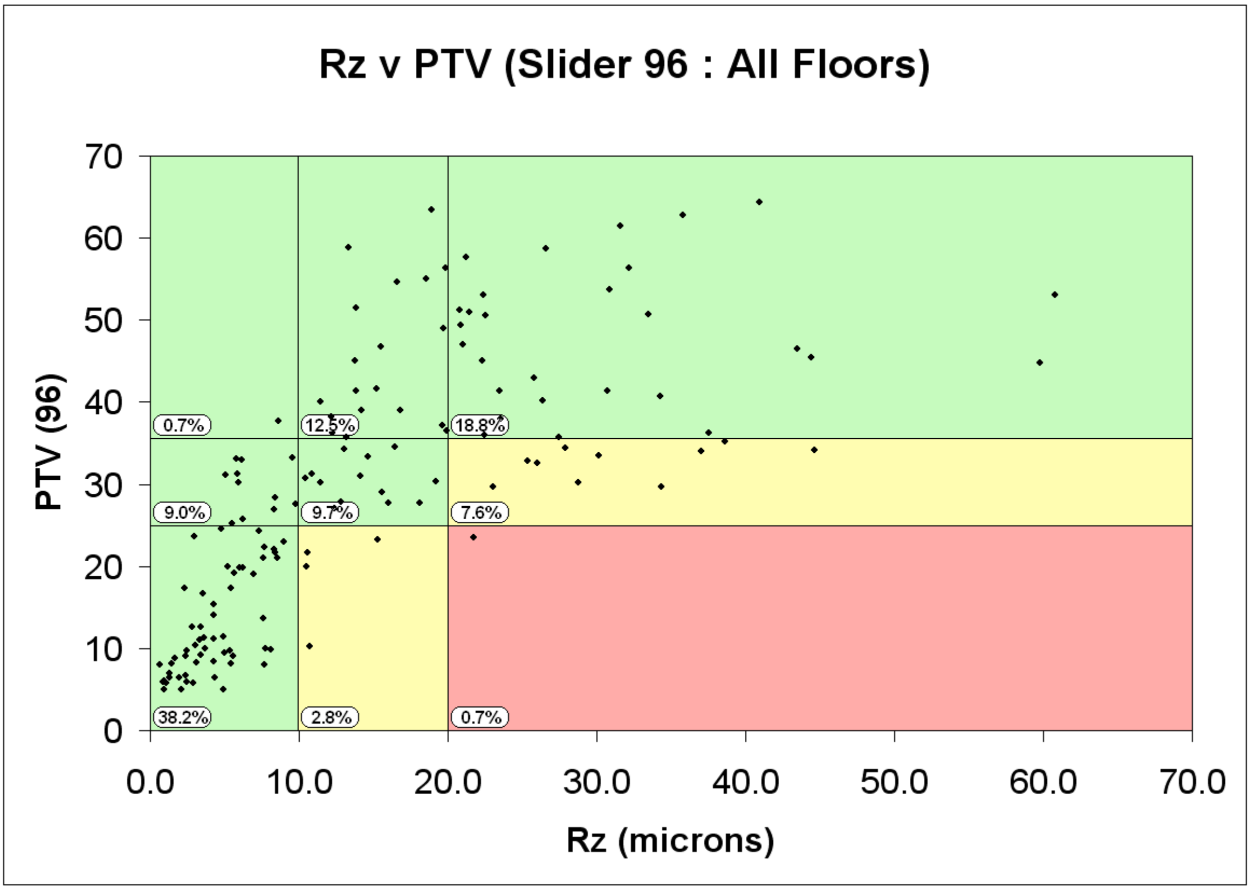


Figure 3.1 Graph of Rz v wet PTV

When interpreted in line with the UKSRG guidelines with Slider 96 (143 data points), Rz data fails safe (i.e. does not suggest a low potential for slip on surfaces characterised as a moderate or high slip potential on the pendulum) over 90% of the time.

Rz suggests a low potential for slip on floors characterised as a high slip potential on the pendulum less than 1% of the time.

Slider 55

The following points should be noted regarding the slider 55 results:

- Rz is a valid indicator on soft floors, even more so on hard floors.
- Rz fails safe over 85% of the time with Slider 55 (139 data points);

Graphs supporting this information are included in Appendix 2.

Rz can therefore be considered a good indicator of the slip classification of floor surface materials.

3.2 GENERAL RESULTS

3.2.1 Slider 96

The following observations were made:

- The relationships between roughness parameters and wet PTV appear to be logarithmic which is not unexpected, as wet Pendulum Test Values with Slider 96 tend to reach a plateau with very rough floors (building on work by Lemon and Griffiths, 97).
- Rp forms the strongest relationship between any single parameter and wet PTV. This parameter has recently become routinely available on a range of portable meters. However, current HSE guidance is based on the Rz parameter and would require reworking to allow the adoption of Rp, as the two parameters are not comparable.
- A value of R3z cannot be routinely obtained on all surfaces.
- A strong relationship between wet PTV and Rp/RS is confirmed with the large data set used in this study. Rp/RS and Rz/RS appear to have a linear relationship with wet PTV.
- When a straight line of best fit is applied, Rp/RS displays a stronger relationship with wet PTV then does Rp alone. However, the relationship between Rp and wet PTV improves with a curved line of best fit.
- No consistent, clear relationship was seen between wet PTV and RPc, Rmr, RS or RSm.

3.2.2 Slider 55

The following observations were made:

- The relationships between roughness parameters and wet PTV appear linear, which is predictable as wet Pendulum Test Values with Slider 55 plateau at a higher value.
- The relationship between Rp and wet PTV is also strong. However the strongest relationship is between R3z and wet PTV.
- A value of R3z cannot be routinely obtained on all surfaces.

- A strong relationship between wet PTV and Rp/RS is confirmed with the large data set used in this study. Rp/RS and Rz/RS appear to have a linear relationship with wet PTV.
- Rp/RS shows the second strongest relationship with wet PTV after R3z.
- No consistent, clear relationship was seen between wet PTV and RPc, Rmr, RS or RSm.

3.3 HARD FLOORS

The following observations were made:

- When considering a single parameter, Rp forms the strongest relationship with wet PTV when Slider 96 is used. R3z forms the strongest relationship when Slider 55 is used.
- When considering combinations of parameters, Rp/RS has the strongest relationship with wet PTV for both Slider 96 and Slider 55. Rp is a measure of peak height and RS is a measure of peak spacing. Both appear to have an impact on slip resistance and the use of Rp/RS allows the relationship between peak height and spacing to be characterised.

3.4 SOFT FLOORS

The following observations were made:

- When considering a single parameter, R3z forms the strongest relationship with wet PTV for both Slider 96 and Slider 55. However, R3z data cannot be generated from all flooring due to the nature of the parameter.
- It should be noted that there were fewer data points for soft floors than hard floors.
- Given the issues with safety vinyl surfaces (see 3.6 below) they were excluded from this analysis.

3.5 ACID ETCHED SURFACES

Experience during laboratory testing and site-based investigation has shown that treating surfaces with an acid etch can result in a significant increase in wet PTV with no corresponding increase in Rz values. It has also been noted that RS values obtained on surfaces treated with acid etches are often lower than values obtained on untreated surfaces. This would be reasonably expected, as a lower RS value indicates more peaks per unit length.

A separate project (Shaw, 2007) has demonstrated that not all hard surfaces show improved levels of slip resistance following treatment with an acid etch, however ceramic surfaces have been seen to show improved levels of friction after treatment. The relationship between RS and wet PTV can be seen in Figure 3.2.

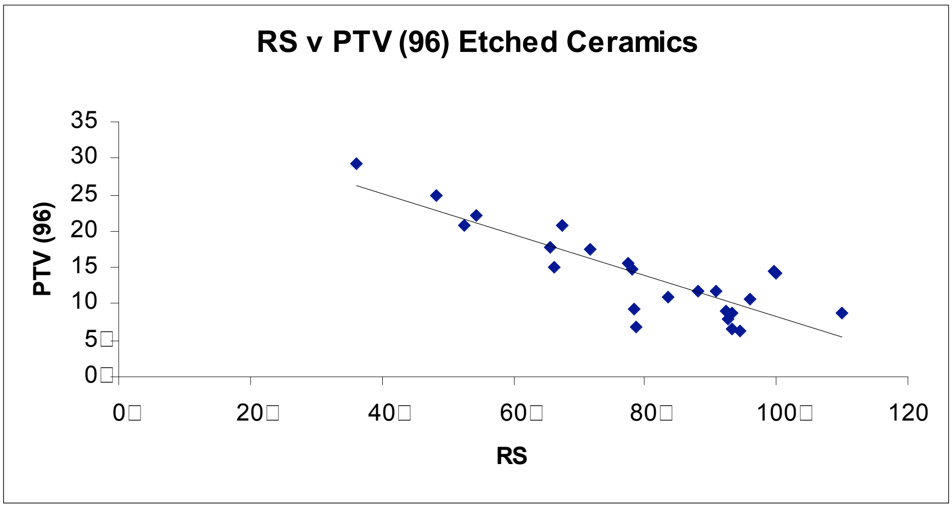


Figure 3.2 Graph of RS v wet PTV for etched ceramic floors

As RS decreases wet PTV increases. The use of Rp/RS as an indicator of slip resistance etched ceramics seems therefore to be a logical choice. This information is supported by Figure 3.3.

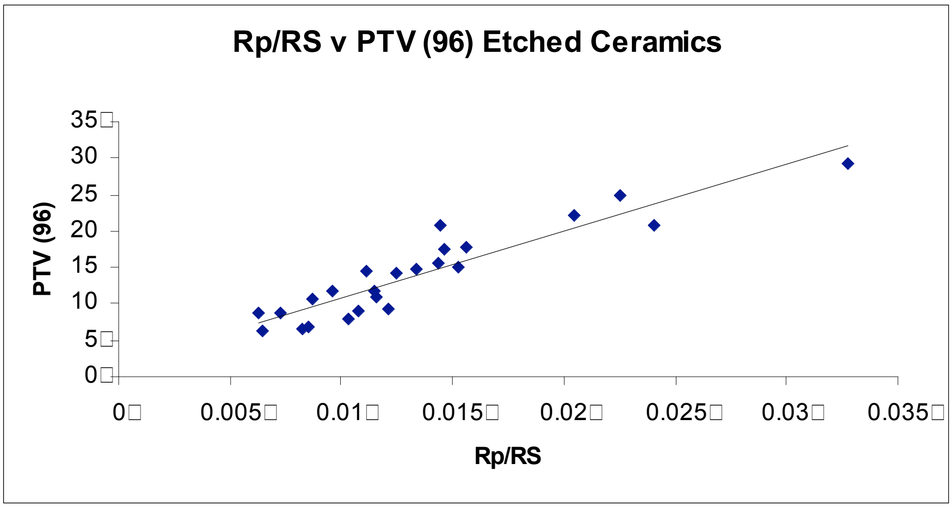


Figure 3.3 Graph of Rp/RS v wet PTV for etched ceramic floors

When combined with Rp, RS provides a good indicator of the slip potential of etched ceramic surfaces.

During this study no information was generated on etched floors using Slider 55.

3.6 SAFETY VINYL SURFACES

In terms of their microroughness, safety vinyl surfaces can be highly variable, with local variation coming largely from the presence or absence of anti-slip particles. Experience has shown that Rz data on safety vinyl surfaces can be extremely variable, and can therefore often misrepresent the level of available friction.

The microroughness data obtained during this study using a traditional 0.8mm cut off showed no obvious relationship with wet PTV for any parameter. This was true for both Slider 96 and Slider 55.

Given the variable nature of these surfaces, the roughness measurements were repeated using a longer cut off length of 2.5mm (five separate samples lengths of 2.5mm are measured across the assessment length) in an effort to form a more representative picture of the surface. Some differences were seen between data obtained with a 0.8mm and a 2.5mm cut off. The accuracy of this information was restricted by the low number of safety vinyl surfaces in this study.

In order to investigate any possible relationships seen with a 2.5mm cut off length, further work would be required with a larger sample of safety vinyl floors.

4 CONCLUSIONS

Data presented in Figure 3.1 shows that Rz remains a valid parameter for providing an indication of slip potential on most floors. Measurement is extremely simple, results are typically robust, and a range of inexpensive Rz microroughness meters are available. Past HSE research (see HSE, 1999) has identified that more advanced parameters, such as Rp, can indicate slip resistance of floor materials with potentially greater accuracy than Rz; this is confirmed in the work presented here. However, combining parameters now available from portable instruments appears to give stronger relationships with wet PTV. These combination parameters can therefore give meaningful data on surfaces where a simple, isolated Rz measurement may not. This reaffirms our view that surface roughness is a very useful complementary measurement for assessing floor slip potential.

Previous work (documented in Houlihan, 2004) has shown that combining roughness parameters can be useful when characterising floor slip potential. The relationship between Rp/RS and wet PTV observed in the initial study was confirmed in the larger data set used in this work. Calculation of Rp/RS gives the strongest indicator of slip resistance for hard floors, stronger than the relationship between Rz and PTV. Both these parameters can now be easily measured using a modern surface microroughness transducer.

The R3z parameter gives an indication of the distribution of the peaks in each sample length. Although it displayed a strong relationship with wet PTV for most floors it is currently impractical as an indicator of slip resistance as it cannot be routinely obtained on all floors. The requirement for a large number of distinct peaks and valleys in each sample length means that a value is not always obtained. If a measure of R3z, or a similar parameter, could be obtained more predictably and combined with Rp and RS it may be useful in better characterising surface slip resistance.

Rz is currently a quite poor measure of slip resistance on surfaces treated with an acid etch. The relationship between etched ceramic surfaces and RS supports site-based experience; as RS decreases (a lower RS value indicates more peaks per unit length) wet PTV tends to increase. The use of Rp/RS as an indicator of the slip resistance of etched surfaces is therefore a logical choice. During this study no information was generated on etched floors using Slider 55. Given the routine use of acid etches on floors in barefoot areas (e.g. poolside tiles and changing room floors) further work should be carried out to examine the relationship between surface roughness and Slider 55 pendulum data on etched surfaces.

The work undertaken during this project has clearly shown that Rp/RS can be used to characterise the slipperiness of hard flooring materials. These parameters can now be routinely measured on site using a range of portable meters. This is a logical progression from traditional Rz measurement. Measurement of Rp/RS also allows the effects of acid-etching to be taken into account.

On soft floors the relationships between surface roughness and wet PTV appear to be more dependent on the slider used. Further work to investigate the specific influence of slider choice would therefore be beneficial.

The data generated during this work suggests that traditional surface microroughness measurements using a 0.8mm cut off length are not ideally suited to the assessment of safety vinyl surfaces. It is likely that the use of a longer cut-off length will increase the validity of the data produced. Further work is needed to confirm this.

Surface roughness has a valuable and unique role to play in the provision of quick, easy floor assessments, and for monitoring the slip resistance of surfaces over time. However, it should not be used in isolation as the basis of floor specification, or to support legal action. In these instances, valid and relevant friction data is required.

5 FURTHER WORK

Valuable relationships could be identified between the wet PTV of safety vinyl surfaces and their surface microroughness, using a longer cut-off length. Using a large set of safety vinyl samples should increase the validity of the relationships formed. Such work could be expanded to include non-safety (i.e. standard) resilient surfaces, such as sheet vinyl and linoleum.

A limited amount of site-based surface roughness data was collected during this study. However, there was insufficient data to make reliable comparisons between laboratory and site data. Future work should analyse data obtained on a range of installed floor surfaces to investigate if the relationships observed in laboratory testing hold true on site.

Given some of the differences seen between hard and soft surfaces in this study it could be beneficial to investigate any potential relationships between surface roughness and surface hardness.

Work is needed to investigate the interaction of hard and soft surfaces with Slider 96 and Slider 55 rubbers on the pendulum. The relationships between roughness parameters and PTV on soft floors appear to be dependant on slider choice, and this is likely to be due to a complex interaction between the floor and the slider.

Given the very strong relationships seen during this study between R3z and wet PTV, more work is required to investigate the possibility of developing a reliable measure of R3z suitable for floor surface analysis. If this is not practical, an alternative method for describing the distribution of peaks within a sample length could be developed. It would also be of use to investigate the possibility of routinely characterising peak shape. Further analysis of the data collected so far may assist with this, possibly by combining more than two different parameters in an effort to more completely characterise the nature of the test surface.

Further work should be done to examine the relationship between surface roughness and Slider 55 pendulum data on etched surfaces.

An investigation into the effect of the size and shape of the stylus used on the microroughness meters would be interesting and may allow the selection of better instruments for on-site measurement.

The work presented has considered the relationships between two discrete methods of assessing the slip resistance of flooring, surface microroughness and Pendulum PTV values. It is beyond the scope of this study to directly investigate the validity of either measurement technique against real accident data.

6 REFERENCES AND FURTHER READING

G.W. Harris and S.R. Shaw, “Slip Resistance of Floors: Users’ Opinions, Tortus Instrument Readings and Roughness Measurement”, Journal of Occupational Accidents, 9: 287-298, 1988.

R. Houlihan, “A Study of Acid Based Etching Products”, HSL Internal Report, PED/08/04, 2004.

P. Lemon and S. Griffiths, “Further Application of Squeeze Film Theory to Pedestrian Slipping”, HSL report, IR/L/PE/97/9, 1997.

R. Shaw, “An Examination of Novel Roughness Parameters to be Used in Conjunction with The HSE Slips Assessment Tool (SAT)”, HSE Research Report RR549, 2007.

UKSRG, United Kingdom Slip Resistance Group, “The Measurement of Floor Slip Resistance - Guidelines Recommended by the UK Slip Resistance Group”, Issue 3, June 2005.

HSE, “Assessing The Slip Resistance Of Flooring – A Technical Information Sheet - Slips and Trips 1” revised, 2007.

HSE Information Sheet, “Preventing Slips in the Food and Drink Industries – Technical Update on Floor Specifications”, FIS22, 1999.

APPENDIX 1

DEFINITIONS OF SURFACE ROUGHNESS PARAMETERS

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

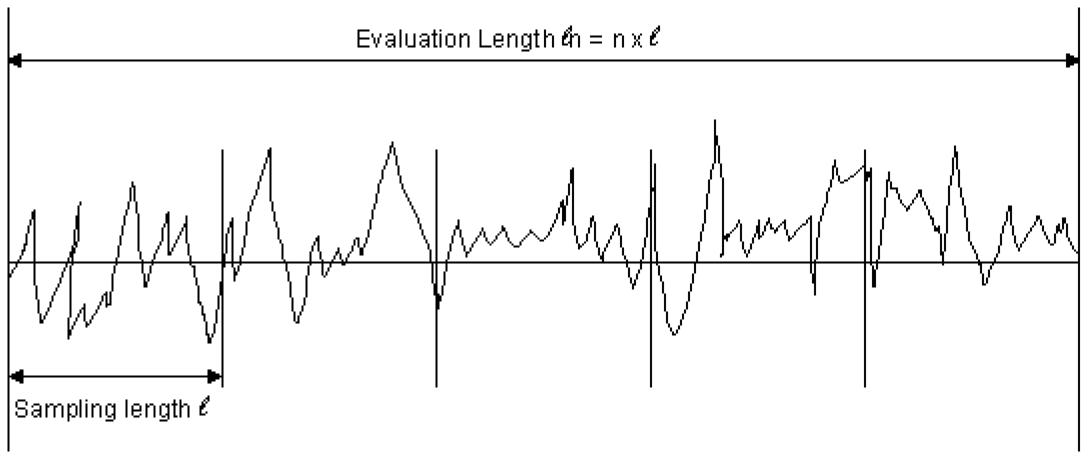


Diagram showing schematic representation of surface roughness trace.

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.

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

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

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 Height of the Profile, R_z (DIN, ISO, ANSI)

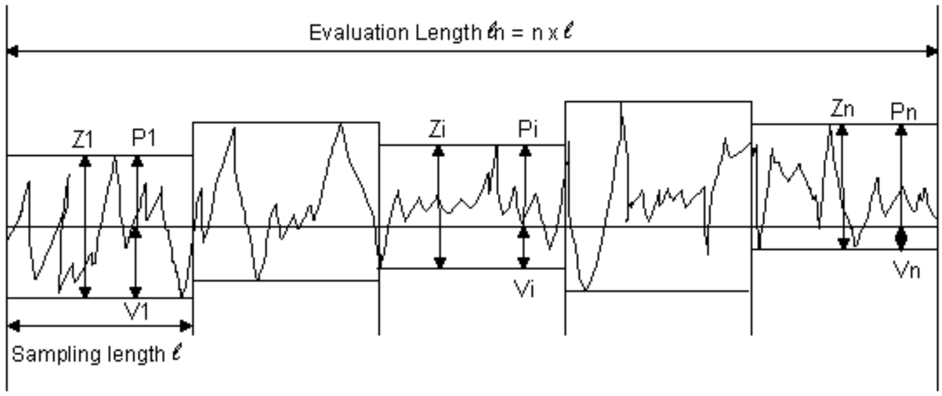


Diagram showing a schematic representation of how Rz is calculated.

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

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.

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

Total Height of the Profile, R_t

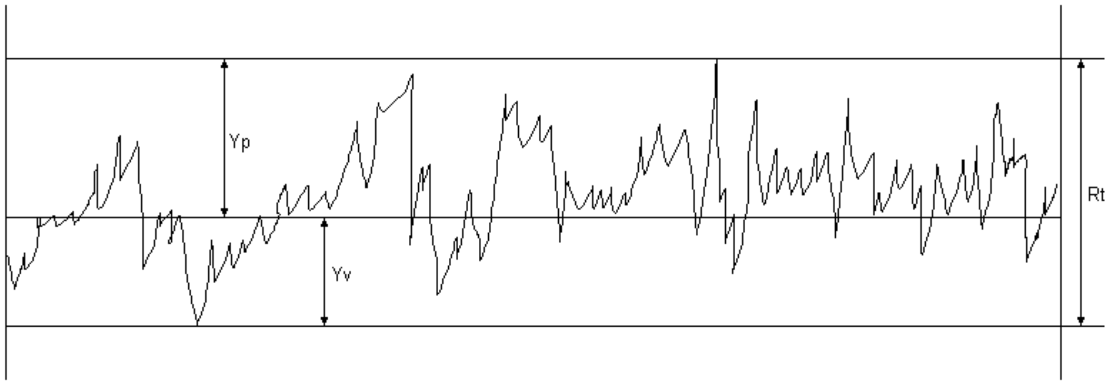


Diagram showing a schematic representation of how Rt is calculated.

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

$$R_t = Y_p + Y_v$$

Maximum Profile Peak Height, R_p (DIN, ISO, 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.

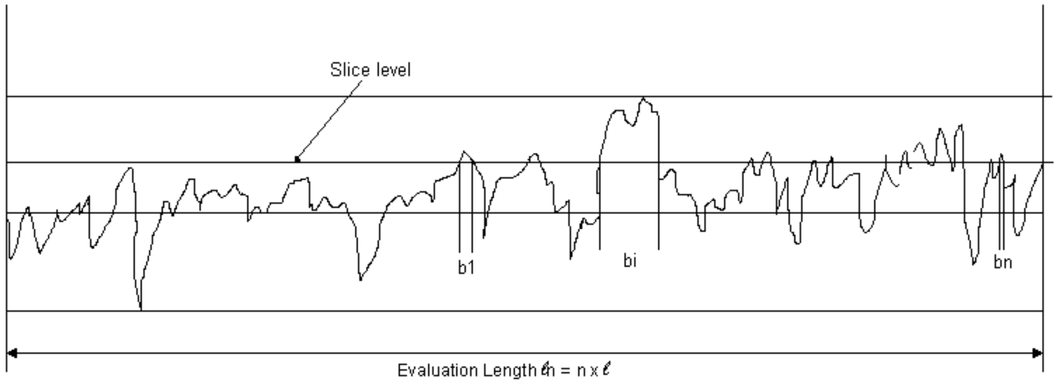
$$R_p = \frac{R_{p1} + R_{p2} + R_{p3} + R_{p4} + R_{p5}}{5}$$

Where the number of sampling lengths n =5.

RPc

RPc is the peak count. It is the number of local peaks which project through a selectable band centred about the mean line.

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.

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

R3z

R3z is the vertical mean from the third highest peak to the third lowest valley in a sample length over the assessment length.

Mean Spacing of Local Peaks of the Profile, R_s

R_s is the mean spacing of adjacent local peaks. 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.

RSm

RSm is the mean spacing between profile peaks at the mean line, measured within the sampling length. (A profile peak is the highest point of the profile between an upwards and downwards crossing of the mean line).

Published by the Health and Safety Executive 11/09

Development of a more accurate assessment of roughness parameters for flooring

Slips and trips are the most common cause of major injuries at work and they occur in all workplaces; 95% of reportable major slips result in broken bones. In a typical year, slips and trips account for over 33% of all reported major injuries and approximately 20% of over-3-day injuries to employees. There is rarely a single cause of a slipping accident, and a holistic approach is required when assessing slip potential. A major contributing factor in any slip accident is the interaction of the pedestrian's heel, the floor surface and any contaminants present. It is therefore important to characterise the slip resistance of a floor surface when assessing the potential for a slip accident.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

RR732

www.hse.gov.uk