



A study of the slip characteristics of applied epoxy resin flooring and thin coat epoxy base materials

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A study of the slip characteristics of applied epoxy resin flooring and thin coat epoxy base materials

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The aim of the current study was to assess the slip resistance of a wide range of epoxy flooring systems. These types of floors are commonly found in a variety of commercial premises, 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 systems would better inform the advice given to duty holders considering the installation of this type of flooring.

During the initial phase of the work, the ramp boards to be used in the study were characterised using the test methods typically employed during site investigations:

- the pendulum test;
- surface roughness.

The objective of this phase of the work was to gain a better understanding of epoxy flooring systems and to provide a comparison with the ramp data to be generated in the future. This will help to better inform how ramp data generated in the laboratory setting, relates to data obtained from real workplaces generated by portable test methods.

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EXECUTIVE SUMMARY

The aim of Phase I of this project was to thoroughly characterise the ramp boards used in the study by means of the portable test methods routinely used forensic site investigations, i.e. surface roughness measurements and pendulum tests.

Rz data for ramp boards resulted in the slip risk in wet conditions presented by floors being classified as follows:

Low Slip Risk:	Floor-Tech PU screed, Floor-Tech Grip-Tech with WD Grip, Floor-Tech RS Satin
Moderate Slip Risk:	Floor-Tech FS System, Floor-Tech WB and WB Aggregate, Floor-Tech TPL, Floor-Tech WBXD Low Gloss
High Slip Risk:	Floor-Tech PSL, Floor-Tech HB, Floor-Tech HB with HD Grip, Floor-Tech HB with LD Grip, Floor-Tech WB, Floor-Tech FBX, Floor Tech FBX with WD Grip, Floor-Tech FBX with LD Grip

The pendulum tests resulted in 9 floors being classified as a Low Slip Risk, 1 as a Moderate Slip Risk, 1 as a Moderate / High Slip Risk and 4 as a High Slip Risk when wet:

Low Slip Risk:	Floor-Tech PU screed, Floor-Tech Grip-Tech with WD Grip, Floor-Tech HB with HD Grip, Floor-Tech HB with LD Grip, Floor-Tech RS Satin, Floor-Tech WB and WB Aggregate, Floor Tech FBX with WD Grip, Floor-Tech FBX with LD Grip, Floor-Tech WBXD Low Gloss
Moderate Slip Risk:	Floor-Tech FS System
Moderate/High	Floor-Tech TPL
High Slip Risk:	Floor-Tech PSL, Floor-Tech HB, Floor-Tech WB, Floor-Tech FBX

Comparison of the slip risk classifications given to the ramp boards based on surface roughness and pendulum data shows significant differences in the classification of the risk presented by the different flooring systems under water wet conditions. When differences in slip risk classification based on surface roughness and pendulum data occur, precedence should always be given to data generated by the pendulum test method.

The findings presented in this report highlighted a number of factors:

- Limitations of our current portable surface roughness measuring techniques to deal with epoxy floors where the aggregate is present as large discrete widely spaced particles.
- The Rz surface roughness parameter may not be the most appropriate measure for assessing the slip resistance of flooring materials which have appreciable macro-roughness.
- The need for possible modifications of future versions of the SAT (slips assessment tool) to account for these findings.

The finding reported in this study of epoxy ramp boards confirms the importance of using the complementary techniques of both surface roughness and the pendulum in assessing the slip resistance of a floor. The results support the current HSE/HSL approach, which indicates that when differences in slip risk classification based on surface roughness and pendulum data occur, precedence should always be given to data generated by the pendulum test method.

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 wide range of epoxy flooring systems. These types of floors are commonly found in a variety of commercial premises, 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 systems would better inform the advice given to duty holders considering the installation of this type of flooring.

During the initial phase of the work, the ramp boards to be used in the study were characterised using the test methods typically employed during site investigations:

- The pendulum test
- Surface roughness

The objective of this phase of the work was to gain a better understanding epoxy flooring systems and to provide a comparison with the ramp data to be generated in the future. This will help to better inform how ramp data generated in the laboratory setting, relates to data obtained from real workplaces generated by portable test methods.

2 EXPERIMENTAL

Fifteen 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 generic types of epoxy flooring systems available in the marketplace. They range from simple clear polyurethane lacquers which may be applied to seal concrete floors, to epoxy coatings combined with polyvinyl alcohol (PVA) flakes used for a decorative finish, to epoxy coatings with 1.5 mm aggregate designed for use in grossly contaminated environments.

Flooring	Type
Floor-Tech PU screed	3 component solvent free polyurethane screed
Floor-Tech Grip-Tech and WD Grip	2 component solvent free epoxy safety system with clear 1.25 mm angular aggregate
Floor-Tech PSL	3 component solvent free self leveling screed
Floor Tech FS System	2 component water based epoxy coating with PVA Flakes and clear polyurethane sealer
Floor-Tech HB	2 component solvent free epoxy coating
Floor-Tech HB and HD Grip	2 component solvent free epoxy coating with 1.5 mm black granular aggregate
Floor-Tech HB and LD Grip	2 component solvent free epoxy coating with 1 mm black granular aggregate
Floor-Tech RS / Floor Tech WS Satin	3 component solvent free epoxy screed and 2 component clear polyurethane sealer
Floor-Tech WB	2 component water based epoxy finish
Floor-Tech WB and WB Aggregate	2 component water based epoxy finish with fine aggregate
Floor-Tech FBX	2 component solvent free polyurethane coating
Floor-Tech FBX with WD Grip	2 component solvent free polyurethane coating with 1.25 mm clear granular aggregate
Floor-Tech FBX with LD Grip	2 component solvent free polyurethane coating with 1 mm black granular aggregate
Floor-Tech TPL	2 component water based clear matt polyurethane lacquer
Floor-Tech WBX Low Gloss	2 component water based epoxy finish

Table 2.1 Floors evaluated in the current investigation.

Each for the floors was laid on to 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 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 will be further characterized using the DIN ramp test in the future.

2.1 SURFACE ROUGHNESS

During the routine slipperiness assessment of a flooring material, 10 R_z measurements are taken in a three directional methodology to account for surface directional inhomogeneity. Given that

is the aim of the current work is to characterise the epoxy flooring systems 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), see Appendix 1.



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; the Mitutoyo was calibrated against a UKAS roughness standard and checked *in-situ* using a calibrated roughness plate. Interpretations of pendulum data are based on the UKSRG Guidelines, 2000. 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.

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
Floor-Tech PU screed	Roughness out of range						
Floor-Tech Grip-Tech and WD Grip	Roughness out of range						
Floor-Tech PSL	0.21	1.36	0.27	2.44	0.82	4.7%	60.9
Floor Tech FS System	3.18	12.69	3.84	24.82	7.17	9.9%	L-P
Floor-Tech HB	0.08	0.53	0.1	1.36	0.23	26.3%	58
Floor-Tech HB and HD Grip	0.96	3.98	1.24	9.80	2.08	2.1%	59.4
Floor-Tech HB and LD Grip	1.62	6.92	1.97	14.80	3.88	2.4%	L-P
Floor-Tech RS / Floor Tech WS Satin	5.06	22.29	60.61	35.60	11.18	18.8%	147.6
Floor-Tech WB	0.23	1.30	0.30	2.14	0.71	18.9%	78.6
Floor-Tech WB and WB Aggregate	3.52	16.47	4.54	33.48	10.41	4.6%	L-P
Floor-Tech FBX	0.21	1.23	0.27	2.26	0.79	3.9%	51.4
Floor-Tech FBX with WD Grip	1.38	6.10	1.74	17.31	3.47	2.3%	L-P
Floor-Tech FBX with LD Grip	1.48	6.43	1.88	15.43	3.61	1.8%	L-P
Floor-Tech TPL	2.25	12.84	2.91	27.28	5.55	22.0%	112.4
Floor-Tech WBX Low Gloss	2.65	15.76	3.41	22.71	9.01	8.7%	88.5

Table 3.1 Table giving average values of a range of surface roughness parameter results for the fifteen ramp boards used in the current study. R_z (λm) results are given in the highlighted column.

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

The R_z 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 and up to 30	Low
Above 30	Extremely Low

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

Table 3.2 Summary of UKSRG guidelines on the interpretation of surface roughness data.

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:

- Low Slip Risk:** Floor-Tech PU screed, Floor-Tech Grip-Tech with WD Grip, Floor-Tech RS Satin
- Moderate Slip Risk:** Floor-Tech FS System, Floor-Tech WB and WB Aggregate, Floor-Tech TPL, Floor-Tech WBXD Low Gloss
- High Slip Risk:** Floor-Tech PSL, Floor-Tech HB, Floor-Tech HB with HD Grip, Floor-Tech HB with LD Grip, Floor-Tech WB, Floor-Tech FBX, Floor Tech FBX with WD Grip, Floor-Tech FBX with LD Grip

3.2 PENDULUM MEASUREMENTS

Pendulum results for the ramp boards used in this study are given in Table 3.3.

Ramp Board	Direction	Dry (SRV)	Wet (SRV)	Slip Risk in wet
Floor-Tech PU screed	Direction I	62	50	Low
	Direction II	66	45	Low
	Direction III	65	48	Low
Floor-Tech Grip-Tech and WD Grip	Direction I	82	81	Low
	Direction II	83	79	Low
	Direction III	91	86	Low
Floor-Tech PSL	Direction I	90	10	High
	Direction II	79	12	High
	Direction III	82	14	High
Floor Tech FS System	Direction I	59	30	Moderate
	Direction II	57	31	Moderate
	Direction III	58	34	Moderate
Floor-Tech HB	Direction I	100	11	High
	Direction II	98	11	High
	Direction III	101	11	High
Floor-Tech HB and HD Grip	Direction I	75	64	Low
	Direction II	72	62	Low
	Direction III	72	56	Low
Floor-Tech HB and LD Grip	Direction I	67	50	Low
	Direction II	66	54	Low
	Direction III	64	49	Low
Floor-Tech RS / Floor-Tech WS Satin	Direction I	60	44	Low
	Direction II	61	42	Low
	Direction III	61	44	Low
Floor-Tech WB	Direction I	87	14	High
	Direction II	77	14	High
	Direction III	80	16	High
Floor-Tech WB and WB Aggregate	Direction I	57	49	Low
	Direction II	60	52	Low
	Direction III	59	47	Low
Floor-Tech FBX	Direction I	97	8	High
	Direction II	88	10	High
	Direction III	84	11	High

Floor-Tech FBX with WD Grip	Direction I	78	56	Low
	Direction II	70	60	Low
	Direction III	67	61	Low
Floor-Tech FBX with LD Grip	Direction I	71	56	Low
	Direction II	70	52	Low
	Direction III	70	56	Low
Floor-Tech TPL	Direction I	69	23	High
	Direction II	70	25	Moderate
	Direction III	71	26	Moderate
Floor-Tech WBX Low Gloss	Direction I	70	61	Low
	Direction II	63	54	Low
	Direction III	67	58	Low

Table 3.3. Table giving 4S pendulum results in dry and wet conditions for each of the ramp boards used in the current work.

The pendulum tests resulted in 9 floors being classified as a Low Slip Risk, 1 as a Moderate Slip Risk, 1 as a Moderate / High Slip Risk and 4 as a High Slip Risk when wet:

Low Slip Risk:	Floor-Tech PU screed, Floor-Tech Grip-Tech with WD Grip, Floor-Tech HB with HD Grip, Floor-Tech HB with LD Grip, Floor-Tech RS Satin, Floor-Tech WB and WB Aggregate, Floor Tech FBX with WD Grip, Floor-Tech FBX with LD Grip, Floor-Tech WBXD Low Gloss
Moderate Slip Risk:	Floor-Tech FS System
Moderate/High	Floor-Tech TPL
High Slip Risk:	Floor-Tech PSL, Floor-Tech HB, Floor-Tech WB, Floor-Tech FBX

Comparison of the slip risk classifications given to the ramp boards based on surface roughness and those based on pendulum data, shows significant differences in the classification of the risk presented by the different flooring systems under water wet conditions. In total 7 out of 15 floors received lower slip classifications (i.e. they had better slip resistance) from pendulum testing than might have been predicted from surface roughness data alone. This difference in predicted slip risk was particularly marked for the following floors:

Flooring System	Type
Floor-Tech HB with HD Grip	2 component solvent free epoxy coating with 1.5 mm black granular aggregate
Floor-Tech HB with LD Grip	2 component solvent free epoxy coating with 1 mm black granular aggregate
Floor Tech FBX with WD Grip	2 component solvent free polyurethane coating with 1.25 mm clear granular aggregate
Floor-Tech FBX with LD Grip	2 component solvent free polyurethane coating with 1. mm black granular aggregate

Table 3.4 Table listing the floors with the greatest change in slip risk classification.

Rz measurements of these floors indicated that they might be reasonably expected to pose a high slip risk in wet conditions and it might at first glance be surprising for pendulum results in the wet to suggest that these floors pose a low slip risk. However all four of the floors listed above are similar in character, consisting of a smooth coating with large aggregate lightly scattered across the surface. The aggregate used in these flooring systems is sufficiently large

to result in an out of range reading if the stylus of the surface roughness meter passes over (or very close to) a piece of aggregate (this may or may not be evident to the operator depending on the type of roughness meter being used). As a result the average surface roughness measured is likely to significantly underestimate the level of surface roughness experienced by a pedestrian walking on these surfaces.

In retrospect the disparity between the measured surface roughness and the pendulum results should not be unexpected on more aggressive (rough) floors, especially in cases where the aggregate is present as large widely spaced particles. The findings presented in this report do however highlight the limitations of our current portable surface roughness measuring techniques in dealing with this type of flooring system, while there are other more sophisticated instruments available which are capable of evaluating macro-rough surfaces they are not suitable for use during site investigations.

The results also confirm the importance of using the complementary techniques of both surface roughness and the pendulum in assessing the slip resistance of a floor, as the surface roughness alone may be misleading. The findings of this investigation confirm the standard UKSRG approach used by HSE / HSL which indicates that when differences in slip risk classification based on surface roughness and pendulum data occur, precedence should always be given to data generated by the pendulum test method.

The limitations of surface roughness alone to adequately characterise some types of epoxy flooring system may have implications for future versions of the SAT (Slips Assessment Tool), and it may be necessary to adjust the weight given to surface roughness measurements, or to add supplementary questions to determine the type, size and distribution of aggregate present.

4 CONCLUSIONS

Surface roughness measurements and pendulum tests were conducted on all 15 ramp boards. Rz data for ramp boards resulted in the slip risk in wet conditions presented by floors being classified follows:

- Low Slip Risk:** Floor-Tech PU screed, Floor-Tech Grip-Tech with WD Grip, Floor-Tech RS Satin
- Moderate Slip Risk:** Floor-Tech FS System, Floor-Tech WB and WB Aggregate, Floor-Tech TPL, Floor-Tech WBXD Low Gloss
- High Slip Risk:** Floor-Tech PSL, Floor-Tech HB, Floor-Tech HB with HD Grip, Floor-Tech HB with LD Grip, Floor-Tech WB, Floor-Tech FBX, Floor Tech FBX with WD Grip, Floor-Tech FBX with LD Grip

The pendulum tests resulted 9 in floors being classified as a Low Slip Risk, 1 as a Moderate Slip Risk, 1 as a Moderate / High Slip Risk and 4 as a High Slip Risk when wet:

- Low Slip Risk:** Floor-Tech PU screed, Floor-Tech Grip-Tech with WD Grip, Floor-Tech HB with HD Grip, Floor-Tech HB with LD Grip, Floor-Tech RS Satin, Floor-Tech WB and WB Aggregate, Floor Tech FBX with WD Grip, Floor-Tech FBX with LD Grip, Floor-Tech WBXD Low Gloss
- Moderate Slip Risk:** Floor-Tech FS System
- Moderate/High** Floor-Tech TPL
- High Slip Risk:** Floor-Tech PSL, Floor-Tech HB, Floor-Tech WB, Floor-Tech FBX

Comparison of the slip risk classifications given to the ramp boards based on surface roughness and pendulum data shows significant differences in the classification of the risk presented by the different flooring systems under water wet conditions. In total 7 out of 15 floors received lower slip classifications from pendulum testing than might have been predicted from surface roughness data alone. This difference in predicted slip risk was particularly marked for the following floors:

Flooring System	Type
Floor-Tech HB with HD Grip	2 component solvent free epoxy coating with 1.5 mm black granular aggregate
Floor-Tech HB with LD Grip	2 component solvent free epoxy coating with 1 mm black granular aggregate
Floor Tech FBX with WD Grip	2 component solvent free polyurethane coating with 1.25 mm clear granular aggregate
Floor-Tech FBX with LD Grip	2 component solvent free polyurethane coating with 1. mm black granular aggregate

Table 4.1 Table listing the floors with the greatest change in slip risk classification.

The findings presented in this report highlighted a number of factors:

- Limitations of our current portable surface roughness measuring techniques to deal with epoxy floors where the aggregate is present as large discrete widely spaced particles.
- The importance of using the complimentary techniques of both surface roughness and the pendulum in assessing the slip resistance of a floor.

- The need for possible modifications of future versions of the SAT (slips assessment tool) to account for these findings.

5 REFERENCES

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

UKSRG, United Kingdom Slip Resistance Group, “The Measurement of Floor Slip Resistance - Guidelines Recommended by the UK Slip Resistance Group”, Issue 2, June 2000.

APPENDIX 1

Definitions of Surface Roughness Parameters.

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

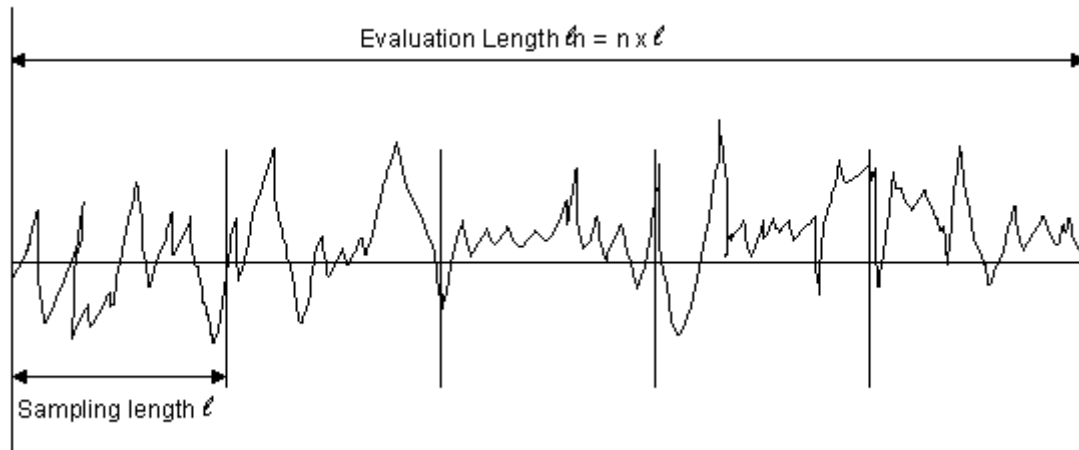


Diagram showing schematic representation of surface roughness trace.

Each of the surface roughness parameters explained in this section is calculated 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

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

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

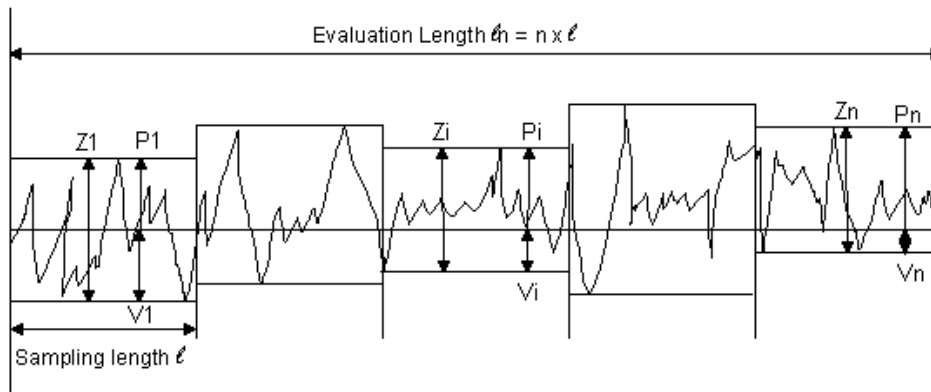
For ANSI, R_a is defined over the entire evaluation length.

ROOT-MEAN-SQUARE DEVIATION OF THE PROFILE, R_q

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

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

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



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

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

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 Z_i 's used to calculate R_z 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_{p_i} over the entire evaluation length, where R_{p_i} 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

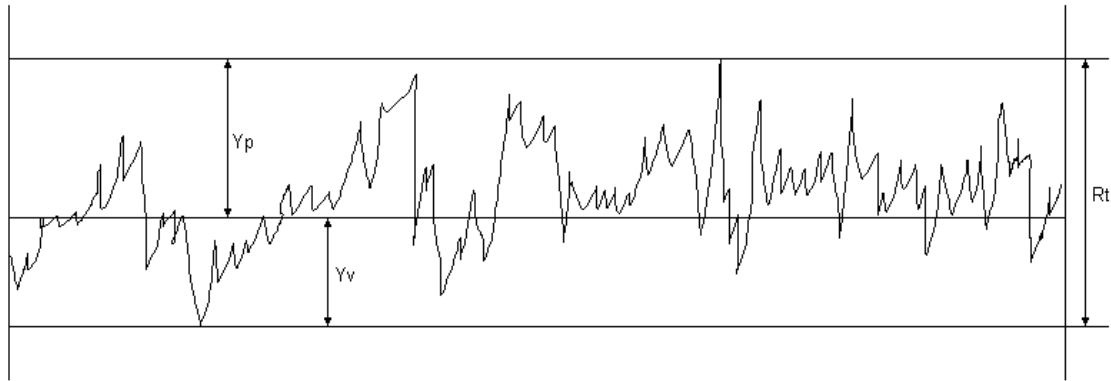
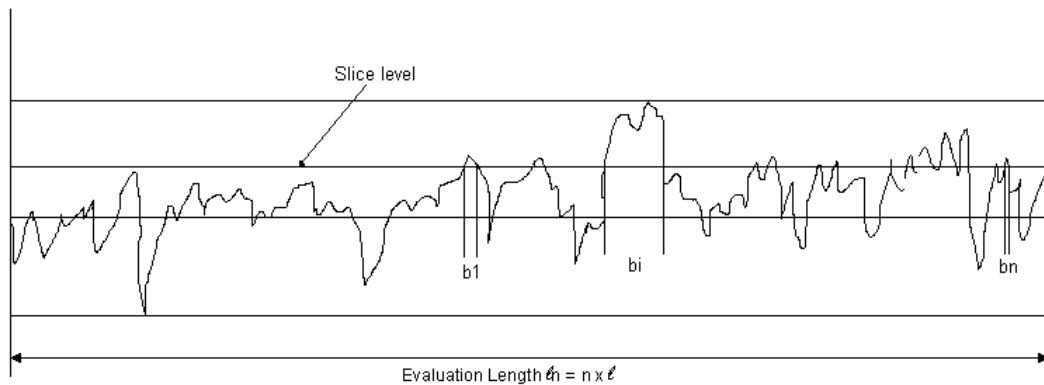


Diagram showing a schematic representation of how R_t is calculated.

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.

$$R_{mr} = \frac{\eta p}{l_n} \times 100(\%) \quad \eta p = \sum_{i=1}^n b_i$$

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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