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ICS 17.140.30; 93.100

National foreword

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Foreword

This document (CEN/TR 15874:2009) has been prepared by Technical Committee CEN/TC 256 “Railway Applications”, the secretariat of which is held by DIN.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

1 Introduction

1.1 Background

It is well established that rolling noise originates in the combined 'roughnesses' of the wheel and rail running surfaces. Through the rolling interaction of the wheel and rail this roughness imposes a time history of relative displacement across the wheel-rail contact that leads to vibration of the wheel and of the track. This vibration, in turn, gives rise to the noise components radiated by the wheel, the rail and the sleeper. The fact that at low ('normal') levels, the roughness gives rise to noise radiation linearly and accounts for the noise fully, has been shown by the comparison of theoretical models and carefully controlled measurements [1]. It has furthermore entered the practice of a number of railways to control the roughness, even of uncorrugated, track as a measure to reduce noise.

In recent years, in line with the European Union's strategy for harmonisation of internationally running train services in Europe, new Technical Specifications for Interoperability (TSI) have been written for the acceptance testing of new rolling stock. The acoustic TSI reflects the understanding of the noise generation mechanisms [2, 3]. In order to ensure that the acceptance test, that may be made at different locations on different rolling stock, is a fair test of the rolling stock and depends as little as possible on the local track design, the TSI specifies conditions for a 'reference track' on which pass-by noise measurements are to be made. The reference track is controlled in terms of the noise produced per unit level of combined roughness and the roughness of the rail head running surface. The first condition is characterised by a minimum decay rate spectrum that must be obtained on the reference track (for how this relates to the noise performance of the track see [4] and to [5] for the method of measurement). The second condition is a limit to the spectral level of rail roughness that may exist on the reference track [6].

To ensure comparable and repeatable pass by noise measurements are made, the TSI calls upon ISO 3095. This standard also contains an Annex concerning the measurement of roughness.

A programme of measurements of noise from both high-speed and some conventional speed rolling stock was undertaken to test the practical applicability of the TSI method of measurements (NOEMIE project [7]). In most respects the tests were successful but it was shown, as previously realised, that the part of ISO 3095 concerning roughness measurements is too limited in the following respects:

a) the wavelength range specified is too short for use for high speed trains;

b) too little data sampling is demanded to give the required certainty in the measured spectrum of roughness over the wavelength required;

c) the standard is written on the assumption of a particular measurement technology; it is preferred that only a performance criterion be implied for the quality of measurements obtained;

d) ISO 3095 imposes a fixed pattern of sample records; this sometimes causes the measurement of rail-head defects that are not wanted in the signal and have a significant effect on the estimated spectrum;

e) the standard specified the averaging of the roughness across a number of lines at different distances across the rail head. Since the variation across the rail-head is significant, closer specification of where to measure is required and the data for separate lines should be presented separately.

For these reasons the TSI Committee requested CEN/TC 256, Working Group 3, to draft a new standard solely for the measurement of acoustic roughness. It is the intention that the TSI should, in future, refer to the new standard for this aspect.

1.2 Objectives of the road test

The purpose of the road test is to check that the standard can be interpreted consistently and leads to a consistent estimate of roughness spectrum when used by different measurers with different instruments. Many of the instructions of the new standard have not been practiced by measurers before and so these are also being tested for practicability and effectiveness. The exercise is not concerned with testing instruments or measurement technology. The standard specifies minimum performance criteria but otherwise is designed to be as inclusive as possible with regard to technology.

In order to gain a proper understanding of the practical difficulties and the outcome in terms of consistency of practice as well and results, it was seen as essential that the 'road test' should take place in an industrial context, i.e. making measurements with instruments used by the industry on running railway lines having normal constraints of access time and safety procedures, etc.

2 Brief review of the nature and requirements of the new standard

For the method of pass-by noise measurement, the current High Speed Rolling Stock TSI (2008) refers to EN ISO 3095: 2005 [8]. The current Conventional Rail TSI refers to ISO 3095:2001. Having said this, there is not a significant difference between the two versions.

The EN ISO 3095 standard itself already sets a limit spectrum for the track on which acceptance tests are made and prescribes a method for its measurement. The limit spectrum set in EN ISO 3095 is not used in the TSI's, rather a tighter limit is set from within the TSI's according to what was found possible by the associated NOEMIE project [7]. The project also found, for high speed trains (above 200 km/h), that a minimum wavelength range up to 0,25 m is required.

2.1 Longitudinal position of measurement records and sample length

EN ISO 3095 specifies a set of six positions for 1 or 1,2 m records of the rail-head profile. These are fixed with respect to 'the microphone position'. This leads occasionally to the measurement of rail-head defects, welds *etc.* Such large localised irregularities are not appropriate to include in the roughness spectrum since they create forces and noise that are not linear with their depth (the contact geometry, and therefore the contact stiffness, changes radically). They also strongly distort the mean of the six sample records leading to both an overestimate of the level and uncertainty in the true operational roughness level. This has been a problem many times in the past and specifically at one of the test sites in the NOEMIE project. In the new standard, the choice of location of the measurement records is made by the measurers and they are advised not to include such irregularities. Moreover, the new standard envisages that a certain track section is to be characterised rather than assuming a microphone position. (The placing of a microphone might be decided on the results or there may be no associated noise measurements at all.)

To keep the variance in the estimated spectrum at 0,25 m wavelength consistent with that at 0,1 m in EN ISO 3095, the new standard requires there to be a 15 m sample length in total.

2.2 Lateral position of the measurements on the rail head

EN ISO 3095 requires that the 'running band' on the rail head be identified (as 'clearly visible') and 1 or 3 lines of roughness measurement record be taken depending on its width. The new standard refers to a 'reference surface' that must be defined by the measurer. The relationship of noise measurements to the measured roughness will then be valid as long as the wheel-rail contact remains inside the reference surface. Its identification from the running band or otherwise is an important subject in the new standard. Three different criteria depending on the situation and the purpose of the measurements are offered:

a) the running band is visible and is known to be a product of the rolling stock for which the roughness measurement is to be used,

b) the contact position can be measured for the specific rolling stock at the time of roughness measurement,

c) the contact position can be predicted from the geometry of rail and wheel transverse test section.

2.3 Processing

The data must be processed to remove some unwanted 'pits and spikes' and produce a one-third octave level roughness spectrum. EN ISO 3095 does not prescribe how the processing is done although it recognises that large differences can result. The processing is much more tightly controlled in the new standard. To remove the effects of dust or grains of dirt on the railhead, an algorithm is included that removes 'spikes', i.e. very short (much shorter than the wheel-rail contact patch), sharp, upward deviations. This recognises that such features would be crushed or strongly deformed in the contact not leading to significant relative displacement between wheel and rail. A second algorithm, 'curvature processing' is specified to deal with downward features short in the direction along the rail head, found by the small tip radius probe of the instrument and that would not affect a much larger radius wheel.

For the production of the wavelength spectrum of roughness from the measured data, the new standard specifies alternative analysis methods,

a) Hanning window, discrete Fourier transform and averaging in one-third octave bands

or

b) digital one-third octave band filtering.

3 The measurement programme

The idea of the 'road test' of the new standard is

a) to have a number of different teams measure roughness according to their own interpretation of the standard;

b) to observe the practices of the teams; and then

c) to examine the data for consistency of output.

Thus the standard should be tested in its practicality, whether it produces a consistent interpretation implemented in the practice of different teams and whether it results in consistent roughness spectra.

Two sites were offered for the measurement exercise, one on a running line at Loriol in the south east of France and the second at the Siemens Transportation Systems test track facility at Wildenrath in northern Germany. Since the purpose of the standard is to fulfil the requirement of the TSI's, it is important that the sites should exercise the measurement of low roughness levels around and below the TSI limit curve.

A number of measurement teams were invited to come to each site and carry out measurements according to their reading of EN 15610:2009. The measurement teams had to bear their own costs and so it was not reasonable to require all teams to attend both sites. It was requested therefore that all teams taking part should attend the site at Loriol. Thus, seven teams attended measurements at Loriol and five at Wildenrath.

All teams taking part were provided with software by the coordinator that attempted to perform the analysis defined in the standard. The software was provided in open Matlab code used by some of teams and in open FORTRAN. This was done so that teams could test and comment on the calculation procedure and raise any areas of uncertainty in the definition of the processing.

3.1 The test procedure

At each site the teams measured separately so that there was no cross-contamination in the interpretation of the standard. The host team at each location, required to be present for the safety arrangements, therefore went first.

Each team was shown the test section of track, in each case 100 m long between kilometre markers at the trackside. The teams were then asked to characterise the roughness of the test section with no other information given except that indicated in the text below concerning the rolling stock to which their reference surface should correspond. After the measurement was made according to their free interpretation of the standard, each team was asked to measure a 15 m sample of roughness along a single line specified by the coordinator. This was done to provide a means of identifying any differences in results that may be due to instruments or the natural limits of repeatability, from those that may be due to different choices of measurement line lateral line positions and longitudinal sampling.

Each team were at liberty to process the data themselves but all data in terms of displacement along the rail head, were given to the coordinator. The coordinator then processed all data with the software distributed before the measurements. This is the basis of the comparisons presented in this report.

All measurements were made within the space of a few days of one another at each site but it remains an assumption of the exercise that no significant change in roughness occurred due to the train running during that time.

3.2 Test sites

3.2.1 Loriol

Measurements were carried out between 14th and 24th May 2007 at Loriol on a conventional-speed service line in southern France. The line at this site is mostly trafficked by freight trains with some regional multiple units, locomotive-hauled passenger stock and a few TGV's. Figure 1 shows a sample of the rail head typical of the Loriol test section. Here the running band was wider and less distinct than at Wildenrath. In these circumstances the teams were guided to test the contact position of the passenger stock in deciding the position of the reference surface. A method used by one team is illustrated in Figure 1.

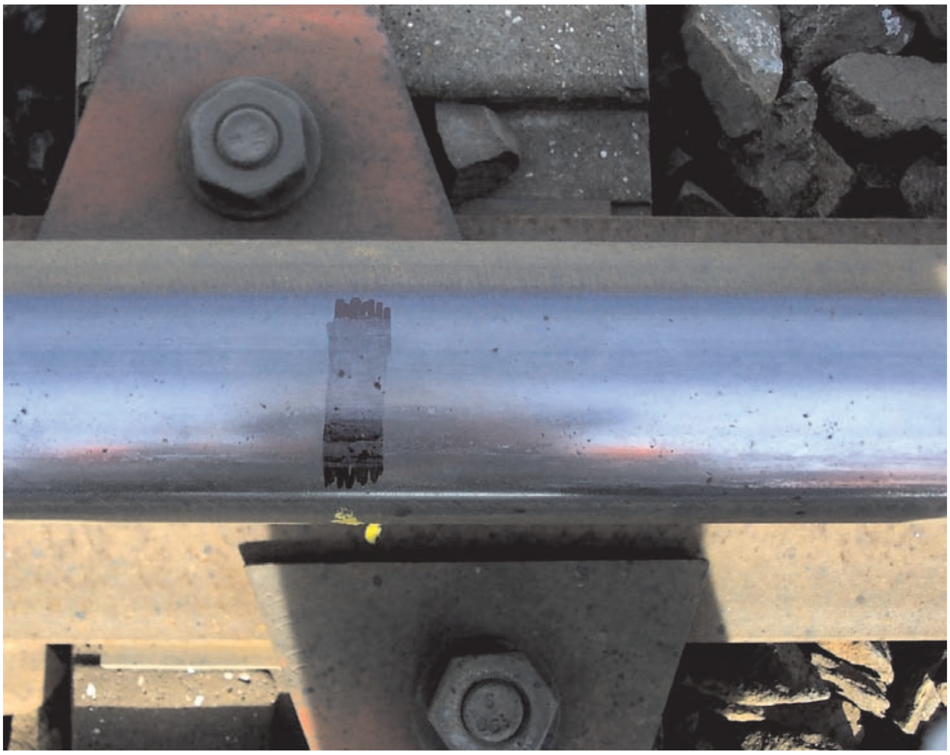


Figure 1 — Photograph of the railhead at Loriol

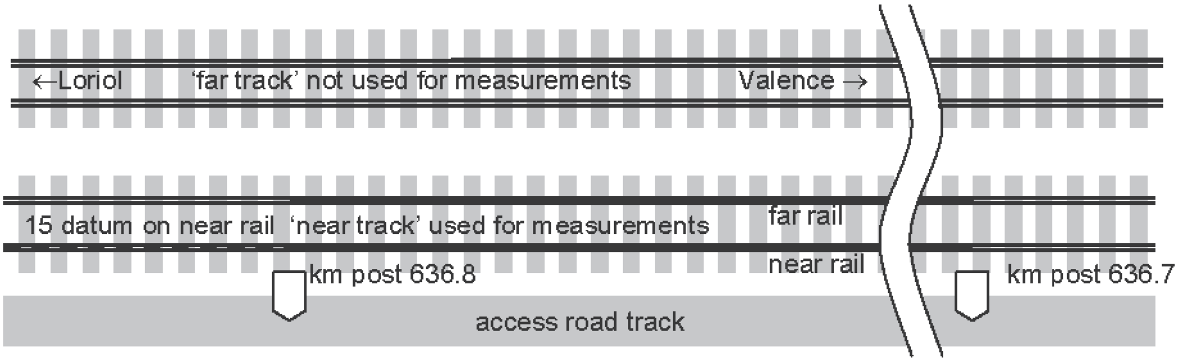


Figure 2 — Layout of the test section of track at Loriol (— reference section, - - - datum)

3.2.2 Wildenrath

Further measurements were carried out between 22nd and 25 April on the main ring of the Siemens Test Track Centre at Wildenrath in northern Germany. The rail-head had been ground about 6 months before the test using a special 'acoustic grinding' with longitudinal grinding action. Figure 3 shows a typical sample of the rail head at this site. There were very few significant defects of the rail head within the 100 m 'reference section' of track. However, an interesting consideration arises; the site is used for testing rolling stock with (mainly new) 1 in 20 and 1 in 40 coned wheel profiles. This has resulted in two clear separate (narrow) running bands. The line speed is 120 km/h.

Figure 3 — Photograph of the railhead at the Wilderath test site

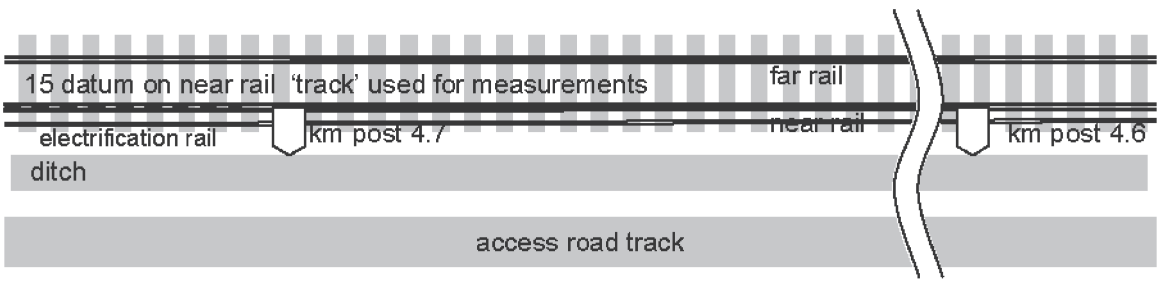


Figure 4 — Layout of the test section of track at Wildenrath (— reference section, - - - datum)

3.3 Teams and instruments

At the Loriol site, seven teams took part with eight instruments. Three separate types of instrument measured 1.2 m records using linear voltage displacement transducers (LVDT's) that moved along a straight edge fixed in position relative to the rail. Two types of instrument measured continuously over the whole 100 m using an accelerometer moved along the rail head by a light 'trolley'. All teams that took part in the test measured at Loriol. The team-instrument combinations for the measurements at Loriol are indicated in Table 1.

Table 1 — The team-instrument combinations at Loriol

Team-instrument	Instrument type	Technology
A	1	1,2 m fixed straight edge with moving displacement transducer
B	1	1,2 m fixed straight edge with moving displacement transducer
C	2	1,2 m fixed straight edge with moving displacement transducer
D	2	1,2 m fixed straight edge with moving displacement transducer
E	4	1,2 m fixed straight edge with moving displacement transducer
G	5	Accelerometer trolley
H	3	Accelerometer trolley

At the Wildenrath site, five teams took part using four of the 1,2-metre fixed straight-edge instruments of two different types. The fifth team used an accelerometer trolley. The team-instrument combinations are set out in Table 2.

Table 2 — The team-instrument combinations at Wildenrath

Team-instrument	Instrument type	Technology
A	1	1,2 m fixed straight edge with moving displacement transducer
B	1	1,2 m fixed straight edge with moving displacement transducer
C	2	1,2 m fixed straight edge with moving displacement transducer
D	2	1,2 m fixed straight edge with moving displacement transducer
F	2	1,2 m fixed straight edge with moving displacement transducer
I	3	Accelerometer trolley

4 Comparison of the practices of the teams

The test coordinator observed the practice of each team in response to the instructions in the standard.

4.1 Choice of lateral position

4.1.1 Loriol

At this site the running band is the product of mixed traffic and this led to a little difficulty for some in deciding the width of the reference surface. Each team used a method of marking the rail at both ends of the test section (some teams used additional positions) and observing the width rubbed off by passing trains (the second method prescribed in the standard). The method worked well with a wide range of paints and markers used, but best with thin coating of ink from marker pens rather than thick coating of paint.

When this method carried out for the modern passenger stock this led to a narrower assessment than for the older, more worn wheels of the freight stock. Team G in particular made a wider estimate than others on the far rail based on the passage of a freight train. Thus team G initially placed three lines 10 mm apart on the far rail. However, all teams were asked to consider the reference surface for the modern passenger stock and this led to a re-evaluation by team G to measure at positions 5 mm apart.

Team H used a lateral rail-head profile measuring device on site before making their decision. The lateral profile was then used in a 'static' geometrical calculation of the running position with a standard unworn profile of the wheel. For illustration the output of this calculation is shown in Figure 5. This information was then used in conjunction with the erased band of paint in order to reach the decision. While it was unnecessary under the circumstances of the test with the relevant rolling stock passing regularly so that the marker method could be used, the exercise showed the practicality of the third method offered in the draft standard.

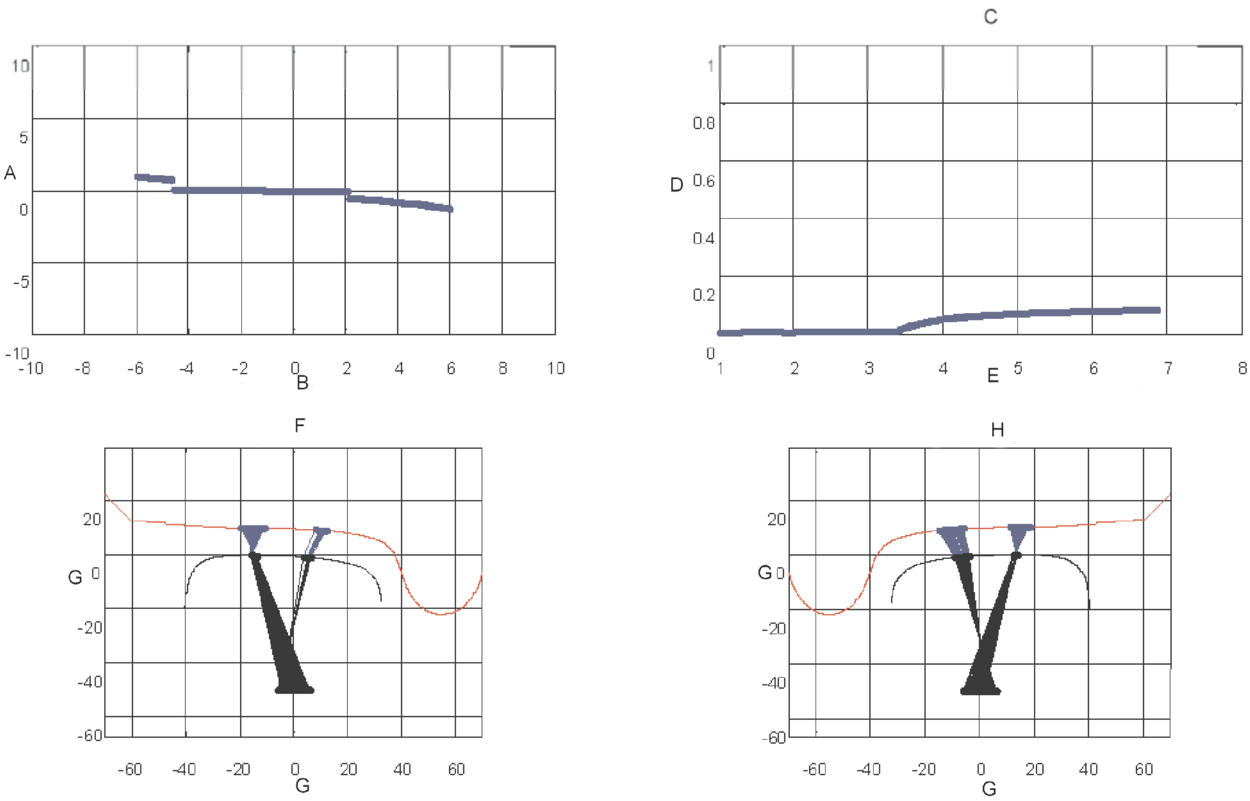


Figure 5 — Output of the on-site guide calculation of likely running position

The decisions on reference surface width and line positions chosen by the different teams is summarised in Table 3.

Table 3 — Chosen lateral measurement positions at Loriol

Team-instrument	Width identified (mm)		Line position(s) chosen (mm from gauge face)		Comments
	near rail	far rail	near rail	far rail	The coordinator chose a line at 39 mm for the datum measurements
A	22	19	39 ± 5	39 ± 5	Centre-line chosen to be same on both rails for convenience
B	28	28	37 ± 5	34 ± 5	
C	22	22	38 ± 5	38 ± 5	Centre-line chosen to be same on both rails for convenience
D	-	-	36 ± 5	36 ± 5	
E	15 – 30	15 – 30	39,5 ± 5	39,5 ± 5	
G	25	35, 25	43 ± 5	37 ± 5, 10	Revised decision on far rail for modern passenger stock
H	-	-	37 ± 5	37 ± 5	

All teams decided to measure 3 lines at Loriol, 5 mm apart. For the near rail, the range of the centre-lines was from 36 mm to 43 mm with no team placing their centre-line further than 4,5 mm from the mean position of 38,5 mm. For the far rail, the situation is not very different with a range of centre-lines from 34 to 39,5 mm from the gauge face. Thus no centre-line was placed more than 3 mm from the mean position of 37 mm.

4.1.2 Wildenrath

The nature of the two running bands at Wildenrath has already been shown in Figure 3. This situation may well arise in measurements of rail roughness in the future and in connection with the TSI's where two country's rolling stock runs on the same tracks. The measurers were directed to consider the more recent, brighter band of the two. The decisions on the width of the running band, the number of lines of roughness required and their lateral position at Wildenrath are summarised in Table 4.

Table 4 — Chosen lateral measurement positions at Wildenrath

Team-instrument	Width identified (mm)		Line position(s) chosen (mm from gauge face)		Comments
	near rail	far rail	near rail	far rail	The coordinator chose a line at 40 mm for the datum measurements
A	10	10	37	37	
B	16, 11	11	34	37	Initial estimate of running band width was re-evaluated during measurements
C	11	11	35	35	
D	10	10	40	40	
F	10	10	37	37	
I	12	15, 12	37	38	Measured three lines on far rail but decided only one was needed when re-evaluated the consistency of the running band width along the site

At Wildenrath all teams eventually decided that only one line of measurement was required, the confusion being caused by the presence of the second running band and whether a partially worn region between them should be included or not. The observation that this partially worn region was not continuous along the whole 100 m of the test section made those who were wavering clear in their decision that a narrower operating running band was correct.

4.1.3 Conclusion on success of the provisions for identifying the reference surface

Given the differences in the running band of the two sites and their relationship to the rolling stock, the first two techniques used for identifying the reference surface, see 1.2, worked well and led to closely similar positions of the reference surface.

The decision on running band could be aided by some improved wording of the standard advising the measurers to consider the reference surface only to lie within the width that is continuous along the track and also to ignore surface that is only partially worn. The wording relating the reference surface to the rolling stock of interest is clearly necessary and useful as it was invoked at both sites.

One team measured the rail head profile and calculated a theoretical (static-geometry) contact position for an unworn wheel; thus demonstrating the practicality of the third approach in the standard to determining the reference surface position.

4.2 Longitudinal sampling and cleaning the rail head

Different teams had different practices in cleaning the rail head before measurement. The teams using short record instruments used solvent and rags. It was clearly not practicable for the long-record measuring teams to follow this practice. At Loriol the rail head was regularly ‘cleaned’ apart from easily-moved dust or moisture, by the running trains. The cleaning practice may have been more significant at Wildenrath where, at the start of the test, there were a lot of bird droppings on the rail head. Apart from removal of some gross matter, the one long-record measurement at Wildenrath was made without cleaning this from the rail.

For the 1,2 m-record instruments, most teams took the strategy of scattering the 13 to 16 records locations (approximately) evenly over the 100 m. One team, however, placed their records in a pattern strongly weighted towards the mid-point of the 100 m.

The trolley instruments measured the whole 100 m with extra length on the ends so that start-up and stopping effects could be discarded from the record afterwards.

In the standard, the measurer is instructed to exclude rail-head defects. The reason for this is that a defect on the scale of curvature and length of the wheel-rail contact patch changes the contact stiffness momentarily as the wheel rolls over it. It is known from modelling studies [1, 9] that, for this reason, these features do not lead to a linearly proportionate generation of noise and that a roughness measurement excluding these features agrees well with measured rolling noise [10, 11].

Upon encountering a geometrical feature judged to be excludable, the teams using 1,2 m measuring instruments merely moved their instruments or decided not to include that record in their average. (Most teams took at least $16 \times 1{,}2$ m = 19,2 m over the 100 m rather than the minimum $13 \times 1{,}2$ m to make up the minimum requirement of 15 m of data.)

Where 100 m of record is taken in one go, it is inevitable that a number of ‘rail-head defects’ and features such as welds are also measured. However, none of the measurement teams using trolleys identified them and avoided recording them. Rather, it is naturally the practice of these teams to measure the whole 100 m and then to remove these features afterwards. Although this is compatible with the practice of the 1,2 m instrument measurers in avoiding rail head defects, no normative procedure or advice for *a posteriori* identification and removal of data has been given in the standard.

No editing of the raw data of the trolley instruments to remove rail-head defects was done before handing the raw data to the coordinator.

5 The common analysis applied to the raw data

All the data were analysed by the coordinator using the Matlab version of the processing algorithm.

5.1 Spike processing

A point of ambiguity was discovered in the standard that affects the processing of 'spikes'. These are identified as features (maxima) in the data that are short in the rail axial direction, *x*, (height in metres > $w^2/3$) and have a small radius of curvature (absolute value of the second derivative with respect to distance > 10^7 µm/m^2). The ambiguity exists in whether only upward 'spikes' of this type are to be removed or whether downward, 'pits' are also to be removed. Past practice by some organisations is to do both but these organisations did not carry out the subsequent curvature processing that treats the pits by applying a simplified physical argument removing pits by running the large curve radius of the wheel over the data.

It was discussed during the measurement exercises and agreed by all measurement teams, only to remove upward features according to the spike removal processing and to rely on the curvature analysis to treat downward features. This clarifies the philosophy of each part of the processing:

a) the upward features are dirt that can be removed if small enough in relation to the contact patch;

b) the pits are reduced using the physical interpretation of the large radius of curvature of a wheel compared to that of the measurement probe.

All data was therefore treated by the agreed spike removal and the curvature analysis.

5.2 DFT and filtering analysis techniques

The 1,2 m records were analysed using the DFT procedure stated in the standard.

The 100 m records were analysed whole using both the DFT technique and the alternative digital filtering technique offered in the standard. It was found that this could not consistently be applied to 1,2 m or even (concatenated) 3 m records of data because of the starting and ending transients of the filters. It was determined that these transients affect approximately 2 m of data at each end of the record (based on 1 mm or 0,5 mm sampling). Thus the processing was changed to discard 2 m at each end. In the case of long records (100 m) this makes little difference but clearly rules out use of the digital filtering method for 1,2 m instruments.

5.3 Treatment of long records in which rail-head defects are present

As already discussed in clause 4, a clear difference in practice of the teams arose out of the nature of taking 100 m of data in one record compared with those taking individual records of 1,2 m. Thus the 100 m records analysed whole contain the effects of the rail-head defects that were not avoided. (This is commented on with respect to specific results below.) In order to compare results on a more equitable basis between different instruments, the whole 100 m records were chopped into segments of 1,2 m by the coordinator and examined to see if they contained features that were clearly rail-head defects that should be excluded or features that would have caused the straight 1,2 m measurers to have rejected that record. A selection of 15 'clean' 1,2 m, records, approximately evenly spaced along the 100 m was then analysed in the same fashion as the discrete records taken with the 1,2 m instruments.

It is not being suggested here that this procedure of selecting data ought to be sanctioned in the standard. Any practical implications in the efficiency and therefore cost of the work should be taken into account.

5.4 Chatter/screech

At both sites, a number of instruments suffered from a slip-stick excitation of the probe as it was moved along the rail head. This gives rise to a screeching sound during measurements but it was not always easy to hear. It is thought to be a similar mechanism to the 'chatter' of a lathe tool. This is known to occur during roughness measurements sometimes but its higher-than-usual rate of occurrence during the tests may be related to the very hot and dry weather conditions that most of the teams measured under. These conditions are known to give rise to high friction coefficients on the rail. Figure 6 illustrates the effect of chatter on the measurement record. It shows that it causes continuous high-amplitude, short-wavelength features to be recorded such that it is inappropriate to rely on the spike removal and curvature processing to improve the data.

It must be emphasised that all types of instrument suffered at least some measure of this effect. In some cases it was noticed while taking measurements, in other cases contaminated measurements were made without it being noticed at the time.

All results for each team-instrument combination are plotted separately in Annex A for Loriol and Annex B for Wildenrath. This includes the additional 15 × 1,2 m analysis for each of the trolley cases. In each case, the average spectrum arising from the measurement of each line of roughness is shown as required by the draft standard.

In addition a measure of the spread of data is indicated. This is the standard deviation of the dB levels of the component spectra making up the average in each case. (It has been shown elsewhere in the work of CEN/TC 256 WG 3 that this is a suitable measure of spread of the data that does not follow Gaussian statistics in its linear form.) This measure is approximately independent of the number of records. This standard deviation is then plotted either side of the arithmetic mean of the spectral levels, however, of course, it is the energy mean of the spectra that is required as the mean roughness level. The spread is therefore not plotted symmetrically either side of the energy-mean spectrum. Only the spread of the central line of roughness measurement is plotted. The spread of the other lines is similar in all cases. It is not possible to derive a measure of the standard error from this measure of spread, i.e. the confidence in the mean. This must be judged from the comparison of the results of measurement of the same roughness, see 5.2.

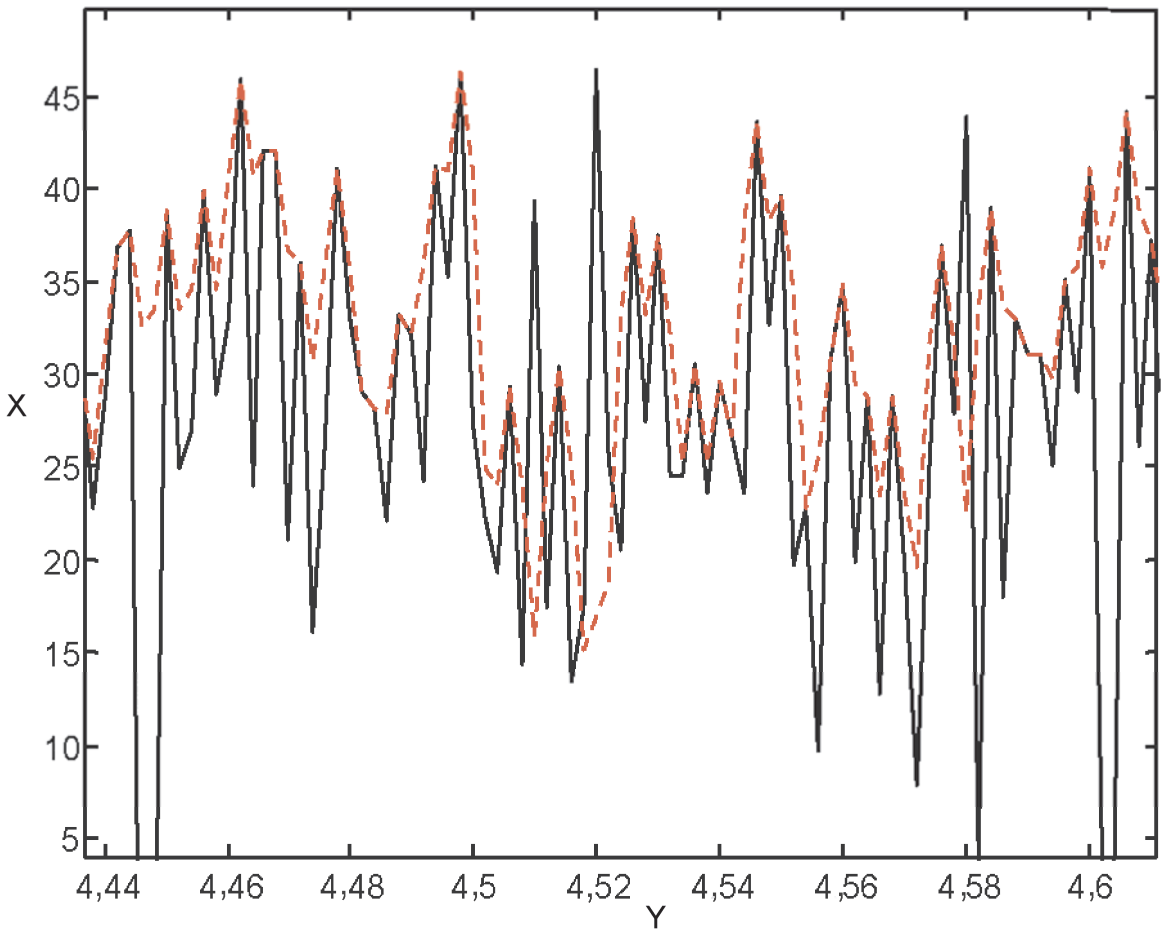


Figure 6 — Close look at some data before (—) and after spike removal and curvature processing (- - -)

5.5 Observations made on results presented in Appendices A and B

The following observations can be made on the results presented individually for each instrument-team combination and each rail.

5.5.1 Loriol

a) Measurements by team-instrument combinations A to E have detail differences but are similar in spread as well as spectral level. They each show similar levels of roughness on the three lines within the reference surface. This tends to be close for long wavelengths and for the shortest wavelengths of the range of interest but with some significant differences in the mid range (0,008 m to 0,63 m) in some of the results.

b) The results from team-instrument G (Figures A16 to A20) are known not to be valid for wavelengths shorter than about 0,025 m. The reason for this is that the instrument has two contact probes. The one that would normally be used for acoustic roughness screeched on the rail head at Loriol although it has not done so elsewhere. A contact used for making roughness measurements for a longer wavelength range (in connection with ground vibration) was therefore used instead.

c) The results for the trolley instruments G and H, show that the digital filtering technique and the DFT technique of analysis produce closely similar results in most cases. The digital filtering technique produces an estimated spectrum that is slightly higher in most bands but not consistently so. This is probably due to the approximate nature of the correction for the removal of energy from the DFT spectrum by the use of the Hanning window. (The Welch periodogram technique is a statistical method of estimating the spectrum of a signal.)

d) It is seen in Figures A18 (G) and A24 (H), comparing the DFT and digital filtering results for the datum 15 m line, that there is a greater difference between the different analyses. The main reason for this is the fact that the digital filtering technique discards 4 m of the signal (2 m) at each end because of transients; this is a significant proportion of the 15 m record but not of the 100 m records analysed in Figures A16, A7, A22 and A23 where the difference is very small.

e) Figures A23 and A24 show a much higher level on the two outer lines of measurement in the 0.02 m wavelength and short wavelength bands. This is due to some intermittent screeching during these measurements rather than measurement outside the valid reference surface. Since this, by chance, only affected the outer lines of measurement on each rail head significantly and not the central line (used below in comparisons between instrument-teams) it was corrected by selection of ‘clean’ 1.2 m records in Figures A25 to A27.

5.5.2 Wildenrath

a) There is no data for the 15 m line for team-instrument B at Wildenrath.

b) Spectra from team-instruments A, B, C, D and F at Wildenrath are broadly similar. Measurements from the only trolley instrument used at this site, I, show a strong rise in the spectrum at long wavelengths that is not observed by the other teams. In particular Figures B16, B19 and B20 show a distinct peak in roughness around the 0,125 m band on the far rail. This feature was visible at the time of measurement (see photograph Figure 7.) However, none of the other measurements (D taken before I on the same day, all others after I) do not show this, indeed they show a rail that is exceptionally smooth at these wavelengths. Besides the visual evidence of the existence of this feature, it is clear from the Loriol measurements that the higher level measured is not an intrinsic feature of the type of instrument (H is the same type though not the same individual instrument.) Moreover, no malfunction of instrument I has been found. One possible explanation is that the feature consists of the contaminant on the rail head at this site. It would have been cleaned off where the 1,2 m instrument D measured and would probably have been removed by the rolling stock movements after measurements with instrument I and before the other instruments. However, it is counter intuitive that this should have caused a raise in the roughness at longer wavelengths and not at shorter wavelengths. Thus there is an irresolvable mystery regarding this feature of the measurements. The much higher level of roughness measured by I at Wildenrath affects measurements on both rails including the datum line (see Figure 11 below).

Figure 7 — Visible feature at approximate 0,125 m wavelength present during trolley measurements at Wildenrath over much of the length of the far rail

c) A further feature worth noting for the Wildenrath site, also shown by the continuous 100 m measurement, is that the roughness at certain wavelengths was not constant over the site at the time of the test. Figure 8 illustrates this. It shows the roughness filtered in the 0,01 m to 0,315 m one-third octave band along the 100 m of the test section. It is clear that the centre of the test section is rougher and that the measured roughness level in these bands would therefore be dependent on the pattern of longitudinal sampling. Although no particular peak is indicated in the roughness spectra from any of the team-instrument combinations, these wavelengths coincide with the broad maximum of all the measured spectra. Note that the trolley instrument is in good agreement with other instruments at these wavelengths.

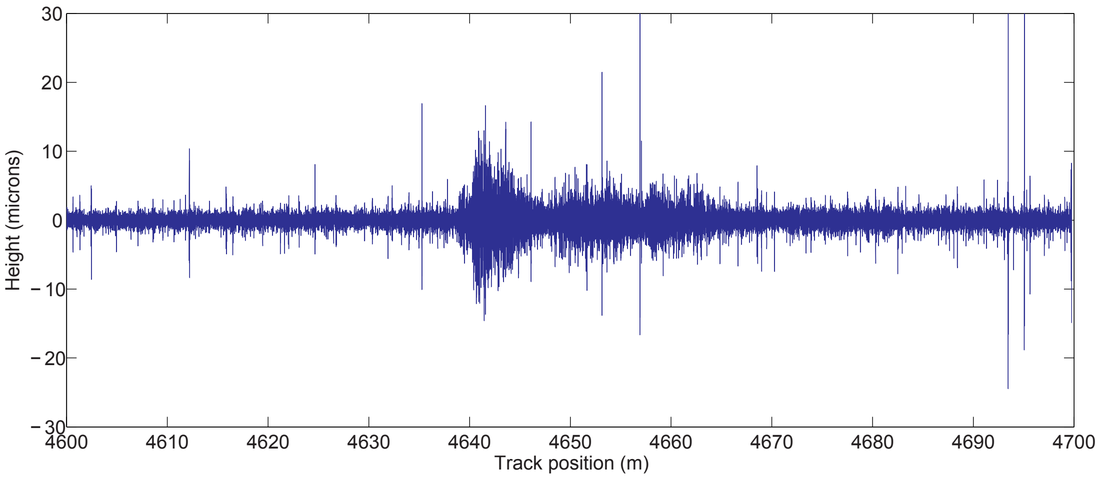


Figure 8 — The variation of roughness along the test section at Wildenrath in the 0,01 m to 0,0315 m wavelength bands (far rail)

5.6 Overall observations

a) The Loriol rail is very smooth – well below the TSI limit curve and, at the short wavelength end of the spectrum, close to the limit of resolution of the instruments using displacement probes.

b) The Wildenrath rail is also smooth being close to the TSI limit curve in the midrange and much smoother at both ends. It is useful that a level close to the TSI limit curve and away from the resolution limit of some of the instruments is also being tested.

c) The instruments generally meet the requirements of the report in that they are clearly capable of measuring roughness spectra at and well below the TSI limit spectrum.

d) The apparent trend in the Wildenrath spectra towards smoother rail at longer wavelengths (shown by all but one instrument) is unusual. It is probably due to the acoustic grinding that has been applied at the site. Beyond the 0,25 m wavelength of the roughness analysis it is expected to rise, both because of the greater influence of the vertical alignment of the sleepers at longer wavelengths and because of the length-limit of the action of the grinding machine. There is evidence in the 0,25 m one-third octave band of this rise.

6 Comparisons of roughness spectra

In comparing the results from different instruments it must be noted that no specific instrument exists which gives an absolute attested precise and calibrated result at the required sub-micron resolution required. An idea of the correctness of a measurement can only therefore be ascertained in this work on the extent to which instruments agree.

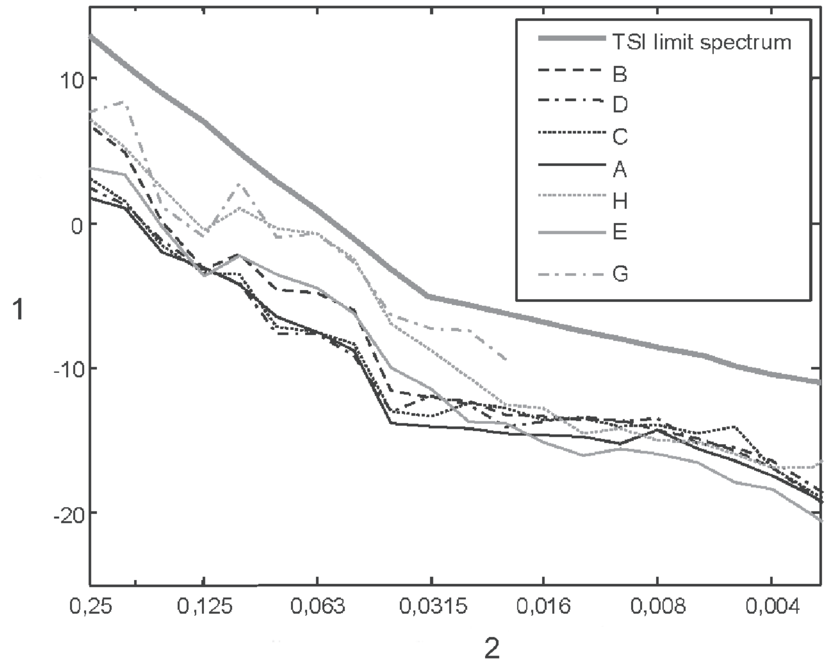
As presented in Appendices A and B, there is clearly a variation in the results that are obtained at each site. The differences are examined below. To avoid over complication, only the central line of roughness is used for the comparison.

6.1 The datum line spectra

In order to examine the repeatability of the measurements using the same equipment on the same line of roughness Figure 9 presents a comparison of the datum measurement at Loriol with all the devices used in the test included. This shows that there is close agreement achieved for wavelengths shorter than 0,02 m with E a little below the others in this range. For longer wavelengths there is a bigger difference. This has been investigated.

Within the 15 m record, there is a local geometrical feature. This causes the higher level of the higher level of the spectra of H and G, the two continuously measuring (trolley) devices, in the wavelength range from 0,02 to about 0,125 m. Although contiguous measurements were made with all instruments, this local geometrical feature does not influence the spectra from the 1,2 m instrument very much because it falls near the end of a 1,2 m record for most of the instruments and thus is strongly attenuated by the Hanning window. It is present in the continuous measurement records analysed by the digital filtering technique. In fact they have all the greater influence because of the 2 m that is removed from the record at either end. In fact the effect is still seen in the continuous records when they are analysed by the DFT because 50% overlapping DFT records are used in the periodogram algorithm but now to a slightly lesser extent because the whole record is used (*i.e.* not dicarding 2 m at either end) and because, in some overlapping sections the feature is still attenuated by the Hanning window. It can be stated therefore that, given that the datum longitudinal sampling was prescribed, the differences in the spectra are a function of the processing applied and the difference in recording continuously or in 1,2 m segments. The differences do not arise from the different measurement technology used; accelerometer or LVDT. To emphasize this, Figure C1, shows the same effect for one of the 1,2 m LVDT instruments when the records are concatenated before DFT analysis and after.

Figure 10 shows the comparison where the segment of data containing the local geometrical feature is missed out of the trolley measurements. Clearly, most of the remaining differences in the range from 0,04 to 0,125 m wavelength are still due to the same effect where not all records and therefore Hanning windows are in exactly the same position.

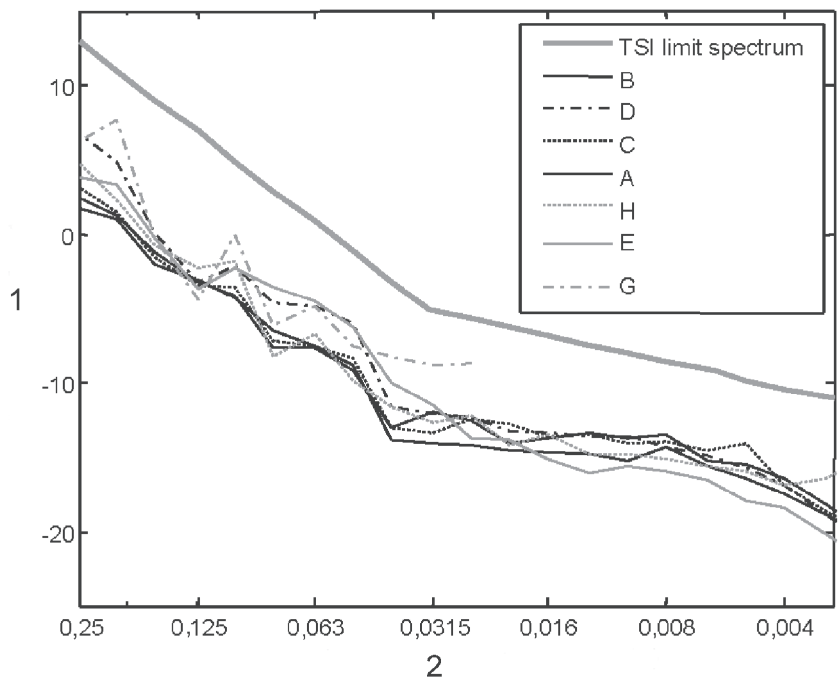


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure 9 — All instruments compared on the datum line at Loriol – record 8 left in analysis from H and G



Key

1 Roughness (dB re 1 um)

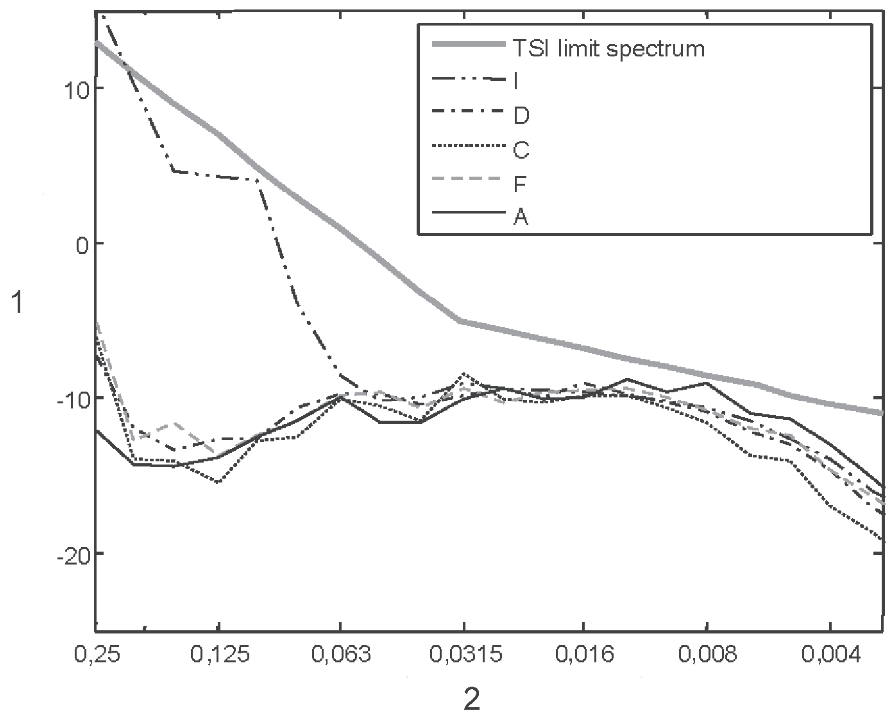
2 1/3 octave band centre wavelength (m)

Figure 10 — All instruments compared on the datum line at Loriol – record 8 left in analysis from H and G

Figure 11 compares the spectra for the 15 m datum line at Wildenrath. The clear difference of the result from instrument-team I has already been discussed in item 7 of clause 5.1. Apart from this, there is close agreement between all instruments in the wavelength range from 0,01 m to 0,05 m. At shorter wavelengths than this 3 instruments agree still very closely and there are more significant differences above these for instrument A and below for instrument C.

Taking account of the mystery surrounding the longer wavelength measurements with instrument I at Wildenrath and the explained differences at Loriol, Figures 10 and 11 can be said to show agreement of all instruments within each band of about ± 2 dB when used to measure the same prescribed line on the rail head.

This approximate ± 2 dB variation has been found right across the spectrum from 0,25 m down to 0,00315 m wavelength bands, i.e. in each band. It is similar at the long wavelength end and at the short wavelength end of the spectrum. At long wavelengths it is approximately what would be expected from the record-length statistics where the precision is limited by the measurement record length. For short wavelengths the statistics, of course, improve and a greater precision is expected. Indeed this can be seen to be the case when looking at results from a single instrument. However, when different instruments are compared, it is seen that there is still a variation between them of about ± 2 dB. It can be assumed that this is due to differences in the calibration of individual instruments. That is not surprising since most of the instruments use LVDT's which are acting near the limit of their resolution on such smooth rails as at Wildenrath and Loriol. These low levels in the spectrum are not however significantly contaminated by instrumentation or digitisation noise, however, as the spectral result is an average over very many samples taken at varying absolute heights of the rail head.



Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

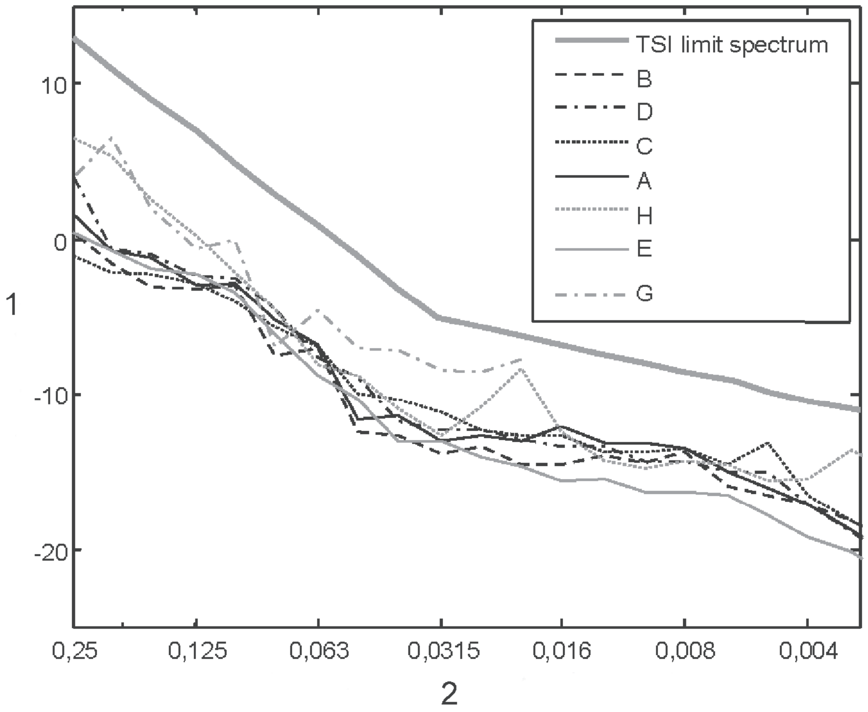
Figure 11 — All instruments compared on the datum line at Wildenrath

6.2 The 100 m test section results

The last section showed the variation that can be expected when instruments are used to measure the same line of roughness. The main test section results are now compared to examine how much further variation is introduced by the variation of sampling practice laterally and longitudinally. This is carried out only for the central line of roughness measurement since the lateral variation of this line is the same for the two outer lines, all teams having chosen 5 mm spacing.

Since it has already been shown that the avoidance of rail head defects is an important issue for the trolley instruments, only the analysis by the selection of 1,2 m sections is used in the comparison here for H and G.

On this basis, Figure 12 shows the spectra from all instrument-team combinations for the Loriol near rail, Figure 13 for the Loriol far rail, Figure 14 for the Wildenrath near rail and Figure 15 for the Wildenrath far rail.

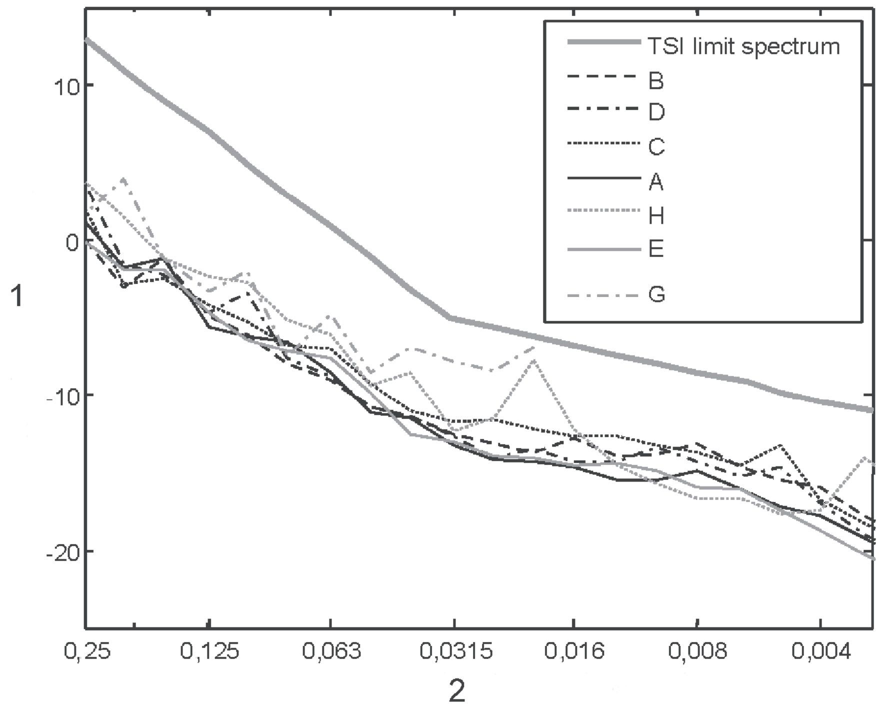


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure 12 — Spectra from all instruments on the near rail at Loriol

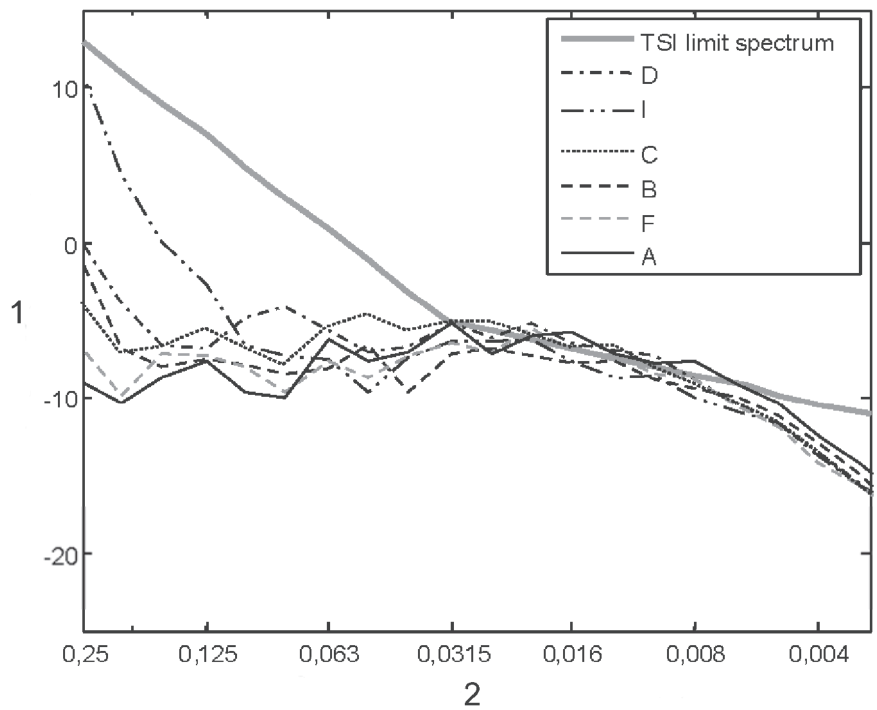


Key

1 Roughness (dB re 1 um)

2 1/3 octaveband centre wavelength (m)

Figure 13 — Spectra from all instruments on the far rail at Loriol

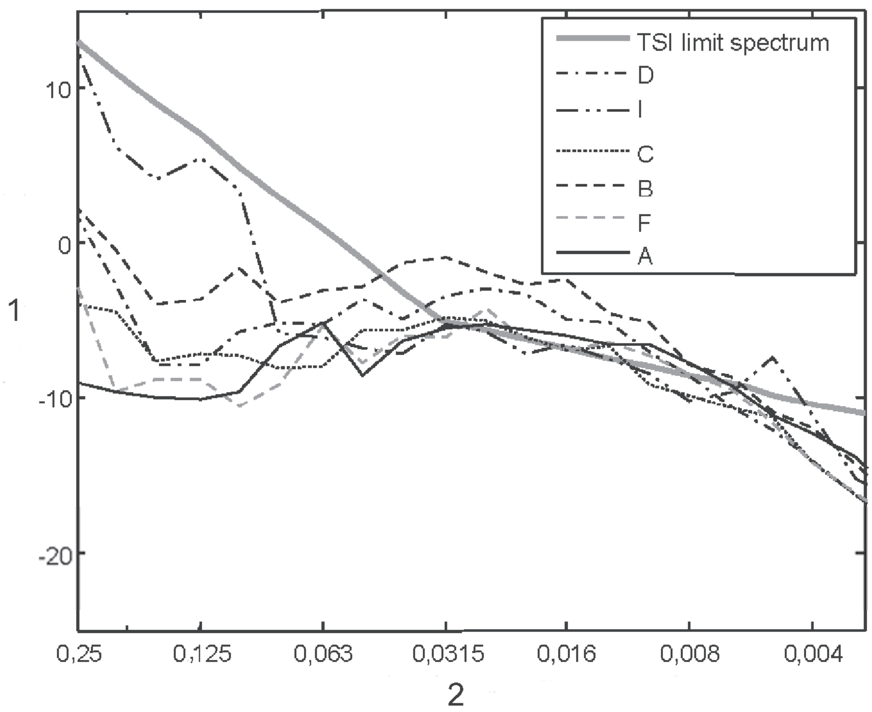


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure 14 — Spectra from all instruments on the near rail at Wildenrath



Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure 15 — Spectra from all instruments on the far rail at Wildenrath

The two accelerometer trolley instruments at Loriol show a higher estimate at longer wavelengths than the others but this is more noticeable on the near rail than the far rail. Given the situation of the only trolley measurement at Wildenrath this cannot be checked in Figures 14 and 15.

At Loriol instrument H picked up a peak of roughness at 0,02 m that was not picked up by other instruments. There is no sign of this being a function of the instrument as results on the datum line do not show this. At shorter wavelengths there appear to be no systematic differences between instruments although some again pick up peaks at 0,003 m or 0,005 m in some cases. The pitch of grinding marks could be the source of this.

With these effects not showing only on any one instrument, and there being counter examples to show that the instruments involved do not always show these peaks, they can only be a function of the different sampling of the rail head. However, as already stated no significant difference in practice for choice of lateral or longitudinal samples was observed that could account for this. (Instrument-team E was the only case where longitudinal sampling differed significantly and no systematic difference emerges for this instrument, only used at Loriol.)

The spectrum of team-instrument B for the far rail at Wildenrath is significantly higher than most and so, to a lesser extent, is that of D. Given the variation of roughness along this rail shown in Figure 8, the significance of this should be discounted somewhat.

Overall the comparisons show that some greater variation due to sampling differences over the test section does exist compared with that on the datum line. This variation is mostly still within an approximate ± 2 dB band across the range but it could be said that there is greater risk of measuring a spectrum than lies beyond this. Since this risk is to include a local geometrical feature, the risk is on the ‘safe’ side since it will tend always to increase the estimated roughness level.

7 Conclusions

A ‘road test’ of the draft roughness measurement standard has been carried out by comparison of measurement of up to seven team-instrument combinations at two sites. The test was designed to differentiate between variation in measurements from instruments and those from the interpretation of the provisions of the standard regarding the sampling of measurement records.

a) A fraction of all measurements go wrong. In this work it is not the purpose to test the reliability of the measurements but to compare the results only where they are successful. Nevertheless, some results have been shown to be poor, e. g., where screeching has occurred, and it serves as a reminder that care must be taken to get good quality data.

b) All instruments have been shown to be capable in principle of measuring roughness at the required level of resolution except for G. This instrument was denied the opportunity to measure validly at short wavelength by the screeching problem it encountered on this occasion.

c) All three methods of locating the reference surface laterally have been used in the exercise and have been demonstrated to be practical to apply. The first two have been shown to produce fairly consistent judgements by different teams. The third method was only used by one team. This success of the standard in producing consistent practice in the choice of lateral position of the reference surface is important because these practices are newly introduced by the standard.

d) Clearly the main difficulty is in reconciling the measurements made 100 m at a time and those made 1,2 m at a time. This is not to do with the transducer technology but the treatment of the record to which the different approaches lead.

e) Closely associated with the difference in practice between continuous measurements and discrete short records, is the judgement to be made on the exclusion of localised geometrical features. For this reason some records from the measurement exercise are shown alongside photographs of particular rail-head features in Annex C.

f) An ambiguity in the draft standard used in the test was identified in the spikes processing. It was agreed upon by all measurement teams that only upward features should be removed in the spikes processing. Downward features are still treated by the curvature processing.

g) The digital filtering technique was used for the long records. It was found that about 2 m of record should be discarded at each end due to the filter transients. This precludes it from use for short-record instruments.

h) Ignoring where systematic differences have been observed, there is an approximate ± 2 dB variation ‘limit to the reproducibility’ of measurements when different teams measure the same line of roughness with different instruments.

i) There is a risk of greater variation than this due to the variations of what is picked up in different samples and the judgements made on what to exclude.

j) The risk mentioned above is on the safe side since it leads to over-estimation of the spectrum that is thought to be relevant to rolling noise generation.

Annex A
(informative)
Results from Loriol for all instruments processed using the common processing method

The results from Loriol of each measurement team and instrument combination are presented in this Annex.

Each team measured 3 lines of roughness at this site. The energy mean spectrum along each line is presented. The ‘spread’ of the sample spectra making up the mean is indicated by dotted lines denoting one standard deviation either side of the arithmetic mean of the decibel levels of the ensemble dB spectra.

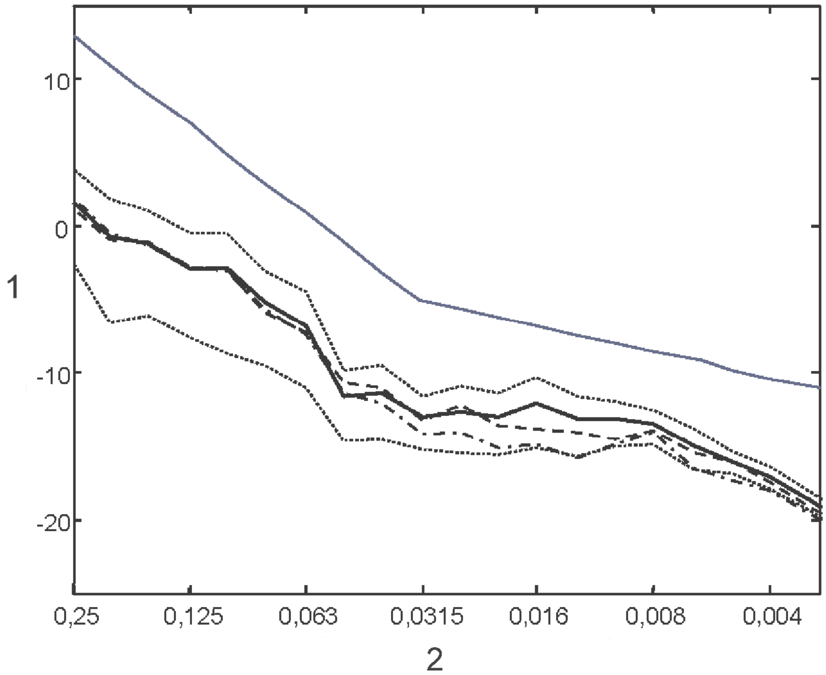
For the trolley measurements, the digital filtering technique has been used. In this case the result for the central line of roughness measurement analysed by the DFT technique is also shown. Note that the digital filtering analysis removes 2 m at either end of the record (11 m analysed) because of the starting and ending transients of the filter. This accounts for the difference compared to the DFT analysis in Figures A18 and A24 since some rail-head defects were present in the 15 m.

In addition to this, for the trolley measurements, the analysis is given for the whole record (i.e. the whole 100 m or 15 m) and for 15 × 1,5 m segments of the data chosen to be approximately evenly spaced along the length of the test section but avoiding the use of segments which obviously contain the record of a rail head defect. The reason for this approach is discussed in the main report.

Table A1 gives the legend that applied to all graphs in this Annex.

Table A1 — Legend applying to all figures

(thin blue solid line)	TSI limit spectrum
(thick solid line)	centre line
(dashed line)	near line
(dash-dot line)	far line
(red dashed line)	centre line by DFT method for trolley data
(dotted line)	one standard deviation either side of the arithmetic mean of the dB levels

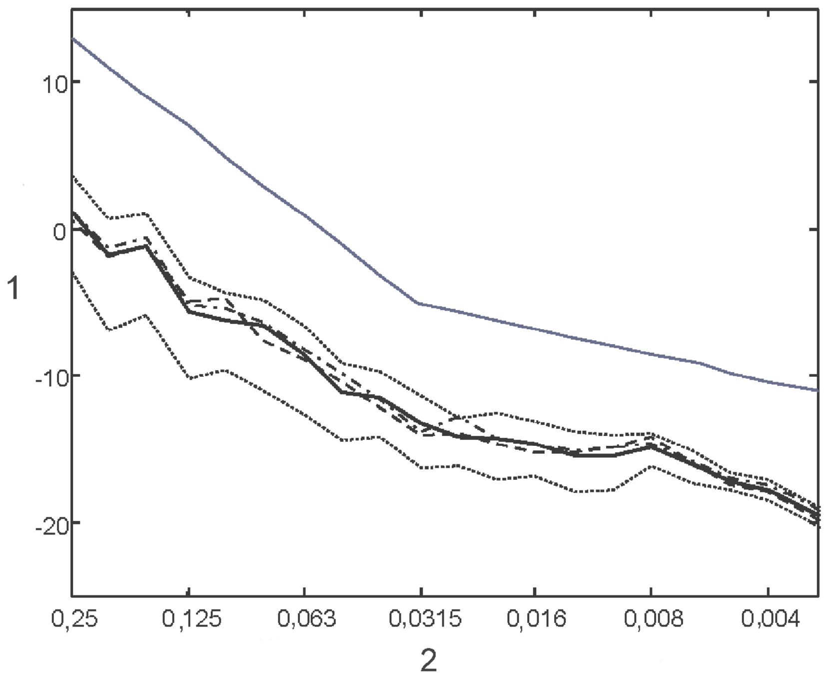


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.1 — Measurement by team-instrument A on the near rail

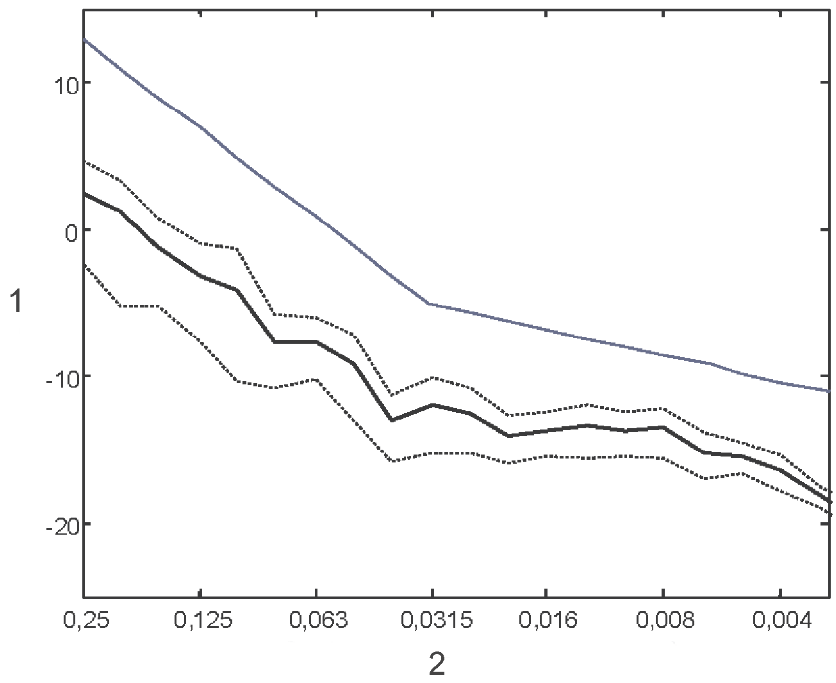


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.2 — Measurement by team-instrument A on the far rail

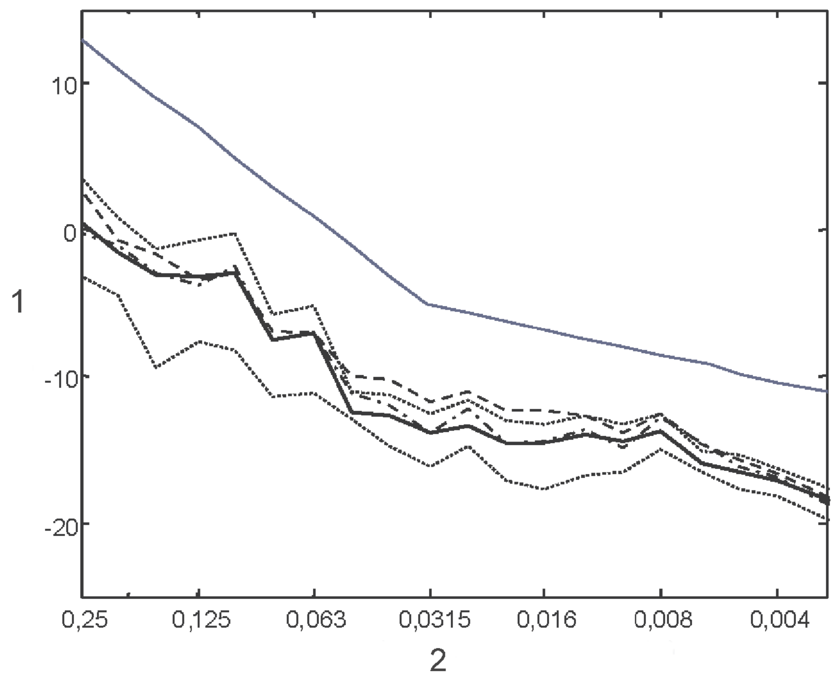


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.3 — Measurement by team-instrument A on the datum length of rail

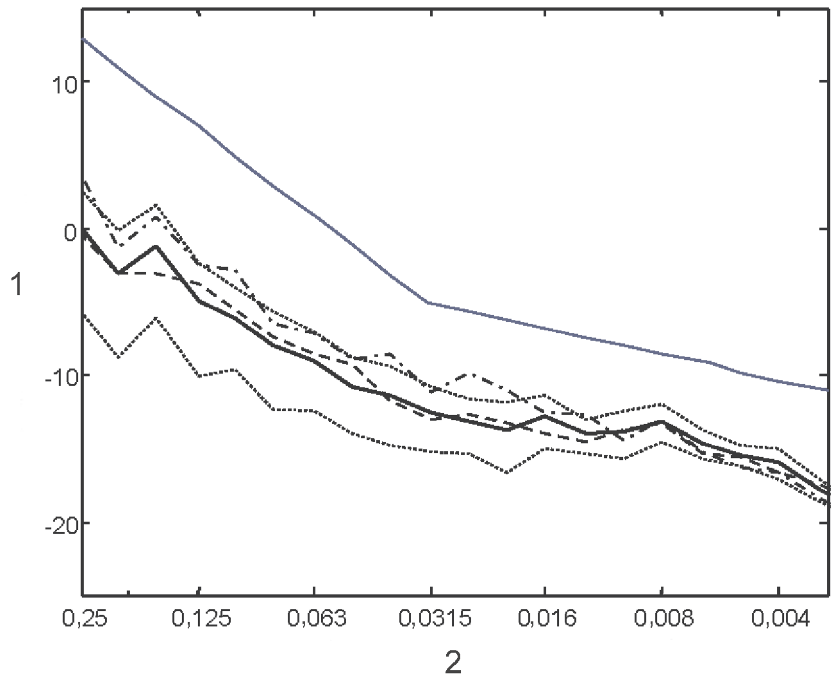


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.4 — Measurement by team-instrument B on the near rail

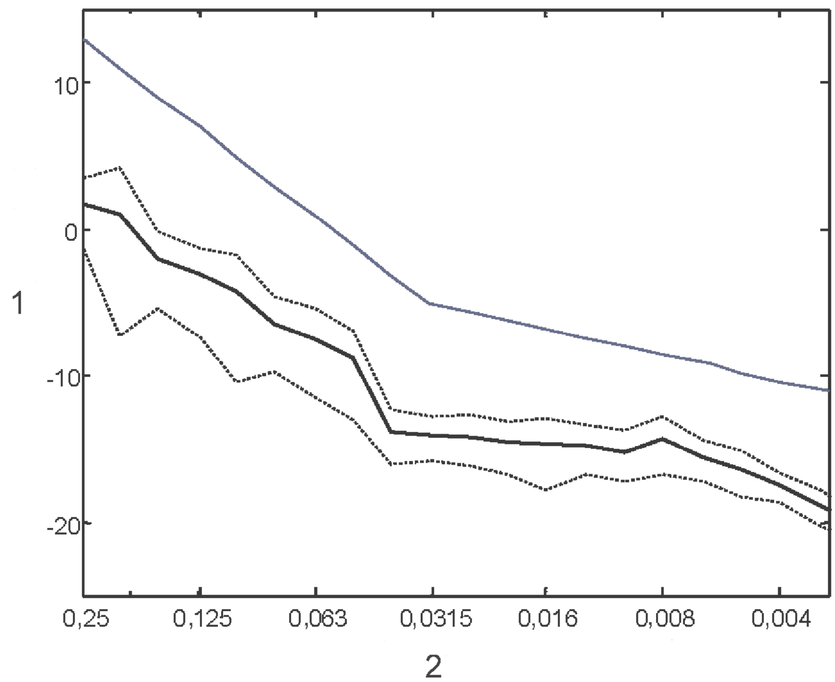


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.5 — Measurement by team-instrument B on the far rail

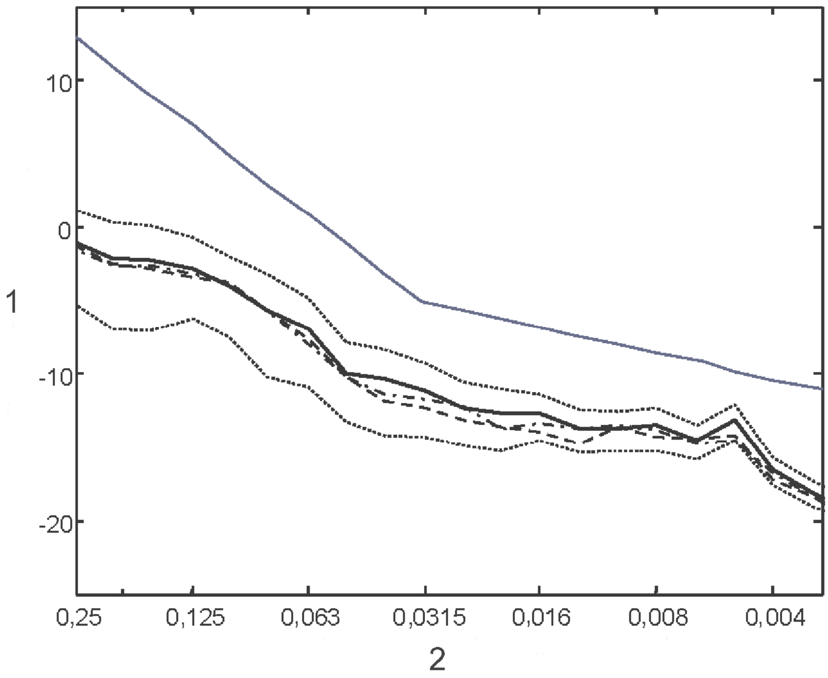


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.6 — Measurement by team-instrument B on the datum length of rail

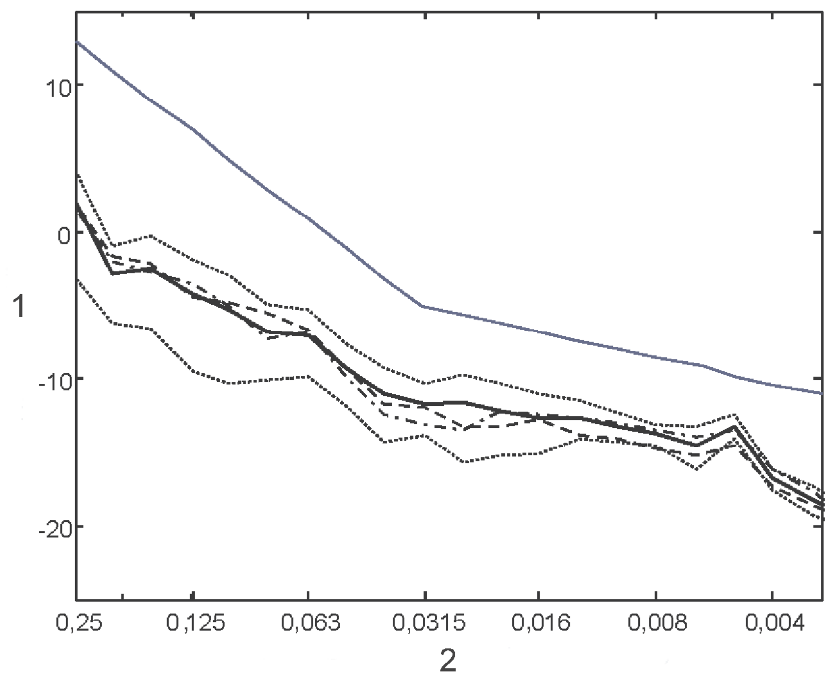


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.7 — Measurement by team-instrument C on the near rail

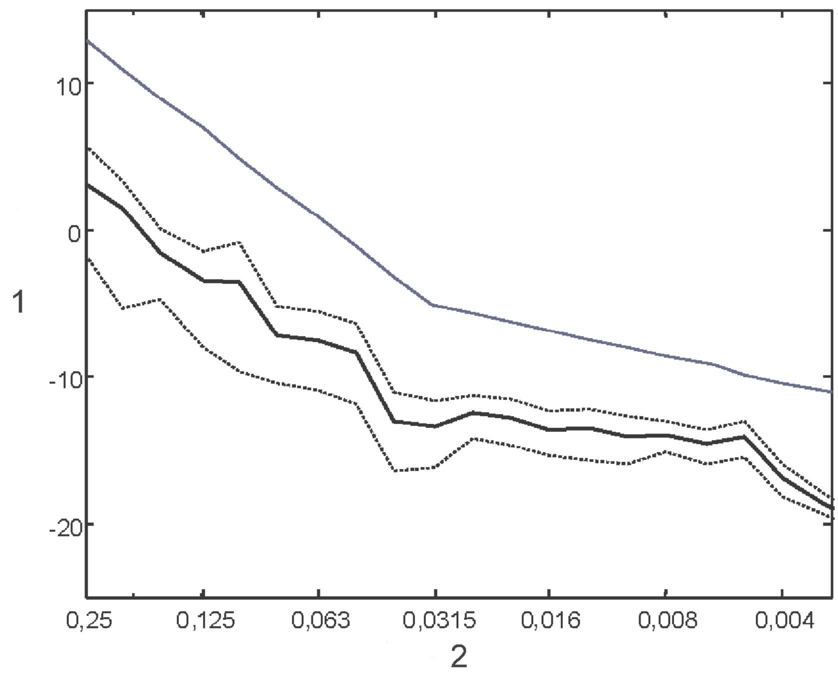


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.8 — Measurement by team-instrument C on the far rail

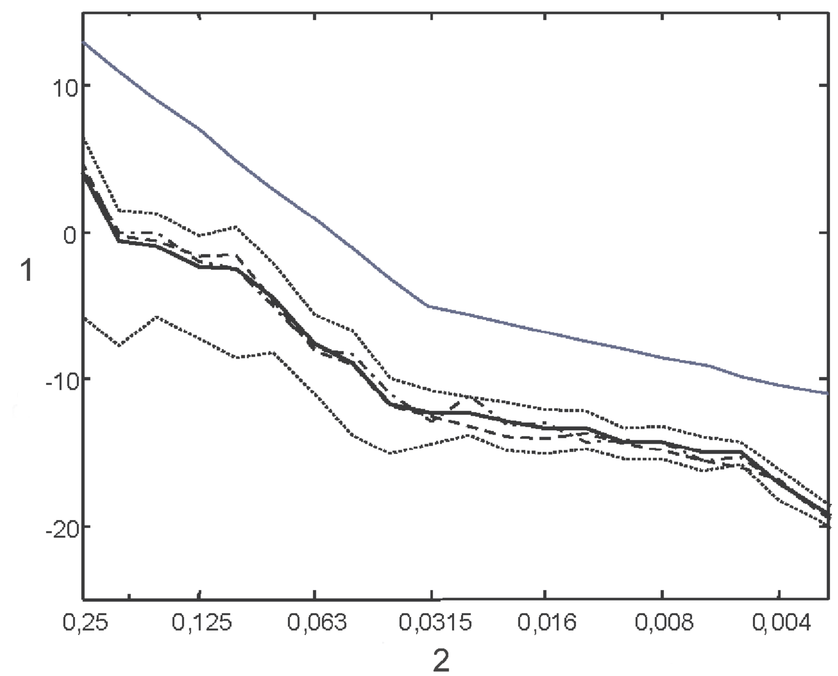


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.9 — Measurement by team-instrument C on the datum length of rail

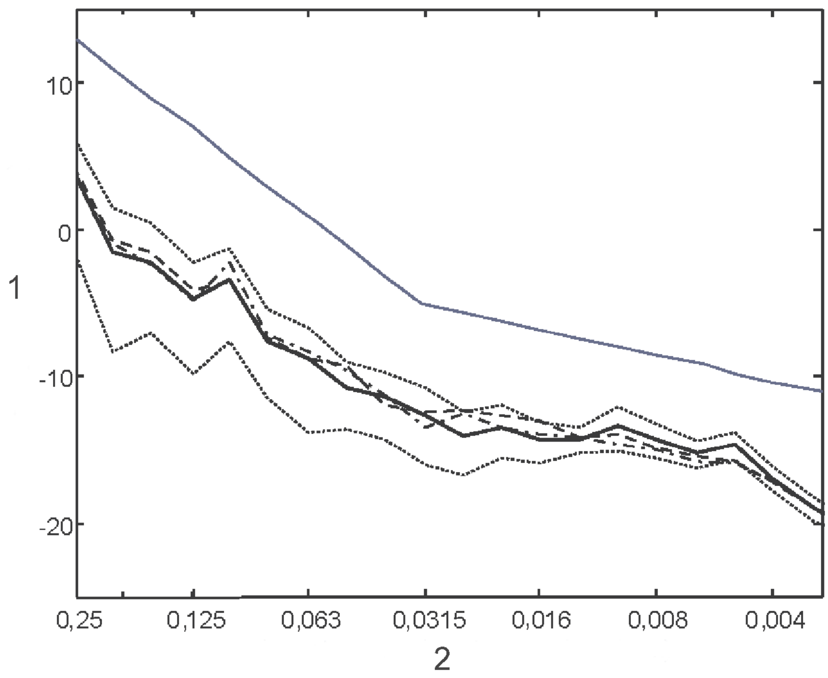


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.10 — Measurement by team-instrument D on the near rail

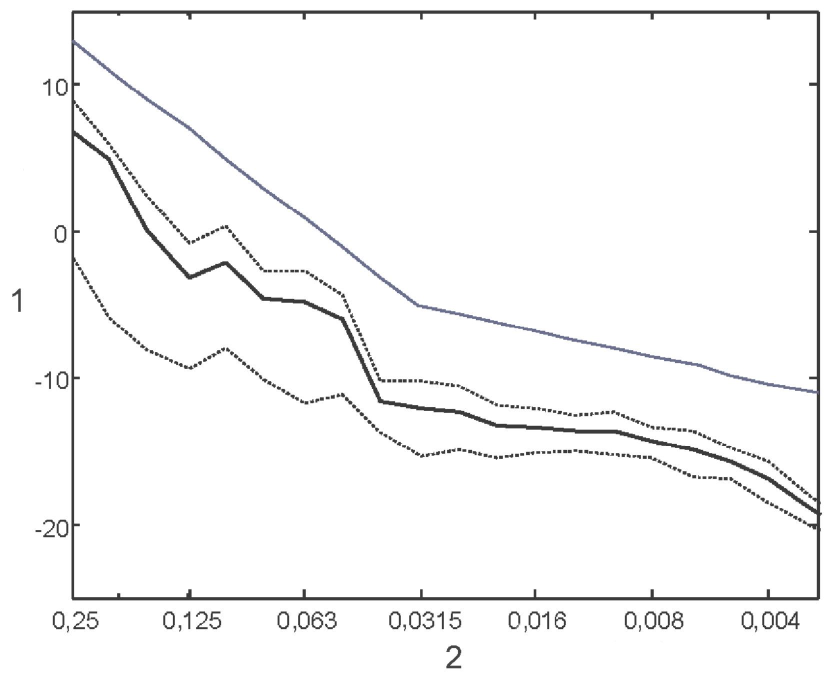


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.11 — Measurement by team-instrument D on the far rail

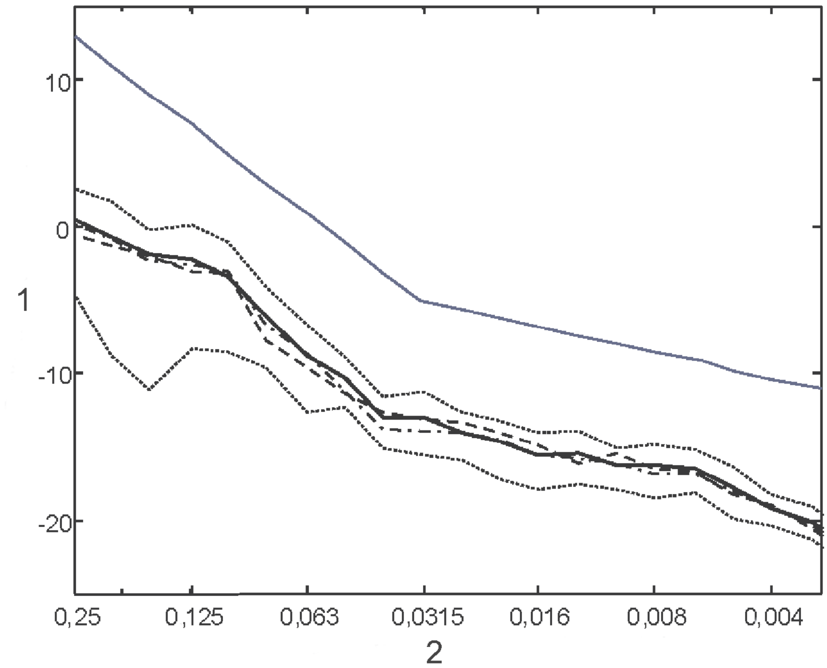


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.12 — Measurement by team-instrument D on the datum length of rail

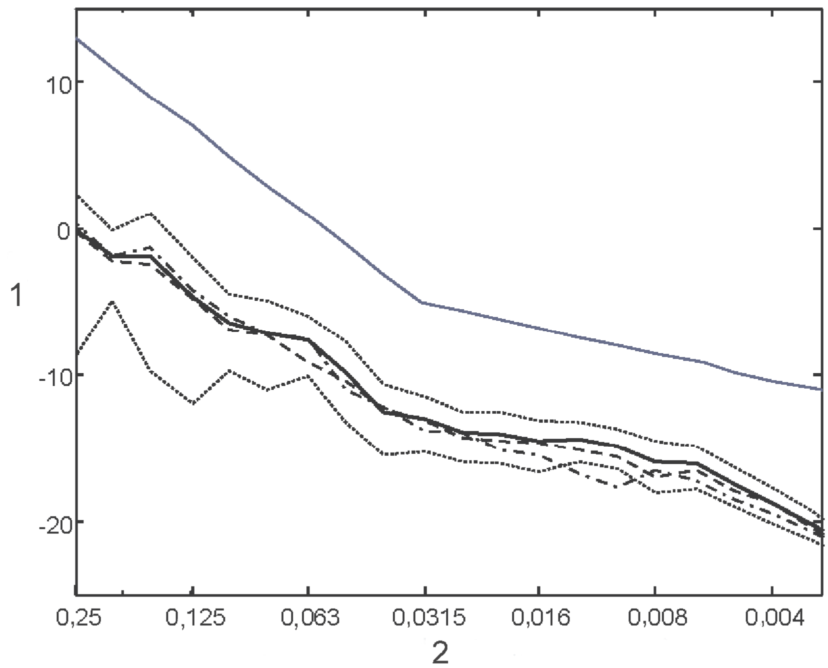


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.13 — Measurement by team-instrument E on the near rail

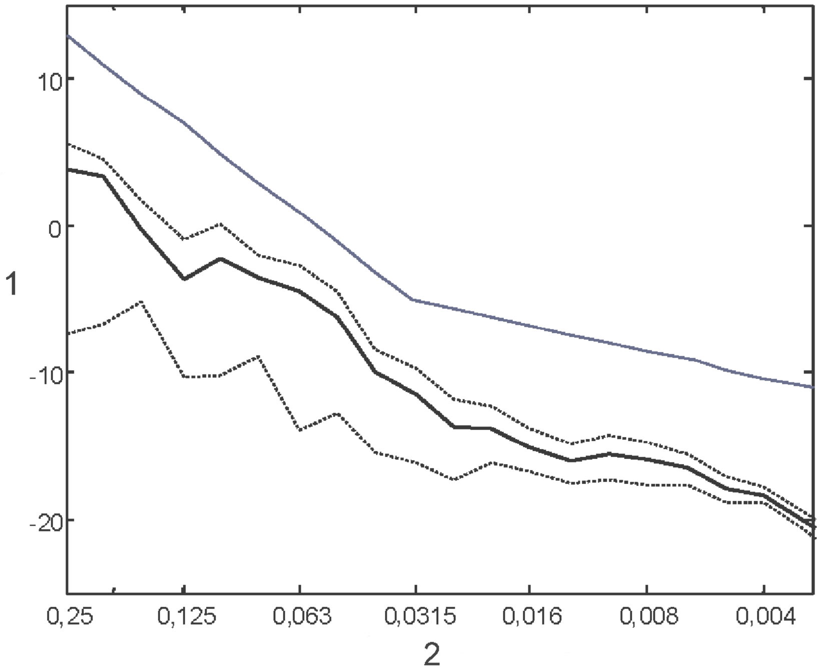


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.14 — Measurement by team-instrument E on the far rail

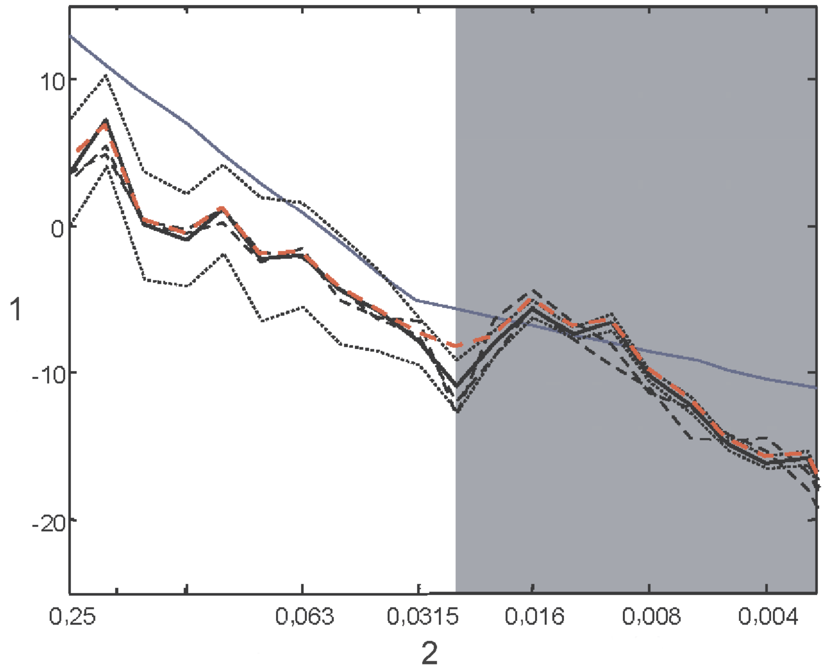


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.15 — Measurement by team-instrument E on the datum length of rail

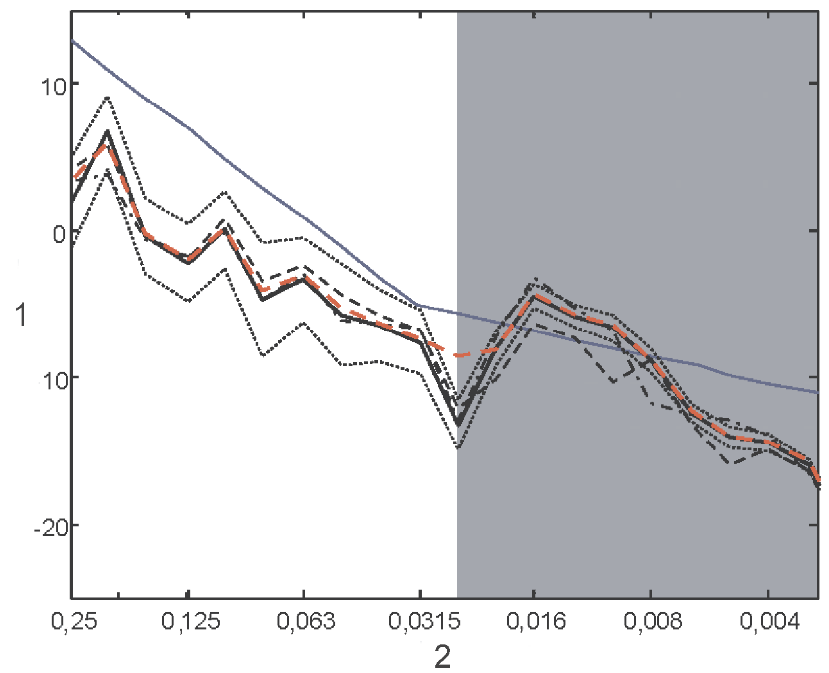


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.16 — Measurement by team-instrument G on the near rail – complete 100 m analysed (shaded area indicates range in which data known not to be valid)

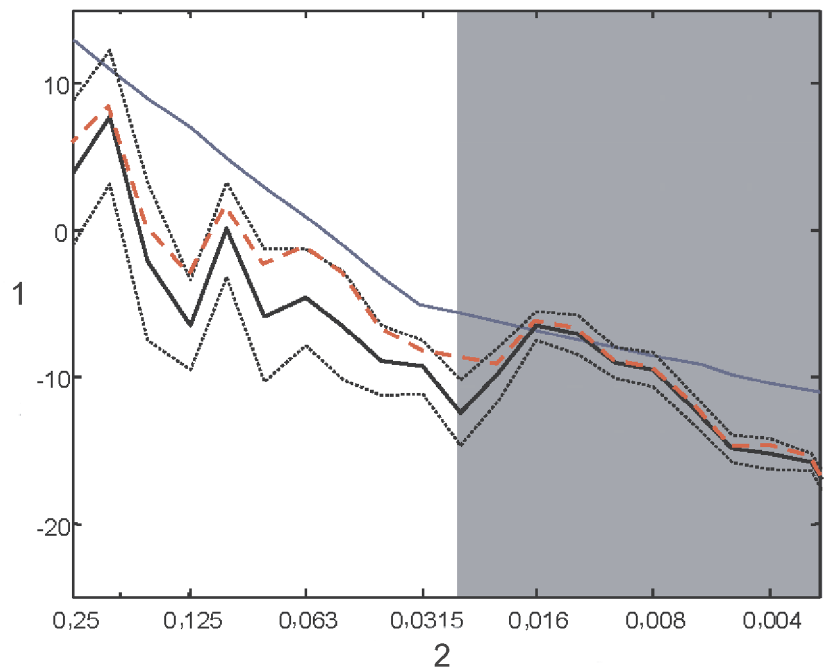


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.17 — Measurement by team-instrument G on the far rail – complete 100 m analysed (shadedarea indicates range in which data known not to be valid)

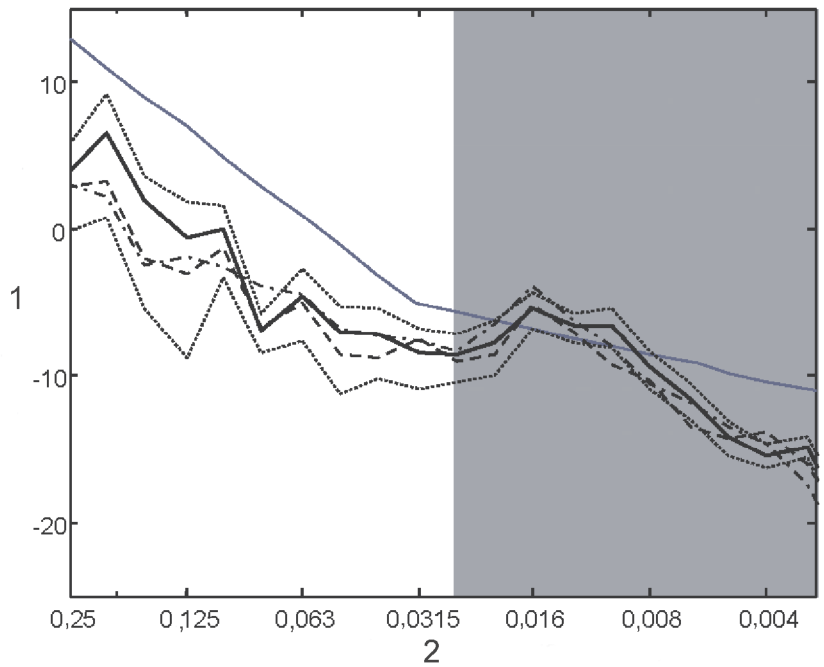


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.18 — Measurement by team-instrument G on the datum length of rail – complete 15 m analysed

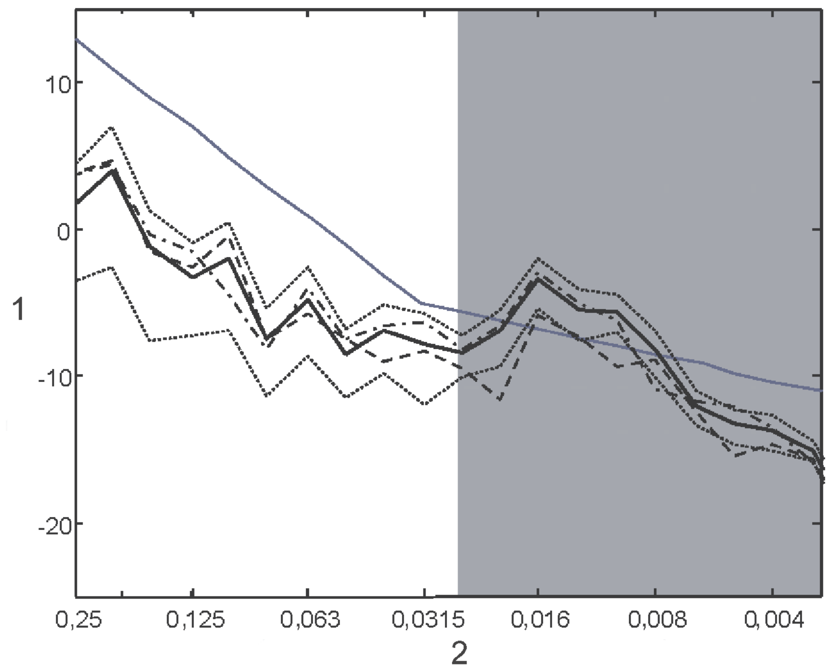


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.19 — Measurement by team-instrument G on the near rail – 15 × 1,2 m sections analysed

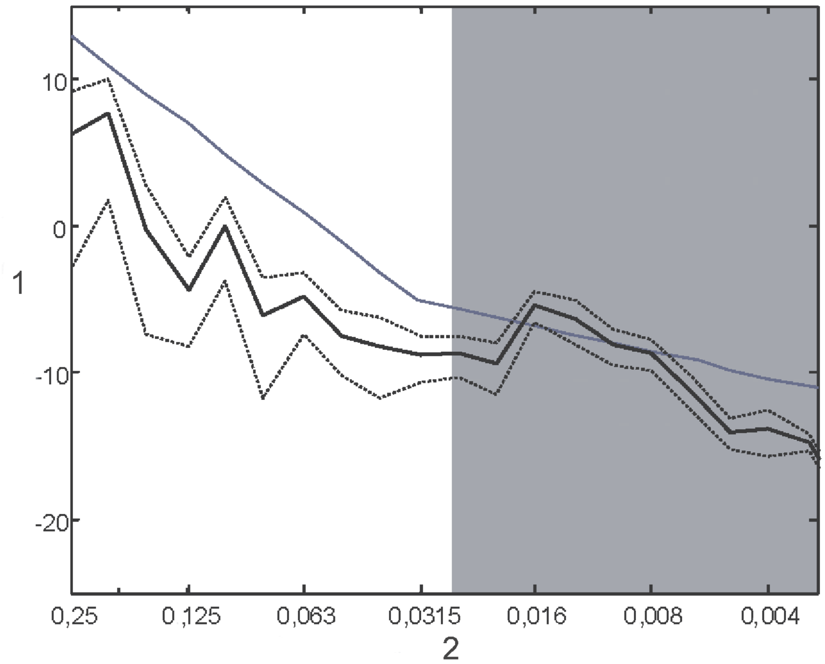


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.20 — Measurement by team-instrument G on the far rail – 15 × 1,2 m sections analysed

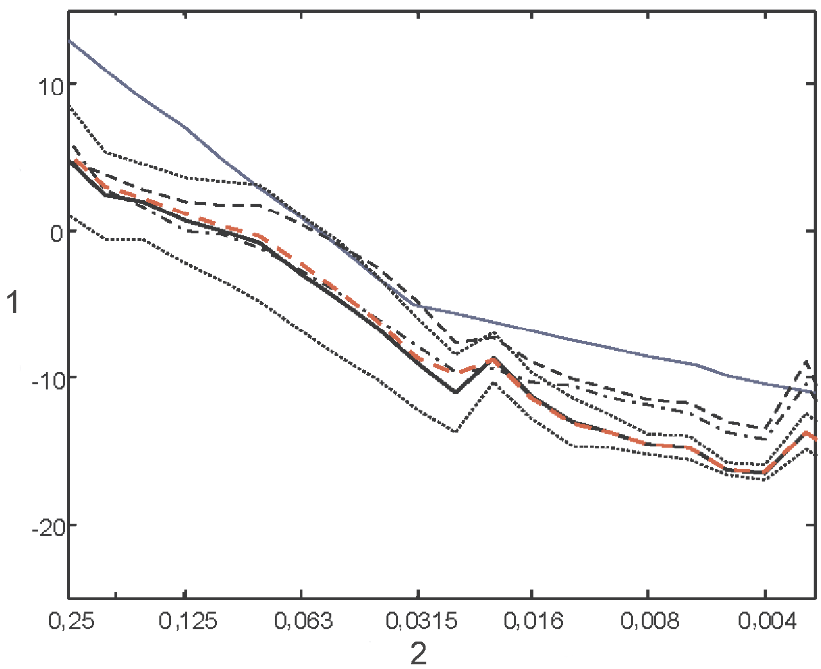


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.21 — Measurement by team-instrument G on the datum length of rail – 9 × 1,2 m sections analysed (here 3 records containing local features were removed)

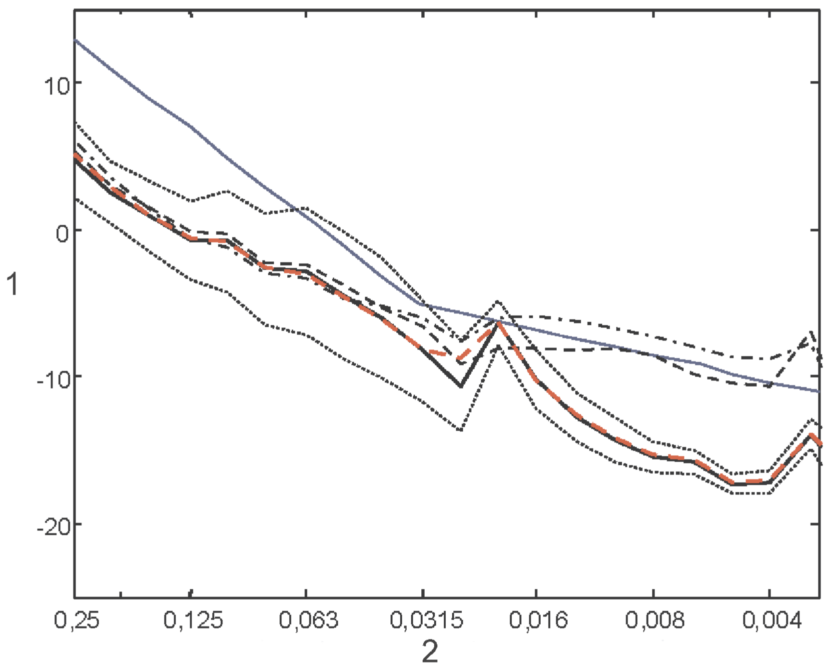


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.22 — Measurement by team-instrument H on the near rail – complete 100 m analysed

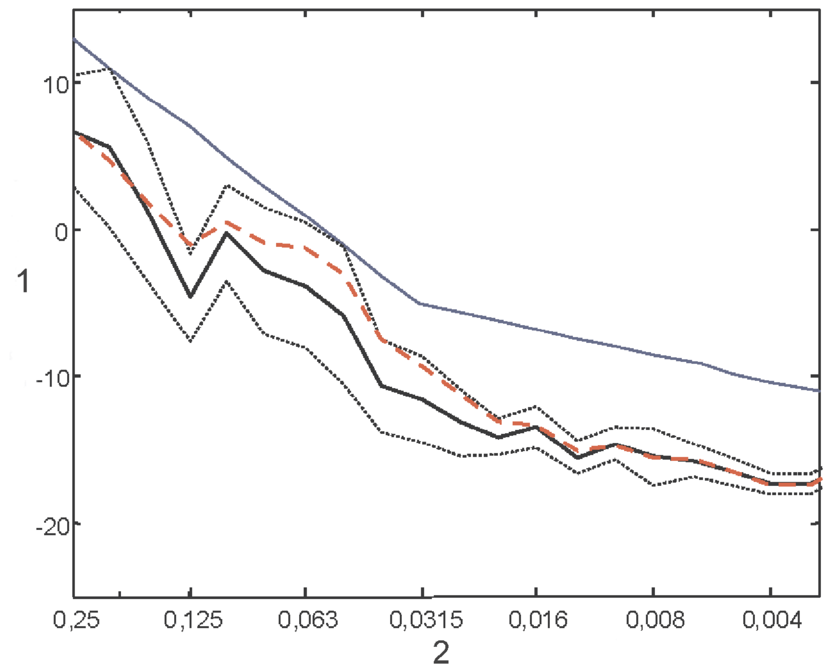


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.23 — Measurement by team-instrument H on the far rail – complete 100 m analysed

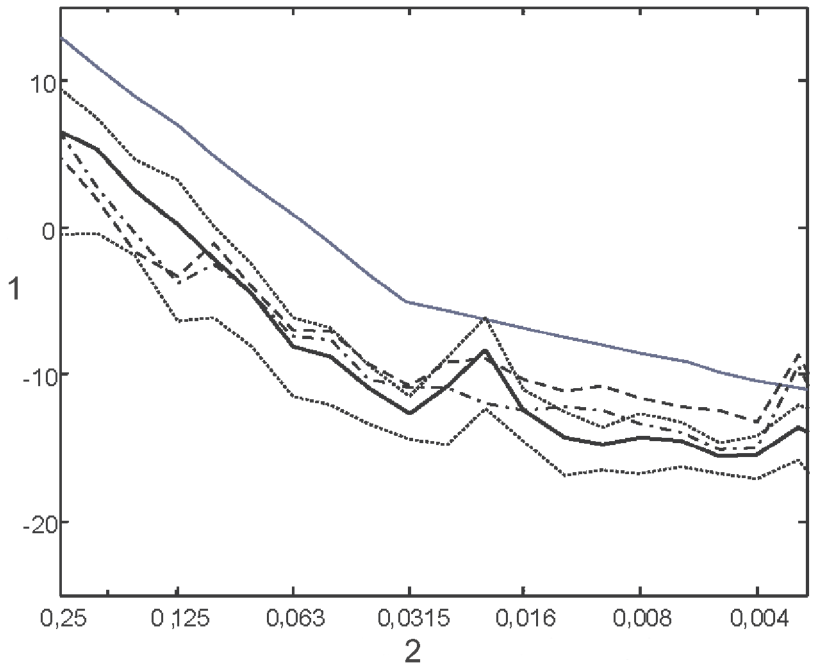


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.24 — Measurement by team-instrument H on the datum length of rail – complete 15 m analysed

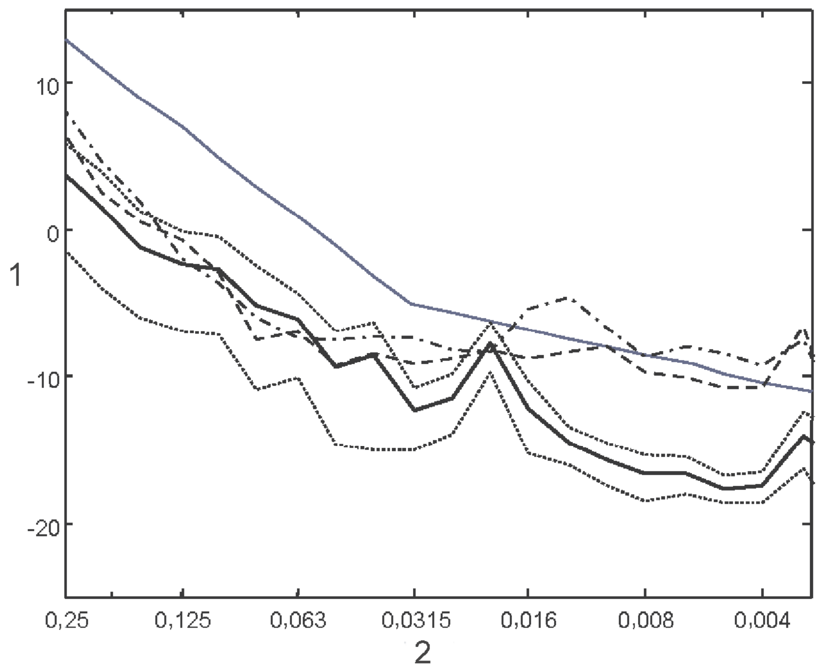


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.25 — Measurement by team-instrument H on the near rail – 15 × 1,2 m sections analysed

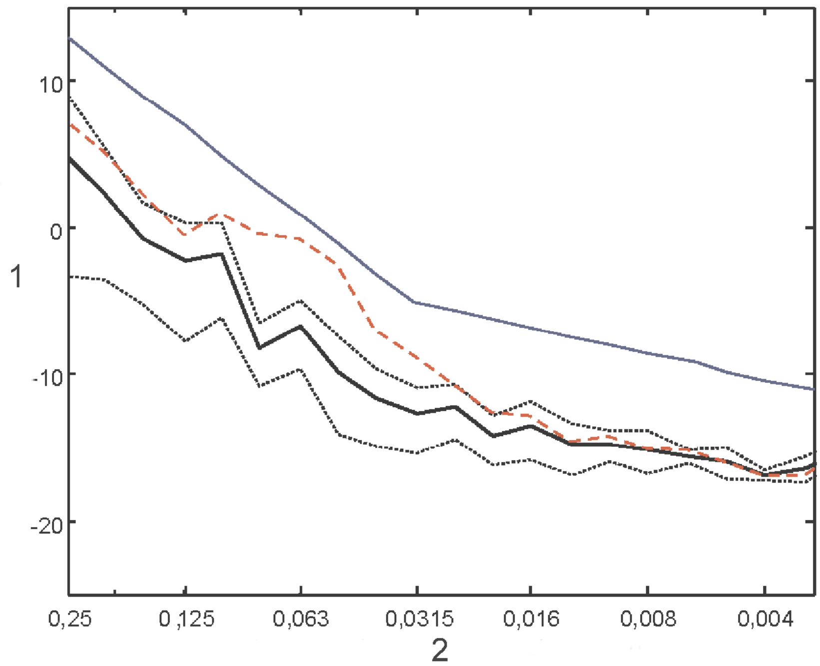


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure A.26 — Measurement by team-instrument H on the far rail – 15 × 1,2 m sections analysed



Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Here 3 records containing local features were removed. The red dashed line is the spectrum without these features removed, i.e. all 1,2 m segments retained.

Figure A.27 — Measurement by team-instrument H on the datum length of rail – 9 × 1,2 m segments analysed

Annex B
(informative)
Results from Wildenrath for all instruments processed using the common processing method

The results from Wildenrath of each measurement team and instrument combination are presented in this Annex.

Each team measured 1 line of roughness at this site. The ‘spread’ of the sample spectra making up the mean is indicated by dotted lines denoting one standard deviation either side of the arithmetic mean of the decibel levels of the ensemble dB spectra.

For the trolley measurements, the digital filtering technique has been used. In this case the result for the central line of roughness measurement analysed by the DFT technique is also shown. Note that the digital filtering analysis removes 2 m at either end of the record (11 m analysed) because of the starting and ending transients of the filter.

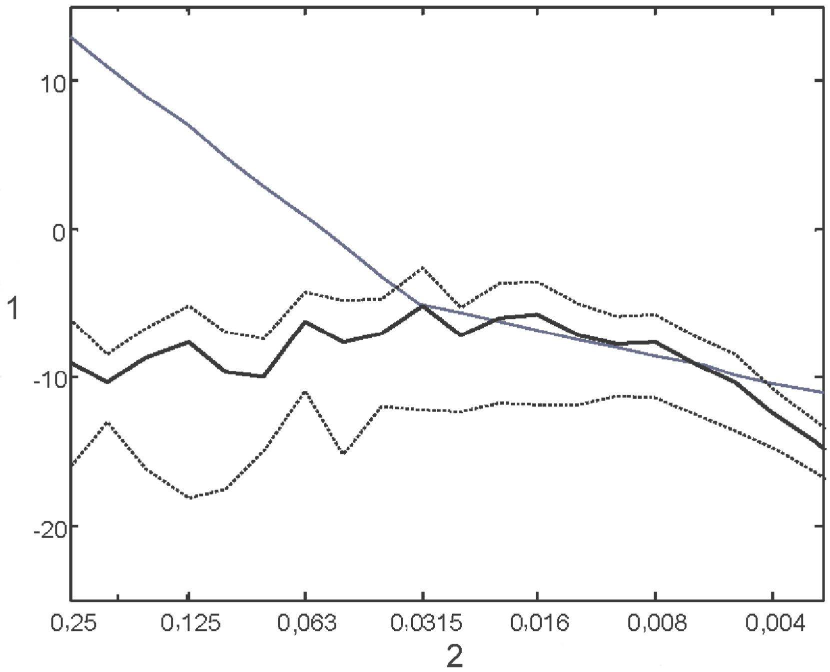
In addition to this, for the trolley measurements, the analysis is given for the whole record (i.e. the whole 100 m or 15 m) and for 15 × 1,5 m segments of the data chosen to be approximately evenly spaced along the length of the test section but avoiding the use of segments which obviously contain the record of a rail head defect. The reason for this approach is discussed in the main report.

No data was produced by team-instrument B for the 15 m datum line at Wildenrath.

Table B.1 gives the legend that applied to all graphs in this Annex.

Table B.1 — Legend applying to all figures

——— (blue)	TSI limit spectrum
——— (black, thick)	mean roughness
– – – (red)	centre line by DFT method for trolley data
·········	one standard deviation either side of the arithmetic mean of the dB levels

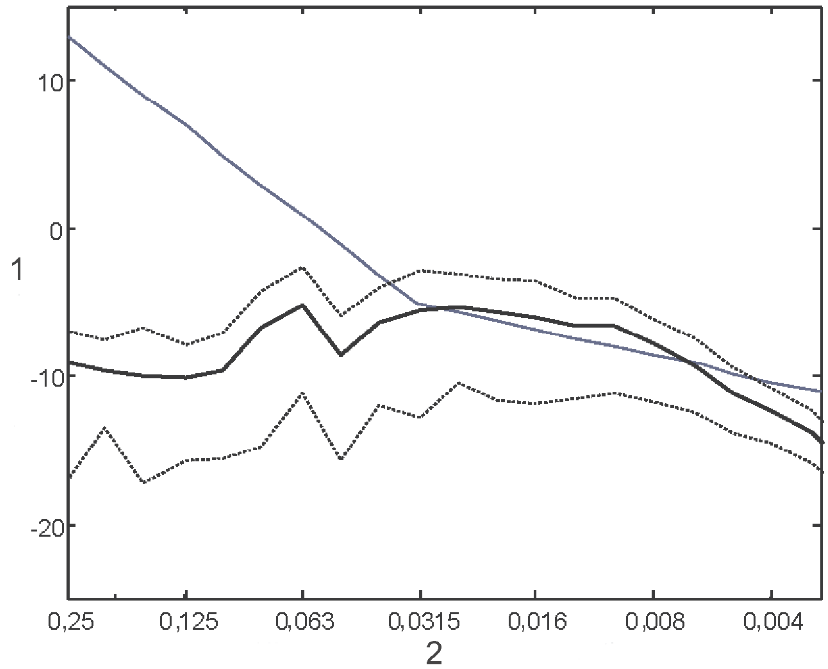


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.1 — Measurement by team-instrument A on the near rail

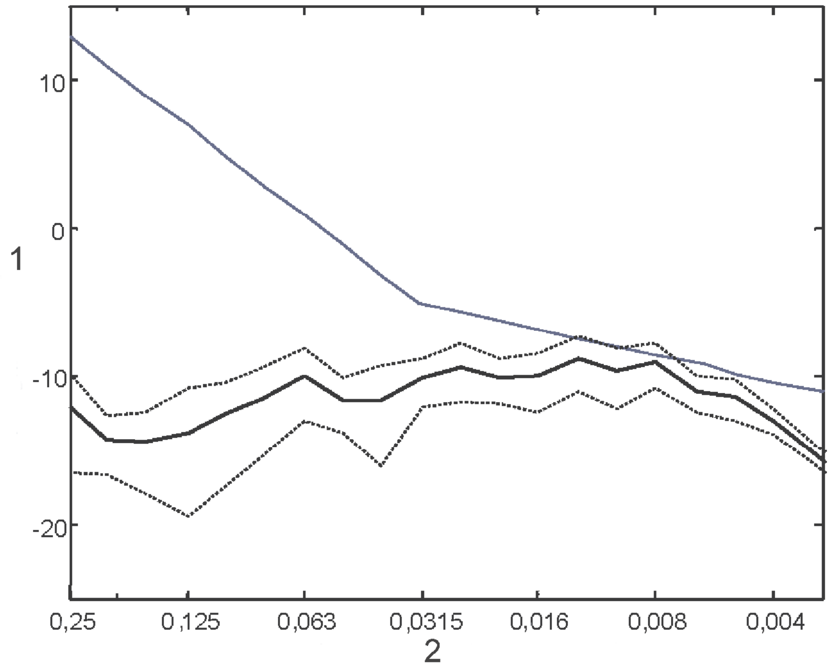


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.2 — Measurement by team-instrument A on the far rail

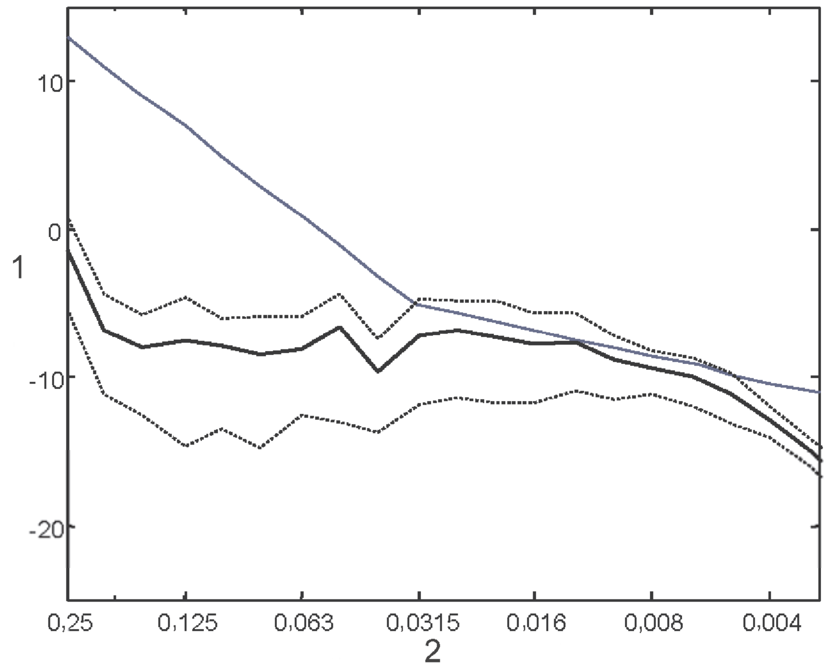


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.3 — Measurement by team-instrument A on the datum length of rail

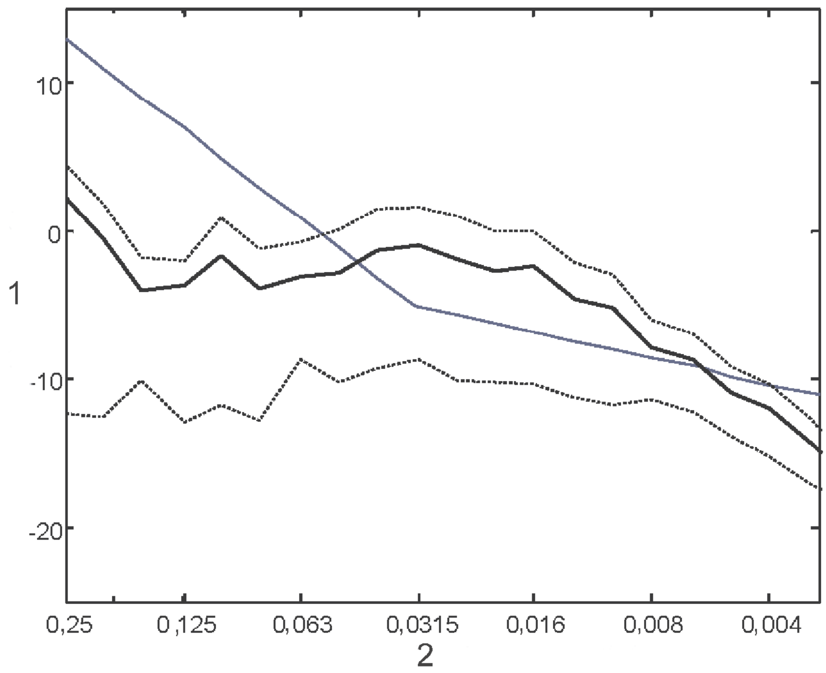


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.4 — Measurement by team-instrument B on the near rail

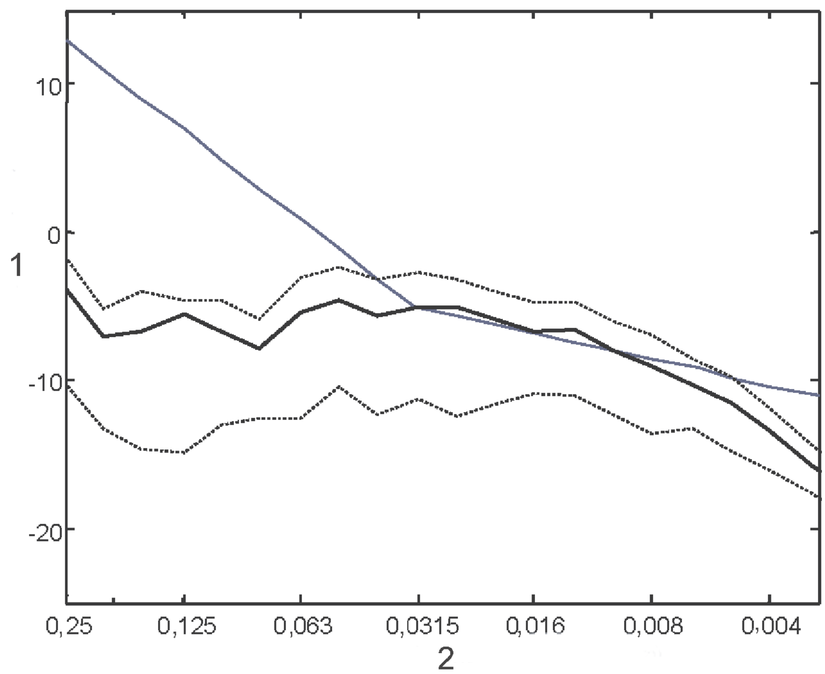


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.5 — Measurement by team-instrument B on the far rail

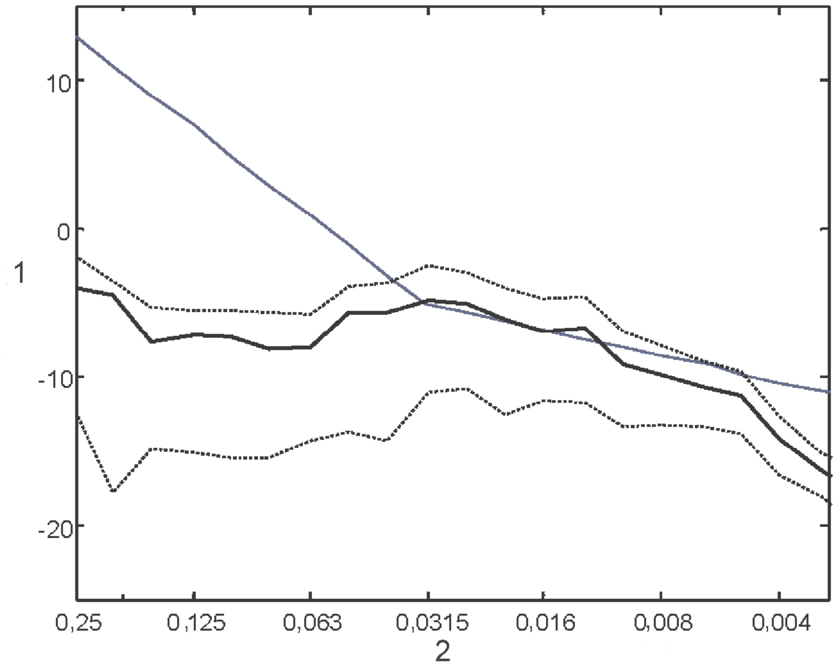


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.6 — Measurement by team-instrument C on the near rail

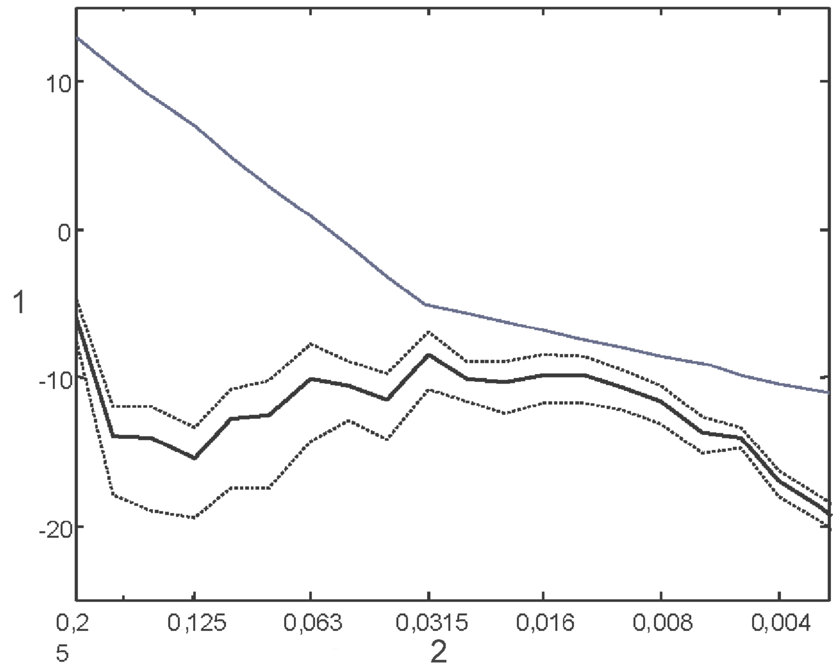


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.7 — Measurement by team-instrument C on the far rail

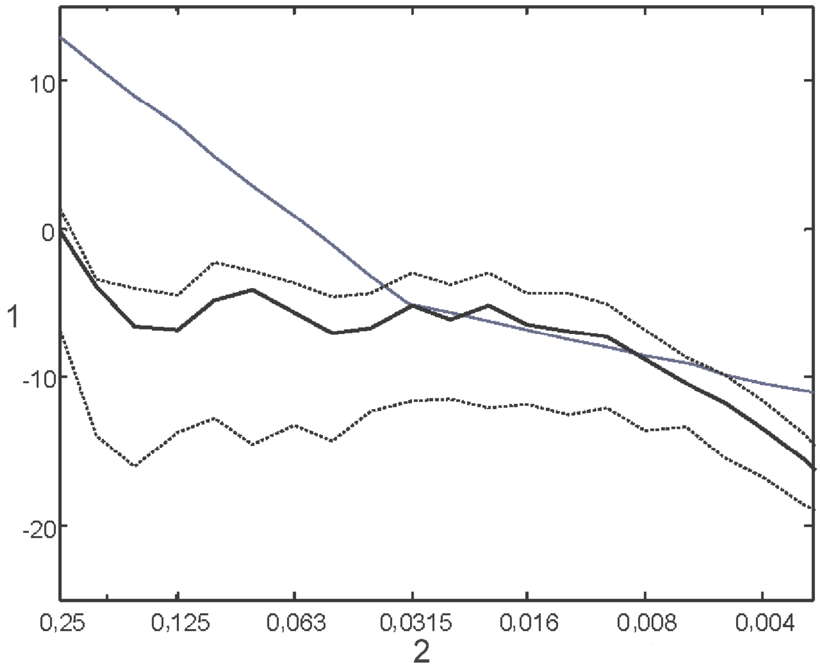


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.8 — Measurement by team-instrument C on the datum length of rail

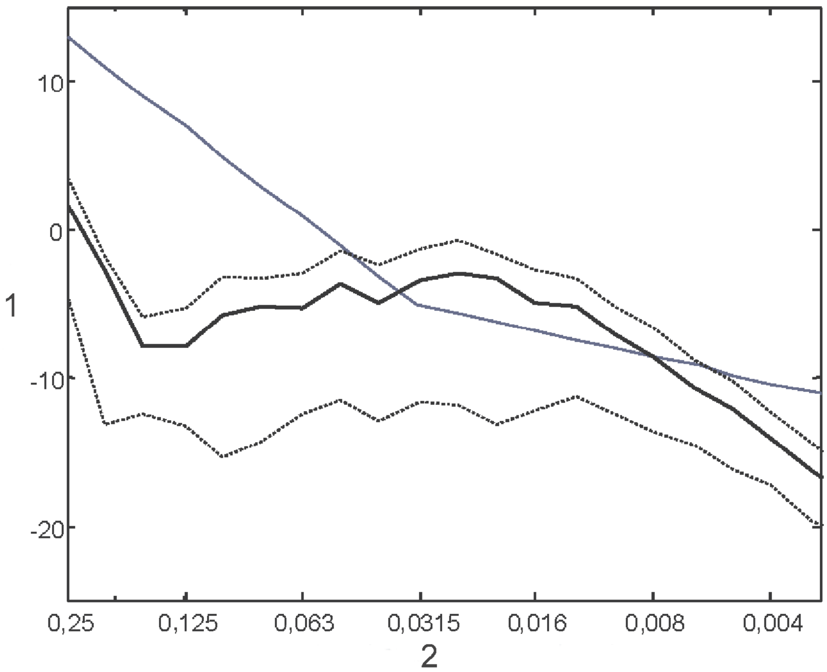


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.9 — Measurement by team-instrument D on the near rail

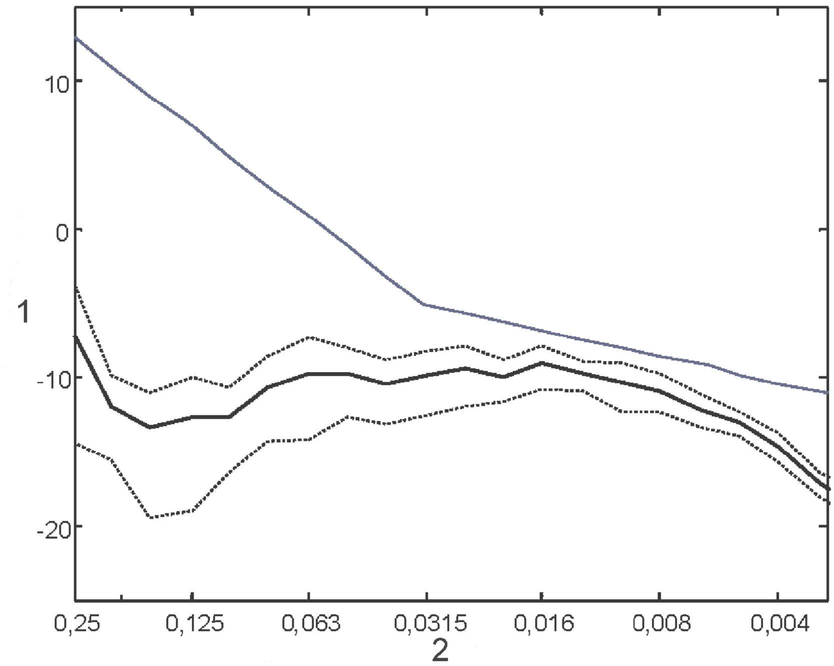


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.10 — Measurement by team-instrument D on the far rail

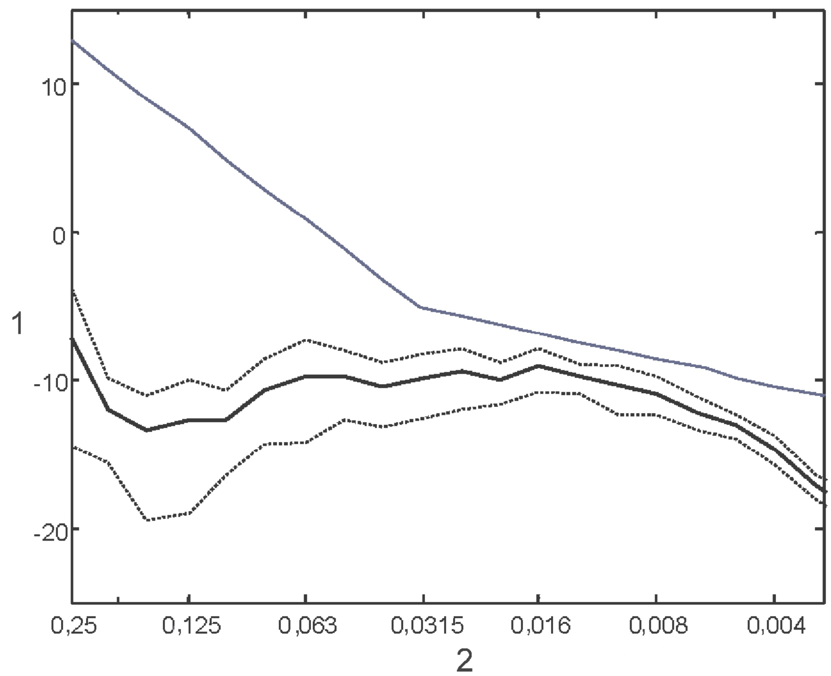


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.11 — Measurement by team-instrument D on the datum length of rail

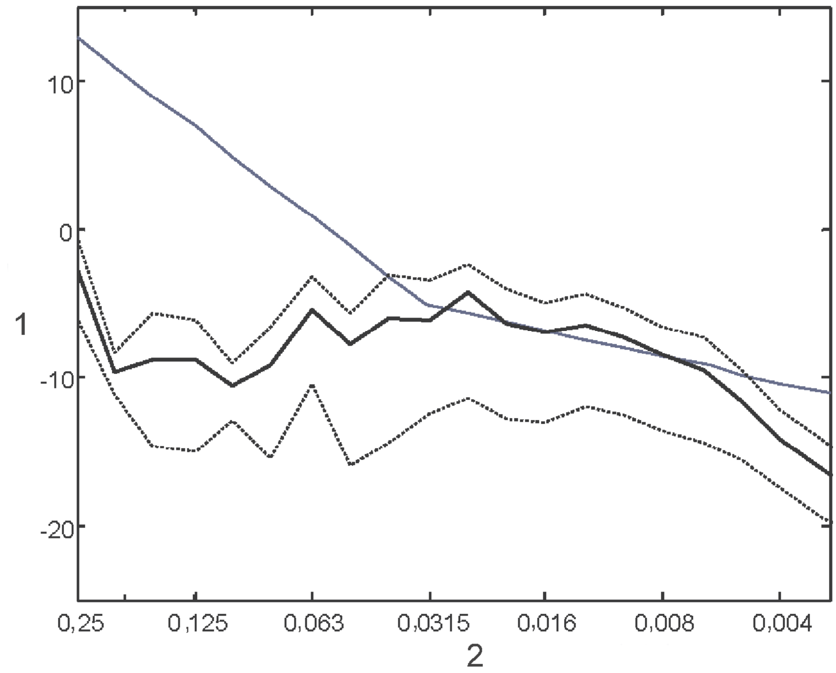


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.12 — Measurement by team-instrument F on the near rail

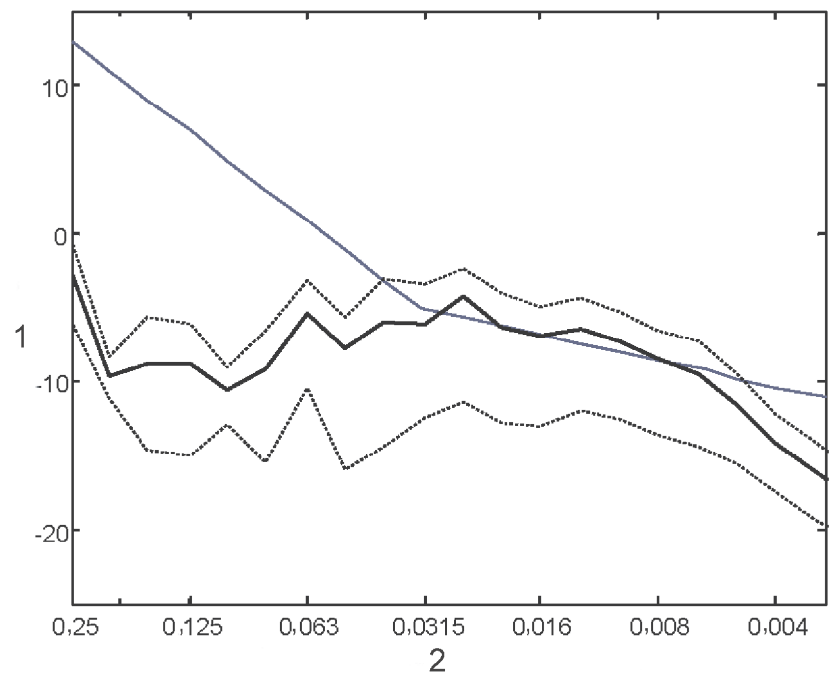


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.13 — Measurement by team-instrument F on the far rail

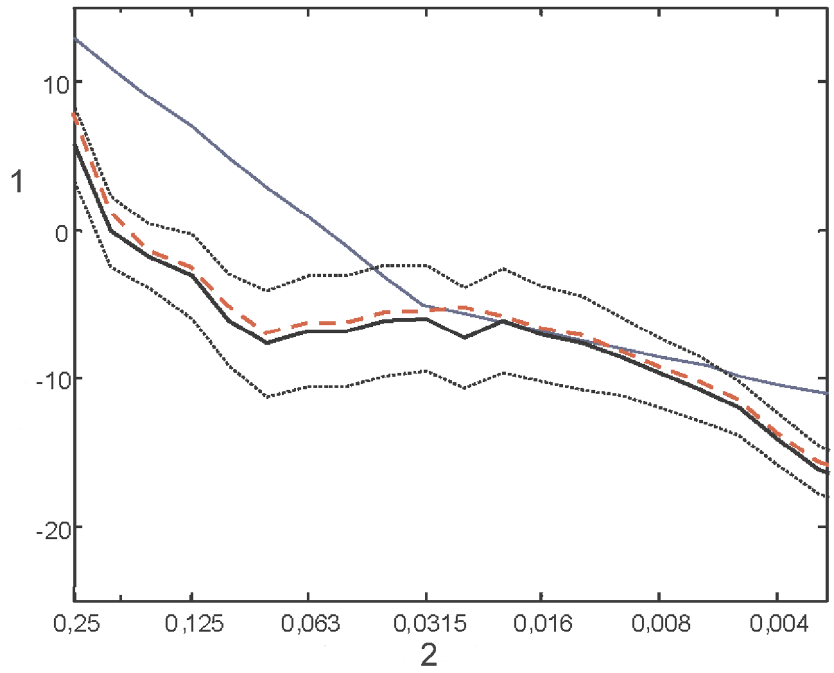


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.14 — Measurement by team-instrument F on the datum length of rail

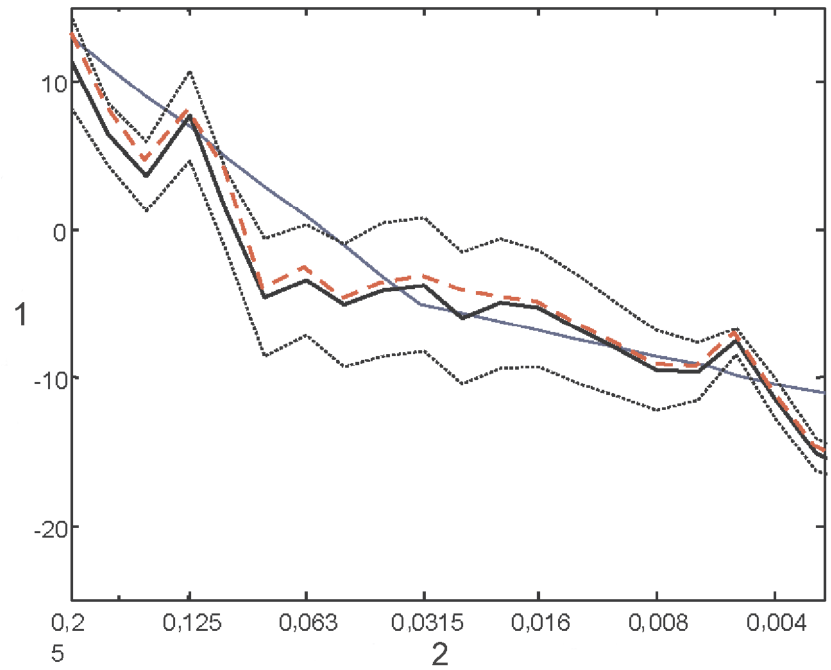


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.15 — Measurement by team-instrument I on the near rail – complete 100 m analysed

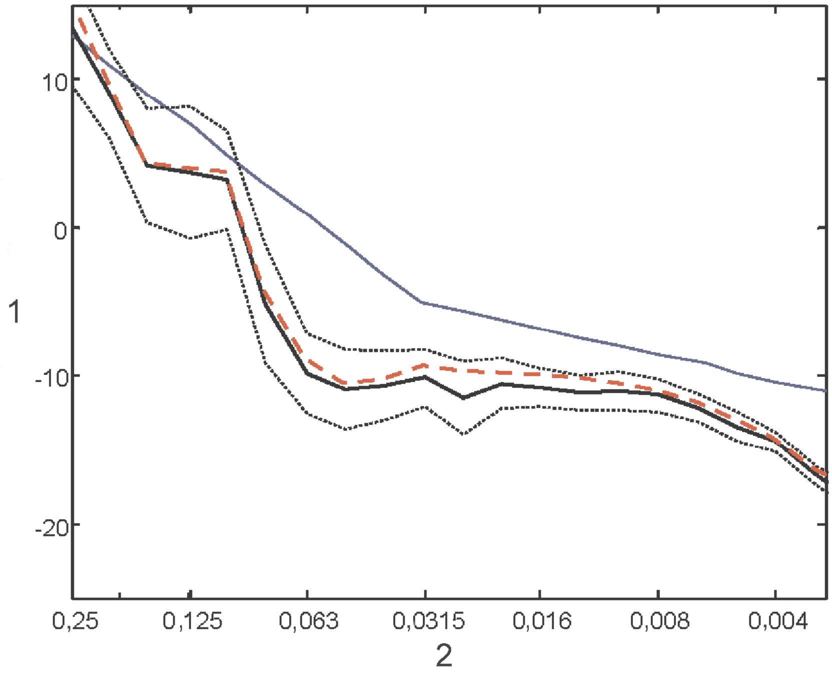


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.16 — Measurement by team-instrument I on the far rail – complete 100 m analysed

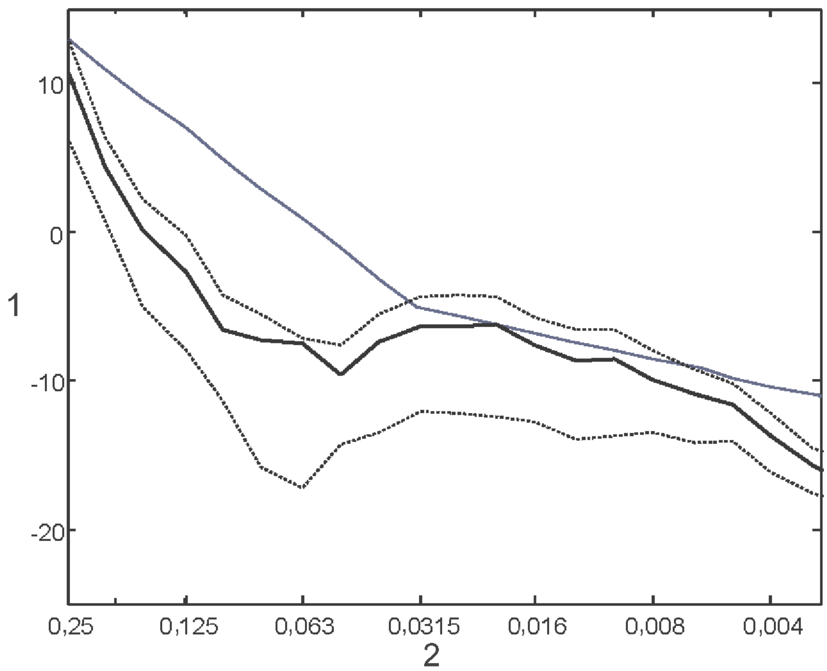


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.17 — Measurement by team-instrument I on the datum length of rail – complete 15 m analysed

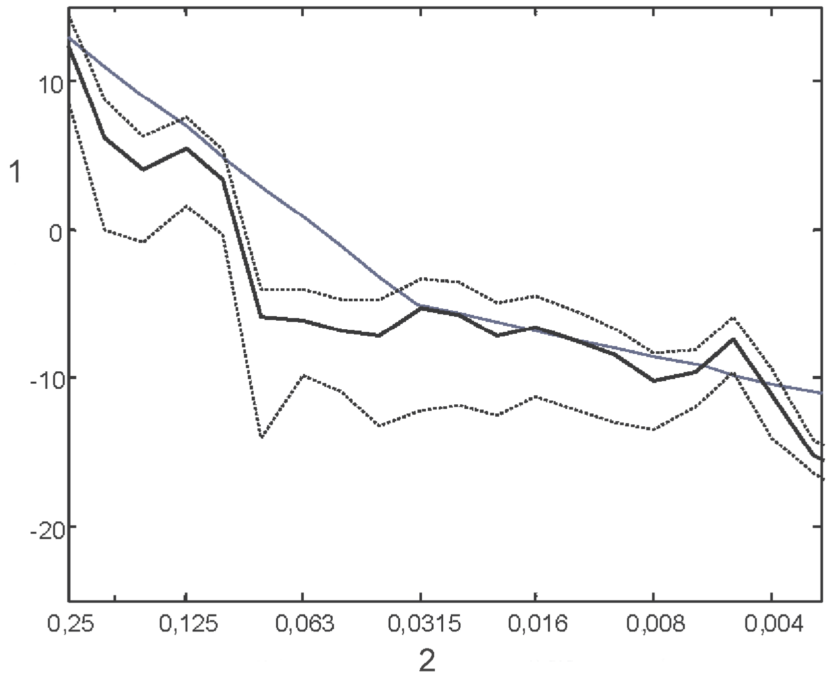


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.18 — Measurement by team-instrument I on the near rail – 15 × 1,2 m sections analysed

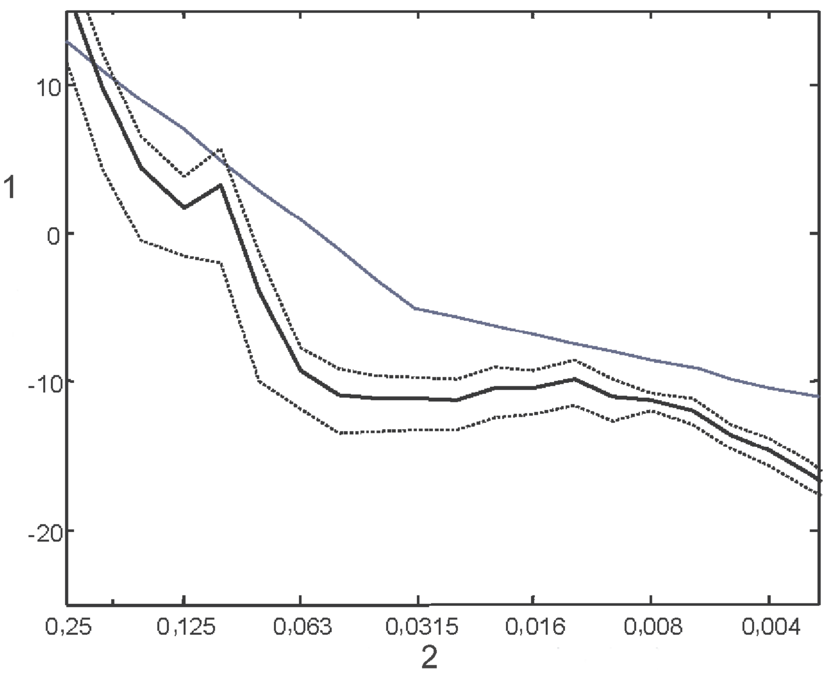


Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.19 — Measurement by team-instrument I on the far rail – 15 × 1,2 m sections analysed



Key

1 Roughness (dB re 1 um)

2 1/3 octave band centre wavelength (m)

Figure B.20 — Measurement by team-instrument I on the datum length of rail – 11 × 1,2 m sections analysed (one section of data with localised feature removed)

Annex C
(informative)

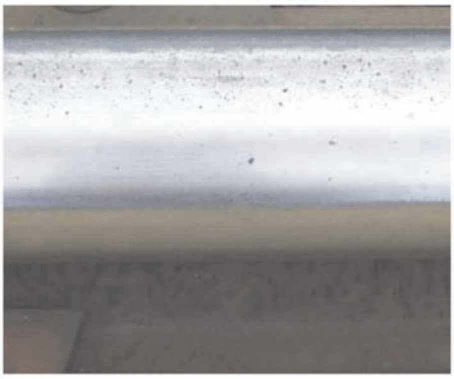
Review of rail-head defects encountered at Loriol

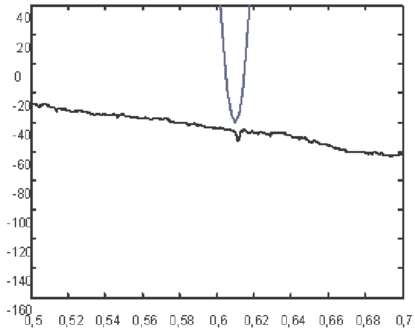
The purpose of this Annex is to assist in the judgement of what features should not be included in measurements. The records shown below were measured using instrument C (a straight edge device). Each defect is shown in a photograph and measured profile alongside the curvature of the wheel (blue line). On the measured profiles the distance axis is in metres and the height axis is in microns. The scales are all the same.

C1 Spot (pit)

small by comparison with wheel radius

- should not be left out of measurement

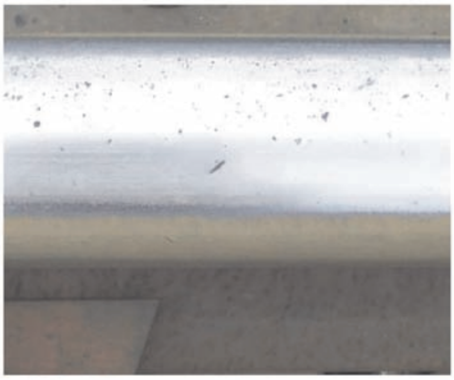


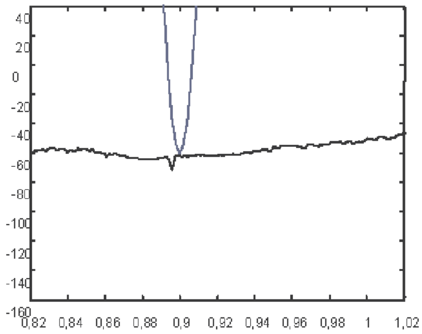


C2 Nick

small by comparison with wheel radius

- should not be left out of measurement

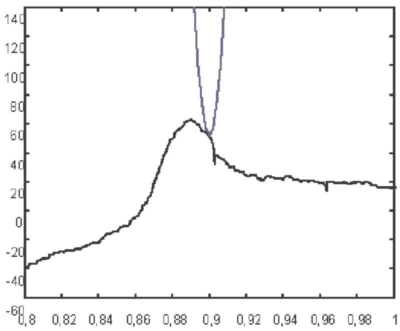




C3 Weld

Large by comparison with wheel radius

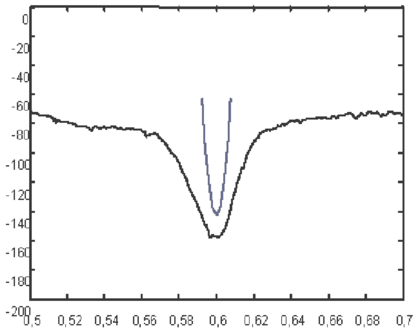
- should be left out of measurement



C4 Hanging sleeper defect

Large by comparison with wheel radius

- should be left out of measurement

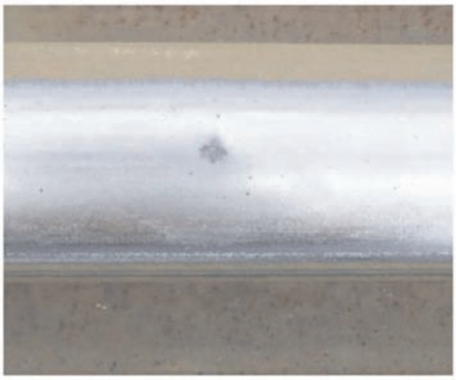


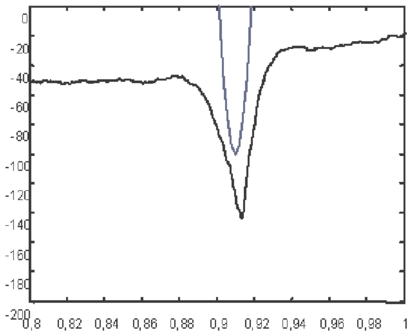
C5 Large dip 1

Large by comparison with wheel radius

- should be left out of measurement.

Clearly visible because wheel does not touch bottom.



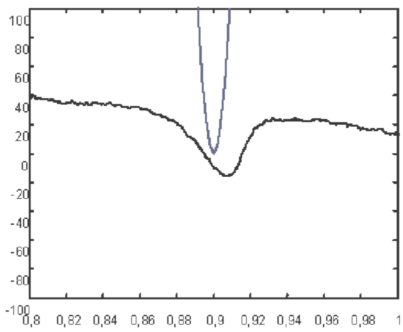


C6 Large dip 2

Large by comparison with wheel radius

- should be left out of measurement.

Not easily visible because wheel touches bottom of dip.



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