



**International  
Standard**

**ISO 13473-5**

**Characterization of pavement  
texture by use of surface profiles —**

**Part 5:  
Determination of megatexture**

*Caractérisation de la texture d'un revêtement de chaussée à  
partir de relevés de profils de la surface —*

*Partie 5: Détermination de la mégatexture*

**Second edition  
2025-03**

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at [www.iso.org/patents](http://www.iso.org/patents). ISO shall not be held responsible for identifying any or all such patent rights.

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This second edition cancels and replaces the first edition (ISO 13473-5:2009), which has been technically revised.

The main changes are as follows:

- default measure  $RMS_{Me}$  in mm instead of  $L_{Me}$  in dB;
- use the same pre-processing procedures as in ISO 13473-1 (drop-out and spikes);
- use digital filters to calculate megatexture, earlier done by spectral analysis;
- improvements of the uncertainty description of megatexture calculations;
- informative annex with reference program and reference calculations, available at the [www.erpug.org](http://www.erpug.org) homepage.

A list of all parts in the ISO 13473 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

Pavement surface texture largely influences factors such as noise emission caused by tyre/road interaction (see Reference [1]), tyre/pavement friction (see Reference [2]), and comfort, as well as rolling resistance (see Reference [3]) and wear of tyres. Reliable methods of measuring and characterizing texture are therefore essential. Texture is subdivided into micro-, macro- and megatexture according to ISO 13473-2. A method for measurement and calculation of a macrotexture indicator based on a profile measurement is specified in ISO 13473-1[4]. A procedure for measuring macrotexture by the volumetric patch method is described in EN 13036-1[5]. Currently, no reliable and practical method of measuring pavement microtexture in situ is available. This document aims to provide means of measuring and calculating a megatexture indicator useful for pavement surface characterization.

Megatexture is an important texture range lying between macrotexture and unevenness. This type of texture has wavelengths of the same order of magnitude as a tyre/road interface and is often a result of potholes or 'washboarding'. Some common types of singularities, such as a single depressed (e.g. a pothole) or protruding (e.g. caused by tree roots) spot on the pavement, will also show up in a texture profile spectrum as megatexture. Although some pavements, such as paving stones, possess an intrinsic megatexture, it is usually an unwanted characteristic resulting from defects in the surface. Megatexture is an undesirable feature, the higher the value, the worse the road is perceived: megatexture is known to increase tyre/road noise by inducing tyre vibrations. At the same time, these tyre vibrations cause energy dissipation in the tyre. The rolling resistance increases and this leads to highly unwanted fuel consumption and CO<sub>2</sub> emission (see also 3.2).

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# Characterization of pavement texture by use of surface profiles —

## Part 5: Determination of megatexture

### 1 Scope

This document specifies a procedure for determining the magnitude of pavement surface megatexture by measuring the surface profile and calculating a megatexture descriptor from this profile. The technique is designed to give meaningful and accurate measurements and descriptions of pavement megatexture for various purposes, such as for the prediction of the acoustic quality of the pavement or the assessment of the rolling resistance.

Since there is an overlap between megatexture and the surrounding ranges, megatexture descriptors unavoidably have a certain correlation with corresponding measures in those ranges. This document specifies measurements and procedures which are in relevant parts compatible with those in ISO 13473-1<sup>[4]</sup>, ISO 8608<sup>[6]</sup> and EN 13036-5<sup>[7]</sup>.

### 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13473-2, *Characterization of pavement texture by use of surface profiles — Part 2: Terminology and basic requirements related to pavement texture profile analysis*

ISO 13473-3, *Characterization of pavement texture by use of surface profiles — Part 3: Specification and classification of profilometers*

ISO/PAS 13473-6, *Characterization of pavement texture by use of surface profiles — Part 6: Verification of the performance of laser profilometers used for pavement texture measurements*

### 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13473-2 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

#### 3.1 General terms

##### 3.1.1

##### texture wavelength

$\lambda$

quantity describing the horizontal dimension of the irregularities of a *texture profile* (3.1.3)

Note 1 to entry: Texture wavelength is normally expressed in metres (m) or millimetres (mm).

Note 2 to entry: Texture wavelength is a descriptor of the wavelength components of the profile and is related to the concept of the Fourier Transform of a series regularly sampled measurement points along a spatial axis. Vertical displacement (height) has an arbitrary reference.

**3.1.2  
pavement texture  
texture**

deviation of a pavement surface from a true planar surface, with a *texture wavelength* (3.1.1) less than 0,5 m

Note 1 to entry: It is divided into micro-, macro- and megatexture according to 3.2.

**3.1.3  
surface profile  
texture profile**

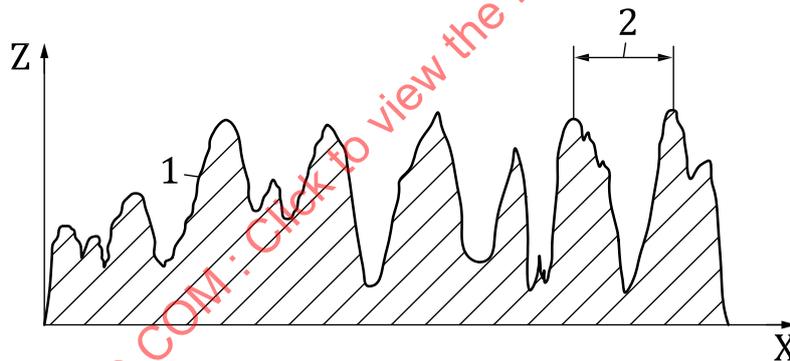
upper contour of a vertical cross-section through a pavement

Note 1 to entry: The surface profile (texture profile) is further indicated with its mathematical descriptor  $Z(X)$ .

Note 2 to entry: A typical profile recording of a pavement surface is illustrated in Figure 1 (vertical scale exaggerated), including the terms profile, distance, vertical displacement and wavelength. "Wavelength" in the figure is an illustration of a component of the profile related to the wavelength concept but it is not correct from a strictly mathematical point of view. Furthermore, the reference (bottom) line is arbitrary.

Note 3 to entry: The profile of the surface is described by two coordinates: one in the surface plane, called distance (the abscissa), and the other in a direction normal to the surface plane, called vertical displacement (the ordinate). An example is given in Figure 1. The distance may be in the longitudinal or lateral (transverse) directions in relation to the travel direction on a pavement, or in a circle or any other direction between these extremes.

Note 4 to entry: Texture profile is similar to surface profile but limited to the texture range.



**Key**

- X distance
- Z vertical displacement
- 1 surface profile
- 2 texture wavelength

**Figure 1 — Illustration of some basic terms describing pavement surface texture**

**3.1.4  
drop-out**

data in the measured texture profile indicated by the sensor as invalid

**3.1.5  
spike**

unusually high and sharply defined peak in the measured texture profile, which is not part of the true texture profile and is not indicated as invalid by the sensor

Note 1 to entry: See Annex A for a quantitative definition of a spike.

### 3.1.6

#### **profilometer**

device used for measuring the profile of a pavement surface  $Z(X)$  to be used for calculation of certain mathematically defined measures

Note 1 to entry: Current designs of profilometers used in pavement engineering include, but are not limited to, sensors based on laser, light sectioning, needle tracer and ultrasonics technologies. The most common sensor type used in profilometers is laser based. In most cases, the profile is recorded for subsequent analysis, in some cases it may be used only in real-time calculations.

Note 2 to entry: Specifications for profilometers are dealt with in ISO 13473-3.

## 3.2 Ranges of texture

### 3.2.1

#### **microtexture**

##### **pavement microtexture**

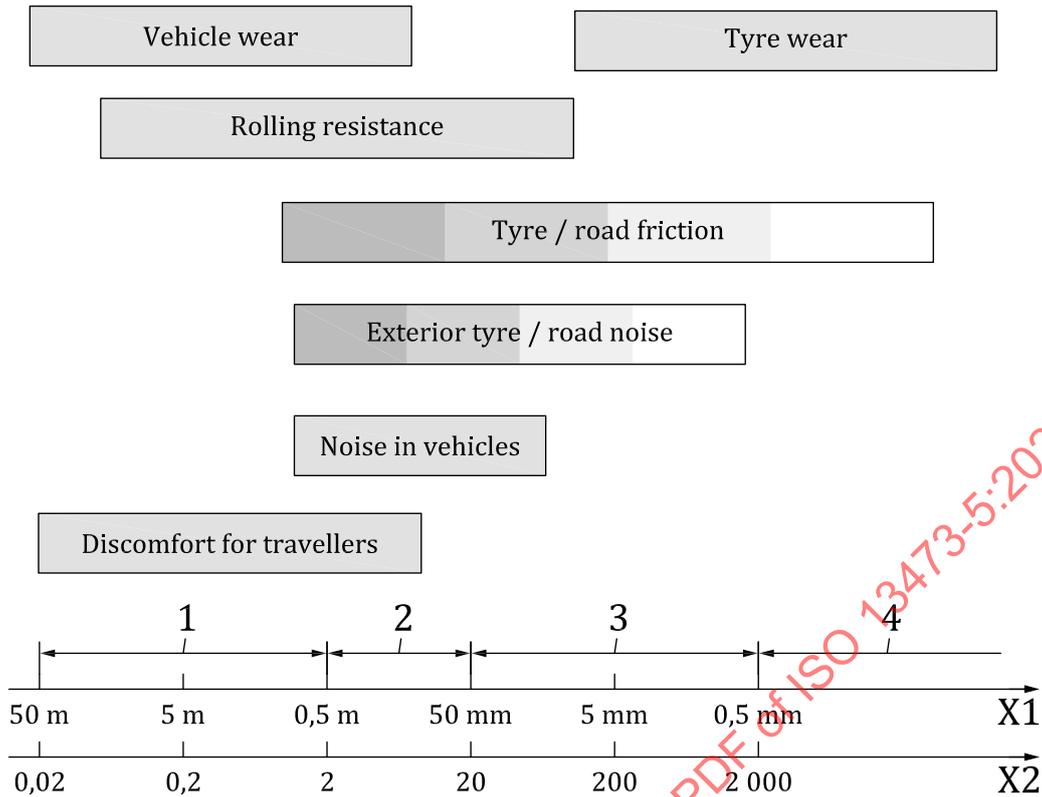
deviation of a pavement surface from a true planar surface with the characteristic dimensions along the surface of less than 0,5 mm, corresponding to texture wavelengths up to 0,5 mm expressed as one-third-octave centre wavelengths

Note 1 to entry: Peak-to-peak amplitudes normally vary in the range 0,001 mm to 0,5 mm. This type of texture is the texture which makes the surface feel more or less harsh but which is usually too small to be observed by the eye. It is produced by the surface properties (sharpness and harshness) of the individual aggregate or other particles of the surface which come in direct contact with the tyres.

Note 2 to entry: Based on physical relations between texture and friction, noise, etc., the World Road Association (PIARC) has defined the ranges of micro-, macro- and megatexture earlier; see Reference [8]. [Figure 2](#) illustrates how these definitions cover certain ranges of surface texture wavelength and spatial frequency, and how various characteristics are influenced within these ranges.

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# ISO 13473-5:2025(en)



## Key

- X1 wavelength
- X2 spatial frequency [1/m]
- 1 unevenness
- 2 megatexture
- 3 macrotexture
- 4 microtexture

NOTE A lighter shade indicates a favourable effect over this range and a darker shade indicates an unfavourable effect.

**Figure 2 — Ranges in terms of wavelength and spatial frequency of texture and unevenness and their most significant, anticipated effects<sup>[8]</sup>**

### 3.2.2

#### macrotexture

#### pavement macrotexture

deviation of a pavement surface from a true planar surface with the characteristic dimensions along the surface of 0,5 mm to 50 mm, corresponding to texture wavelengths with one-third-octave bands including the range 0,63 mm to 50 mm of centre wavelengths

Note 1 to entry: Peak-to-peak amplitudes may normally vary in the range 0,1 mm to 20 mm. This type of texture is the texture which has wavelengths of the same order of size as tyre tread elements in the tyre/road interface. Surfaces are normally designed with a sufficient macrotexture to obtain a suitable water drainage in the tyre/road interface. The macrotexture is obtained by suitable proportioning of the aggregate and mortar of the mix or by surface finishing techniques. The size of the macrotexture has a positive correlation with the stone size of the pavement.

### 3.2.3

#### **megatexture**

#### **pavement megatexture**

deviation of a pavement surface from a true planar surface with the characteristic dimensions along the surface of 50 mm to 500 mm, corresponding to texture wavelengths with one-third-octave bands including the range 63 mm to 500 mm of centre wavelengths

Note 1 to entry: Peak-to-peak amplitudes normally vary in the range 0,1 mm to 50 mm. This type of texture is composed of wavelengths with the same order of size as a typical tyre/road interface and is often created by potholes or ripples in the surface. It is usually an unwanted characteristic resulting from defects in the surface, but it can as well be intrinsic to the pavement (e.g. cobble stones). Surface roughness with longer wavelengths than megatexture is referred to as unevenness and typically takes the form of undulations in the surface.

### 3.2.4

#### **unevenness**

#### **pavement unevenness**

deviation of a pavement surface from a true planar surface with the characteristic dimensions along the surface of 0,5 m to 50 m, corresponding to wavelengths with one-third-octave bands including the range 0,63 m to 50 m of centre wavelengths

Note 1 to entry: Pavement characteristics at wavelengths longer than 0,5 m are considered to be above that of texture and are referred to here as "unevenness". For airfield applications, even wavelengths longer than 50 m would be considered.

Note 2 to entry: Longitudinal unevenness is a type of surface roughness which, through vibrations, affects ride comfort in, and road holding of vehicles. Transverse unevenness, e.g. due to the presence of ruts, affects safety through lateral instability and water accumulation. It is not the intention of this document to include terms which are specifically related to unevenness. Such terms are defined in ISO 8608<sup>[6]</sup>, ISO 16063-1<sup>[9]</sup>, ASTM E950/E950M-09<sup>[10]</sup> and EN 13036-5<sup>[7]</sup>.

## 3.3 Megatexture measurement method

### 3.3.1

#### **measurement length**

$l_m$

length of an uninterrupted texture profile which has been or is to be measured

Note 1 to entry: Measurement length is normally expressed in metres.

### 3.3.2

#### **evaluation length**

$l_e$

length of a portion of one or more profiles for which megatexture  $RMS_{Me}$  (3.3.5) is to be evaluated

Note 1 to entry: Evaluation length is normally expressed in metres.

Note 2 to entry: The evaluation length is always smaller or equal to the measurement length.

### 3.3.3

#### **calculation length**

$l_c$

length of a portion of one or more profiles for which megatexture  $RMS_{Me}$  (3.3.5) is to be calculated

Note 1 to entry: Calculation length is normally expressed in metres or millimetres.

Note 2 to entry: The calculation length is always smaller or equal to the evaluation length. One  $RMS_{Me}$  value is presented per calculation length.

### 3.3.4

#### **megatexture profile $Z'(X)$**

texture profile after application of the megatexture digital filters (see [Annex D](#)) to the *texture profile*  $Z(X)$  (3.1.3)

### 3.3.5 megatexture root mean square deviation of the profile

$RMS_{Me}$

root mean square (*RMS*) value of the ordinate values of megatexture profile  $Z'(X)$  within a calculation length  $l_c$

$$RMS_{Me} = \sqrt{\frac{1}{l_c} \int_0^{l_c} Z'^2(X) dX}$$

where

$l_c$  is the calculation length;

$Z'(X)$  is the megatexture profile.

Note 1 to entry:  $RMS_{Me}$  is normally expressed in millimetres (mm) in this application.

Note 2 to entry:  $RMS_{Me}$  is denoted  $R_q$  (from “rugosité quadratique” in French) in ISO 4287. However, when dealing with pavements,  $RMS_{Me}$  is preferred, since it is already one of the most used terms in pavement analysis. Furthermore, there is a risk of confusing of the terms  $R_q$  and  $R_{ku}$  which are pronounced similarly.

Note 3 to entry: In case the texture level  $L_{Me}$  (expressed in dB re. 1  $\mu\text{m}$ ) is given, the  $RMS_{Me}$ , expressed in mm, is easily calculated with the equation  $RMS_{Me} = 0,001 \cdot \log(L_{Me}/20)$ . Inversely, if the  $RMS_{Me}$  is given (expressed in mm), the  $L_{Me}$  is found with the expression  $L_{Me} = 20 \cdot \log(RMS_{Me} \cdot 1\,000)$  (dB re. 1  $\mu\text{m}$ ).  $L_{Me}$  was used as a standard indicator in the previous version of this standard.

## 4 Measurement instruments

### 4.1 Instruments in general

#### 4.1.1 General

The technology for measuring the profile can be chosen freely by the user as long as the requirements of this document are met. An instrument which produces a signal that is proportional to the distance between a sensor's reference plane and a given surface sample point, can be used. Typically, the sensor would normally be an electro-optical device or a video camera, but other devices that comply with the requirements of ISO 13473-3 may be used. The final output shall be linearly related to the texture profile and linearity may be obtained either in hardware or software.

The profilometer system shall also provide means of moving the sensor along or across the surface at an elevation (vertically) which is essentially constant over at least one full wavelength. However, this is not applicable when the profile is produced by a technique such as light sectioning where the profile and its reference line or plane are recorded instantaneously.

The profilometer system shall meet the following specifications in accordance with ISO 13473-3:

- mobility class: mobile, fast or slow;
- texture wavelength: class EF (63 mm to 500 mm) or wider;
- minimum vertical measuring range: 60 mm;
- vertical resolution: 0,04 mm or better;
- horizontal resolution: less than or equal to the sampling interval;
- maximum sampling interval: 5 mm;
- texture wavelength range of sensor and recording system: the frequency response of the entire measuring and data collection system shall be within  $\pm 1$  dB over the entire megatexture range;
- background noise: maximum *RMS* value: 0,05 mm (see further in ISO 13473-3);

— alignment of sensor and local slope limitation: see ISO 13473-3.

#### 4.1.2 Performance check

Regular performance checks shall be made in accordance with ISO/PAS 13473-6.

#### 4.1.3 Indication of invalid readings (drop-outs)

Invalid readings, also known as 'drop-outs', can occur due to the photometric properties of the surface or shadowing of light in deep troughs of the profile. Therefore, the system shall have means to identify drop-outs.

In addition, laser diodes deteriorate over time, which can eventually result in excessive invalid readings. For this reason, and for checking that the intensity is within the manufacturer's specification, it is recommended that there be a means of checking the laser intensity at certain intervals. A method for this is described in ISO/PAS 13473-6.

## 5 Test surface considerations

### 5.1 General

The measurements shall not be taken in rain or snow. The surface shall be dry during measurements, unless it has been established that the equipment used works equally well on a wet and dry surface. In addition, the surface shall be clean and free of all elements which could disturb the measurements.

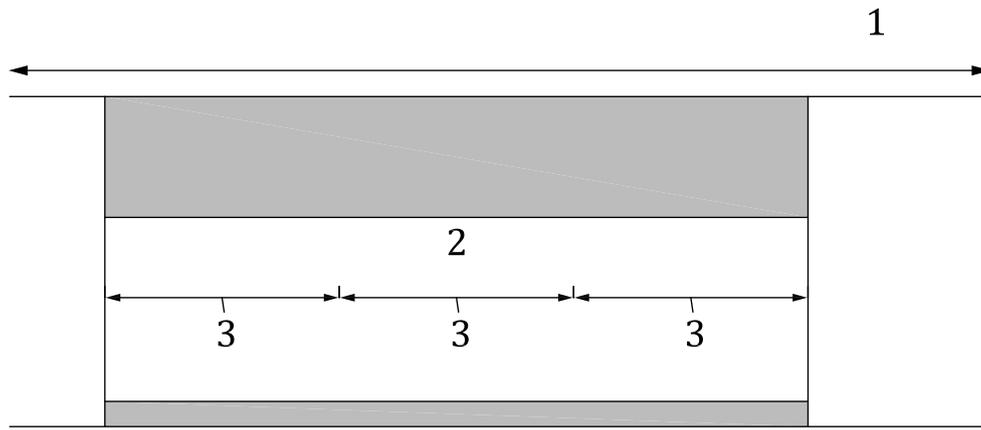
NOTE Measurements with an optical system are not necessarily very reliable for asphalt surfaces which have recently been paved, since these are usually exceptionally dark and shiny. If megatexture tests are carried out during or rather soon after laying of asphalt, distortions due to temperature gradients in the air above the test surface can influence the measurement results.

For roads open to traffic, texture normally varies over a cross-section. In this case, the lateral position of the measurements should be in accordance with the planned use of the results. Megatexture root mean square deviation of the profile,  $RMS_{Me}$ , can even be heavily dependent on the exact lateral position where it is measured, which can be e.g. the case if a bituminous pavement ravel or is after-compacted in the wheel tracks. This should be assessed by means of visual observations. The lateral position should be defined as accurately as possible and in some cases, it may be advisable to perform several runs over the same road section in order to evaluate the uncertainty due to lateral heterogeneity, see also discussion on measurement uncertainty in [Clause 8](#) and [Annex C](#).

### 5.2 Test lengths

The calculation length shall be 1 m ([Figure 3](#)).

NOTE This length provides a BT product (bandwidth  $\times$  length) of about 16. Shorter calculation lengths do not accurately include the longer wavelengths of the megatexture range and introduce offsets and trends not consistent with the interpretation of texture.

**Key**

- 1 measurement length
- 2 evaluation length
- 3 calculation lengths (1 m)

**Figure 3 — Illustration of the concepts “measurement length”, “evaluation length” and “calculation length”**

It is recommended that measurements and evaluations (and hence calculations) are made along the entire test section; i.e. if a profile is recorded longitudinally along the test section, 100 % of the measurement length should be utilized.

Although a continuous measurement is the ideal, the measured profile shall include no less than five evenly distributed profiles of at least 1 m each per 100 m test section. The calculation length shall be 1 m.

When characterizing a long test section with relatively short sample lengths, ensure that the texture within the sample length(s) is sufficiently representative of the total length. If it is not possible to evaluate the entire section, it is necessary to determine the minimum number of samples necessary to minimize the effect of any suspected non-homogeneities. The selection of these samples can be done according to the procedure as outlined in [Annex F](#).

## 6 Measurement method

### 6.1 General

The measurements shall comprise the following operations:

- a) testing of the sensitivity to vertical motion of the vehicle (only at certain intervals, see [6.2](#));
- b) calibration of the profilometer system (see [6.3](#));
- c) running the profilometer over the test section and measuring the pavement surface profile (see [6.4](#)), using a suitable test speed as specified in [6.4](#).

### 6.2 Sensitivity to vertical motion of the vehicle

Ensure that the sensor is stable at least during the measurement of a full calculation length and for all operating speeds, or that it has some means of compensation for vertical motions. This requires that vertical motions, e.g. those occurring at the natural suspension frequency of the sensor and/or its carrier, shall have negligible influence, i.e. shall not violate the background noise requirements specified in [4.1](#).

A suitable test is to run the carrier of the measuring device on a smooth and even surface so that the tyres roll over an object, having a height of 20 mm to 25 mm, a width of 200 mm and a length of 100 mm to

150 mm, placed on the surface at the same time as the sensor does not measure the object. Rolling over the object will excite vertical motions in the vehicle. The difference in recorded profile with and without the object is an indication of the influence of vertical motion of the vehicle.

The testing described in this clause is necessary when the performance of the measuring system is checked the first time, as well as at later intervals when the vehicle suspension system performance may have changed.

A recent experiment simulating car body vibrations showed that the incurred uncertainty is not more than 4 % of the texture amplitude<sup>[11]</sup>.

### 6.3 Calibration

Calibration shall be carried out by running the sensor over a special calibration surface utilizing a well-defined profile. The vertical deviation of the calibration surface, in relation to its theoretical profile, shall not exceed 1 % of its peak-to-peak amplitude.

The background noise when measuring stand still against a white paper with a simulated speed of 70 km/h should be less than 0,05 mm  $RMS_{Me}$ .

Calibration procedures are not further specified here. They shall be designed such that the extra standard uncertainty introduced by the procedure (in addition to the calibration surface, see above) is no worse than 10  $\mu\text{m}$   $RMS_{Me}$ .

Report the type of calibration used.

For testing the calculation procedures presented in this standard, the reader is referred to [Annex E](#).

NOTE For calibration procedure and examples of calibration surfaces, refer to the principles explained in ISO 13473-3:2002, Annex A. Consider the possibility of an adaptation to the appropriate wavelength range for megatexture, although a calibration surface intended for the macrotexture range can be used also for megatexture if the fundamental wavelength is at least 10 mm.

### 6.4 Measuring speed

The speed with which the profile is sampled shall be such that the requirements on sampling and bandwidth are met.

NOTE Modern profilometers have bandwidths which are typically between 30 and 70 kHz, which allows (theoretical) measuring speeds of 5 400 and 12 600 km/h, respectively. Hence way above any physical or legal speed limitation.

### 6.5 Measurement of the texture profile

The texture profile shall be measured with sample intervals less than or equal to 5 mm. Sample intervals longer than 5 mm introduce excessive error in the measurements<sup>[12]</sup>.

NOTE The error caused by longer sampling intervals is from aliasing. Aliasing error occurs when a function is sampled without first being low-pass filtered. Texture profiles measured with sample intervals less than or equal to 5 mm can still have aliasing but the effect on the megatexture result is not significant. When the sample interval is greater than 5 mm, the error caused by aliasing becomes significant.

If the measured profile is used also for determining macrotexture according to ISO 13473-1, then the maximum sampling interval shall meet the requirements in ISO 13473-1.

## 7 Data processing

### 7.1 General

The measurements and calculations shall comprise the following operations:

- a) eliminate the effect of drop-outs;
- b) eliminate the effect of spikes;
- c) resampling to a certain spatial resolution;
- d) application of the megatexture digital filters to the part of the profile which will be used for the calculation of the  $RMS_{Me}$  value(s);
- e) calculation of the  $RMS_{Me}$  value  $RMS_{Me,i}$  of part  $i$  of the profile with calculation length  $l_c$ ;

### 7.2 Preprocessing: drop-out rate and validity of measurements

Care shall be taken to eliminate invalid readings from the profile. For example, invalid measurements can occur due to surface photometric properties or shadowing of light in deep surface troughs. Instead, the invalid part of the profile shall be replaced with interpolated data from the nearest valid points.

As illustrated in [Figure 4](#), several drop-outs can occur in succession. When a series of invalid samples is preceded and followed by valid samples, each of the invalid samples shall be replaced by an interpolated value. Linear interpolation shall be used.

With regard to linear interpolation, the invalid samples are replaced by an interpolated value  $z_i$  according to [Formula \(1\)](#):

$$z_i = \frac{z_n - z_m}{n - m} (i - m) + z_m \quad (1)$$

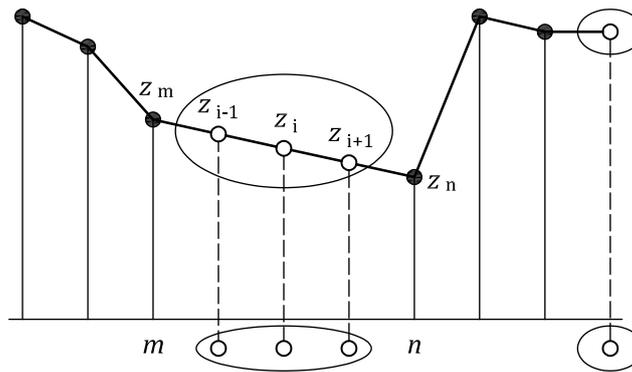
where

- $i$  is the sample numbers where the value is invalid;
- $m$  is the sample number of the nearest valid value before  $i$ ;
- $n$  is the sample number of the nearest valid value after  $i$ ;
- $z_i$  is the interpolated value for sample  $i$ ;
- $z_m$  is the value of sample  $m$ ;
- $z_n$  is the value of sample  $n$ .

When the invalid sample(s) constitute(s) the beginning or the end of a sampled profile, the invalid samples shall be replaced by the value of the nearest valid sample. This method of extrapolation shall be limited to a maximum length at either side of the sampled profile data series equal to 5 times the sampling interval. If there are more invalid samples than 5 times the sampling interval in the beginning or the end of a sampled profile the affected  $RMS_{Me}$  value(s) should be discarded.

An illustration of the application of the above procedure is shown in [Figure 4](#).

For the study of road surface singularities (like joints), such singularities can be intentionally included in the analysis, on condition that no drop-out readings of the sensor occur.



NOTE Drop-outs are illustrated by unfilled symbols.

**Figure 4 — Illustration of interpolation and extrapolation of drop-outs**

NOTE In the case illustrated in [Figure 4](#), there are three intermediate consecutive drop-outs, which are linearly interpolated between the samples at positions  $m$  and  $n$ , and one extreme drop-out at the end of the profile, which is extrapolated from the preceding sample.

The measurement on a particular pavement profile is considered valid only if the drop-out rate meets the following criterion<sup>[13]</sup>:

- calculation lengths with loss of data due to drop-out less or equal to 10 % (of the total number of samples), otherwise  $RMS_{Me}$  for the calculation length shall be discarded.

### 7.3 Spike identification and reshaping the profile

The spike removal procedure shall be as described in [Annex A](#). Spike removal shall be performed. For the segment to be valid, the removed spikes should not correspond to more than 5 % per calculation length.

### 7.4 Resampling to a certain spatial resolution

This requirement is applicable to the majority of profilometer systems, particularly those performing sampling on a time basis (constant sample time interval) which, because of variations in measurement speed, can result in a profile with variable spatial resolution (non-constant sample distance intervals). This resampling step may not be required if the measurement system samples on a distance basis, or if a similar resampling process is performed within the measurement system.

The resampling is done by calculating the arithmetic average of all original samples that fall within the sample interval. Calculate  $RMS_{Me}$  using a 5 mm sampled or resampled profile. All texture profile samples in the spatial domain above 0 mm up to and including 5 mm are averaged.

NOTE 1 For example, if a profile has a sampling interval larger than 5 mm, then it is not suitable for an  $RMS_{Me}$  calculation.

NOTE 2 Using the average of all original samples that fall within the new interval is a form of low-pass filtering which reduces the error due to aliasing.

### 7.5 Filtering of the profile

Low-pass and high-pass filtering shall be made in order to exclude the contributions from the evenness and the macrotexture range respectively. The filter shall be of the Butterworth type 2<sup>nd</sup> order, applied in forward-reverse application and shall result in a cut-off wavelength of approximately 56,2 mm and 562 mm, respectively, when applied in both directions. The appropriate filters and technique are described in [Annex D](#).

Ideally, a “run in” and a “run out” section of 1 m each is available before and after the section to be computed. If there are no data available before and after this section to be computed, one should extend the signal by

mirroring the first and the last segments before filtering. In any case, a large offset should be avoided and therefore the regression line should be subtracted from the profile. The mandatory procedure for this shall be as provided in [Annex G](#).

## 7.6 Calculation of $RMS_{Me}$

The filtered profile is used to calculate  $RMS_{Me}$ .  $RMS_{Me}$  shall be calculated according to Formula in [3.3.5](#) based on data at the calculation length (1 m).

## 7.7 Averaging

When  $RMS_{Me}$  at the calculation length are to be averaged, root mean square shall be used to create a representative value for a longer connected section or for repeated measurements of one or several section(s), see [Formula \(2\)](#).

$$\overline{RMS}_{Me} = \sqrt{\frac{\sum_{i=1}^n RMS_{Me,i}^2}{n}} \quad (2)$$

where

$n$  the number of samples (calculation lengths) within the evaluation length;

$RMS_{Me,i}$  is the  $RMS$  of an individual calculation length (see [3.3.2](#));

$\overline{RMS}_{Me}$  is the  $RMS_{Me}$  mean of  $RMS_{Me}$  values of all the calculation lengths.

## 7.8 Longitudinal standard deviation

The longitudinal standard deviation may be useful as a measure of homogeneity of a surface in the megatexture wavelength range. The longitudinal standard deviation,  $\sigma_{RMSMe}$ , is the standard deviation of  $RMS_{Me}$ , for all the calculation lengths within the evaluation length given by [Formula \(3\)](#):

$$\sigma_{RMSMe} = \sqrt{\frac{\sum_{i=1}^n (RMS_{Me,i} - \overline{RMS}_{Me})^2}{n-1}} \quad (3)$$

where

$n$  is the number of samples (calculation lengths) within the evaluation length;

$RMS_{Me,i}$  is the  $RMS_{Me}$   $i$ -th calculation length (see [3.3.2](#));

$\overline{RMS}_{Me}$  is the  $RMS_{Me}$  mean of  $RMS_{Me}$  values of all the calculation lengths.

## 7.9 Singularities

A singularity is a roughness feature of the surface that does not repeat itself from one evaluation length to another within a 100 m section. Examples of singularities are:

- potholes, if not repeated or continued over a distance longer than 10 m;
- sunken manholes;
- bridge joints;
- damaged joints between concrete slabs (although the joints themselves are usually repeated regularly and shall not be considered as singularities);
- severe loss of chippings at a single place;

- f) level changes on a pavement where a section has been ground away temporarily or between two types of wearing courses;
- g) markings at pedestrian crossings;
- h) depressions due to mechanical damage to the pavement.

To represent the  $RMS_{Me}$  value of a singularity, process the measured profile as follows:

Calculate the  $RMS_{Me}$  over a 1 m evaluation length within which the singularity is located and use this level as a typical value representing the singularity. The symbol for this threshold is  $RMS_{Sg}$ .

## 8 Measurement uncertainty

The measurement procedure described in this document is influenced by several factors that lead to variation in the results observed for the same subject. The source and nature of these perturbations are not fully known. The measurement uncertainty shall be determined in accordance with Reference [14].

According to Reference [14] each significant source of uncertainty shall be identified. Sources of uncertainty are identified and shall be processed according to the procedure described in Reference [14]. For the case of megatexture measurements, at least the following uncertainty categories should be determined:

- a) instrumentation uncertainty;
- b) uncertainty due to operational variations;
- c) uncertainty due to external disturbances;
- d) uncertainty to signal processing and calculation.

A more detailed analysis of the uncertainty contributions on a measurement of the  $RMS_{Me}$  of a road section is shown in [Table 1](#). Note that the uncertainties are expressed as standard deviation.

NOTE The lists of uncertainty categories and uncertainty contributions suggested here are not exhaustive.

**Table 1 — Template of an uncertainty analysis for an  $RMS_{Me}$  value measurement according to the measurement procedure outlined in this standard**

Uncertainty category	Source of uncertainty on $RMS_{Me}$	Estimand	Probability distribution	Uncertainty contribution $c_i u_i$	Subclause
1	Measurement equipment				<a href="#">4.1</a>
1	Environmental influences on the equipment				<a href="#">5.1</a>
2	Variation of the calculation length				<a href="#">3.3.3</a>
2	Variation of the start and stop position of the calculation length				<a href="#">3.3.3</a>
2	Vertical motion of the measurement vehicle				<a href="#">6.2</a>
2	Variations in measuring speed				<a href="#">6.4</a>
3	Environmental influences on the measurement				<a href="#">5.1</a>
4	Drop out correction				<a href="#">7.2</a>
4	Spike removal				<a href="#">7.3</a>
4	Megatexture filter imperfections				<a href="#">7.5</a>
Combined uncertainty $u_c$					

The value of these uncertainty contributions shall be evaluated by the procedure given in Reference [14]. It can be based on existing statistical data, analysis of tolerances stated in this document and engineering judgment. The information needed from which to derive the overall uncertainty is given in [Table 1](#). [Table C.1](#) is a copy of [Table 1](#) but includes some typical values.

NOTE 1 The estimand is the average deviation by a given uncertainty contribution.

NOTE 2  $c_i$  is the sensitivity coefficient reflecting the relative weight of each uncertainty contribution, but in this application all  $c_i$  equal 1.

NOTE 3 The contribution “Environmental influences on the equipment” deals with external factors influencing the functioning of the equipment (e.g. a high temperature causing a higher electronic noise of the laser sensor) whereas the contribution “Environmental influences on the measurement” covers external influences potentially disturbing the measurement result.

Consecutive measurements with the same equipment over the same test section can yield significantly different results, due to lateral inhomogeneity of the texture over the calculation length, but this is not considered as an uncertainty contribution. But it is recommended to take special care about this phenomenon: typically, the effect is negligible for young asphalt surfaces without any trace of wear, post compaction in the wheel traces or pollution. Worn or post compacted asphalt surfaces or concrete pavement – even new – can show a very high transversal inhomogeneity and can potentially jeopardize the reliability of texture measurements. In case of doubt about the transversal homogeneity, repeated measurements are recommended, yielding a more robust result by averaging and an estimate for the uncertainty on the result.

The combined standard uncertainty  $u_c$  is calculated with [Formula \(4\)](#):

$$u_c = \sqrt{\sum_{i=1}^{10} (c_i u_i)^2} \tag{4}$$

where  $c_i u_i$  is the sensitivity coefficient times the uncertainty contribution.

The expanded uncertainty  $U$  is determined by multiplying the combined standard uncertainty  $u_c$  with the appropriate coverage factor for the chosen coverage probability as described in Reference [14].

[Annex C](#) provides a detailed listing of the standard uncertainties and sensitivity coefficients of each source, as well as typical values for a surface giving an  $RMS_{Me}$  value of around 0,5 mm and based on an evaluation length of 100 m. Using these values, the uncertainty budget analysis results in a standard uncertainty in the  $RMS_{Me}$  value of 0,04 mm.

[Table 2](#) is a template presenting the expanded uncertainty and coverage probability in the case where the method is applied and individual source uncertainties are consistent with [Table C.1](#).

**Table 2 — Expanded uncertainty,  $U$ , and coverage probability (based on [Table 1](#))**

Coverage probability	Expanded uncertainty, $U$
%	mm
95	

See [Annex C](#) for an example of a quantitative analysis.

## 9 Safety considerations during measurements

**WARNING — This document can involve hazardous operations when measurements are made on trafficked pavements. The personnel and the vehicles present on the measuring site shall be equipped with safety or warning devices in accordance with the local regulations in force for work in the traffic flow (if any) on that specific site and at that particular time. Otherwise, this document does not purport to address the safety problems associated with its use. It is the responsibility of the user of this document to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.**

## 10 Test report

Present the results in a form comprising at least the following items.

NOTE Some of the reporting fields are optional.

- a) references:
  - 1) identification of the organization carrying out the test,
  - 2) description and identification of the measuring system,
  - 3) name of the organization requesting the tests (optional),
  - 4) identification of the measuring team (optional),
  - 5) date at which the measuring device was checked and/or calibrated by an authorized agency as well as the name of the organization that performed this service;
  - 6) a reference to this document, i.e. ISO 13473-5:2025;
  - 7) any deviations from the procedure;
- b) identification of the site:
  - 1) road number or street name,
  - 2) measured section, preferably indicating both beginning and end (e.g. including coordinates or kilometre markings),
  - 3) class of road including number of lanes (optional), as well as the history of the site, e.g. the date of paving (optional),
  - 4) lane and driving direction of the measurements,
  - 5) measured track (e.g. left wheel track, right wheel track or between wheel tracks);
- c) test surface description:
  - 1) type of pavement(s),
  - 2) maximum aggregate size and gradation (optional)
  - 3) origin of the materials (optional),
  - 4) condition of the surface (optional),
  - 5) particular features of the paving technique used (optional);
- d) special characteristics of the test area and the test:
  - 1) date of measurement,
  - 2) weather conditions (optional),
  - 3) particular test conditions, e.g. any presence of dirt or other contamination on the pavement (optional);
- e) presentation of results comprising:
  - 1) evaluation length and calculation length,
  - 2) measured  $RMS_r$ , including the root mean square as well as its standard deviation,  $\sigma_{RSM_e}$ ,
  - 3) measurement identification number (optional),

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- 4) longitudinal location of each measurement (optional),
- 5) value,  $RMS_{Me,g}$ , of any prominent singularity,
- 6) histogram of the values obtained on the tested section (optional),
- 7) expanded measurement uncertainty.
- 8) any unusual features observed.

[Annex B](#) contains an example of test report.

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## Annex A (normative)

### Spike removal procedure

#### A.1 General

As stated in [4.1.2](#), it is mandatory that laser profilometers are equipped with a system to detect invalid readings. Nevertheless, this system can make mistakes and sometimes drop-outs are not recognized as such. This can lead to “phantom” peaks (spikes) in the profile, which can seriously bias the results.

Therefore, it is mandatory to apply an a posteriori procedure<sup>[15]</sup> to a measured texture profile to remove “suspect” high and sharp peaks from the profile. The procedure outlined in this annex is intended to be inserted in the data processing chain *after* the handling of the invalid readings as described in [7.2](#); i.e. the drop-out readings are replaced by values which are interpolated between the closest valid readings before spike removal takes place. Spike removal, thus, intends to remove spikes which “slip through” the drop-out procedure.

The procedure basically consists of assigning the status of “invalid” reading to data points which meet certain criteria, even if they were not recognized as a drop-out during the measurement. The procedure, called the “excessive slope” procedure, is very straightforward:

Consider a profile with amplitude  $z_i$ , belonging to horizontal position index  $i$  and step size  $\Delta x$ . The criterion for assigning a posteriori the status of invalid reading to the  $i^{\text{th}}$  data point is given by [Formula \(A.1\)](#):

$$|z_i - z_{i-1}| \geq \alpha \cdot \Delta x \quad (\text{A.1})$$

where  $\alpha$  is a constant factor ( $\alpha = 3$ ).

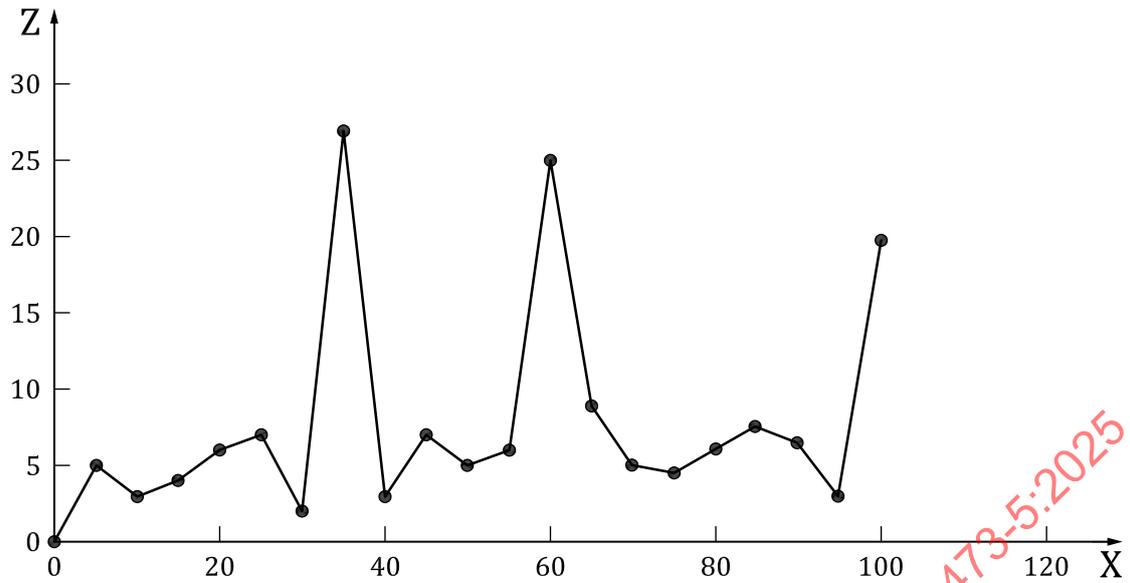
NOTE It has been found that  $\alpha = 3$  is a good choice<sup>[12][15]</sup>.

The criterion (see [Formula \(A.1\)](#)) is checked for all the data points  $i$  of the profiles. After this, the procedure shall be repeated but done in the reverse direction. The spikes are first identified in forward and reverse direction before replacing them with the interpolated value.

Subsequently, an interpolation procedure according to the drop-out treatment, as described in [7.2](#), is applied. An example is demonstrated in [A.2](#).

#### A.2 Example

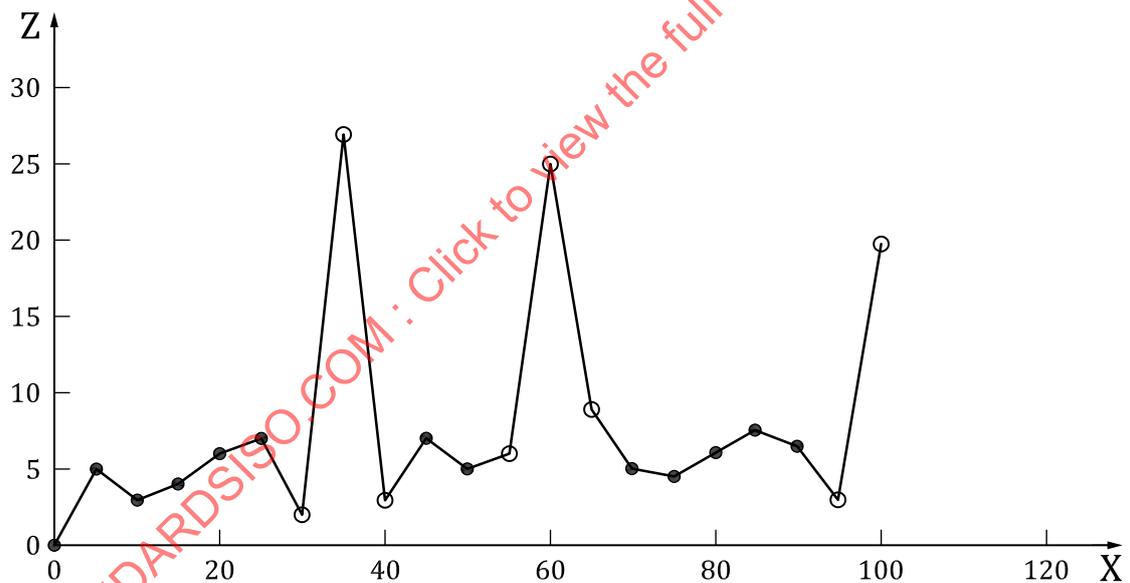
The procedure is illustrated with an example; according to [Figure A.1](#), [Figure A.2](#) and [Figure A.3](#).



**Key**

X distance, mm  
Z amplitude, mm

**Figure A.1 — Measured profile (as illustrated above) subject to analysis**

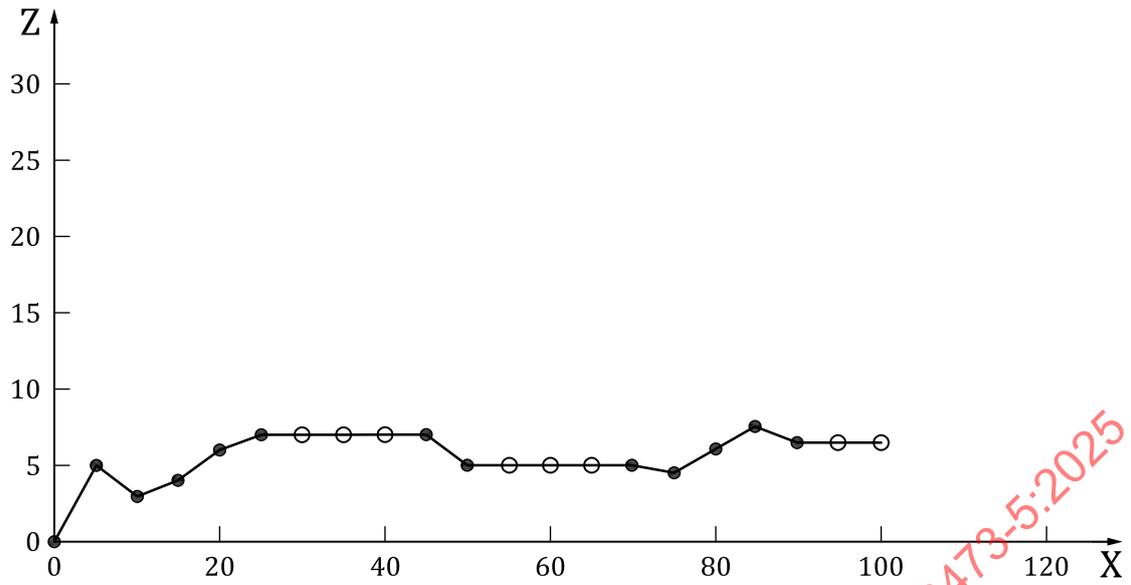


**Key**

X distance, mm  
Z amplitude, mm  
○ eight points detected as suspect readings

NOTE These points are identified by checking the criterion [A.1](#) in forward and reverse direction.

**Figure A.2 — Step 1: result of the spike removal identification procedure**



**Key**

- X distance, mm
- Z amplitude, mm
- interpolated values between the nearest valid readings

**Figure A.3 — Step 2: invalid readings replaced by interpolated values**

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## Annex B (informative)

### Example of test report and graphical presentations

#### B.1 Form suitable as a test report

The form on the following page is an example of how a test report can be designed (see [Table B.2](#)). The user of this document is allowed to copy this form.

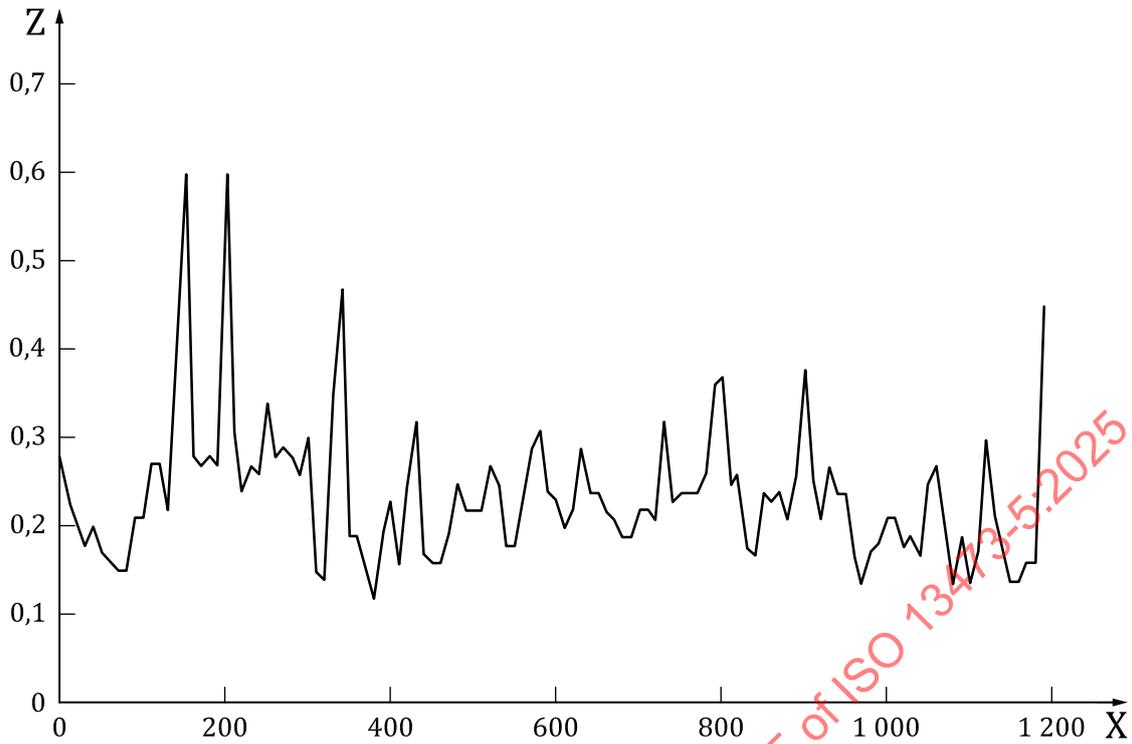
It is recommended that the test report is supplemented with graphical presentations as shown in [Figure B.1](#) and [Figure B.2](#).

#### B.2 Graphical presentations

##### B.2.1 Amplitude versus distance and histogram

For a measurement representing a certain road test section, it is appropriate to show the measured single number indicators. [Figure B.1](#) shows such a measurement running over an 1 200 m test section. Note that if the test section is much longer than 1 km, it is advisable for synchronization purposes to include in the measurement data, as well as in the presented diagram, kilometre markers made by the measurement operator or by some automatic means. [Figure B.2](#) shows the same data, but in a histogram, illustrating the frequency of occurrence of each level. The histogram gives a good overview and the signature of the evaluated section and it could also be used to compare with recurrent measurements to follow the degradation of a section.

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**Key**

X distance along test section, in m

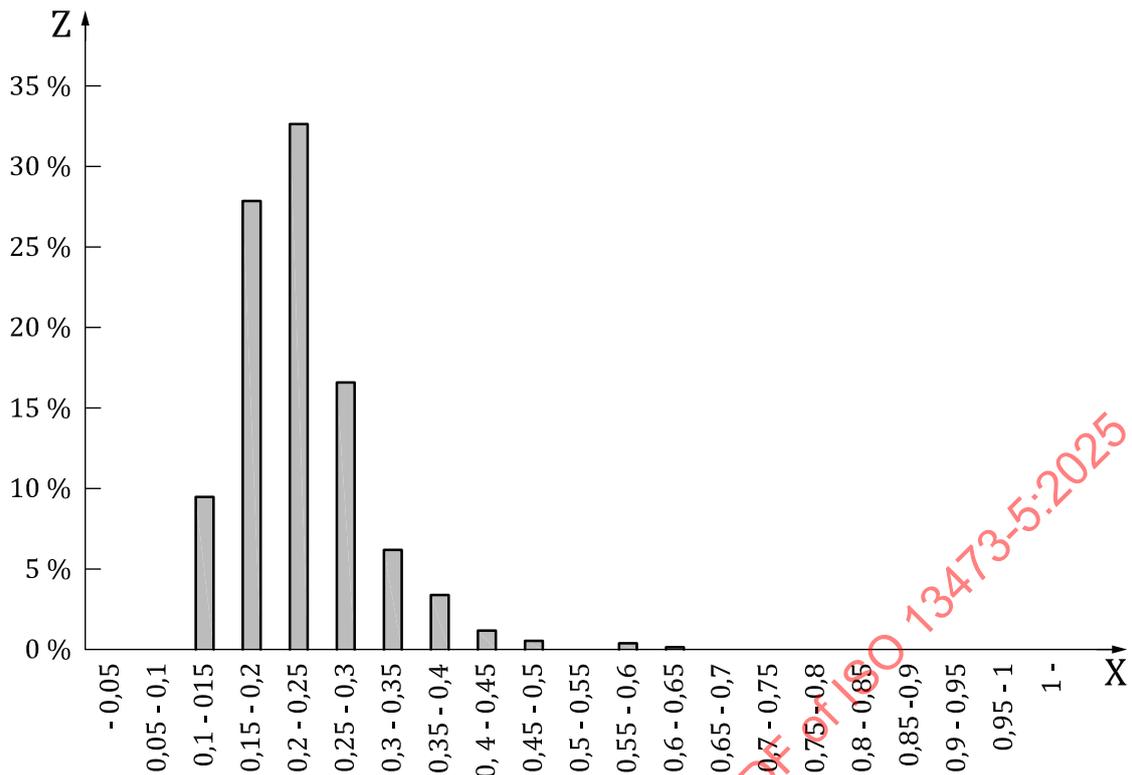
Z  $RMS_{Me}$  in mm

The pavement was a 10 years old dense asphalt concrete DAC 16.

NOTE Evaluation length was 1 200 m, calculation length was 10 m.

**Figure B.1 — Example of measured  $RMS_{Me}$  values over a test section 1 200 m long**

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**Key**

X  $RMS_{Me}$  megatexture RMS, expressed in mm

Z frequency of occurrence of observed values of  $RMS_{Me}$ , expressed in %

**Figure B.2** — Example of histogram of measured megatexture level,  $RMS_{Me}$  for the case shown in [Figure B.1](#)

**Table B.1** — Example of megatexture data

Road E854, northbound, lane 1		
<b>Start</b>	58,515 5; 16,345 8	
<b>Stop</b>	58,508 6; 16,328 0	
<b>Distance from start</b> m	$RMS_{Me}$ left mm	$RMS_{Me}$ right mm
0 to 10	0,39	0,28
10 to 20	0,47	0,23
20 to 30	0,41	0,20
30 to 40	0,36	0,18
40 to 50	0,33	0,20
50 to 60	0,38	0,17
60 to 70	0,39	0,16
70 to 80	0,26	0,15

Table B.2 — Measurement of megatexture – Model for test report

Measurement done by (organization)	Company X	Measurement system	RSTXX
Client <sup>a</sup>	Contractor X		
Operator <sup>a</sup>	Mr X	Driver <sup>a</sup>	Ms Y
Approval of measurement system, issuer and valid until	Swedish Transport Administration	Valid until 2023-12-31	

Identification of Site

Measurement object, road/street	E854	Reference system (coordinates)	WGS84
Start of measurement (coordinates or km-post)	58,515 5; 16,345 8	End of measurement	58,508 6; 16,328 0
Road type <sup>a</sup>	Highway	Pavement date <sup>a</sup>	2012-06-11
Direction	Northbound	Lane	1 (slow lane, far right)
Measured track (e.g. left, right)	Left and right wheel track		

Test surface description

Type of pavement	DAC	Max aggregate size	16
Gradation <sup>a</sup>	See attachment A	Origin of material <sup>a</sup>	See attachment A
Condition of the surface <sup>a</sup>	Old rough pavement, >10 years	Paving technique <sup>a</sup>	Conventional

Special characteristics of the test area and the test

Measurement date	2022-06-28	*Weather condition	Sunny, 25 °C
Any disturbance <sup>a</sup>	Working area between 1 100 km and 1 200 km, no measurement done	Any objects on the surface <sup>a</sup>	Debris on road between 1 000 km and 1 100 km

Presentation of results comprising

Evaluation length	1 200 km	Calculation length	10 m
Overall mean $RMS_{Me}$	0,25 mm	Overall standard deviation $\sigma_{RMS_{Me}}$	0,08 mm
Measurement identification number <sup>a</sup>	File name, E854_58.5155; 16.3458_northb_221102	Number of measurements	3 measurements
Longitudinal location <sup>a</sup>	Start at 58,515 5; 16,345 8 equals distance 0 m in diagrams	Prominent singularity ( $RMS_{Me,sq}$ )	0,36 mm
Histogram <sup>a</sup>	See attachment B	Expanded measurement uncertainty	0,04 mm

<sup>a</sup> Optional properties are marked with \*. Fill in or refer to an attachment. Example information/answers is written with grey text.

B.3 Example of measured values

Table B.3 shows typical examples of measured values on various pavements expressed as  $RMS_{Me}$  [16]. Note that these are just examples. There can be large differences in values measured on similar surfaces at other places.

Table B.3 — Typical examples of measured values expressed as  $RMS_{Me}$

	Average mm	Standard deviation mm
SMA11	0,47	0,14
SMA16	0,58	0,17
DAC11	0,33	0,19
DAC16	0,29	0,16
Thin surface 11	0,59	0,08
Thin surface 16	0,60	0,20
Surface dressing 11	0,77	0,20
Surface dressing 16	0,82	0,18

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## Annex C (informative)

### Measurement uncertainty

#### C.1 Example of an elaborated uncertainty analysis

Uncertainties can be expressed as standard uncertainties or expanded uncertainties. In summary, standard uncertainties are expressed as the standard deviations of a given measure around the estimated average value, whereas the expanded uncertainty multiplies the standard uncertainty with a coverage factor that, under the assumption of a normal distribution, equals 1,95 for a coverage probability of 95 %.

The expanded uncertainty rather than the standard uncertainty should be reported since the former provides a better coverage probability; i.e. a “safer” estimate of the uncertainty.

As stated in [clause 8](#), an uncertainty analysis should be carried out according to the procedure outlined in Reference [14] and a canvas for such an analysis was presented. An example of a completed table is given in [Table C.1](#).

**Table C.1 — Example of an elaborated uncertainty analysis for an  $RMS_{Me}$  value measurement**

Uncertainty category <sup>a</sup>	Source of uncertainty on $RMS_{Me}$	Estimand mm	Probability distribution	Uncertainty contribution $c_i u_i$ mm	Subclause
1	Measurement equipment <sup>b</sup>	0	normal	0,02 to 0,03	<a href="#">4.1</a>
1	Environmental influences on the equipment <sup>c</sup>	~0	half normal	<0,001	<a href="#">5.1</a>
2	Variation of the calculation length <sup>d</sup>	0	normal	<0,001	<a href="#">3.3.3</a>
2	Variation of the start and stop position of the calculation length <sup>e</sup>	0	normal	0,019	<a href="#">3.3.3</a>
2	Variations in measuring speed <sup>f</sup>	0	normal	<0,001	<a href="#">6.4</a>
2	Vertical motion of the measurement vehicle <sup>g</sup>	0,04 to 0,28	rectangular	0,012 to 0,035	<a href="#">6.2</a>
3	Environmental influences on the measurement <sup>h</sup>	~0	half normal	<0,001	<a href="#">5.1</a>
4	Drop out correction <sup>i</sup>	~0	half normal	<0,001	<a href="#">7.2</a>
4	Spike removal <sup>j</sup>	~0	half normal	<0,001	<a href="#">7.3</a>

Table C.1 (continued)

Uncertainty category <sup>a</sup>	Source of uncertainty on $RMS_{Me}$	Estimand mm	Probability distribution	Uncertainty contribution $c_i u_i$ mm	Subclause
4	Megatexture filter imperfections <sup>k</sup>	0	normal	0,005	7.5
Combined uncertainty $u_c$				0,03 to 0,05	
<p><sup>a</sup> The categories are described in <a href="#">Clause 8</a>.</p> <p><sup>b</sup> The uncertainty contribution originating from the <i>Measurement equipment</i> comprises several sub contributions, such as the background noise of the equipment, the non-linearity and uncertainty coming from an imperfect calibration. From ISO/PAS 13473-6 one can estimate the <math>RMS_{Me}</math> due to background noise to be between 0,01 and 0,06 mm, dependent on the quality of the equipment, and the uncertainty due to non-linearity about 0,01 mm. Allow another 0,01 mm for the uncertainty on the calibration, and one finds a combined uncertainty contribution for the measurement equipment between 0,02 and 0,03 mm. The probability distribution is a combination of several independent variables and can according to the Central Limit Theorem be approximated by a normal distribution.</p> <p><sup>c</sup> <i>Environmental influences on the equipment</i> comprise the influence of temperature and relative humidity on the functioning of the equipment (e.g. high temperature could lead to an increase of background noise). In case properly shielded and stabilized modern equipment is used in the within the environmental limits prescribed by the manufacturer, this contribution is generally negligible, but this shall be checked in the equipment manual/specifications.</p> <p><sup>d</sup> The calculation length should be precisely determined, hence no significant uncertainty contribution to be expected</p> <p><sup>e</sup> This contribution is dependent on the longitudinal homogeneity of the pavement and the precision of the start and stop procedure of the measurement. On a quite homogeneous (no visible inhomogeneities) and a sufficient calculation length, the exact start and stop positions are not very critical and this contribution can be neglected. An annual start/stop leads typical to an uncertainty on the start and stop positions of 1 m to 2 m at 50 km/h but this is in the case of a good homogeneity hence no problem. On a pavement with clear longitudinal inhomogeneities one has to be aware that this uncertainty contribution could become significant, especially with a short calculation length and an imprecise start/stop procedure. In that case it is advised to use a precise start/stop procedure, e.g. systems with a photocell and reflex.</p> <p><sup>f</sup> Variations in the measurement speed should not lead to any significant contribution, provided the speed remains within the allowable limits determined by the bandwidth of the measurement and the sampling is done properly (should be checked).</p> <p><sup>g</sup> The frequency (<math>f</math>) of the suspension of modern cars is always between 1 Hz (a lower frequency would induce car sickness) and 4 Hz (a higher frequency would cause resonances with car interior parts). The higher the eigenfrequency of the suspension of the test vehicle, the bumpier the road and the lower the measurement speed, the higher the influence of the car body movement on the <math>RMS_{Me}</math>. For <math>f = 4</math> Hz, an amplitude of 1 mm and a measurement speed of 10 m/s, the car body movement induces an uncertainty of about 0,11 mm. A typical value can be considered <math>f = 2</math> Hz, an amplitude of 1 mm and a measurement speed of 14 m/s (50 km/h), yielding an uncertainty of 0,06 mm. The distribution is considered to be rectangular as it depends on car and measurement parameters which have the same likelihood. Note that the average induced error (the estimand) is not zero.</p> <p><sup>h</sup> Environmental influences on the measurement can be omitted: temperature, air pressure, and wind speed have a negligible influence on texture measurement. Moisture on the road can disturb the measurement of an optical system by specular reflection, but this problem does not occur if the measurements are carried out under dry conditions, unless it has been demonstrated that the measurement is insensitive to moisture, complying with <a href="#">5.1</a>. Disturbances due to environmental factors generally increase the measured <math>RMS_{Me}</math>, hence the distribution is considered a one sided half normal probability distribution. The uncertainty contribution can however be considered as negligible.</p> <p><sup>i</sup> The uncertainties caused by the drop-out removal procedure can be neglected in the megatexture range, provided the requirements on drop-out rate are observed.</p> <p><sup>j</sup> The uncertainties caused by the spike removal procedure can be neglected in the megatexture range, provided the requirements on drop-out rate are observed.</p> <p><sup>k</sup> The uncertainty contribution due to megatexture filter imperfections can be neglected.</p>					

## C.2 Combined and expanded uncertainty

The sources of uncertainty in [Table C.1](#) are considered to be uncorrelated. Therefore, the estimated combined standard uncertainty,  $u_c$ , is given by the square root of the sum of squares of the individual uncertainties contained in [Table C.1](#).

The individual standard uncertainties should be multiplied by their respective sensitivity coefficients prior to squaring. However, in this case and as aforesaid, the sensitivity coefficients are all assumed to be equal to 1; thereby simplifying the equation. The expanded uncertainty,  $U_{exp}$ , for a coverage factor of 1,95,

corresponding to a coverage probability of 95 % in accordance with the guidelines given in<sup>[14]</sup> is given by [Formula \(C.1\)](#):

$$U_{\text{exp}} = 1,95 u_c \quad (\text{C.1})$$

The expanded uncertainty for  $RMS_{\text{Me}}$  based on the combined standard uncertainties derived from [Table C.1](#) is 0,06 mm up to 0,1 mm.

NOTE The expanded uncertainty obtained in this way is the same as the 95 % confidence interval (single-sided) provided the values are normally distributed. For detailed explanations, see Reference [\[14\]](#). For a summary refer to ISO 16063-1:1998, Annex A.

The uncertainty values can be determined, based on special measurements and experience from the device which is used. However, in cases where these data are not available, the values given in [Table C.1](#) may be used for temporary guidance.

The following advice for performing uncertainty studies can be useful: the values of the above mentioned standard uncertainties (per each type) should preferably be evaluated for actual parameter values and conditions that apply to a specific measurement and analysis case. This evaluation may be done by executing comparative measurements and analyses of representative or typical pavement sections for different values of one of the parameters influencing the uncertainty, while all other parameters remain unchanged.

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## Annex D (informative)

### Megatexture digital filters

A digital filter can easily be implemented by a recursive relationship. For a 2<sup>nd</sup> order Butterworth high-pass filter, the recursive equation has the following form:

$$y_i = (x_{i-2} - 2x_{i-1} + x_i) / A_0 + A_1 y_{i-2} + A_2 y_{i-1} \quad (D.1)$$

where  $A_0$ ,  $A_1$  and  $A_2$  are coefficients that are determined by the cut-off and the sampling frequencies using the bilinear transform method. [Formula \(D.1\)](#) is recursive because the filtered output ( $y_i$ ) depends on previous inputs ( $x_{i,j}$ ) and previous outputs ( $y_{i,j}$ ).

A 2<sup>nd</sup> order Butterworth high-pass filter, [Formula \(D.1\)](#), with cut-off wavelength (half power wavelength) of 701 mm shall be applied to the profile twice; the first time in the forward direction and the second time in the reverse direction. After applying the filter twice (once forward and once reverse), the cut-off wavelength (half power wavelength) is approximately 562 mm and the stop band slope will resemble that of a 4<sup>th</sup> order filter, i.e., it will have a slope around 24 dB/octave.

For a 2<sup>nd</sup> order, Butterworth, low-pass filter, the recursive equation is

$$y_i = (x_{i-2} + 2x_{i-1} + x_i) / A_0 + A_1 y_{i-2} + A_2 y_{i-1} \quad (D.2)$$

Also, a 2<sup>nd</sup> order Butterworth low-pass filter, [Formula \(D.2\)](#), with cut-off wavelength of 45,1 mm shall be applied twice; in the forward direction and then in the reverse direction. After applying the filter twice (once forward and once reverse), the cut-off wavelength is approximately 56,2 mm.

The final, resulting wavelength range of 56,2 to 562 mm encompasses the one-third-octave bands from 63 mm to 500 mm centre wavelengths, which corresponds to the megatexture range (see [3.2.3](#)).

The formulae can be implemented easily in a spreadsheet or a programming language. The implementation should use double precision (8 byte) floating point format to insure exact filter performance. The coefficients and necessary filter parameters depend on the sampling interval and some examples are presented in [Table D.1](#). They were calculated using LabVIEW<sup>TM1</sup>). All digits after the decimals should be used.

Due to filter initialization effects, the start and end of the filtered profile is expected to be invalid. To allow for filter initialization, the unfiltered profile shall have a lead-in and lead-out segment, a minimum of 1 meter in length, at the beginning and end of the profile. The lead-in and lead-out segments shall not be included in the  $RMS_{Me}$  calculations. If lead-in and lead-out segments are not available, then one can extend the profile by mirroring the first and last 1-meter segments before filtering. Again, the mirrored segments shall not be included in the  $RMS_{Me}$  calculations. If neither lead-in/out or mirrored segments are available, then the  $RMS_{Me}$  values from the first and last calculation lengths are considered invalid and should be left out of consideration.

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1) LabVIEW<sup>TM</sup> is the trademark of a product supplied by National Instruments Corp. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

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Table D.1 — Filter parameters for 2<sup>nd</sup> order Butterworth low-pass and high-pass filters in forward-reverse application, resulting in a cut-off wavelength of approximately 56,2 mm and 562 mm, respectively, when applied in both directions

Sample interval mm	Cut-off wavelength mm	$A_0$	$A_1$	$A_2$
<b>Low-pass</b>				
0,5	45,1	865,274 463 076 395	-0,906 185 036 941 246	1,901 562 226 294 81
1,0	45,1	226,691 242 838 705	-0,821 172 756 601 034	1,803 527 610 939 87
5,0	45,1	12,480 007 813 669 1	-0,375 818 195 845 803	1,055 305 576 004 42
<b>High-pass</b>				
0,5	701	1,003 173 987 203 03	-0,993 682 120 807 352	1,993 662 099 662 81
1,0	701	1,006 358 048 777 47	-0,987 404 157 214 090	1,987 324 325 217 42
5,0	701	1,032 197 196 008 55	-0,938 587 486 191 576	1,936 641 021 953 74

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## Annex E (informative)

### Megatexture reference program code

This refers to testing the calculation procedures in this standard. However, some of the procedures there, such as resampling and spike removal are also used in other applications. Therefore, part of the context in this annex may be useful also in ISO 13473-1 and ISO 13473-4.

The purpose of the annex is to give a program developer of megatexture calculations the possibility to verify his/her program code. For this purpose, a number of “standard” road surface digital profiles have been made available. The profiles, from real measured pavements in service, have been made available for those who want to check that their software follows this international standard. Each digital profile is available with calculated reference  $RMS_{Me}$  values for comparing with own calculations from the digital profiles.

The digital profiles are measurements conducted on the surfaces listed in [Table E.1](#).

**Table E.1**

Object	Location	$RMS_{Me}$ mm	Pavement
1	Tjallmo	0,833 921	Surface dressing, 11 mm
2	Katkesuando	0,306 578	Chipseal
3	Huskvarna	0,713 106	Porous asphalt, 16 mm
4	Sturefors	0,512 814	Stone mastic asphalt, 16 mm
5	Gistad	0,338 376	Stone mastic asphalt, remix 16 mm
6	Lingham	0,197 035	Dense asphalt concrete, 11 mm
7	Bestorp	0,626 281	Chipseal
8	Nykil	0,430 768	Dense asphalt concrete, 11 mm

All eight test profiles have been resampled to 5 mm, as specified in [7.4](#). The calculation length is 1 000 m. The profiles can be downloaded from [www.erpug.org](http://www.erpug.org)<sup>2)</sup> (“reference profiles” in the header). The profiles measured on new asphalt pavements and the porous pavement will have spikes (which will be rare on the other pavements). For each digital profile the correctly calculated  $RMS_{Me}$ , with which the user may compare the result of his/her own calculations, can be found in [Table E.1](#). Deviations should be less than what can be justified from uncertainty, excluding irrelevant uncertainty contributions, such as from the speed.

2) ERPUG European Road Profile Users’ Group – a non-profit organization to serve as a forum for exchanging information about road condition monitoring in an informal setting.