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SLOVENSKI STANDARD
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Road and airfield surface characteristics - Test methods - Part 5: Determination of longitudinal unevenness indices

Oberflächeneigenschaften von Straßen und Flugplätzen - Prüfverfahren - Teil 5: Bestimmung der Längsunebenheitindizes

Caractéristiques de surface des routes et aérodromes - Méthodes d'essais - Partie 5 : Détermination des indices d'uni longitudinal

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17.040.20	Lastnosti površin	Properties of surfaces
93.080.10	Gradnja cest	Road construction
93.120	Gradnja letališč	Construction of airports

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Road and airfield surface characteristics - Test methods - Part 5: Determination of longitudinal unevenness indices

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Oberflächeneigenschaften von Straßen und Flugplätzen - Prüfverfahren - Teil 5: Bestimmung der Längsunebenheitindizes

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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European foreword

This document (EN 13036-5:2019) has been prepared by Technical Committee CEN/TC 227 "Road materials", the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2020, and conflicting national standards shall be withdrawn at the latest by March 2020.

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

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Introduction

Through road/vehicle dynamic interaction and vehicle vibration, the road profile evenness affects safety (tyre contact forces), ride quality, energy consumption, vehicle wear as well as pavement and road durability. The road profile evenness is consequently key information for road maintenance-management-systems and performance control.

The purpose of this document is to provide a standard practice for calculating and reporting estimates of road evenness from digitized longitudinal profiles.

This practice covers the mathematical processing of longitudinal profile measurements to produce evenness statistics (indices) covering the wavelength range 0,5 m to 50 m. These wavelengths cover most situations for cars[1]. The practice describes the calculation procedure for the International Roughness Index (IRI), wave band analysis (Root Mean Square (RMS) and Longitudinal Profile Variance (LPV)) and the Weighted Longitudinal Profile (WLP).

The purpose of the practice is to ensure that when applying one of the possible procedures, exactly the same steps are carried out, with the aim of facilitating the comparison of evenness measurements carried out with different profiling instruments in European countries. The Wave band analysis procedures are informative and therefore IRI is preferred as benchmarking parameter.

NOTE   As a control of the implementation of calculation of the evenness indices, three longitudinal profiles are available including the "true values". They can be found at www.erpug.org in the directory *reference profiles*. More on this can be found in Annex F.

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1)   For higher speed, e.g. on airport runways or highways, longer wavelengths could also be important.

1 Scope

This document specifies the mathematical processing of digitized longitudinal profile measurements to produce evenness indices. The document describes the calculation procedure for the International Roughness Index (IRI), Root Mean Square (RMS) and Longitudinal Profile Variance (LPV) from three separate wavelength bands and the σWLP and ΔWLP from the Weighted Longitudinal Profile (WLP).

The purpose of this document is to provide a standard practice for calculating and reporting estimates of road evenness from digitized longitudinal profiles. Other aims with this document are to facilitate the comparison of evenness measurement results carried out with different profiling instruments in European countries.

The evenness range covered in this document is defined as the wavelength range 0,5 m to 50 m. It is noted that both shorter and longer wavelengths can also influence the driving comfort but those are not covered in this document.

The quantified evenness indices derived from this document are useful support for pavement management systems. The output can also be used for type approval and performance control of new and old pavements. The indices can be used on rigid, flexible and gravel road surfaces.

This document doesn't define from what position on the road the longitudinal profile should be obtained.

The derived indices are portable in the sense that they can be obtained from longitudinal profiles measured with a variety of instruments.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

- IEC Electropedia: available at http://www.electropedia.org/

- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
reporting repetition interval
measurements made over the road surface which are often analysed using shorter parts or samples to allow for a more precise description of the measured profile and which is the length of such a sample

Note 1 to entry: For more information on samples see key 4, l_0 to l_n in Figure 1

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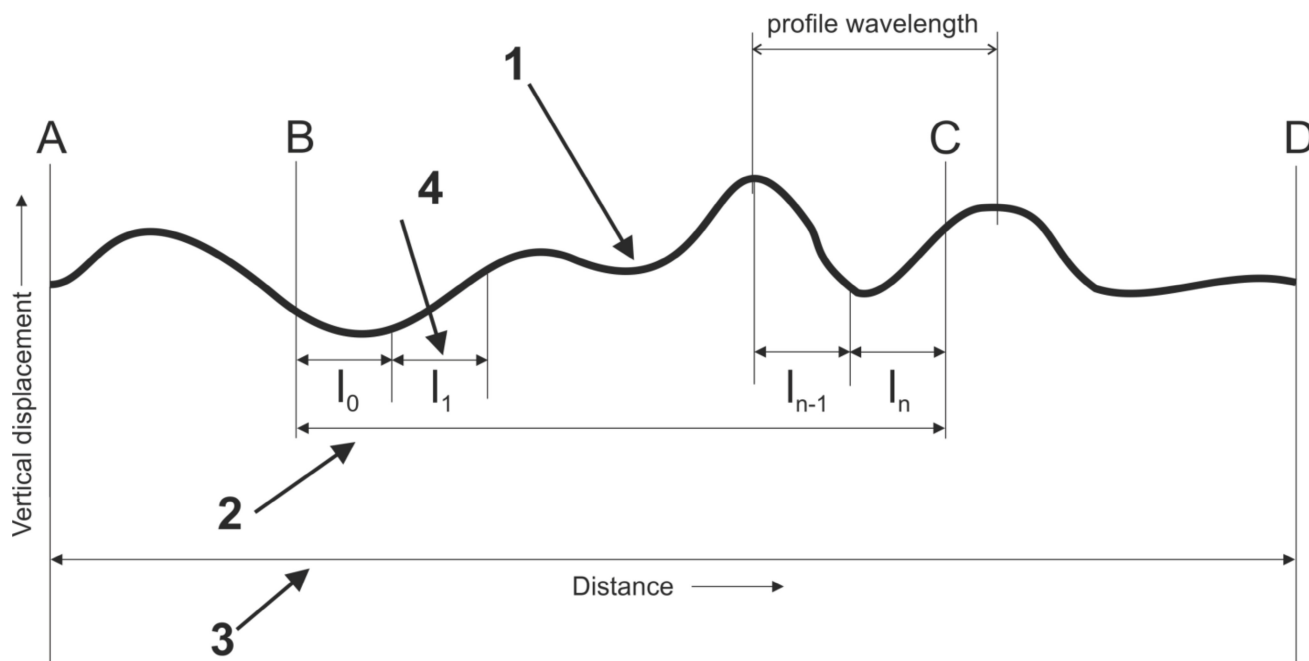
Key

1   longitudinal profile
2 B to C   profile measurement length
3 A to D   overall profilometer route
4 $l_0...l_n$ reporting repetition interval

Figure 1 — Profile lengths definitions

3.2
longitudinal evenness
deviation of the longitudinal profile from a straight line in a defined wavelength range, e.g. 0,5 m to 50 m

3.3
longitudinal profile
intersection between the pavement surface and a conventional reference plane perpendicular to the pavement surface and parallel to the lane direction

Note 1 to entry: Usually one of the profiles measured in the wheel paths is used.

Note 2 to entry: The longitudinal road profile is typically saved every 50 mm or 100 mm (acquisition repetition interval).

3.4
measuring path
selected intersection path, of all possible profiles along the transverse direction

3.5
pre-processed profile
profile obtained by applying resampling and filtering procedures

6

3.6
profile

profile of the surface that is described by two coordinates: one in the surface plane following the line of travel of the profilometer called distance (the abscissa), and the other in a direction normal to the surface plane, called vertical displacement (the ordinate)

3.7
profilometer

instrument to measure and collect profiles covering the evenness from, e.g., roads and airfields

3.8
profile measurement length

length of an uninterrupted profile measurement and which expresses the length over which the profilometer continuously and accurately digitises and records the profile (from point B to C in Figure 1)

Note 1 to entry: Most profilometers need to run for some minimum distance before and after the profile they are to measure; these starting (from point A to B in Figure 1) and ending phases (from point C to D, in Figure 1) should not be included in the profile measurement length.

3.9
longitudinal raw profile

profile given by a profilometer when measuring a longitudinal road profile, the characteristics of which depend on the profilometer used

3.10
resampling

procedure applied on the original measured profile (longitudinal raw profile) to create a new profile with an alternative sampling distance

3.11
spatial frequency
N

reciprocal of a wavelength in cycles per metre that defines the number of waves N, of wavelength λ, per metre:

$$N = \frac{1}{\lambda}$$

(1)

3.12
acquisition repetition interval

absolute value of the difference of abscissa between two adjacent points of the digitised longitudinal profile line

Note 1 to entry: This definition assumes that the distance measured by the profilometer, which is usually related to the curvilinear abscissa, is close enough to the abscissa in the mathematical sense

3.13
wavelength

quantity describing the horizontal dimension of the irregularities of a longitudinal profile

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

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3.14
wheel paths
area of a pavement surface where the large majority of vehicle wheel passages are concentrated

4 Symbols and abbreviations

B	is the base used for IRI calculation in metres (m). It is the length over which the IRI calculation is performed (or reporting length using the terminology of this document)
L	denotes the measurement length
N	is the spatial frequency, in cycles per metre: $N = \dfrac{1}{\lambda}$; N is usually called a wave number
x_i	is the abscissa of the sampled point i, in metres (m)
z_i	is the elevation of the profile determined at the sampling point i, in metres or millimetres
δ_x	is the acquisition repetition interval for the digitization of the profile, in metres or millimetres
λ	is the wavelength, in metres (m)
Δ	sample interval
IRI	is the International Roughness Index
WB	is the wave band index calculated by using root mean square analysis applied to the pre-processed profile elevations for the wave band W, in metres
RMS	root means square
SW	is the Root Mean Square value for the short wavelength band
LPV	longitudinal profile variance
MW	is the Root Mean Square value for the medium wavelength band
LW	is the Root Mean Square value for the long wavelength band
w	is the waviness of the reference spectrum used for the WLP
WLP	is the Weighted Longitudinal Profile
σWLP	is the standard deviation of the WLP
ΔWLP	is the range of variation of the WLP

5 Calculation of evenness indices

A profile can be obtained starting from any lateral position in the lane. This document doesn't specify which of those profiles that should be used, only how to calculate any of the four evenness indices specified.

The calculation of evenness indices, involves the following steps:

— the measurement of the profile, which includes identification of the start and end points of the profile measurement length and possible events (e.g. roundabouts, speed bumps, milestones, etc.);

— if the purpose is benchmarking it is preferred that the profile are sampled with a 0,1 m step. It is essential to consider the method of resampling to avoid erroneous energy in the signal;

— the calculation of one or more indices;

Pre-processing including resampling and filtering is essential in the case of wave band analysis and is recommended to homogenize the profiles and facilitate comparisons. For benchmark purposes a resampling procedure according to the resample function in Matlab®[2] is needed. For other use a linear model could be used. Depending on purpose there are four possible evenness indices groups to choose from. The first is the calculation of the International Roughness Index, IRI, described in Annex A (normative) that should be used in international comparison and benchmark tests, second is calculating evenness-energy in three different wavelength bands using the bi-octave processing (RMS) described in Annex C (informative). The third is an alternative method to calculate evenness-energy in three wave band bands using profile variance (LPV) in Annex D (informative). Finally, the fourth method is to calculate the range of evenness-variation and deviation using the weighted longitudinal profile (WLP) described in Annex E (informative). In Annex B, an example code to calculate IRI is presented. The general process on calculation of evenness indices is illustrated in Figure 2.
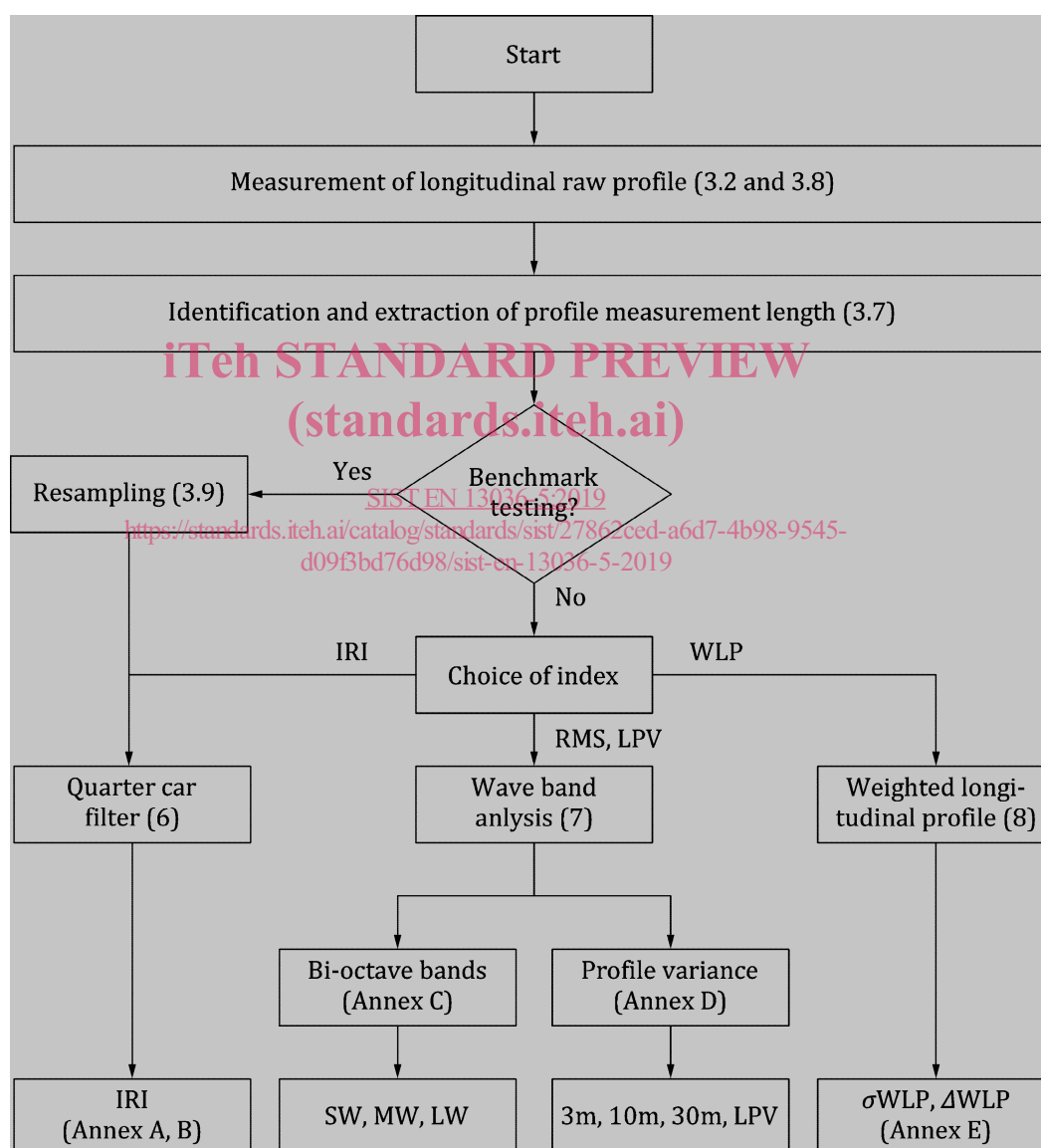
**Figure 2 — Overview of the calculation process of indices (references to chapter in paranthesis)**

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6 International Roughness Index (IRI)

6.1 General

The IRI is an index computed from a longitudinal road profile measurement using a virtual response type system, quarter-car simulation, running at a speed of 80 km/h, see Figure 3. The quarter-car simulation applied on the digitized road profile calculates the accumulated suspension motions Z_s and Z_u in Figure 3 divided by the distance travelled. The description of the IRI calculation is based on [7]:

— IRI is computed from a single longitudinal road profile. The acquisition repetition interval should be no larger than 125 mm for accurate calculations. The required vertical sensor resolution depends on the evenness level, with finer resolution being needed for smooth roads. A vertical sensor resolution of 0,5 mm is suitable for all conditions;

— the profile is assumed to have a constant slope between sampled elevation points;

— the profile is smoothed with a moving average whose base length is 250 mm;

— the smoothed profile is filtered using a quarter-car simulation, with specific parameter values, at a simulated speed of 80 km/h;

— the simulated suspension motion is linearly accumulated and divided by the length of the profile to yield IRI. Thus, IRI has units of slope, such as millimetres per meter or metres per kilometre.
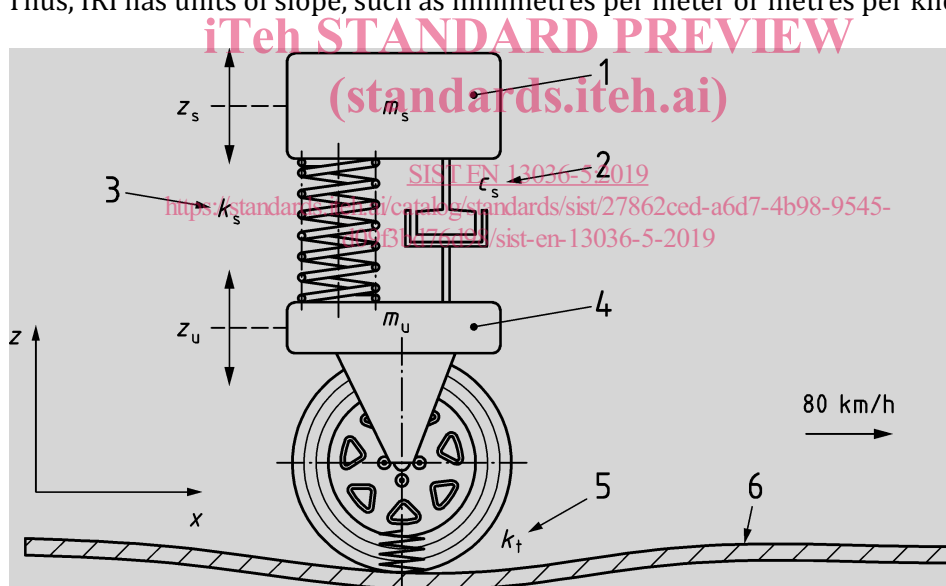
Key

1	sprung mass m_s	4	unsprung mass m_u
2	suspension damping rate c_s	5	tyre spring rate k_t
3	suspension spring rate k_s	6	longitudinal profile $Z(x)$

Z_s and Z_u accumulated suspension motions

Figure 3 — Quarter car (virtual response type system)

More details on the method of IRI calculation and sample code are given in Annex A and Annex B.

6.2 Representation of the obtained results

The IRI can be calculated with a different evaluation length L. For a more detailed analysis of the road profile data, one can vary the evaluation length L. Therefore, this should be indicated as the first sub index, e.g. IRI_{20} if the length $L = 20$ m. For the purpose of European benchmarking 100 m evaluation length is recommended and should be denoted IRI_{100}.

Variations in IRI parameters as shown in Figure 3 or in the simulation speed are beyond the scope of this document. If, however, for whatever reason the Quarter-car simulation is calculated with other parameters than those mentioned, it should not be denoted as IRI.

7 Wave band analysis

7.1 General

In order to perform wave band analysis, the pre-processed profile is split into different wave band limited profiles using filters, see Figure 4. The wave bands are generally selected to represent different features of ride quality. For example, applying a short wavelength filter can result in an index that reflects the presence of small undulations in the road surface, which could be more significant at lower speeds. In contrast, applying a longer wavelength filter can result in an index that reflects the presence of long wavelength undulations that would be most likely to affect ride quality at higher speeds.

The definition of the wave bands used as well as the characteristics of the filters used to obtain band limited signals, from the original longitudinal profile shall be reported. How indices are derived from the band limited signals shall also be defined.
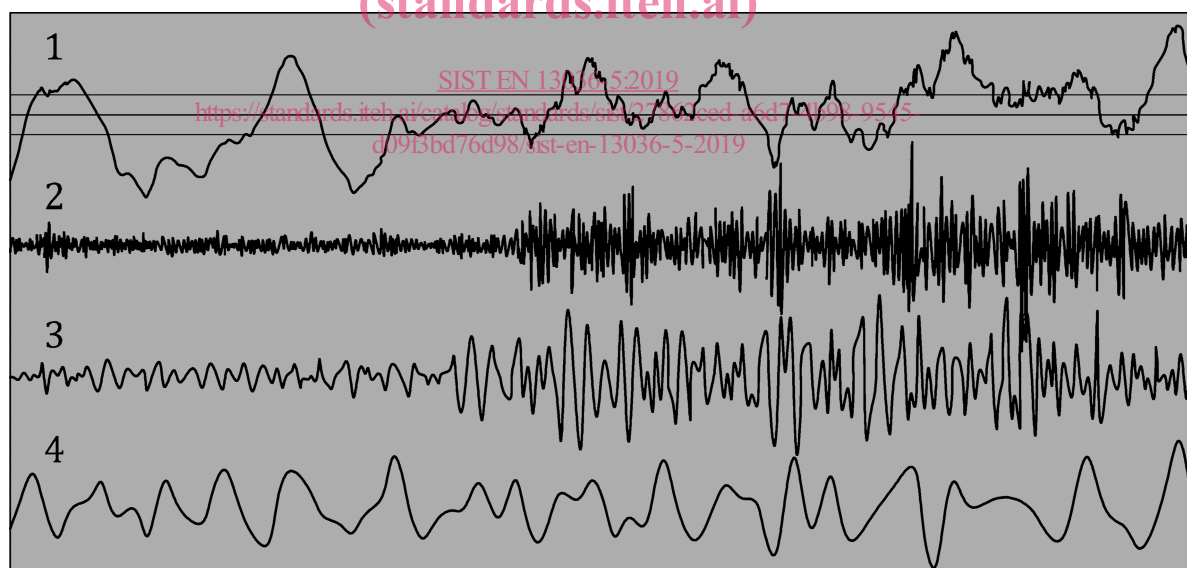
Key

1 pre-processed profile

2 short wavelength filtered profile

3 medium wavelength filtered profile

4 long wavelength filtered profile

Figure 4 — Wave band splitting

The filters applied to the longitudinal profile are generally either:

— band-pass filters, where wavelengths outside of a defined range are attenuated; or

— high-pass filters, where wavelengths greater than a defined wavelength are attenuated.

The filters used to break the original longitudinal profile into the previously defined bands, should be carefully chosen in order to introduce as little distortion as possible in the filtered signals, a common technique in that view is to use digital forward and reverse filtering associated with measured section extending beyond the profile which is to be assessed.

7.2 Wave band indices

In order to characterize the different wave band filtered profiles two methods including indices are specified:

— Root Mean Square (RMS) over bi-octave bands (see Annex C);

— Longitudinal profile variance (LPV) over selected wavelengths (see Annex D).

8 Weighted Longitudinal Profile (WLP) analysis

8.1 General

The Weighted Longitudinal Profile (WLP) is the longitudinal profile which has been weighted by a weighting function in the frequency domain. The weighting function enhances small wavelengths and decreases large wavelengths in such a way that their respective power contents become measurable later by the same scale in the spatial domain. Following the weighting of the spectrum, the WLP is calculated by carrying out the following steps:

— filtering the weighted signal in octave bands,

— multiplying the octave band-filtered signals by pre-factors (which take into account their respective power distributions to the total power content), and

— adding up the signals to give the WLP.

The WLP is characterized by the standard deviation, σWLP, and the range of variation, ΔWLP.

8.2 Prerequisites

The WLP calculation is based on the pre-processed profile. The pre-processing involves:

— De-trending the raw profile using a linear regression to remove the offset and trend of the signal.

— Resampling by applying a constant interval of 0,1 m, using a linear interpolation algorithm.

— Pre-filtering by applying a high pass filter to attenuate wavelengths in excess of 100 m. The filter shall be such that the amplitude of wavelengths greater than 150 m are attenuated by at least 50 %. The filter should not distort the phase of any profile features with wavelengths shorter than 100 m.

9 Reporting

The calculated evenness index should be reported per an agreed presentation length. In the case of international benchmarking this should be 100 meter. This should be indicated as a sub-index as described in Figure 1 and explained in IRI in 6.2. It is recommended to include the following administrative information:

— geographic position and information about the measured object;

— the lateral position of longitudinal profile, e.g. right or left wheel path. For benchmark purposes this should be the outermost wheel path;

— distance measured;

— date and time;

— conditions that could affect the result.

More mandatory information can be found in EN 13036-6 and should be included in the reporting. Finally any deviation from this document, EN 13036-5, should be documented and reported.

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