Academic Society "Matei-Teiu Botez" Iaşi, România

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INVITATION

You are kindly invited to participate to
THE 5TH INTERNATIONAL SYMPOSIUM

Highway and Bridge Engineering
2007

December 7, 2007, Technical University "Gh. Asachi" Iaşi, România

Important dates:
- participation confirmation and abstract - October 10th, 2007
- full paper - November 15th, 2007

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“Highway and Bridge Engineering 2007”, International Symposium
Iaşi, Romania, December 7, 2007

Analysis of the functional quality of pavements from texture measurements

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Summary

The surface texture of a pavement, including uneveness, is largely determinant of drivers’safety and comfort. It is undoubtedly a major cause of road traffic accidents all over the world. Statistics show that one million killed and 50 million injured are reported every year by Competent Authorities.

The effect of traffic noise has also become a critical public issue. On the road networking the surface characteristics of pavements also contributed to nearly 80-90% of roadway traffic noise. Not only engines or exhaust systems generate noise. The impact of tire-surface at speeds above 50 km/h also needs to be added to prime offenders. Functional requirements such as roadway safety, environmental quality, driving comfort and operating costs in the road network are assessed by indicators whose limits are continuously adjusted. The roadway texture is again a main intervenient.

This paper aims at describing the texture indicators that can be used for the assessment of the texture of a pavement from a network point of view, based on profiles acquired at high speeds, including megatexture.

First an overview of the concepts related to texture and the effects of texture, including unevenness, on safety, driving comfort, ride quality and environmental quality is given. Then, a case study related to a highly trafficked road in the north of Portugal is presented. This study is the second phase of a broader study that started with the analysis of the structural capacity of that road. In this second phase, a high speed profilometer was used to measure the pavement profile with a sampling rate which is considered to be adequate for the analysis of longitudinal profile, macrotexture and unevenness. Indicators such as the mean profile depth, the IRI and the rutting depth and the corresponding effects were addressed.

KEYWORDS: pavement; profile, texture ranges, texture spectrum, texture level, indicator, mean profile depth, IRI.

INTRODUCTION

Road pavements have two main functions, structural and functional, the indicators and corresponding limits of which evolve with time. Relatively to the functional component, that evolution is a consequence of the road users' demands. These demands include safety and driving comfort. Moreover, environmental indicators such as noise are also included. At present, it is estimated that there are more than one million killed and 50 million injured annually on the road network all over the world, [1]. In addiction, 80 to 90% of noise results from roadway traffic (according to European Community). Among other factors, the accurate definition of the functional indicators related to texture can help reducing these statistics.

Factors such as tyre/pavement friction, [2], noise emission caused by tyre/road interaction, [3], driving comfort, [4], as well as rolling resistance, wear of tyres, [5], and other operating costs are influenced, to a great extent, by pavement irregularities and therefore by road texture and unevenness.

In order to assess, compare and improve the functional quality of roads, there has been an effort to standardize the measurement methods of texture at high speeds (travelling speeds), based on surface profiles. An exception is made for the case of the microtexture due to technical issues that are expected to be shortly overcome. Meanwhile research on predicting friction based on microtexture profiles is being carried out at present, [6].

This study is the second phase of a broader study that aimed at assessing the structural and the functional quality of a highly trafficked road in the north of Portugal.

This second phase aims at presenting a full assessment of the texture of a pavement from a network point of view by introducing indicators related to megatexture based on profiles acquired at high speeds.

Initially an overview of the concepts related to texture and to the effects of texture is portrayed, followed by the assessment of the functional quality of a road.

CONCEPTS RELATED TO TEXTURE

The profile of a surface may be described by two coordinates: the distance along a certain travel direction, the amplitude which is normal to the surface plane (Figure 1) and the texture wavelength defined as the (minimum) distance between periodically repeated parts of the curve.

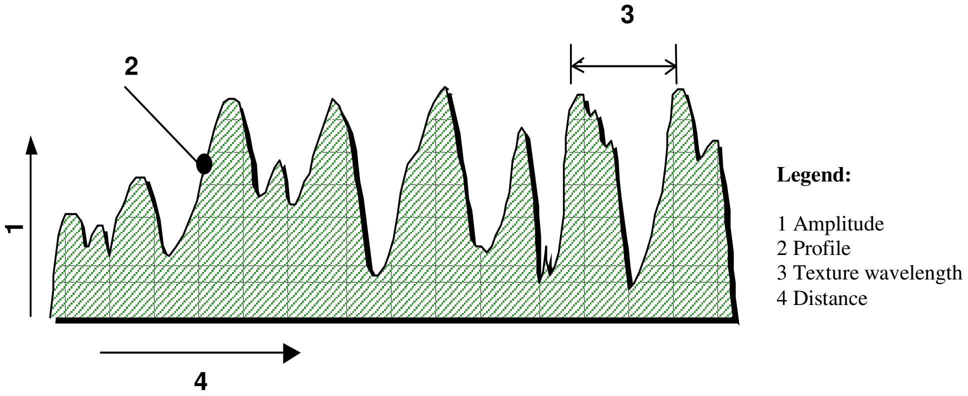

Figure 1. Example of a surface profile, [7]

Due to that possibility, the profile of a surface may be described as the sum of several sinusoids with a certain phase, wavelength or frequency and amplitude by means of mathematical Fourier techniques and therefore by its spectrum.

A texture spectrum is obtained when a profile curve has been analyzed by either mathematical Fourier techniques or by the corresponding filtering processes in order to determine the amplitude of its spectral components (wavelengths or spatial frequencies), [8].

In its turn, the pavement texture is the deviation of a pavement surface from a true planar surface within the wavelength range of the microtexture, the macrotexture, the megatexture and the unevenness, [8]. Although unevenness is described by the amplitude and the wavelength, some authors do not consider it as a texture descriptor.

According to ISO13473-1, the ranges of texture are defined as follows [8]:

- microtexture: the deviation of a pavement surface from a true planar surface with the characteristic dimensions along the surface of less than 0,5 mm; peak-to-peak amplitudes normally vary in the range of 0,001 mm to 0,5 mm;
- macrotexture: the deviation of a pavement surface from a true planar surface with the characteristic dimensions along the surface of 0,5 mm to 50 mm; peak-to-peak amplitudes may normally vary in the range of 0,1 mm to 20 mm;
- megatexture: the deviation of a pavement surface from a true planar surface with the characteristic dimensions along the surface of 50 mm to 500 mm; peak-to-peak amplitudes normally vary in the range of 0,1 mm to 50 mm;
- unevenness: the deviation of a pavement surface from a true planar surface with the characteristic dimensions along the surface of 0,5 m to 50 m.

INFLUENCE OF TEXTURE AND UNEVENNESS

The surface texture is mostly determined by the selection of the materials (especially aggregates), the mixture design, the finishing techniques and the behaviour of the mixture throughout time. In its turn, the surface texture determines the functional quality of the road for what respects to safety, [1], and driving comfort, [4], the structural quality due to dynamic loading, [9], and the environment quality relatively to vehicle emissions, wear, [5], and noise, [3]. Figure 2 shows the influence of texture ranges on pavement surface characteristics.

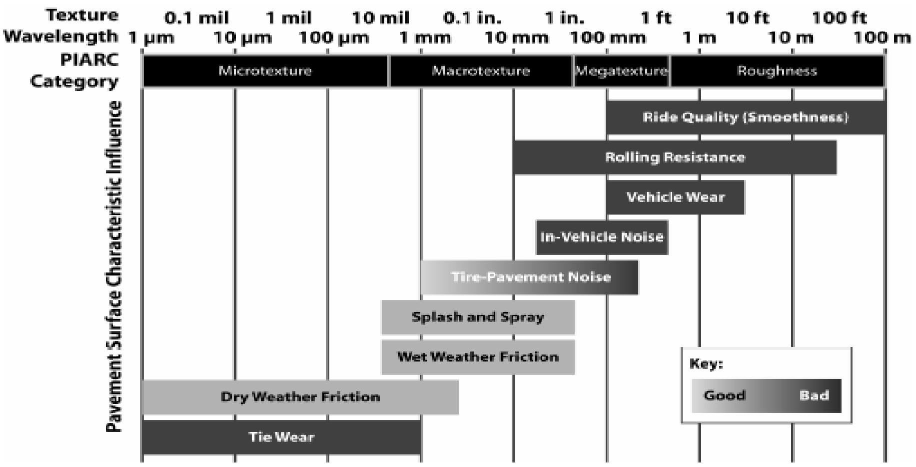

Figure 2. Influence of texture ranges on pavement surface characteristics, [10]

The microtexture is usually too small to be observed by the eye. It is obtained by the surface properties (sharpness and harshness) of the individual aggregates or other particles of the surface which are directly in contact with the tyres and therefore originating tyre-wearing. The microtexture provides adequate stopping on dry surfaces at typical vehicle operational speeds and on wet (not flooded) surfaces when vehicle speeds are inferior to 80 km.

The macrotexture is the texture which has wavelengths in the same order of size as tyre tread elements in the tyre/road interface. The macrotexture is obtained by a suitable proportion of the aggregate and mortar of the surface or by certain surface finishing techniques. Surfaces are normally designed with a certain macrotexture in order to obtain suitable water drainage in the tyre/road interface. The macrotexture provides adequate wet-pavement friction (in conjunction with the microtexture) and reduces splash and spray at high speeds. It greatly determines the tyre-pavement noise. High wavelengths (> 10 mm) also determine the noise inside the vehicles and the rolling resistance.

The megatexture is the texture of which wavelengths have the same order of size as a tyre/road interface. It results from inadequate compaction of the surface and from surface distresses such as potholes. High levels of megatexture increase the vehicle wear, the rolling resistance and have a negative impact on ride quality.

The unevenness includes longitudinal and transverse long waves. They result from a poor construction quality and from traffic loading. The longitudinal unevenness, through vibrations, affects the ride comfort (Figure 3 (a)), creates dynamic loadings and the road holding of vehicles and indirectly affects safety (Figure 3 (b)). The transverse unevenness, for instance due to rutting, affects safety through lateral instability and water accumulation. They also increase vehicle delay costs, fuel consumption and maintenance costs.

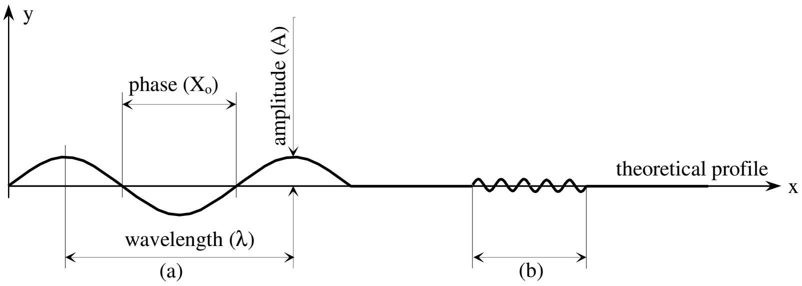

Figure 3. Characterization of the road profile: (a) long waves; (b) short waves, [11]

TEXTURE AND UNEVENNESS INDICATORS

There a number of texture and unevenness indicators. Some result from direct measurements of the surface profile by means of high speed profilometers, such as the texture profile level and the International Roughness Index, and others are indirect measures of the texture such as the friction coefficient or the Sand Patch used to assess microtexture and macrotexture. Nevertheless, whenever a surface profile is defined by its spectrum, the resulting amplitudes within a certain band may be transformed into a unique indicator defined as texture profile level (L). The texture profile level is a logarithmic transformation of an amplitude representation of a profile (Equation 1), [12].

Figure 4 shows an example of the use of this indicator to define several texture spectra for comparison purposes, which include all texture ranges. The texture level is usually between 20 dB and 80 dB, [13].

$$L_{\mathrm{tx},\lambda} \text{ or } L_{\mathrm{TX},\lambda} = 20 \lg \frac{a_\lambda}{a_{\mathrm{ref}}} \tag{1}$$

where:

$L_{\mathrm{tx},\lambda}$ = texture profile level in one-third-octave bands (re 10^{-6} m, in dB);

$L_{\mathrm{TX},\lambda}$ = texture profile level in octave bands (re 10^{-6} m in dB);

a_λ = root mean square value of the surface profile amplitude (in m);

a_{ref} = reference value = 10^{-6} m;

λ = subscript indicating a value obtained with a one-third-octave-band filter or octave bad filter having centre wavelength λ.

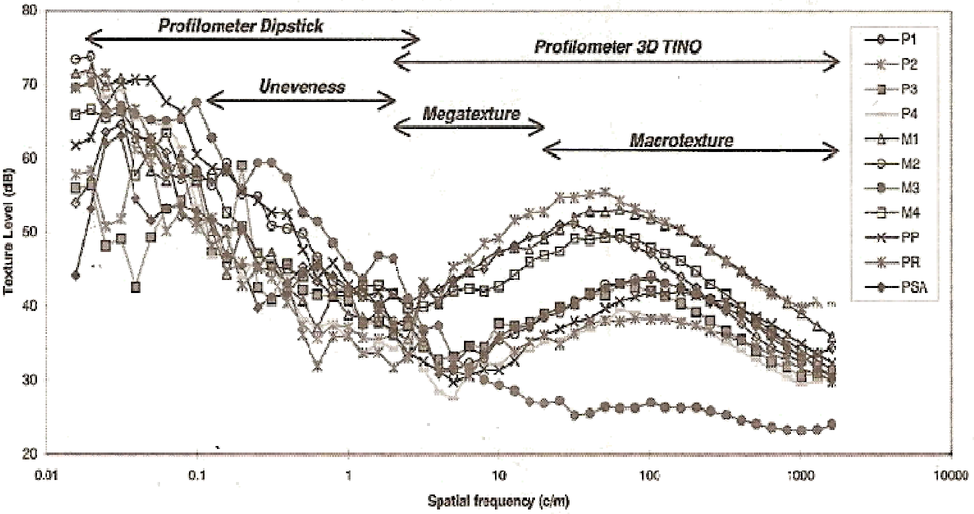

Figure 4. Examples of texture spectra for 1/3 octave bands, [15]

Microtexture

Due to the fine resolution necessary to acquire a profile on the microtexture range, no automated methods for measuring microtexture at highway speeds in situ exist. As a consequence, measuring the pavement surface microtexture is commonly carried out in laboratory, with laser profilers, or estimated in the field by using friction measurements. In the field either punctual measurements are effectuated by means of the British Pendulum, [14], or continuous measurements by means of high speed friction testers. In this case the higher the microtexture, the higher the friction coefficient.

Macrotexture

Two commonly used methods are the mean texture depth (MTD) and the mean profile depth (MPD). The MTD is determined by using the volumetric method (commonly referred to as the "sand patch test", [16], whereas the MPD is determined using laser technology at highway speeds, [8].

The first method consists of spreading sand or glass spheres in a patch. The material is distributed with a rubber pad to form an approximately circular patch, whose average diameter is measured. The mean texture depth is obtained by dividing the volume of the material by the area covered.

The second method is calculated at a certain profile distance (base line) as indicated in Figure 5 (usually 10 cm). The MTD may be estimated through a conversion equation (presented in Figure 4). In this case the MTD is indicated as Estimated Texture Depth (ETD).

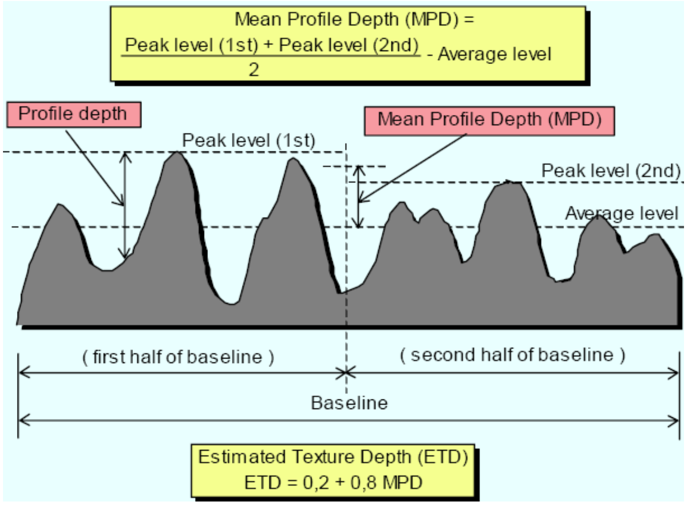

Figure 5. Illustration of the concepts of base line and profile depth and the texture indicators mean profile depth and estimated texture depth (in millimetres), [8]

Megatexture

Specifically for the analysis of the megatexture, which is probably the less studied range of the texture, the International Organization for Standardization (ISO) is preparing the ISO/CD 13473-5 "Characterization of pavement texture by use of surface profiles – Part 5: Measurement of megatexture", [7], where the following texture profile level indicators (L) are proposed:

L_{Me} - an indicator representing an overall description of defects existing in the deviation between the pavement surface and a true planar surface, the characteristic dimensions of which range between 50 mm and 500 mm along the surface (this deviation corresponds to texture wavelengths analysed in one-third-octave bands, which include centre wavelengths from 63 mm to 500 mm);

L_{TX63} - it represents a description of the pavement defects having the shortest dimensions within the megatexture range (deviation between the real surface and a true planar surface corresponding to texture wavelengths analysed in one-third-octave bands which include centre wavelengths from 50 mm to 80 mm, being equivalent to an octave band with a centre wavelength of 63 mm);

L_{TX500} - it represents a description of the pavement defects having the longest dimensions within the megatexture range (deviation between the real surface and a true planar surface corresponding to texture wavelengths analysed in one-third-octave bands which include centre wavelengths from 400 mm to 630 mm, being equivalent to an octave band with a centre wavelength of 500 mm).

The L_{Me} is used when there is a requirement to characterise megatexture by a single measure. The L_{TX63} facilitates the characterisation of defects which correspond approximately to the length of a normal tyre/pavement contact patch and which, for this reason, play a direct role in the generation of tyre/road noise. The L_{TX500} indicator enables the characterisation of defects which can lead to tyres losing contact with the surface and therefore reduce safety (increase in stopping distances, loss of steering control in bends) and the comfort of the driver and passengers. This indicator is complementary to the information obtained by unevenness measurements at short unevenness wavelengths (0, 7 m to 1,3 m). An illustration of these indicators is presented in Figure 6.

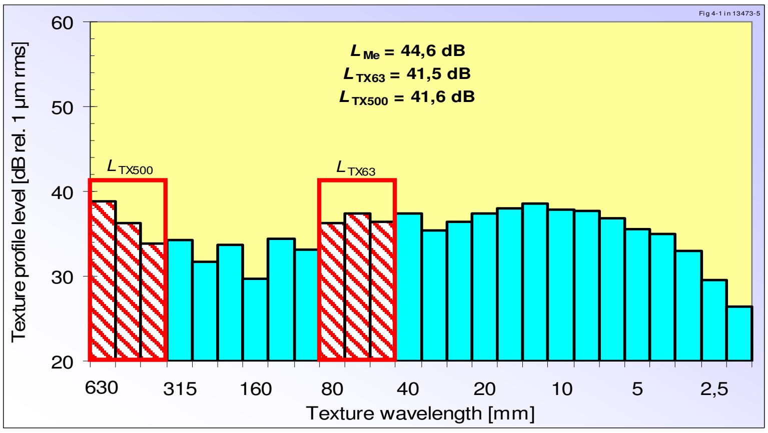

Figure 6. Example of one-third-octave band texture spectrum with indication of the texture levels of the octave bands L_{TX500} and L_{TX63}, [7]

Unevenness

The International Roughness Index is one of the most used indicators for the assessment of the unevenness of a road.

The IRI was developed by the World Bank in the 1980s. This index is used to assess the condition and the evolution of the longitudinal profile usually in the wheel track. The IRI constitutes a standardized roughness measurement and represents the average rectified slope of the profile, which is a filtered ratio of the accumulated suspension motion of a standard vehicle, [17], divided by the distance travelled by the vehicle during the measurement. The commonly recommended units of the IRI are meters per kilometre (m/km) or millimetres per meter (mm/m).

Other indicators based on the response of a users' panel have been developed, [18]. Since these indicators take into account the users' opinion on driving comfort, they are appropriate for defining functional maintenance strategies, [19].

CASE STUDY

Road location and geometry

The study of the texture was carried out on the EN 206 Variant, between Carreira and Guimarães (Portugal) as shown in Figure 7.

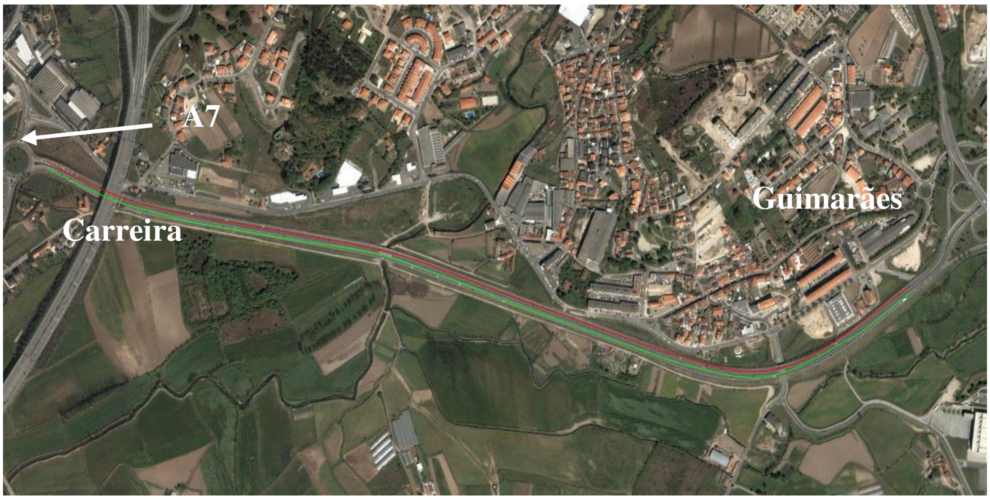

Figure 7. General view of the EN 206 Variant

This road is 2 km long and it is constituted by 2 lanes per direction (3,5 m each), a 3 m separation between carriageways, 2 service lanes (2,5 m each), and shoulders (1 m each). The current cross-section has a transversal slope of 2,5 % on both sides. The design structure of the pavement is constituted by 3 asphalt layers (wearing course – 6 cm; binder course – 6 cm; base layer – 12 cm) and an unbound sub base (graded aggregates – 20 cm).

Surface Condition

In a phase previous to this work that focused the structural condition of the road, [20], [21], the assessment of the surface condition was performed through visual inspection. The main distresses recorded were ravelling and cracking.

It was observed that, in general, the exterior lanes are more distressed than the interior ones. A different behaviour between driving directions was registered. In the direction from Guimarães to Carreira, the condition of the pavement is relatively homogenous and in a better condition if compared to the other direction. A small increase of the distress severity is recorded near the A7 roundabout, probably due to the high tangential forces as a result of breaking.

On the Carreira–Guimarães direction, two homogenous stretches can be established regarding distress severity. The most distressed one is comprised along the first 700 m of the analyzed length and exhibits the highest distress severity and extent, if compared to the other stretches.

The raveling observed on the surface of the road exhibits different levels of severity. Some possible causes for the appearance of raveling are: loss of bond between the aggregate particles and the asphalt binder; aggregate segregation; inadequate compaction during construction; mechanical dislodging from certain types of traffic, such as vehicles with studded tires.

The cracking observed also exhibits different levels of severity which were originated at the top and progressed downwards. As a consequence, low MPD and high megatexture levels are expected.

Equipment and testing methodology

A high speed profilometer was used for data collection. It is equipped with 1 inertial motion sensor, 2 accelerometers and 5 lasers, 2 of which are prepared for measuring the macrotexture in both wheel paths (Figure 8).

Figure 8. University of Minho and Coimbra High Speed Profilometer

One pass-by was done on each lane and the following data were registered:

- Vehicle speed;
- Longitudinal profile - every 10 meters;
- Cross Profile Rutting: full rut, left and right wheel path - every 10 meters;
- Geometrical Data: crossfall, grade and radius of curve - every 10 meters;
- Roughness (IRI): every 10 meters;
- Macrotexture (MPD) - every meter.

ANALYSIS OF THE RESULTS

Longitudinal profile

The longitudinal profile of a road is defined after removing the grade and very long undulations. Figure 9 presents 12 profiles which correspond to 3 measurements per lane.

In each direction, the profiles are similar. This is an indication of small transverse variations along the road. On the traffic direction, the profile is variable. In this case, the range of deviations is -20 mm to 20 mm. Higher deviations may be also found, specifically near Carreira and at a distance of 800 m from there. For the latter, insufficient bearing capacity is a possible cause. For the former, there exists the possibility of settlement of the embankment that supports a bridge.

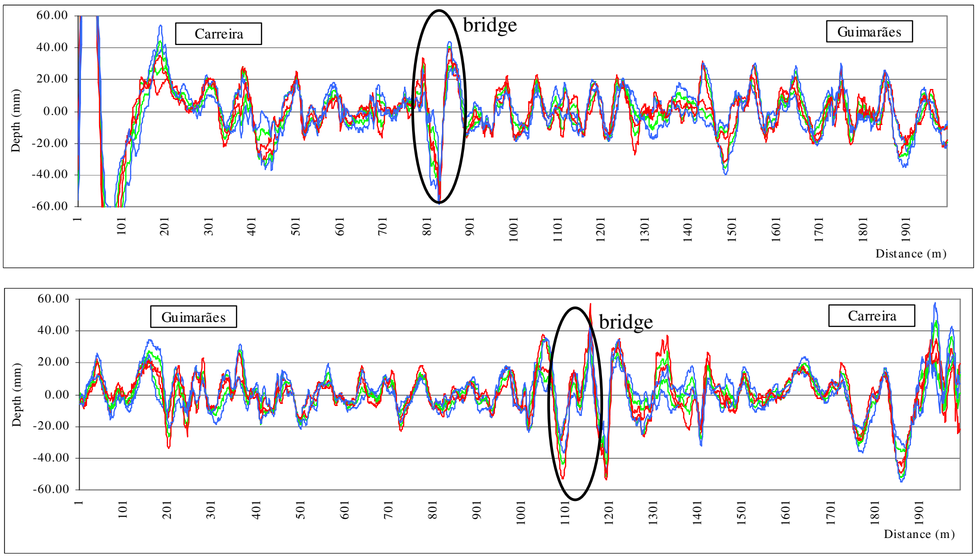

Figure 9. Profile depth

Unevenness

Figure 10 shows the IRI for the 12 profiles previously analyzed (3 in each lane).

Generally, the IRI is similar for the 3 profiles in each direction. In both directions, very high values may be found (more than 3 m/km). These high values correspond to the location of the bridge and to Carreira, as previously observed from the longitudinal profile. If these specific points are disregarded, a single homogeneous section can be considered in the direction from Carreira to Guimarães, while in the opposite direction two homogeneous sections may be identified. The first one from a distance 0 mm to 1200 m and the second one from 1200 m until the end of the road.

In this case the IRI evolution with distance does not match with the described surface condition. This fact may be an indication of the contribution of the subgrade condition on the evolution of IRI throughout time. In the future, the assessment of the surface condition and the IRI would confirm this hypothesis.

A general classification of the road unevenness is proposed by the Portuguese Road Administration, based on the percentage of road length of which the IRI obtained by 100 m overcomes a certain limit.

For the wearing course, the unevenness is classified with excellent if the following limits are simultaneously respected:

- IRI < 1,5 – 50% of the road length;
- IRI < 2,5 – 80% of the road length;
- IRI < 3,0 – 100% of the road length.

As can be verified in Figure 10, there are a few IRI values superior to 3 m/km which leads to less than 10% of the total distance out of compliance with the recommendations. For this situation, the road is classified with good. Thus, there are no major consequences in what respects the rolling resistance, riding quality and safety.

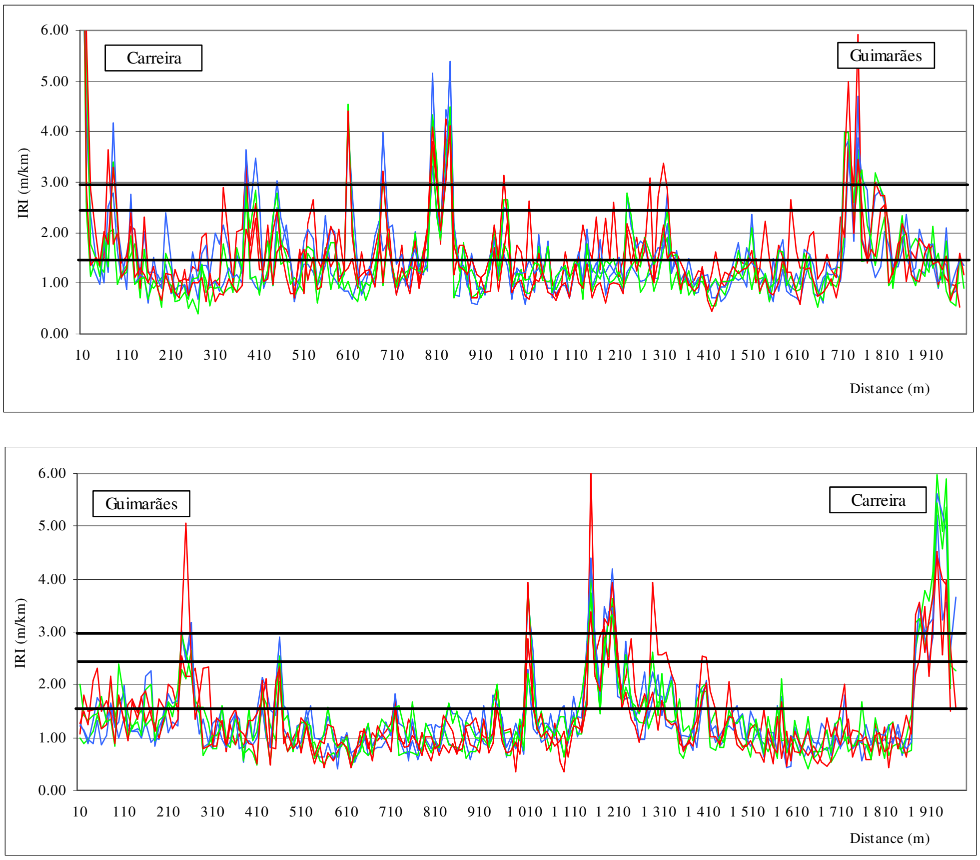

Figure 10. IRI for the right and the left lane in both directions

Rutting

Figure 11 sows the rutting measured in the 4 lanes for the right and left wheel paths.

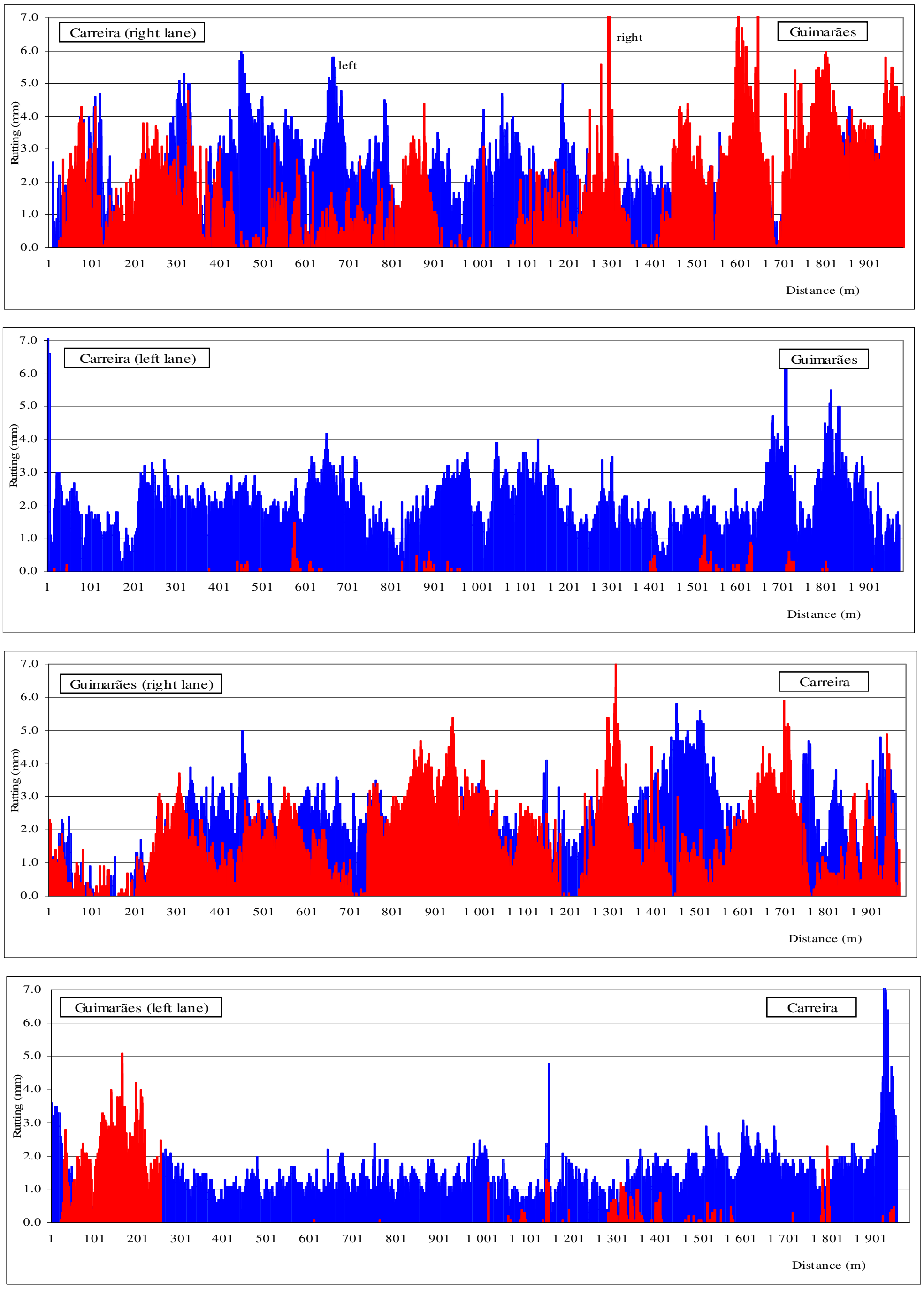

Figure 11. Rutting depth

In general the rut depth is lower than 3 mm. The right lane shows in both directions the highest variability and the highest values, although the threshold value considered for maintenance has never been reached. This threshold is 20 mm for the Portuguese conditions.

The best behaviour obtained for the Guimarães-Carreira direction is probably due to a better construction quality as supported by surface condition analysis.

For this road, safety is not compromised in what concerns water accumulation on the wheel paths.

Macrotexture

The indicator chosen for the analysis of the macrotexture was the Mean Profile Depth. Figure 12 shows the MPD for the right and left wheels path in both directions.

In view of the fact that about half of the design life of the pavement has passed by, a MPD near 0,6 mm would be expected, which is the threshold limit value. For both directions, the left lane, which is also the less trafficked, is quite homogeneous: Nevertheless, MPD of the right wheel path reaches values over 1,2 mm, which are characteristic of porous surfaces.

The MPD in the right lane is very heterogeneous, for both directions. In this case, the MPD is higher and may be related to the surface condition. In the direction of Carreira to Guimarães, at a distance of 1300 m, it is possible to notice a decrease of the MPD that corresponds to a change of the properties of the mixture that leads to less distress and thus a smaller MPD.

Based on these facts, it seems that the safety in what respects to friction in wet weather conditions is not affected. Nevertheless, environmental concerns must be taken into account as far as noise and rolling resistance are concerned. An important increase in noise levels has certainly occurred and it is predictable to continue increasing if no maintenance works are carried out in the near future.

Megatexture

For the analysis of the megatexture based on the indicators recommended in draft standard ISO 13473-5 a second pass-by on each lane is required. In this case the data required is as follows:

- Vehicle speed;
- Longitudinal profile - every 2,5 centimeters;
- Geometrical Data: crossfall, grade and radius of curve.

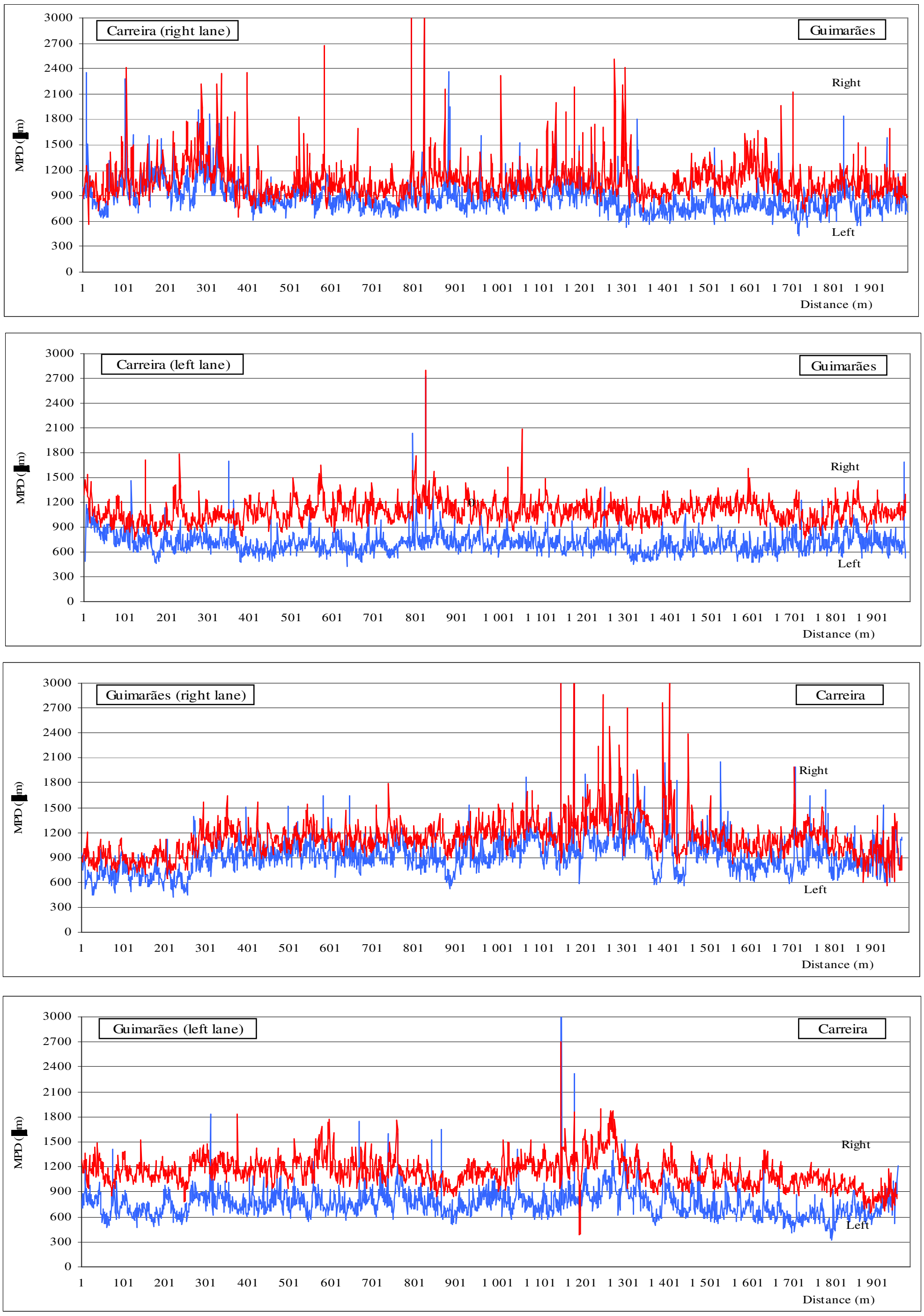

Figure 12. Mean profile depth

A computer software is being specifically developed for the analysis of the megatexture. This program is based on the power spectral density (PSD) of the measured profile. The PSD is a well-known method for the interpretation of complex signals containing a variety of wavelengths and amplitudes. The PSD analysis can be accomplished using the *pwelch* algorithm included in the Matlab® signal processing toolbox, [22]. Then the texture level and the texture level indicators are calculated from Equation 1.

CONCLUSIONS

Texture and unevenness highly influence safety, driving comfort and environment quality. Dealing with texture should be an easy assignment at a network level. For that reason, this paper dealt with both texture and unevenness. The concepts related to these surface characteristics were extensively presented. The ordinary texture indicators which regard microtexture, macrotexture and unevenness, such as the friction coefficient, the mean profile depth and the IRI were addressed. Indicators to assess megatexture at high speeds, relying on the concept of texture-profile level that can be used at a network level, were also included. The texture profile level is based on pavement profiles measured at high speeds. It represents a description of defects existing in the deviation between the pavement surface and a true planar surface within the megatexture wavelength ranges. Although it is recommended for the assessment of megatexture, it may be used for the assessment of texture in all ranges.

The second phase of a study regarding the condition of a roadway in Guimarães was also presented. The first phase was addressed to its structural condition. In this paper the aim of research was its functional condition. Important deviations of the longitudinal profile were measured, although, as far as unevenness is concerned, these deviations had led to a classification of good.

The macrotexture correlated well with the surface condition previously observed. The segregation and the raveling observed contributed to the high MPD. As a result, an increase of the noise level is expected.

Future work will include the assessment of the megatexture based on spectral analysis of the pavement profile obtained at high speed by means of the software under development.

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