SILENT SURFACES: AN EXPERIENCE IN PORTUGAL

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ABSTRACT

It is acknowledged that traffic noise affects human behaviour and health. Measures aiming at mitigating the impact of traffic noise are not always viable in urban areas. In Portugal, road designers have recently started to consider silent surfaces as alternative within their road pavement projects.

In this paper the tire-surface noise of three surface layers integrated in a rehabilitation project carried out in an urban road that carries more than 40000 vehicles per day is assessed: i) one dense asphalt layer with limited maximum aggregate size, following the SILVIA recommendations for low noise surfaces; ii) two very-thin surfaces with different grading, which are an adaptation of the very-thin layers widely used in France to Portuguese conditions.

The surface layers were constructed consecutively, involving segment lengths with more than 500 m. The surface texture was measured using a high speed profilometer. Skid resistance was also measured. The noise level was measured both by pass-by tests with selected traffic (trucks and light vehicles) at several speeds and by close proximity tests. The thin layers tested provided very good noise reduction values, especially at high speeds, and had a better performance than gap graded asphalt rubber surfaces frequently used in Portugal.

1. INTRODUCTION

Urban development in Portugal has been closely accompanied by traffic growth and, consequently, by the construction of accesses and main roads. A crescent and more severe environmental noise limitation policy since the 1980's has forced road administrations and builders to apply the new policy on road noise mitigation in force at present. General mitigation measures have implied a massive construction of noise barriers, which have not often been accepted by the local population, and, more recently, the construction of silent surfaces, such as porous asphalt and asphalt with rubberized binder. Nevertheless, those silent surfaces have two main problems, i.e. clogging and ravelling, compromising their durability within a fairly short time.

The work presented hereafter is a case study carried out in a rehabilitated urban road aiming at introducing silent thin layers other than those with rubberized asphalt in the Portuguese design practices and at going further towards noise classification and prediction in urban areas.

2. OVERVIEW OF PAST PORTUGUESE EXPERIMENTS

At present, there are two types of silent road surfaces which are used in Portuguese roads: porous asphalt, widely used in motorways, and asphalt with rubberized binder, used either in motorways or in national roads.

As far as noise is concerned, advantages and disadvantages in the use of porous asphalt are well known and documented [1-2]. The same does not apply for the rubberized asphalt. In Portugal, only three studies carried out in motorways focused on these types of mixtures. The first one compared a gap graded rubber asphalt with a “rough” dense asphalt and with cement concrete. The second one assessed the noise produced on a porous rubber asphalt mixture. In the first case, abatements of 5 to 8 dB(A) and 8 to 10 dB(A) were obtained [3]. In the second case, a reduction of 3 to 5 dB(A) was reported [4]. The third one compared a porous asphalt with a dense asphalt considering two surfaces under the following conditions: dry and wet. When surfaces were dry, a poor abatement of less than 2 dB(A) for the reference speed of 80 km/h was obtained. When surfaces were wet the noise abatement doubled [5].

Another study was carried out in national roads more recently. This study addressed a set of seven surfaces: a) three gap graded with rubberized asphalt; b) one dense asphalt; c) three unconventional gap graded mixtures with a small aggregate size. On the contrary to what was expected, the mixtures with rubber did not show a significant better performance than the other mixtures [6]. In fact, the same performance was achieved with other type of gap graded mixtures.

Figure 1 shows seven typical grading curves used in several types of surfaces, such as dense asphalt (DA), porous asphalt (PA), rough thin layers (TL), smooth thin layers, rough asphalt rubber (RA) and gap graded asphalt rubber (GGAR). For comparison purposes, an additional grading curve of a low noise surface widely used in France was included. The most important differences between that reference curve and the others are related to the maximum aggregate size. This leads to the conclusion that Portuguese conventional road surfaces have a big maximum aggregate size which seems to control noise in a great extent.

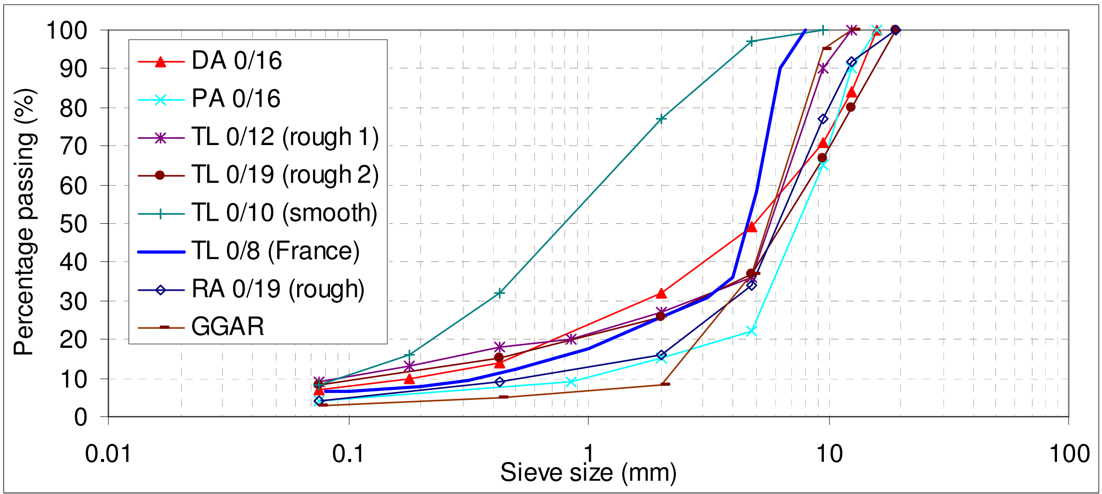

Figure 1 – Common grading curves of Portuguese road surfaces

3. EXPERIMENT

An experimental program was carried out in an urban distribution road in the centre of the city of Braga (northern Portugal) with a traffic flow of more than 40000 vehicles (Figure 2). Three surface layers were constructed consecutively: i) one dense asphalt layer with 12 mm of maximum aggregate size, following the SILVIA recommendations for low noise surfaces [7]; ii) two very-thin surfaces with different grading, which are an adaptation of the very-thin layers, widely used in France [8], to Portuguese conditions. The construction of a fourth surface layer with rubberized asphalt binder, as initially designed, was excluded due to severe weather conditions.

Figure 2 – Urban context of the road

Three months after the reconstruction, a complete characterization of the road was performed, including friction, evenness, texture and noise. Friction was measured with the GRIP-tester and the surface texture was measured by a high speed profilometer. Road traffic noise levels were measured both by pass-by tests with selected traffic (1 truck and 2 light vehicles) at several speeds and by close proximity tests. A total of 75 vehicle pass-bys was carried out, with the engine switched on, at three speed levels. Wind speed, air and road surface temperature were also measured.

3.1. Testing site

The layout of the testing site is depicted in Figure 3 where five sections are located and identified. Those sections have three different surface layers composed of:

- 3 cm of a very thin layer, whose grading curve was specifically chosen to bear the aggressive traffic action, particularly in curves (TL1) (Figure 4 A);
- 3 cm of a very thin layer, whose grading curve was specifically selected to bear less aggressive traffic action (TL2);
- 4 cm of a dense asphalt whose maximum aggregate is 12 mm (DA 0/12), divided afterwards in DA1 and DA2 (Figure 4 B).

Initially, a set of five surface layers, which included gap graded rubber asphalt and dense asphalt with larger aggregates (16 mm), were considered. Nevertheless, the bad weather during construction led to a simplification of the initial plan.

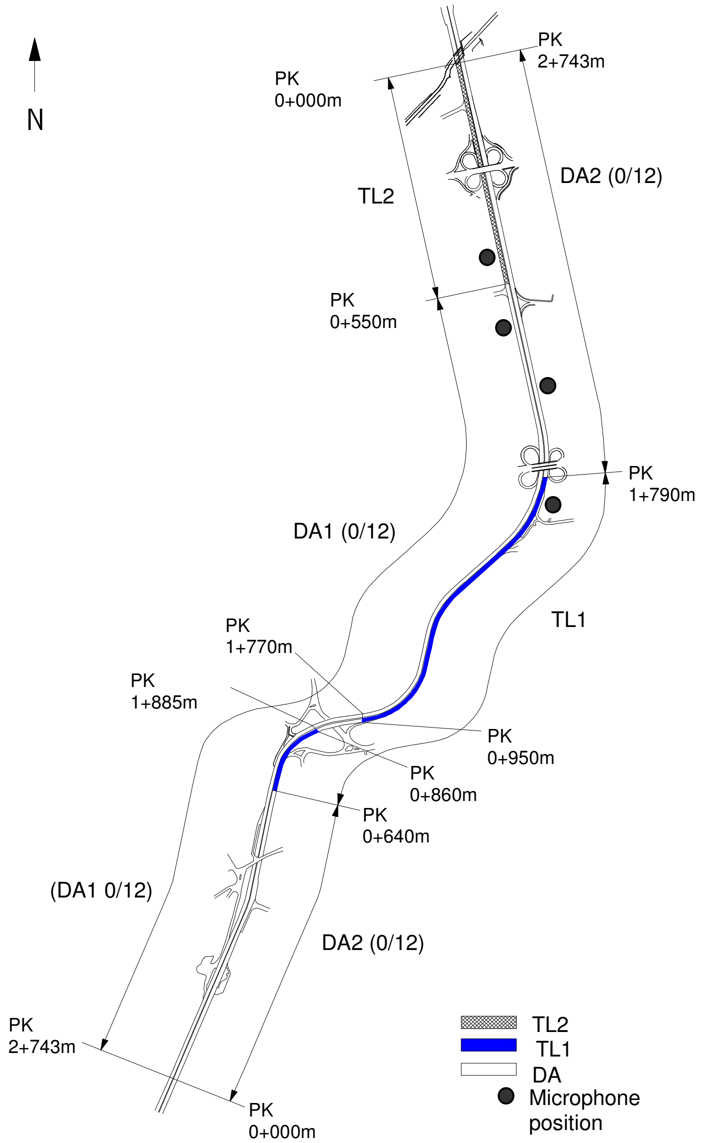

Figure 3 – Layout of the testing site

(A) (B)

Figure 4 - View of the testing site: (A) during reconstruction and (B) testing

3.2. Properties of asphalt mixes

The main properties of asphalt mixtures and grading curves are presented in Table 1 and Figure 5, respectively. The most important differences among the mixtures regard the grading curve, which, in turn, determines the void content.

Table 1 – Properties of the asphalt mixes

Type of mix	Maximum aggregate size (mm)	Binder content (%)	Void content* (%)
TL1	8	5.7	15.0
TL2	8	5.7	18.5
DA (0/12)	12	5.1	4.9

* from Marshal cores

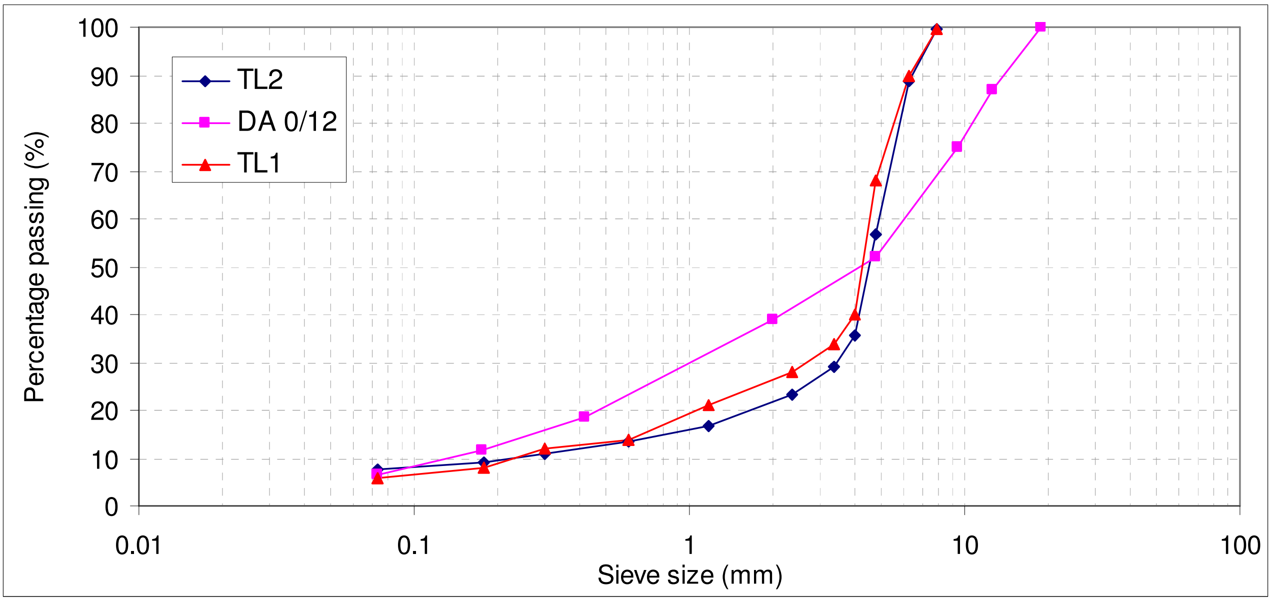

Figure 5 – Grading curves of the asphalt mixes

3.3. Testing vehicles and speed

The vehicles selected for testing may be grouped into the following categories, as recommended by the standard ISO 11819-1:1997(E) [9]:

- Passenger cars – 1 Volkswagen Polo and 1 Mazda (equipped with the CPX device);
- Multi-axle heavy vehicles – Tri-axle truck.

The testing speeds chosen were the reference speeds recommended in ISO 11819-2:1997(E) [10]. Accordingly, in both testing directions, the following speeds were adopted:

- Light vehicles – two pass-bys at 50 km/h, 80 km/h and 110 km/h;
- Heavy vehicle – two pass-bys at 60 km/h, 80 km/h and 90 km/h.

Real testing speeds were measured at every pass-by by means of a radar.

3.4. Noise measurement

In each lane direction, noise measurements were conducted simultaneously by the Close Proximity Method (CPX) and by the Controlled Pass-By Method (SPB).

3.4.1. CPX method

Close Proximity noise measurements were based on the draft standard method for measuring the influence of road surfaces on traffic noise [10]. This method involves the measurement of the tire-noise using microphones mounted near to a tire on a vehicle (Figure 6). To carry out the CPX measurements, a support system was designed to hold the mandatory microphones steady and in the right position as shown in Figure 7.

The captured signals were stored and processed in a dedicated audio module based on the Matlab platform.

The estimation of the overall noise emission was evaluated by applying the linear average approach to the signal for several road sections with an extension longer than 100 m. Each different section pavement under test extended for more than 100 m avoiding the need for averaging different runs of the same road. However, the tests involved two pass-bys for each reference speeds.

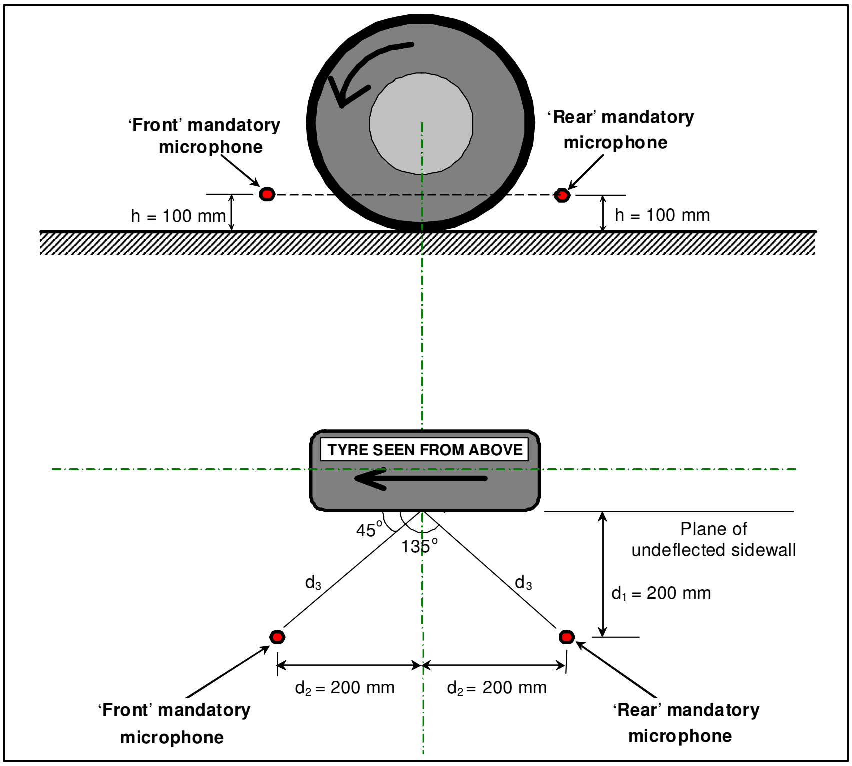

Figure 6 – Microphone positions for the measurements [9]

Figure 7 – Close proximity system used for the CPX tests

The noise levels measured at the ‘front’ and at the ‘rear’ mandatory microphones were arithmetically averaged.

The calibration procedure was applied to each microphone at the beginning of the tests.

3.4.2. SPB method

Pass-by noise measurements were based on the ISO 11819-1:1997 – ”Acoustics – Method for Measuring the Influence of Road Surfaces on Traffic Noise – Part 1: Statistical Pass-By Method” [9]. In each traffic direction and surface type, two microphones were positioned at 1.2 m above the pavement surface and 7.5 m from the centre of the carriageway. The placement of the microphones for the assessment of TL1 was difficult due to the geometry of the road and the surrounding environment (Figure 2). In order to guarantee reliable noise results without the influence of other vehicles, all the tests were carried out at night and the traffic was closed on both directions.

4. ANALYSIS OF RESULTS AND DISCUSSION

4.1. Weather

Wind speeds lower than 5 m/s, air temperature in the range of 5ºC to 30ºC and a surface temperature in the range of 5ºC to 50ºC assured valid noise measurements results [9].

During the experiment, wind speed and temperature were measured at every pass-by. The wind speed was below 1 m/s. Since the tests were performed at night, the air temperature and the surface temperature were similar. Temperatures varied from 5.5ºC to 7.9ºC.

4.2. Texture

The macrotexture of the complete road section was measured with a High Speed Profilometer (HSP). The Mean Profile Depth provided every 20 m by the HSP was then converted to the Estimated Texture Depth (ETD) for comparison purposes. Figures 8 and 9 show the ETD variation on both travelling directions.

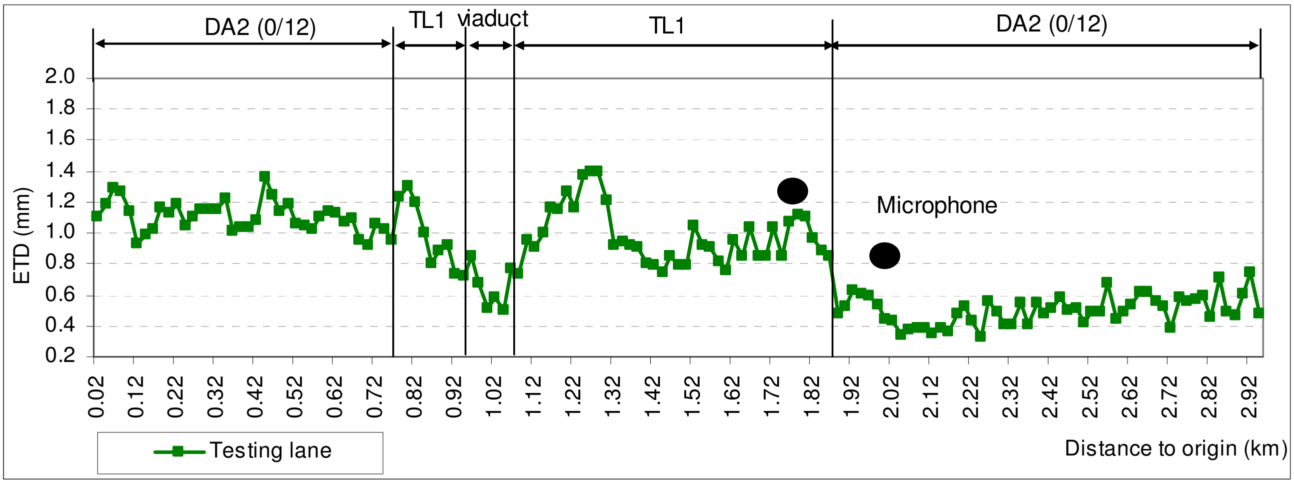

Figure 8 – Estimated texture depth in the South-North direction

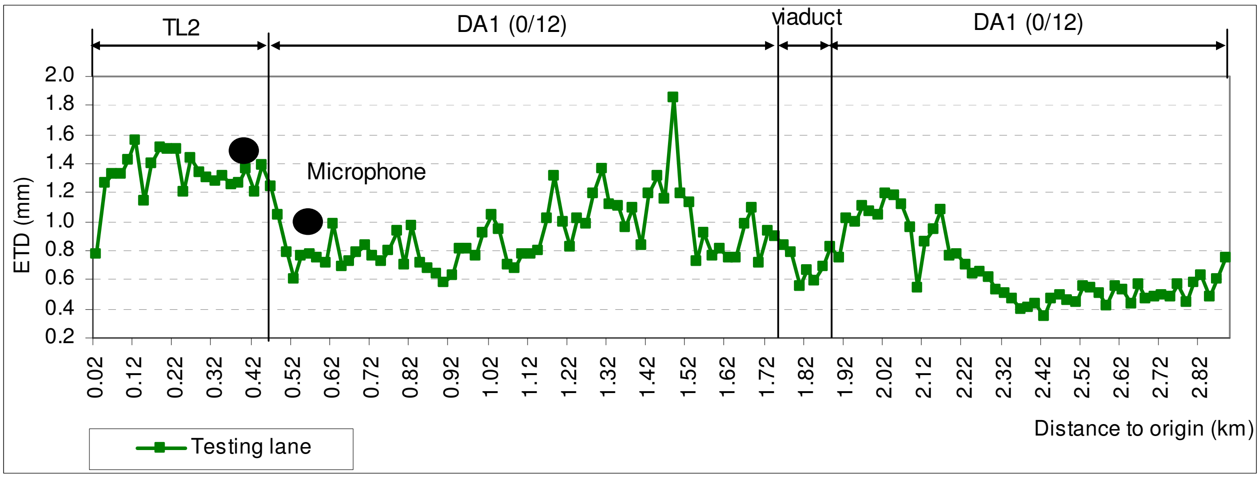

Figure 9 – Estimated texture depth in the North-South direction

Regardless the type of mixture, the ETD variation is considerably high. The cause for such high variation was poor construction quality, particularly of the dense asphalt (DA). For this reason, DA in each direction will be treated as an independent mixture. In the South-North direction it will be identified as DA2 and in the opposite direction as DA1.

4.3. Skid resistance

Low noise surfaces are composed in a great extent of small maximum grain size. This fact leads to question the safety provided by silent surfaces. Among these surfaces, gap graded mixes were reported to need more attention [11]. Therefore skid resistance tests were performed on the road under study (Figures 10 and 11).

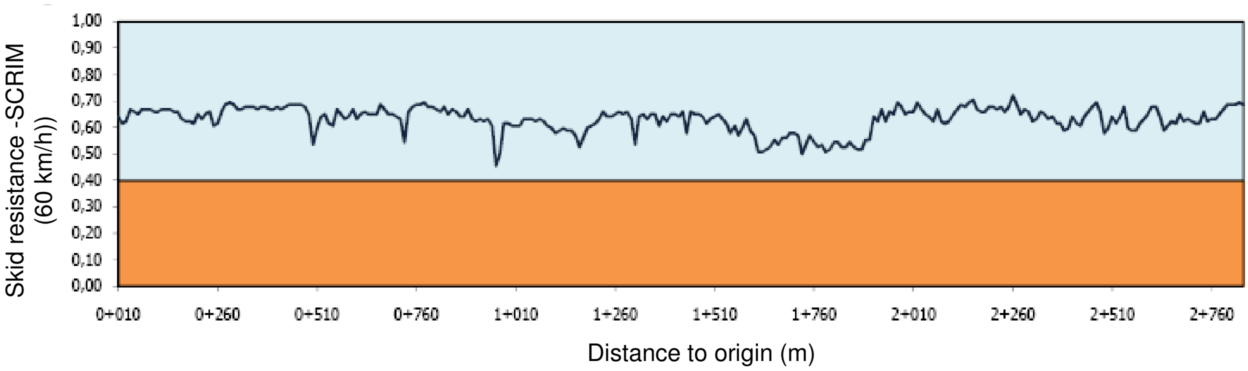

Figure 10 – Skid resistance Direction North-South

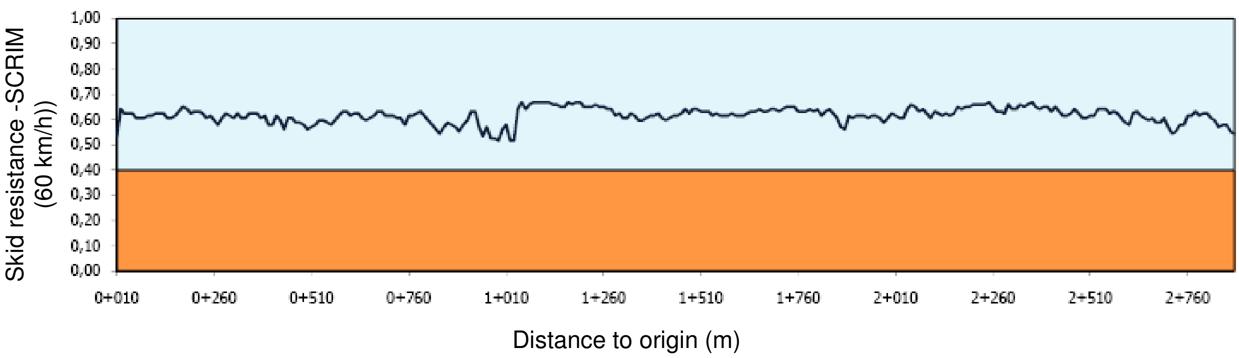

Figure 11 – Skid resistance direction South-North

On both directions, skid resistance is above the recommended limit of 0.4. Therefore, according to Portuguese standards, the drivers' safety is assured. By the testing time no differences among the three layers could be pointed out. Nevertheless, a different behaviour should be expected throughout time. For this reason, skid resistance will be surveyed periodically.

4.4. Noise

The noise generated on each surface layer was assessed by far field tests and by near field tests, as described above. Therefore, in the next sections the corresponding results and the relation among them are discussed.

4.4.1. Far field test

The maximum noise levels (*Lmax*) measured at each pass-by at different speed levels are presented in Figure 12 for the heavy vehicle and in Figure 13 for the light vehicles. Table 2 shows the linear regression parameters (slope and interception (b)) of *Lmax* with the logarithm of speed which were used next to calculate noise levels at reference speeds (Table 3).

For the heavy vehicle and at all speed levels, TL1 had the best performance, exhibiting the lowest noise levels. It was followed by TL2 and next by DA1 and DA2. Differences in noise level which result from the effect of the type of surface are not significant at 60 km/h.

For the light vehicles and at all speed levels, the best performance was achieved with TL2. In this case, DA1 showed slightly lower noise levels than DA2, although both were higher than TL1. The maximum noise difference is significant at all speed levels, particularly at high speeds. Noise level differences between DA1 and TL1 are about 1 dB(A) smaller than between DA1 and TL2, although higher than 3 dB(A). Therefore, if DA is taken as a reference surface, both TL1 and TL2 can be considered as silent surfaces. Noise reductions up to 6.8 dB(A) at 110 km/h can be obtained if dense asphalt with a maximum grain size of 12 mm is replaced by TL1 or TL2.

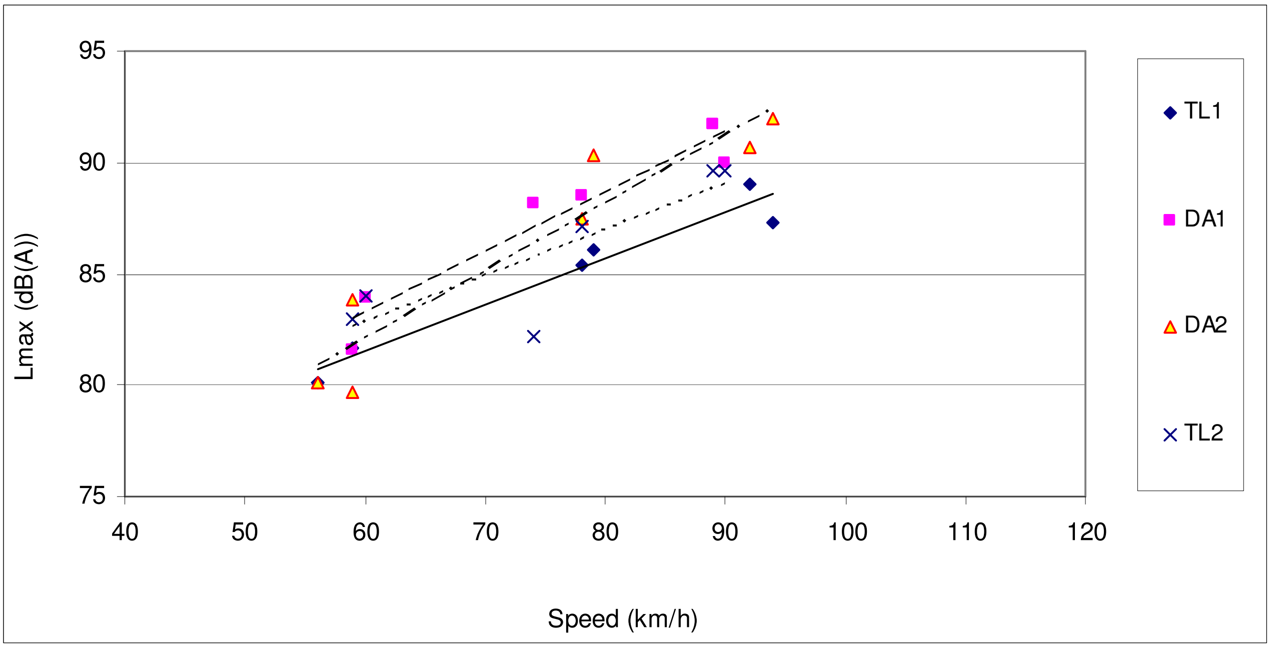

Figure 12 – Pass-by noise level for the heavy vehicle

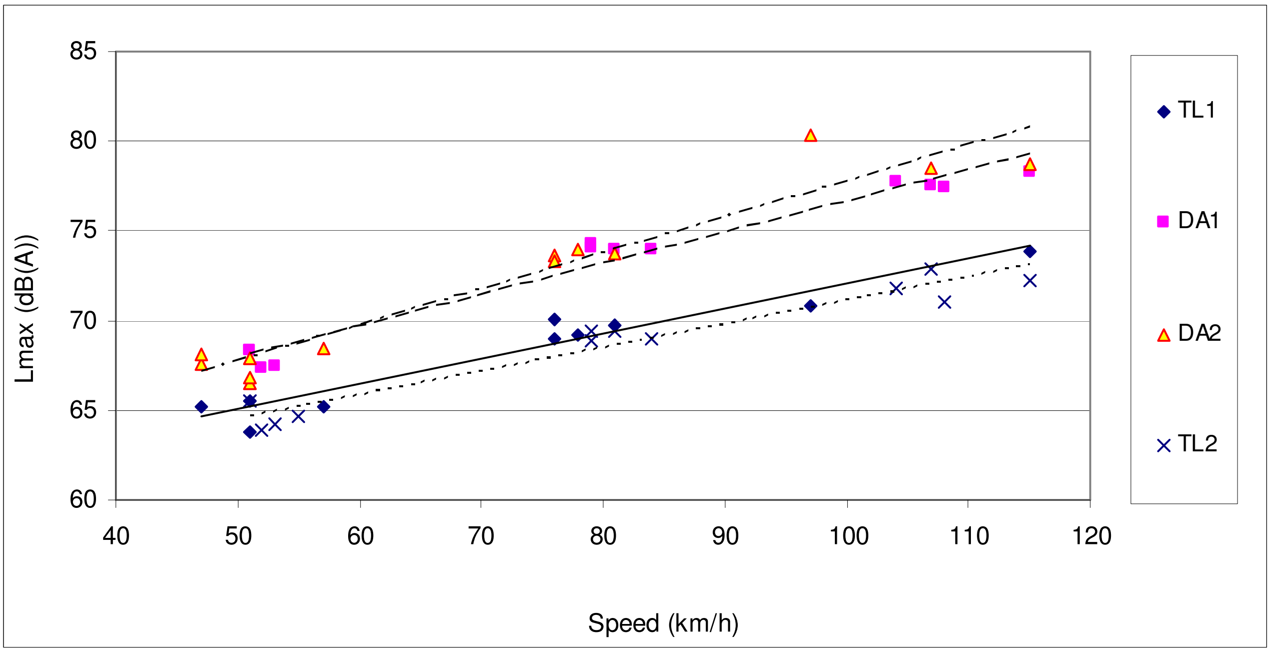

Figure 13 – Pass-by noise level for light vehicles

Table 2 – Regression parameters

Vehicles	TL1		DA1		DA2		TL2	
	slope	b	slope	b	slope	b	slope	b
heavy	34.9	19.6	46,0	1.4	51.4	-9.2	34.1	22.1
light	23.9	24.3	31.2	14.4	34.1	9.6	23.5	24.3

Table 3 – Noise levels at reference speeds

Type of vehicle	Speed (km/h)	Noise level (dB(A))				
		TL1	DA1	DA2	TL2	Max-Min
Heavy	60	81.6	83.1	82.2	82.8	1.6
	80	85.9	88.9	88.6	87.1	2.9
	90	87.7	91.2	91.2	88.8	3.5
Light	50	65.5	67.0	67.7	63.8	3.9
	80	69.5	73.4	74.1	68.5	5.6
	110	72.2	77.8	78.5	71.7	6.8

If the noise levels at reference speeds for TL2 are compared with those reported in [6] for dense asphalt 0/16 (DA 0/16), then noise reductions up to 10.4 dB(A) can be achieved (Table 4).

If the best performing surface found in that study is likewise compared, a gap graded asphalt rubber with 10 mm of maximum grain size, it is possible to reduce noise by more than 2 dB(A) by using TL2.

Table 4 – Noise levels at reference speeds

Type of vehicle	Speed (km/h)	Noise level (dB(A))			
		DA (0/16)	GGAR (0/10)	DA (0/16) –TL2	GGAR (0/10) – TL2
Light	50	71.2	66.5	7.4	2.7
	80	77.7	71.0	9.2	2.5
	110	82.1	74.1	10.4	2.4

4.4.2. Near field test

The same analysis procedure was used on the data registered in the near field tests, on the CPX data acquisition system. Figure 14 depicts the *Lmax* noise levels using the CPX method with speed. Tables 5 and 6 show the regression parameters of *Lmax* with the logarithm of speed and the noise levels at reference speeds calculated for the instrumented vehicle.

As expected, the results followed the same trend as the far field test results. TL2 and TL1 generated the lowest noise levels and were quite similar. DA1 and DA2 generated the highest noise levels and had a slight difference in *Lmax,* probably due to different estimated texture depths (ETD).

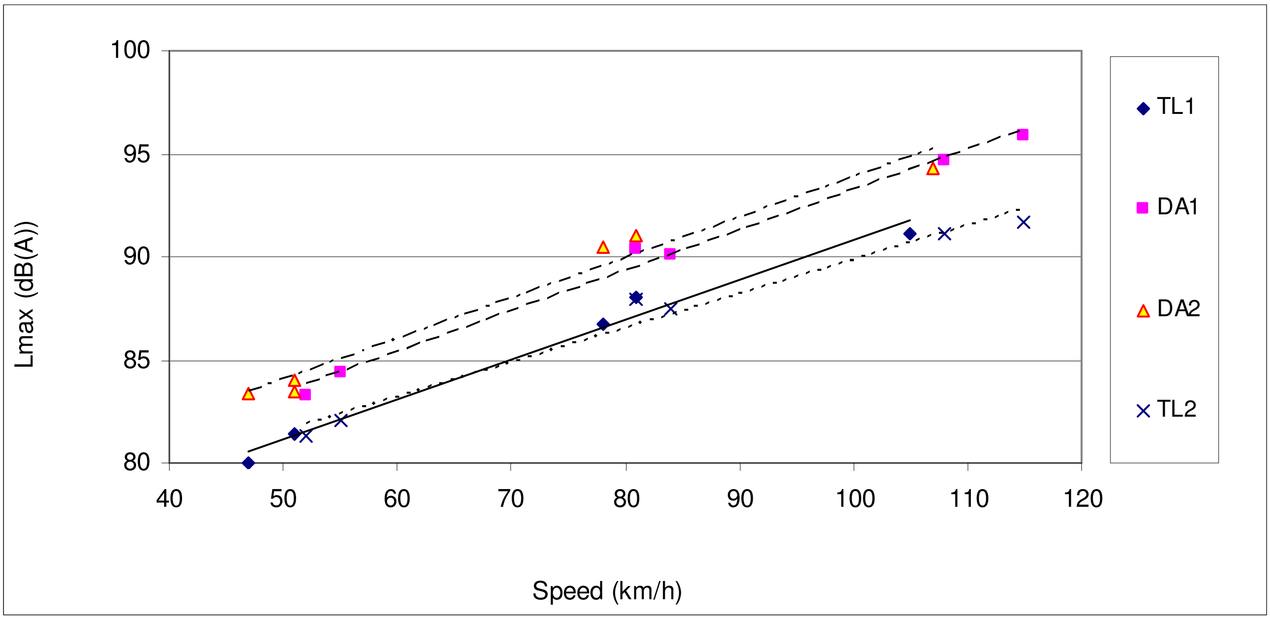

Figure 14 – *Lmax* noise levels using the CPX method

Table 5 – Regression parameters for close-proximity tests

Type of vehicle	TL1		DA1		DA2		TL2	
	slope	b	slope	b	slope	b	slope	b
Light (CPX)	31.6	27.3	32.7	28.3	35.8	22.0	30.4	29.2

Table 6 – Noise levels at reference speeds for close-proximity tests

Type of vehicle	Speed (km/h)	Noise level (dB(A))				
		TL1	DA1	DA2	TL2	Max-Min
Light	50	81.0	83.8	82.7	80.9	2.9
	80	87.4	90.5	90.0	87.1	3.1
	110	91.8	95.0	95.0	91.3	3.3

In this case, the difference between the highest *Lmax* and the lowest *Lmax* provided by the four surfaces was about 3 dB(A) at all speed levels.

4.4.3. Far field test versus near field test

There is a great difference between the noise signals captured by the CPX and by the SPB methods. In the first method, a correct analysis for the generation and propagation of the acoustic waves is carried out by considering near field conditions, given the distance of the acoustic transducers to the sound sources when compared to the wavelength. In such case, small displacements of the sound probe around the tire led to pronounced variations in the sound field due to the existence of multiple independent sound sources. The occurrence of signal cancellation or reinforcement is responsible for the spatial sound distribution. The analysis of the sound field through the SPB method is carried out by considering free field conditions. In this case, the sound field estimation is based on the acoustic plane wave theory.

Another important consideration refers to the total sound sources responsible for the noise levels measured through both methods. The noise component in the CPX method is essentially due to the tire/pavement interaction of the tire to which the microphones are coupled. In the SPB, assuming far field conditions, the noise radiated by the vehicle can be modelled by an equivalent noise source from the four tires, assuming that the noise engine component is insignificant at the speeds involved. The resulting noise levels are estimated by taking into account the attenuation of the sound waves between the equivalent noise source and the receptor. The sound attenuation is related to the geometric wave spreading and to the attenuation inserted by the ground between the vehicle and the target microphone (the air absorption attenuation can be neglected).

In order to evaluate the practical consequences of the considerations stated above, the global *Lmax* noise levels and the spectrum magnitude of the signal noise were considered. The relative dependence between the *Lmax* for CPX and for the SPB is depicted in Figure 15 and the Regression parameters of *Lmax* with the logarithm of speed in Table 7.

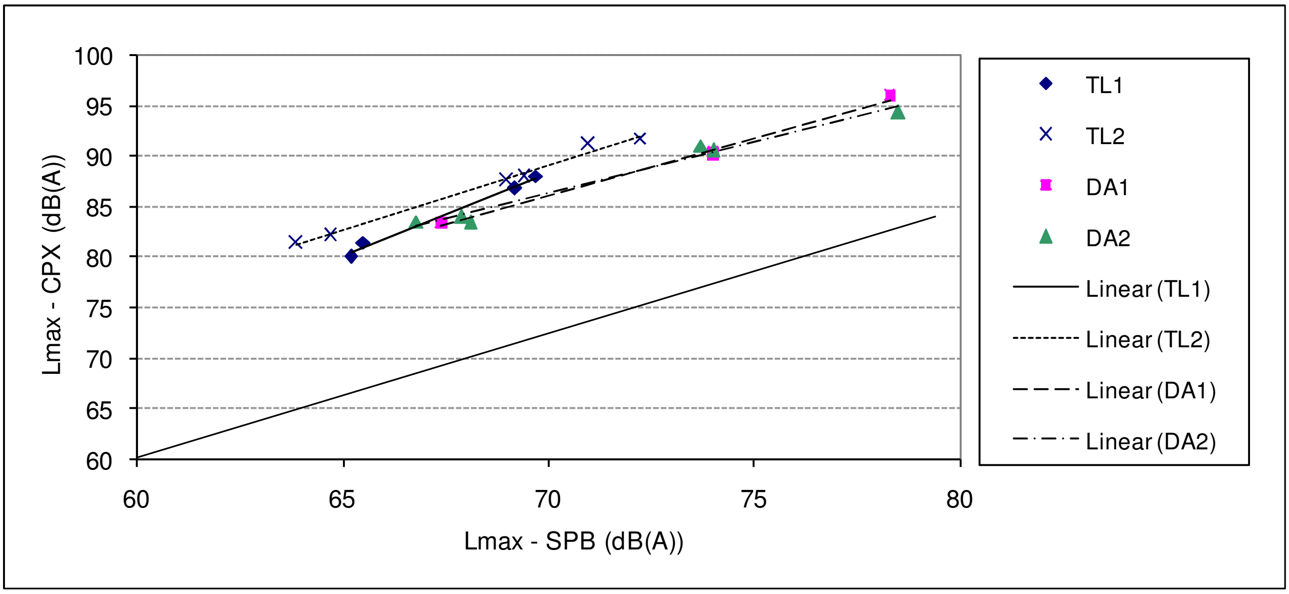

Figure 15 – *Lmax* from CPX tests vs. SPB tests for the surfaces tested

Table 7– Regression parameters

Instrumented vehicle	TL1		DA1		DA2		TL2	
	slope	b	slope	b	slope	b	slope	b
SPB	19.4	32.7	31.4	13.6	31.5	14.2	23.2	24.4
CPX	31.6	27.3	30.4	29.2	32.7	28.3	35.8	22.0

For the TL2 surface, an increase of the *Lmax* at the source corresponds to the same increment at the target. For the other surfaces, the slope of the curves shows a decrease in the attenuation at increasing speeds. The explanation is related to the near field conditions concerning the CPX system.

The noise attenuation related to the sound propagation between the source and the receptor, given by the two methods, is depicted in Figure 16 for different speeds and for the surfaces under test. In the case of the Dense Asphalt (DA) surfaces the attenuation is almost constant at all speeds. Nevertheless, an increase is shown for the thin layers (TL).

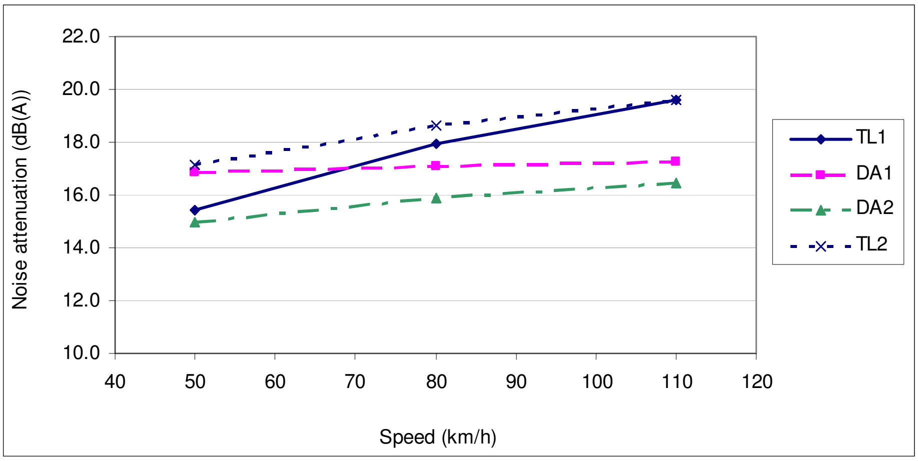

Figure 16 – Noise attenuation between CPX and SPB measurements

Noise spectra for the different surfaces are shown in Figure 17. As expected, a difference of more than 1 dB for the DA mixtures for the band frequencies of higher energy (between 800Hz – 2500Hz) can be observed. A significant noise reduction of about 5 dB between the TL and the DA mixtures is reported for those frequency bands. This fact results from a noise reduction of more than 4 dB in the overall *Lmax* noise levels. A cancelling effect is observed for the 1600 Hz frequency band suggesting the existence of two distinct local sound sources in phase opposition.

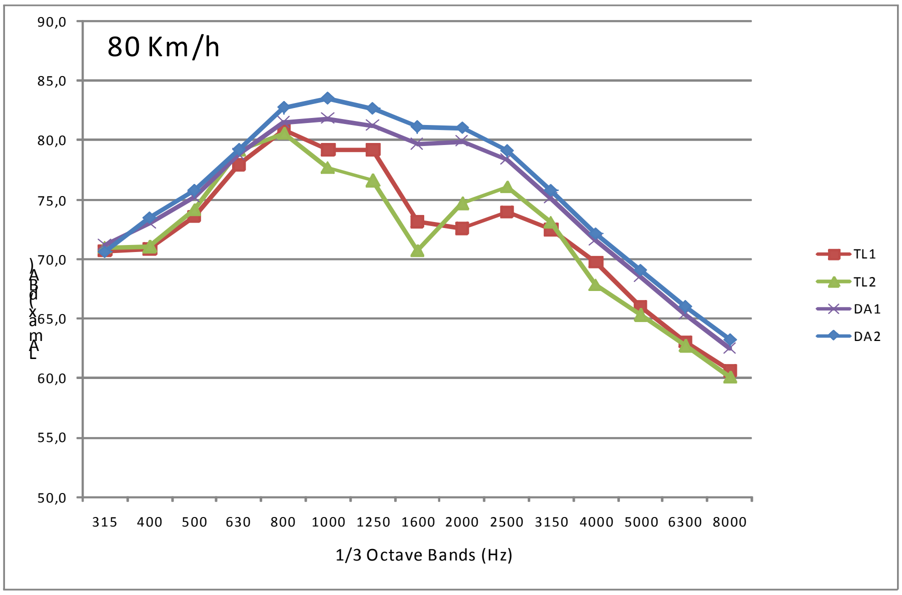

Figure 17 – Noise spectra based on the CPX measurements for the different surfaces at vehicle speed of 80 km/h

Bearing in mind that the captured noise for the two methods, CPX and SPB, has different genesis, differences should be expected in relation to the shape of the noise spectrum magnitude. Figure 18 shows CPX and SPB spectra for comparison purposes. For the SPB, the cancelling effect is not so prominent, what shows that a local deficiency concerning the geometry of the microphones may exist. The attenuation provided by the two methods is also shown in Figure 18.

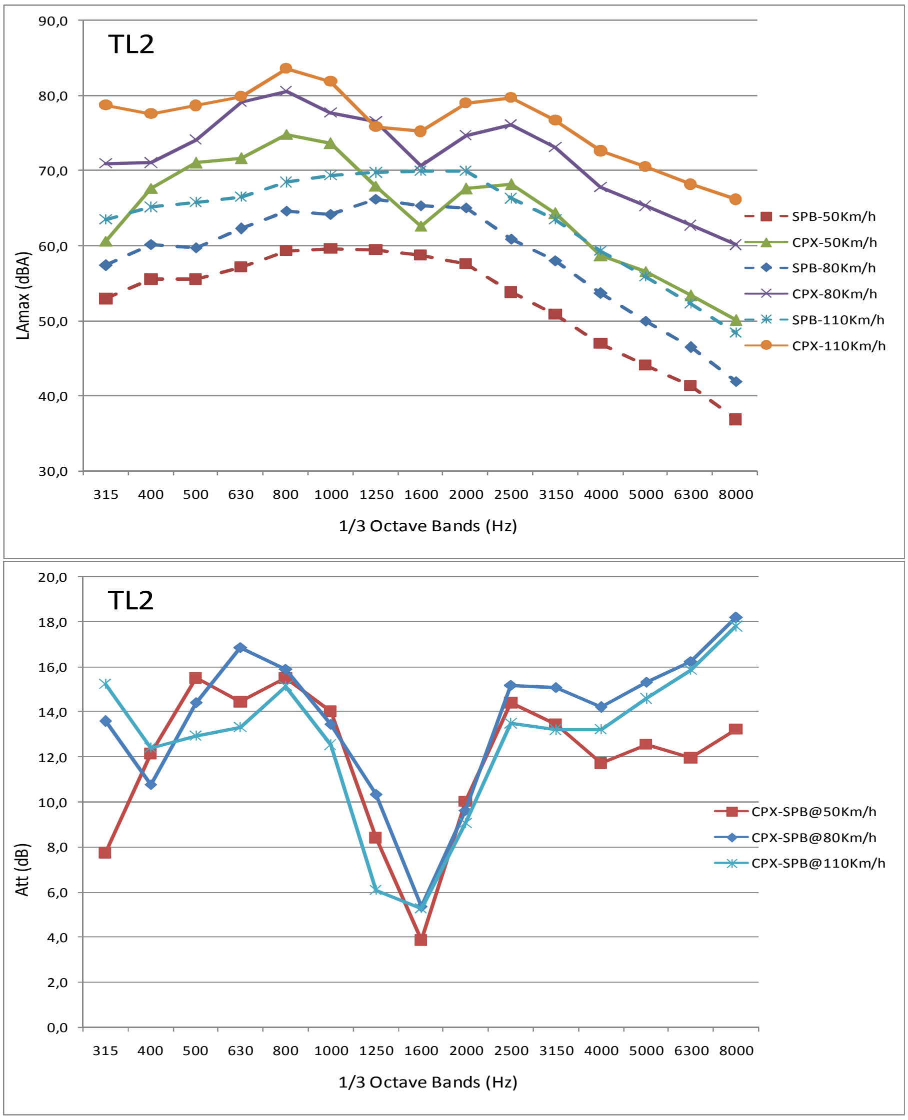

Figure 18 – Noise spectrum magnitude of the CPX against the SPB methods (upper) and related attenuation (lower), for the TL2 surface at different speeds

5. CONCLUSIONS

Silent surfaces as a measure to mitigate road noise effects are not sufficiently studied in Portugal. Thin surface layers with small grain size, with or without rubberized asphalt in high speed roads, are widely used to reduce noise. In this paper, a study carried out in an urban road in the centre of the Northern city of Braga was presented. Three asphalt mixes were tested using near field and far field tests.

To evaluate the performance of the different surfaces, SPB and CPX methods were used. Although these methods are very different in their basic concept, the first one is based on far field conditions and the second one on near field conditions. Complementary statements and conclusions can be stated. The results using the CPX system gives a first approach to the emission of noise levels at the sound source.

Noise reductions up to 7 dB(A) at 110 km/h, 5 dB(A) at 80 Km/h and 3 dB(A) at 50 km/h were obtained for the adapted thin layers compared to dense asphalt with maximum grain size of 12 mm. Much better performances may be attained if these thin layers are used to replace the widely used 0/16 dense asphalt. Concerns related to safety do not seem to be relevant. Therefore, the thin layers studied can be recommended to be used in all types of roads: a) in motorways, given their very good noise reduction at high speeds; b) in rural and urban roads. In rural and urban roads further noise protection is provided to the population living in the surrounding areas.

In the future, these testing procedures will be repeated periodically in order to assess the variation of the acoustic behaviour with time and to develop predictive models for near field and far field noise. Together with the macrotexture data and other relevant parameters such as absorption, megatexture will be used for modelling noise. A complementary tool using robust algorithms to analyse the effect of megatexture acquired with a high speed profilometer is being developed. Furthermore, the data provided by the CPX system will be used with machine learning algorithms for automatic classification of road pavements.

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