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IMPACTS OF THE REPLACEMENT OF DISTRESSED PAVEMENTS BY LOW NOISE – A CASE STUDY IN BRISA PORTUGUESE MOTORWAYS

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Resumo

A BRISA tem aplicado esforços no sentido de avaliar a influência do pavimento como fator de redução do ruído na origem e a estudar formas de adequar a aplicabilidade do método de previsão de ruído CNOSSOS à realidade da rede rodoviária concessionada, de modo a cumprir as diretivas europeias sobre avaliação e gestão do Ruído Ambiente. Este projeto avalia os efeitos do ruído ambiente da substituição de uma camada de desgaste de Betão betuminoso drenante (PA12.5) e de Betão Betuminoso (AC14) em fim de vida por uma camada de *Stone Mastic Asphalt* (SMA12) e nova camada de desgaste de Betão Betuminoso Rugoso (AC14). Para a avaliação do ruído Pneu-Pavimento foram aplicadas duas metodologias, (i) através do método *Statistical Pass-By* e (ii) método *Close Proximity Method*. Com estas metodologias, foi possível avaliar o efeito da intervenção e a evolução do ruído nos primeiros meses de uso das camadas de desgaste e monitorizar o desempenho acústico dos pavimentos durante a sua vida útil. Atualmente a Brisa prossegue o desafio de ter um melhor conhecimento dos pavimentos para alargar a biblioteca de pavimentos do CNOSSOS e atualizar os modelos de ruído.

Palavras-chave: CNOSSOS, SPB, CPX, pavimentos, ruído pneu-pavimento

Abstract

BRISA is employing efforts to evaluate the pavement influence as a factor of source noise reduction while studying forms of adjusting the applicability of the CNOSSOS noise prediction method to the reality of the concession road network to comply with European directives about Environmental Noise evaluation and management. This Project evaluates the environmental noise effects of replacing a wearing course of Porous and Bituminous Asphalt at end-of-life for a course of SMA12 and new Bituminous Asphalt. Two methodologies were applied to evaluate Tire-Pavement noise, (i) through Statistical Pass-By and (ii) Close Proximity methods. Using these methodologies, it was possible to evaluate the effect of the intervention and the evolution of the noise in the first few months of the exploration of the wearing courses and to monitor the noise performance of the pavements during their entire lifetime. Brisa is challenged to have better knowledge of pavements to extend the CNOSSOS pavement library and update noise models.

Keywords: CNOSSOS, SPB, CPX, pavements; tyre-road noise

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1 Introduction

Tyre-road noise is influenced by several factors, namely driver behavior (speed control and tyre pressure), tyre characteristics (structure, dimension, rubber stiffness, tread, wear, and age), pavement surface characteristics (macro and mega texture, irregularity, porosity, stiffness, age, wear, and water presence) and weather conditions (temperature and wind) (Sandberg and Jerzy, 2002). There are specific test methods for measuring tyre-road noise, which must be complemented with other surface characterization tests such as texture, sound absorption, and surface layer stiffness determined by mechanical impedance [3].

The cause-effect relationships established have been confronted or confirmed and are summarized, for example, in “Factors Affecting Tire-Pavement Noise and Prediction Models, Sustainability” [2]. The evolution of tyre-pavement noise over time has not received much attention. However, the perceived need to adjust the applicability of the CNOSSOS noise prediction method to the reality of each road network has prompted this type of study.

In Portugal, the Statistical Pass-By method (SPB) and the Close ProXimity method (CPX) have only recently begun to be applied systematically to the road network, with older studies being exploratory or aiming to support research activities [4, 5].

Recently, the manual on ecological public procurement criteria was adapted to Portuguese conditions as part of a National Strategy for Green Public Procurement (ENCPE 2020), which aims to support the processes of "Design, construction, rehabilitation and conservation of roads" [6]. This document sets out the minimum requirements applicable to the design of low-noise pavements, which, within the essential criteria for new low-noise pavements, take the following values, but only for the CPX method:

- 90 dB(A) at 50 km/h; and/or
- 95 dB(A) at 70 km/h; and/or
- 98 dB(A) at 90 km/h.

This document allows for an increase of less than 3 dB(A) from the maximum noise level, measured by the CPX method, during the minimum guarantee period (five years). However, it is only a guideline document, as in Portugal, no technical documentation that defines reference values regarding conformity of production or performance over time.

Within the framework dictated by the European directives on the assessment and management of environmental noise (2002/49/EC [7] and (EU)2015/996 [8], of 25 June and 19 May respectively), Brisa - *Concessão Rodoviária*, S.A., the biggest Portuguese highway concessionaire, has made efforts to determine the influence of pavements as a noise reduction measure at source and, at the same time, to validate the applicability of the CNOSSOS noise prediction method to the reality of its Concession road network.

In this context, this work analyses the effect of replacing the end-of-life wearing courses of Porous Asphalt (PA 12.5) and Asphalt Concrete (AC 14) with Asphalt Concrete (AC 14) and a high-performing wearing course of Stone Mastic Asphalt (SMA 12), through SPB and CPX methods. It also analyses the use of experimental data obtained from the SPB method as input data for noise predictive models.

2 Study sections and test methods

2.1 Study Methodology

For this exploratory study, three highway sections were selected where pavement interventions were foreseen, i.e., replacing the existing wearing course with SMA 12 and AC14 type. Before and after the interventions, tyre-road noise was evaluated using the Statistical Pass-By Method (SPB) and the Close ProXimity Method (CPX). Three phases were considered: phase 1 corresponds to the moment before the intervention and reflects the state of the pavement at end-of-life; phase 2 corresponds to the assessment carried out shortly after the intervention; and phase 3 reflects the acoustic performance after about 1 year of useful life.

The data resulting from the CPX and SPB methods can contribute to obtaining basic data on pavement characteristics for predictive noise models [9]. This data, collected on-site, should be better adapted to reality and could lead to models that are more in tune with existing conditions. This hypothesis is checked using the data collected for the SPB method and the software CADNA ®.

2.2 Descriptions of the study sections

Table 1 identifies the motorway sections selected for the study and characterizes them in terms of type, age, and the volume of traffic, that are considered in this study.

Table 1: Identification and characterization of the Motorways.

Motorway	**A**	**B**	**C**
Extension (m)	9,4	8	20,1
Type of mixture before intervention	PA12.5	AC14	PA12.5
Type of mixture after the intervention	AC14	SMA	SMA
Age at Phase 2 (months)	1	1	1
Age at Phase 3 (years)	-	1,4	1,4
Accumulated traffic F1-F2	420930	312720	561840
Accumulated traffic F2-F3	-	5129173	10939758

2.3 Statistical Pass-By method (SPB)

The Statistical Pass-By method (SPB) is a standardized method published by ISO 11819-1:1997, aiming to determine an indicator that considers the noise emitted by pass-by road traffic.

In this way, obtaining a quantitative classification of road pavement surfaces related to traffic noise is possible to satisfy the necessities expressed by road infrastructure managers, designers, contractors, pavement manufacturers, and other parties interested in predicting and controlling road traffic noise.

A reference speed for light and heavy vehicles is adopted to determine the sound pressure levels that characterize a given pavement surface (wearing course). The method is applicable at constant traffic speed, i.e., free flow conditions (without interference from other vehicles) circulating at speeds equal to or greater than 50 km/h, meaning, for Motorways, a speed of 90 km/h for heavy vehicles, and 120 km/h for light automobiles. The SPB method requires several in situ measurements, under normal driving conditions, of the maximum sound pressure level (Lmax) and the circulating speed of a passing vehicle using a sound meter (class 1 as specified in IEC 61672-1) positioned at 7,5 m from the centre line, and a kinemometer (radar).

Maximum sound pressure levels differ according to the class of the vehicle. Thus, the maximum A-weighted sound pressure level is recorded at each vehicle pass-by, along with the speed and the vehicle type (light, heavy dual-axle, and heavy multi-axle vehicles). After the passage of 100 light vehicles and 80 heavy vehicles, at the least, a linear regression is established between the logarithm of the speed and the maximum sound pressure level. Subsequently, the corresponding sound level for a certain reference speed is determined according to the road type. The SPB Indicator (SPBI) resulting from this method is an index value, in dB(A), based on the noise levels of different vehicle classes.

In this work, since the method requires measuring each vehicle's noise without the interference of others, only the events which fulfilled such criteria were selected. Therefore, passages that were influenced by the noise from other sources were excluded. Only two classes of vehicles (light and heavy) were considered.

2.4 Close ProXimity method (CPX)

With the advantage of measuring the tyre-road noise continuously, the Close ProXimity method (CPX) was used as defined in the EN/ISO 11819-2:2017 standard. In the present case, the noise measurement was performed close to one of the wheels of the testing vehicle, where two microphones were placed according to the mounting scheme defined by the standard. An analysis software processed the signals recorded during testing, and the noise emission (A-weighted) was evaluated in 20-metre sections as the arithmetic mean of the sound levels recorded by each microphone and by the corresponding sound spectrum in 1/3 octave bands (LCPX). Only the tyre representative of light vehicles (P) was considered in this study. The measurements were taken along the three sections for reference speeds of 50 km/h, 80 km/h, and 100 km/h.

3 Presentation and analysis of the results of the SPB method

3.1 Noise level measured on each motorway

Table 2 shows the results obtained by the SPB method on the three motorway sections before and after replacing the wearing course. Figures 1, 2 and 3 show the sound spectra for each motorway.

Table 2: SPB results.

Highway	**Phase**	**Type of vehicle**	**% vehicle pass (Light/ Heavy)**	**Lmax average**	**Average speed**	**Lveh (Ref. velocity) dB(A)**	**SPBI**
				dB(A)	**(km/h)**	**90km/h e 120km/h**	**dB(A)**
A	**1**	Light	93%	80	114	80	81
		Heavy	7%	83	82	84	
	2	Light	93%	79	115	79	80
		Heavy	7%	83	88	83	
B	**1**	Light	77%	82	114	82	84
		Heavy	23%	86	87	87	
	2	Light	77%	82	122	82	85
		Heavy	23%	89	92	88	
	3	Light	77%	82	107	83	86
		Heavy	23%	87	84	88	
C	**1**	Light	90%	87	120	86	86
		Heavy	10%	87	90	87	
	2	Light	93%	82	121	81	82
		Heavy	7%	84	93	82	
	1a	Light	94%	78	120	78	78
		Heavy	6%	81	85	79	

The sound spectra coming from tyre-pavement contact are determined by various mechanisms and factors, the main ones being the vibrations promoted by the texture of the pavement on the tyres and the condition of the pavement (frequencies below around 1000 HZ), and the air movements resulting from the interaction of the tyre tread with the irregularities of the pavement surface (frequencies above around 1000 Hz) and also sound absorption [10].

The frequency spectrum analysis shows identical behavior at low and high frequencies on all motorways. Specifically, there was a reduction in Lmax values after the pavement was applied at low frequencies, and at high frequencies, there was an increase.

The spectrum of motorway B shows a reduction in Lmax in the 3rd phase measurement compared to the 2nd phase, at low frequencies in the case of light vehicles and at high frequencies in the case of heavy vehicles. However, the SPB value increased by 1 unit when comparing successive phases.

Table 2 shows the measurement results of the 3rd phase, referring to motorway C, but the respective spectral curve is not shown in Figure 3 because the measurement position has changed. Therefore, it is not possible to compare these results with those of the previous phases.

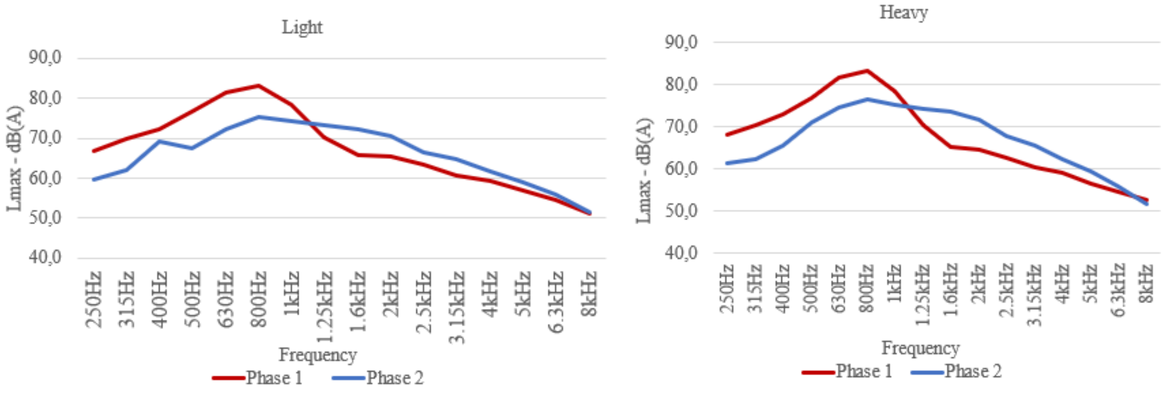

Figure 1: Sound Level vs frequency of Motorway A.

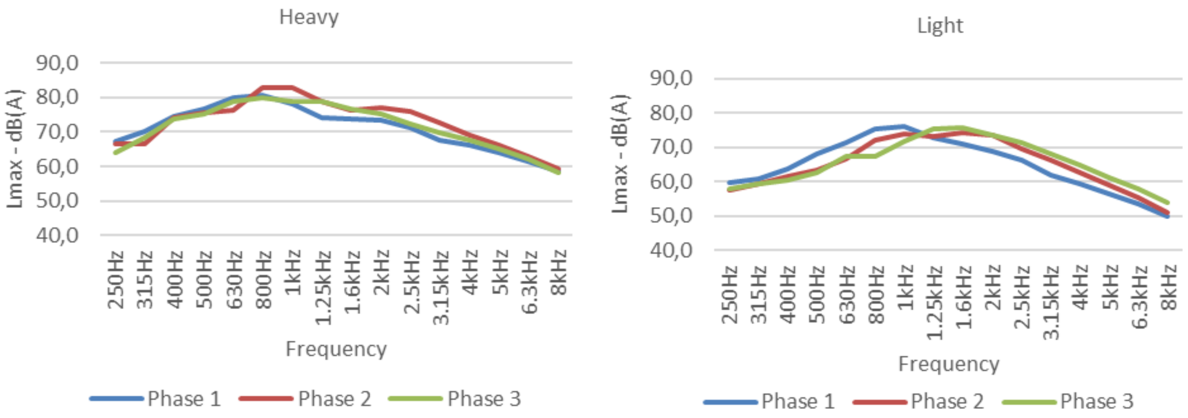

Figure 2: Sound Level vs frequency of Motorway B.

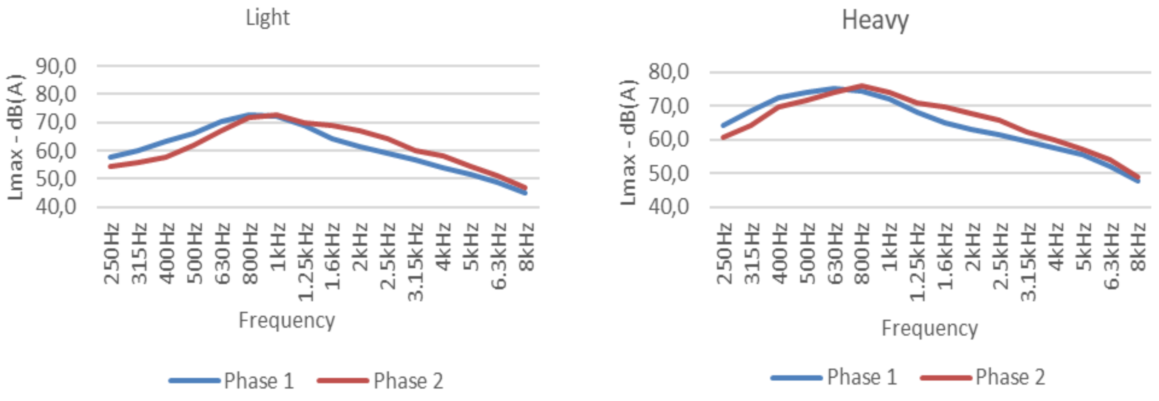

Figure 3: Sound Level vs frequency of Motorway C.

4 Presentation and analysis of the results of the CPX method

4.1 Noise level measured on each motorway

The speed at which the vehicle travels during acquisition determines the noise level measured. To make it possible to compare results at the 3 speed levels defined, the noise levels determined on each 20 m segment and the corresponding speed were used to define regression lines LCPX -log10(speed), whose slope (m) can be used to correct the LCPX measured for a given reference speed. Figure show the data obtained and the fitting lines for motorways B and C. On Motorway A, there has only been one measurement to date. These figures also show the parameters of the regression line obtained, slope (m) and ordinate at the origin (b), and the coefficient of determination (R2).

The parameter representing the increase in noise with speed changes significantly from phase 1 to phase 2, i.e., before and after rehabilitation. Furthermore, the impact of the intervention in terms of noise reduction is greater at higher speeds. Between phases 2 and 3, the slope remained relatively stable and close to the reference value recommended for correcting the effect of speed (m = 30).

All the LCPX values were adjusted to the reference speeds (50, 80, and 100 km/h) from the regression lines. Figures 6 and 7 show the values obtained for Motorways B and C for the reference speed of 80 km/h before and after intervention (phases 2 and 3). This type of visualization not only makes it easier to compare the noise levels obtained along a stretch at different points in the pavement's life but also helps to identify areas of homogeneous and heterogeneous behaviour, which can be related to factors that explain performance, such as texture. Along the stretch, before the intervention, the noise variability is noticeable, particularly for motorway C. After the intervention, as well as a significant reduction in the LCPX, there is also a reduction in the noise variability.

For an overall assessment of the effect of changing the wearing course, the average LCPX was determined at each reference speed, in both directions of traffic, and the respective coefficient of variation (Table 3). Motorway C benefited the most from the wearing course change, reducing noise by around 5 dBA, while Motorway B only showed a small reduction. There was also a higher coefficient of variation before the intervention, which indicates that the tyre-pavement noise became more homogeneous and that the effect of the intervention in some places is much greater than the average effect determined by the difference in the average LCPX.

Comparing the average values with those proposed in ENCPE2020 (Figure 8), it is easy to see that the values are exceeded for pavements at the end of their life, which is justified by their age.

For the new pavement, SMA 12, on motorway B, at 50 km/h, and in phase 2, the average LCPX exceeds the limit value by 2 dB(A), which is reduced in phase 3. On motorway C, this value is also exceeded, but only slightly. At a speed of 80 km/h, the mixture adopted provides around 1 dB(A) more; at 100 km/h, it can reach 2 dBA on average.

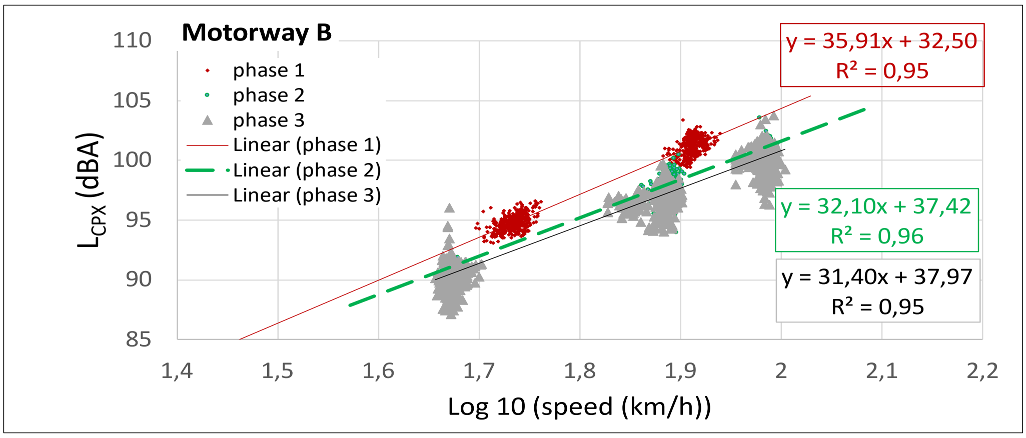

Figure 4: LCPX at 50 (1,7), 80 (1,9) e 100 (2,0) km/h in motorway B.

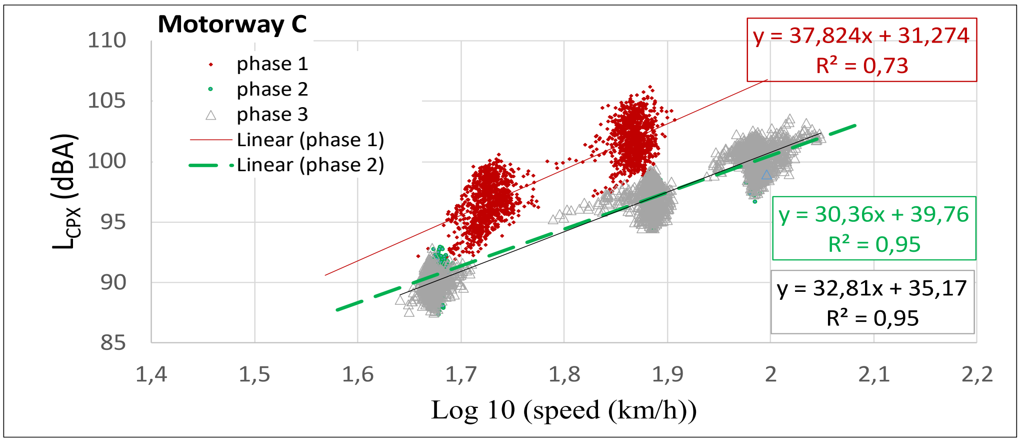

Figure 5: LCPX at 50 (1,7), 80 (1,9) e 100 (2,0) km/h in motorway C.

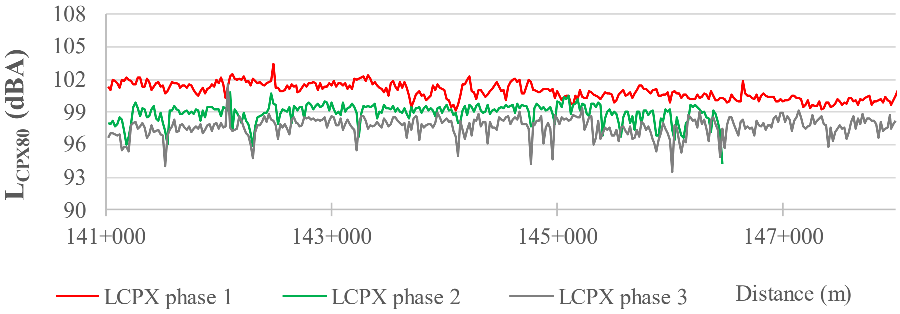

Figure 6: LCPX at 80 km/h in motorway B before and after the intervention (example).

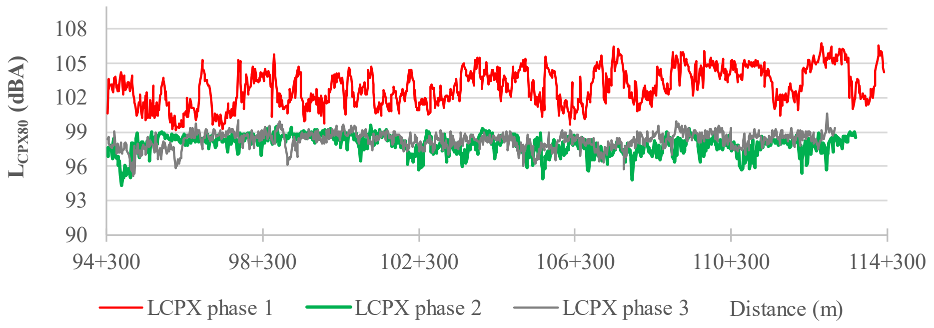

Figure 7: LCPX at 80 km/h in motorway C before and after the intervention (example).

Table 3: LCPX Noise Levels at 50, 80 and 100km/h in Motorways A, B and C and the respective coefficient of variation in Phases 1, 2 and 3.

Motorway B - direction 1		Phase 1		Phase 2			Phase 3		
Reference speed (km/h)		50	80	50	80	100	50	80	100
L_{CPX} (dBA)	Maximum	95,7	103,4	92,9	101	104	92,4	99,8	103
	Minimum	92,4	99,1	89,5	94,2	96,3	87	93,5	96,6
	Average	93,7	100,9	91,8	98,8	101	90,7	97,7	101
Average cv (%)		0,65	0,73	0,76	0,88	0,98	0,88	0,89	0,88
Motorway B - direction 2		Phase 1		Phase 2			Phase 3		
Reference speed (km/h)		50	80	50	80	100	50	80	100
L_{CPX} (dBA)	Maximum	96,4	102,6	94,1	101	104	96,3	99,9	103
	Minimum	90,9	98	88,9	94,6	96,4	87,6	94,5	98,4
	Average	93,2	100,3	92,5	99,4	102	90,9	98	101
Average cv (%)		1,06	0,86	0,77	0,79	1,13	1,18	0,98	0,91
Motorway C - direction 1		Phase 1		Phase 2			Phase 3		
Reference speed (km/h)		50	80	50	80	100	50	80	100
L_{CPX} (dBA)	Maximum	99,3	107,4	93,6	99,6	102	93,1	101	104
	Minimum	91,7	99,2	88	94,1	96,6	87,8	95,2	99
	Average	95,5	103,2	90,8	97,4	100	90,6	98,3	102
Average cv (%)		1.58	1,56	1,04	1,05	0,89	0,71	0,75	0,73
Motorway C - direction 2		Phase 1		Phase 2			Phase 3		
Reference speed (km/h)		50	80	50	80	100	50	80	100
L_{CPX} (dBA)	Maximum	99,5	106,8	92,8	99,1	101	93,4	99,6	103
	Minimum	92,5	98,7	88,3	94,1	96,6	87,3	94,3	97,9
	Average	95,7	102,7	90,2	96,9	99,3	90,1	97,2	101
Average cv (%)		1,45	1,54	1,21	0,93	1,02	0,9	0,88	0,87

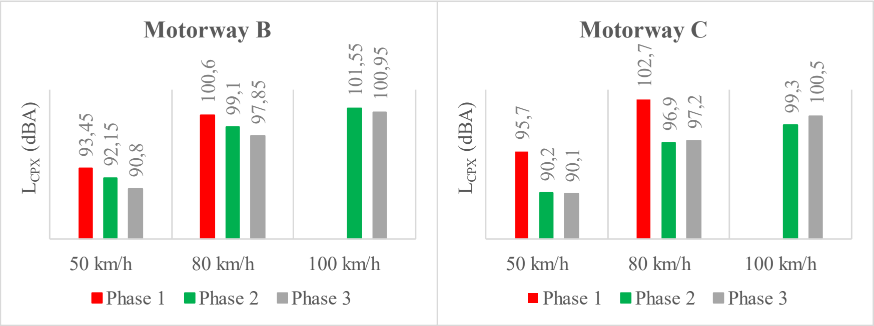

Figure 8: Average LCPX Noise Levels at 50, 80 and 100km/h in Motorways B and C in Phases 1, 2 and 3.

4.2 Spectra analysis

Figure 9 shows the sound spectra for the reference speed of 80 km/h, by direction, before and after the intervention on motorways B and C.

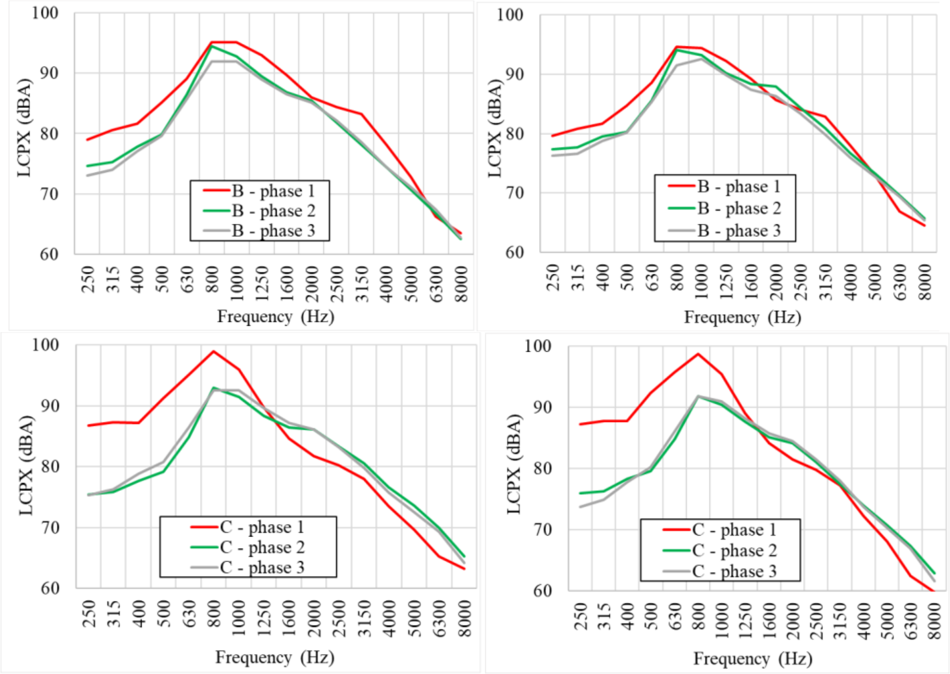

Figure 9: LCPX at 80 km/h in Motorways B and C vs. sound spectra in Phases 1, 2 and 3 (presented 2 road direction).

On motorway C, after the intervention, there is a very significant reduction in noise at low frequencies and a small increase at high frequencies. In this way, the new wearing course has reduced tyre vibrations and negatively affected the air movement mechanisms resulting from tire-pavement interaction.

On Motorway B, the effect of the wearing course change is visible throughout the spectrum, which means that the noise reduction was due to both the reduction in tyre vibration and the favoring of air movements, both of which are possibly provided by the texture.

Considering the speed of 100 km/h, as it is closer to the operational speed on this type of road, it should be noted that the performance pattern is very similar.

5 Comparison of the SPB and CPX methods

By analyzing the data obtained by the two methods, it is possible to see the reduction in noise after replacing the wearing course with SMA12, except for the results obtained by the SPB method for Motorway B, which point to a slight increase.

The results of both methods allow the same hierarchy to be established regarding the ordering of motorways according to the levels of noise reduction following the replacement of the wearing course - Motorway C and Motorway B.

There is some similarity in the levels of noise reduction after replacing the wearing course on the various motorways obtained by the 2 methods; namely, for light vehicles, there is a reduction of around 5 dB(A) on motorway C and varying between a reduction of 1.6 dB(A) and an increase of 1 dB(A) on motorway B.

Only in a detailed analysis of the reduction in noise levels by frequency ranges can be seen a greater dissonance between the two methods. In fact, when comparing Phase 1 with the other Phases, the results of the CPX method indicate that replacing the wearing course generates a greater reduction in noise levels at low frequencies, in the case of motorways B and C, although there is also some reduction at high frequencies, in the case of motorway B. The results of the SPB method, on the other hand, indicate that replacing the wearing course does not reduce noise levels at high frequencies on any of the motorways and that it does reduce them at low frequencies.

6 Environmental noise simulation using CNOSSOS road surface library vs. user-defined road surface

The measurements for tyre-road noise evaluation enable better pavement knowledge. They provide data for calculating specific characteristics of pavements, and this characterization can be used in noise calculation predictive model inputs, representing better local conditions.

The models make use of a reference road surface. Consequently, to calculate noise resulting from other road surfaces, the models require the input of correction coefficients. The correction coefficients for road surface characteristics on, respectively, rolling noise emission and propulsion noise emission, are defined by the following formulations:

$$\Delta L_{WR,road,i,m} = \alpha_{i,m} + \beta_m * \lg\left(\frac{v_m}{v_{ref}}\right) \tag{1}$$

$$\Delta L_{WP,road,i,m} = \min\{\alpha_{i,m} ; 0\} \tag{2}$$

$\alpha_{i,m}$ is the spectral correction in dB at the reference speed v_{ref} for category m (1, 2 or 3) and octave band i. In the case of a porous road surface, the $\alpha_{i,m}$ coefficient will decrease the propulsion noise, but dense surfaces will not increase it.

β_m is the speed effect on the rolling noise effect for category m (1, 2, or 3) and is supposed to be identical for all frequency bands.

The experimental data obtained from the SPB method was used to calculate the correction coefficients using the directive 2002/49/CE guidelines and some studies available [11] [12].

Table 4 shows the comparison between the results of in situ noise measurements and the output of models using CNOSSOS library road surfaces vs user-defined road surfaces based on the correction coefficients obtained from the experimental data.

Table 4. Results of noise measurements and the output of models using CNOSSOS library road surfaces vs user-defined road surfaces obtained from the experimental data.

Motorway/ Phase	**Road surface**	**CNOSSOS Library Road Surface**	**Difference between measurements and user-defined road surfaces (dB(A))**	**Difference between measurements and CNOSSOS library road surfaces (dB(A))**
C - Phase 1	PA 12.5	CNS02	6,1	11,3
C - Phase 2	SMA 12	CNS02	0,5	3,9
C - Phase 3	SMA 12	CNS02	1,4	5,1
A - Phase 1	PA 12.5	CNS14	2,1	7
A - Phase 2	AC 14	CNS05	2,4	8

As can be seen from Table 4, the difference between measurements and user-defined road surfaces are lower than those between measurements and CNOSSOS library road surfaces. Therefore, in this sample the sample that should be further developed in the future, the noise levels (Ld) obtained from models using the user-defined road surfaces (based on the correction coefficients obtained from the experimental data) are more in line with the Ld obtained during the noise measurements and are, therefore, in this more adjusted to reality.

7 Conclusions

With the data obtained by the CPB and CPX methods, it was possible to see a reduction in noise after replacing the wearing course with SMA 12, except for the results obtained by the SPB method for Motorway B, which indicates a slight increase.

Furthermore, the differences in the SPB and CPX values are very small after intervention and with time. To help explain the noise changes of the wearing courses over time, it will be necessary to continue assessing these characteristics after the intervention and complement it with other surface characteristics like the macrotexture.

The two methods, SPB and CPX, point to similar levels of overall noise reduction due to the wearing course replacement. However, the analysis of the noise levels by frequency revealed the sound propagation effect in the results of the SPB method, which led to differing changes. It, therefore, seems that the use of the two methods could be complementary, firstly because the SPB method allows noise level reductions to be observed on a wider range of vehicle types and considers a greater diversity of factors, and the CPX method allows a long stretch of road to be characterized in a short period.

Finally, comparing the simulation results performed with the model inputs based on the SPB method and the CNOSSOS pavement surface library with the in-situ noise levels revealed the relevance of adopting model parameters adjusted to the network operated by Brisa.

Nevertheless, this study is only exploratory and requires to be strengthened by reproducing it with a wider sample.

Therefore, it is a future challenge to increase further the use of these methodologies for obtaining pavement characterization parameters for noise simulation models. It is also another challenge to deepen the design of CPX and SPB methods with this objective in mind.

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References

[1] U. Sandberg and E. Jerzy. Tyre/road noise. Reference book. Informex, 2002.

[2] . O. Sirin. State-of-the-Art Review on Sustainable Design and Construction of Quieter Pavements-Part 2: Factors Affecting Tire-Pavement Noise and Prediction Models. Sustainability, 8(7), 692, 2016.

[3] S. Ling, F. Yu, D. Sun, G. Sun, and L. Xu. A comprehensive review of tire-pavement noise: Generation mechanism, measurement methods, and quiet asphalt pavement. Journal of Cleaner Production, 287, 125056, 2021.

[4] A. Santos. Estudo da eficácia da redução do ruído de tráfego em pavimentos drenantes. Dissertação de Mestrado em Engenharia Rodoviária, Universidade do Minho, 2007. (in portuguese)

[5] M. Antunes, S. Coutinho, J. Patrício, E. Freitas, J. Paulo, J. Coelho. Avaliação do ruído de Tráfego: Metodologia para a Caracterização de Camadas de Desgaste Aplicadas em Portugal. Evaluation of Pavement Surfaces Characteristics, Proceedings of the Seminar, pp 137-145, Guimarães, Portugal, 2008. (in portuguese)

[6] APA. Critérios de contratação pública ecológica, no âmbito da ENCPE 2020, para Conceção, Construção, Reabilitação e Conservação de Estradas. Agência Portuguesa do Ambiente, 2020. (in portuguese)

[7] Dir. 2002/49/CE do Parlamento Europeu e do Conselho de 25 de junho de 2002 – Avaliação e gestão do ruído ambiente. (portuguese version)

[8] Dir. (UE) 2015/996 da Comissão de 19 de maio de 2015 - métodos comuns de avaliação do ruído de acordo com a Diretiva 2002/49/CE do Parlamento Europeu e do Conselho. (portuguese version)

[9] F. Anfosso-Ledee and L. Goubert. The determination of road surface corrections for CNOSSOS-EU model for the emission of road traffic noise. Universitätsbibliothek der RWTH Aachen, 2019.

[10] E. Bühlmann and T. Ziegler. Interpreting measured acoustic performance on Swiss low-noise road surfaces using a tyre/road interaction model. Acoustics 2012, Hong Kong, 2012.

[11] B. Peeters and G. van Blokland. Correcting the CNOSSOS-EU road noise emission values. Euronoise 2018-Conference, 2018.

[12] A. Kok. Refining the CNOSSOS-EU calculation method for environmental noise. INTER-NOISE and NOISE-CON Congress and Conference Proceedings, Institute of Noise Control Engineering, Vol. 259, No. 8, pp. 1842-1849, 2019.