# Impacts of the shift from distressed pavements to low noise pavements in motorways – a case study in Portugal

**ABSTRACT.**

Road traffic noise is a relevant environmental problem, resulting essentially from the contact mechanisms between tyre and pavement surface**.** According to the current legislation, noise management actions must primarily intervene at the source. BRISA is employing efforts to determine pavement influence as a parameter of source noise reduction in order to address the well-being of the population surrounding highways and simultaneously comply with European directives regarding 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, using two different methodologies for tyre-road noise measurement: the Statistical Pass-By method and the Close Proximity method**.**

**Keywords.** Tyre-road noise; CPX/SPB; SMA.

## Introduction

Tyre-road noise is influenced by several factors, namely driver behaviour (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 characterisation tests such as texture, sound absorption, and surface layer stiffness determined by mechanical impedance.

In Portugal, a few studies were carried out based on those methodologies, namely the Statistical Pass-By method (SPB) and the Close ProXimity method (CPX), only with an exploratory nature or to support research activities (Antunes et al., 2008, Freitas et al, 2008, Freitas et al, 2009, Freitas et al, 2019). There is yet no technical documentation that defines reference values or surfaces, regarding the conformity of production or performance over time. Recently, the EU Green Public Procurement Criteria for Road Design, Construction and Maintenance was adapted to Portuguese conditions (APA, 2020), in the framework of the National Strategy for Green Public Procurement (ENCPE 2020). Nevertheless, it is a guiding document where minimum applicable requirements for the design of low noise pavements are indicated. Despite the lack of references for tyre-road noise assessments, the framework dictated by the European directives on environmental noise assessment and management (2002/49/EC and (EU) 2015/96, of June 25th and May 19th, respectively, in which noise predictions are based on road-noise, must be respected. Therefore, a gap must be fulfilled concerning tyre-road noise characterization for the Portuguese conditions.

In this context, *Brisa – Concessão Rodoviária*, S.A., the biggest Portuguese highway concessionaire, has developed efforts to determine pavement influence as a source noise reduction method and gather the information necessary to apply the CNOSSOS noise prediction method to its highway network, following the work developed by Anfosso-Ledee and Goubert (2019).

This study analyses the effect of replacing wearing courses of Porous Asphalt (PA 12.5) and Asphalt Concrete (AC 14), at end-of-life, with a high-performing wearing course of Stone Mastic Asphalt (SMA 12), through SPB and CPX methods.

## Study sections and test methods

### *Study Methodology*

For this exploratory study, three highway sections were selected where pavement interventions were foreseen, i.e., replacing the existing wearing course with one of the SMA 12 type. Before and after the interventions, tyre-road noise was evaluated through two different methodologies: Statistical Pass-By Method (SPB) and Close ProXimity Method (CPX).

### *Description of the Study Sections*

The main characteristics of the pavement wearing course of the three highway sections are summarised in Tables 1-3, before and after replacing the wearing course. These characteristics include grading curve, bitumen content, air void content, and macrotexture.

The Mean Profile Depth (MPD) values obtained for the pavements of the three highway sections before replacing the wearing course are presented in Table 4.

Table 1. Characterisation of the mixtures of wearing courses before and after intervention (Highway A)

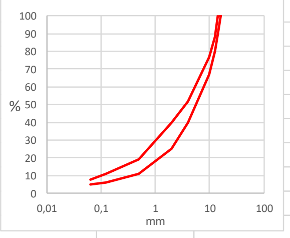
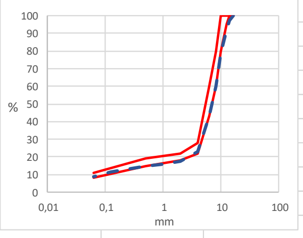
| Highway A<br>Old Pavement - AC 14 Surf 35/50 | | | | | | Highway A<br>Rehabilitated Pavement - SMA 12 Surf PMB 45/80-65 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grading Curve<br>AC 14 Surf 35/50 | | | Bitumen Content | Air void content | Macrotexture MTD | Grading curve (Quality Control)<br>SMA 12 Surf PMB 45/80-65 | | | | | Bitumen content | Air Void content | Macrotexture |
| Sieves # mm | Grading Specification (% pass) | | Specification limits | | | Sieves # mm | Grading Specification (% pass) | | Passing values % | STD - passing % | % avg | % avg | MTD$_{avg}$ |
| 16 | 100 | 100 | ≥ 5,0% | 6,0% ± 2,0 | ≥ 0,7 mm | 16 | 100 | 100 | 100 | ± 0 | 6,3 ± 0,2 | 6,3 ± 1,2 | 1,3 ± 0,1 |
| 14 | 100 | 90 | | | | 14 | 100 | 100 | 97 | ± 1 | | | |
| 12,5 | 88 | 80 | | | | 12,5 | 100 | 95 | 92 | ± 2 | | | |
| 10 | 77 | 67 |  | | | 10 | 100 | 80 | 79 | ± 3 |  | | |
| 8 | | | | | | 8 | 80 | 60 | 60 | ± 3 | | | |
| 6,3 | | | | | | 6,3 | 60 | 43 | 43 | ± 3 | | | |
| 4 | 52 | 40 | | | | 4 | 28 | 22 | 23 | ± 2 | | | |
| 2 | 40 | 25 | | | | 2 | 22 | 18 | 18 | ± 2 | | | |
| 1 | | | | | | 1 | | | 16 | ± 2 | | | |
| 0,500 | 19 | 11 | | | | 0,500 | 19 | 15 | 15 | ± 1 | | | |
| 0,250 | | | | | | 0,250 | | | 13 | ± 1 | | | |
| 0,125 | 11 | 6 | | | | 0,125 | | | 11 | ± 1 | | | |
| 0,063 | 8 | 5 | | | | 0,063 | 11 | 8 | 8,8 | ± 1,1 | | | |

Table 2. Characterisation of the mixtures of wearing courses before and after intervention (Highway B)

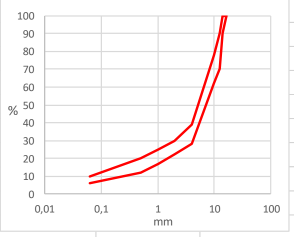
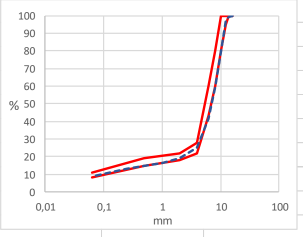
| Highway B<br>Old Pavement - AC 14 Surf 35/50 | | | | | | Highway B<br>Rehabilitated Pavement - SMA 12 Surf PMB 45/80-65 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grading Curve<br>AC 14 Surf 35/50 | | | Bitumen Content | Air void content | Macrotexture MTD | Grading curve (Quality Control)<br>SMA 12 Surf PMB 45/80-65 | | | | | Bitumen content | Air Void content | Macrotexture |
| Sieves # mm | Grading Specification (% pass) | | Specification limits | | | Sieves # mm | Grading Specification (% pass) | | Passing values % | STD - passing % | % avg | % avg | MTD$_{avg}$ |
| 16 | 100 | 100 | ≥ 5,0% | 6,0% ± 2,0 | ≥ 1,1 mm | 16 | 100 | 100 | 100 | ± 0 | 6,5 ± 0,1 | 6,2 ± 0,01 | 1,4 ± 0,1 |
| 14 | 100 | 90 | | | | 14 | 100 | 100 | 99 | ± 1 | | | |
| 12,5 | 90 | 70 | | | | 12,5 | 100 | 95 | 97 | ± 3 | | | |
| 10 | 78 | 62 |  | | | 10 | 100 | 80 | 80 | ± 3 |  | | |
| 8 | | | | | | 8 | 80 | 60 | 60 | ± 4 | | | |
| 6,3 | | | | | | 6,3 | 60 | 43 | 41 | ± 4 | | | |
| 4 | 39 | 28 | | | | 4 | 28 | 22 | 25 | ± 3 | | | |
| 2 | 30 | 22 | | | | 2 | 22 | 18 | 19 | ± 1 | | | |
| 1 | 25 | 17 | | | | 1 | | | 17 | ± 1 | | | |
| 0,500 | 20 | 12 | | | | 0,500 | 19 | 15 | 15 | ± 1 | | | |
| 0,250 | | | | | | 0,250 | | | 13 | ± 1 | | | |
| 0,125 | | | | | | 0,125 | | | 11 | ± 1 | | | |
| 0,063 | 10 | 6 | | | | 0,063 | 11 | 8 | 8,6 | ± 0,7 | | | |

Table 3. Characterisation of the mixtures of wearing courses before and after intervention (Highway C)

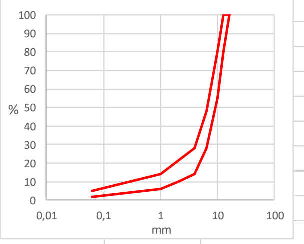
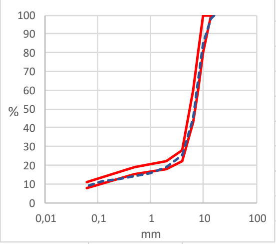
| Highway C<br>Old Pavement - PA 12,5 PMB 45/80-65 | | | | | | Highway C<br>Rehabilitated Pavement- SMA 12 Surf PMB 45/80-65 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grading Curve<br>PA 12,5 PMB 45/80-65 | | | Bitumen Content | Air void content | Macrotexture MTD | Grading curve (Quality Control)<br>SMA 12 Surf PMB 45/80-65 | | | | | Bitumen content | Air Void content | Macrotexture |
| Sieves # mm | Grading Specification (% pass) | | Specification limits | | | Sieves # mm | Grading Specification (% pass) | | Passing values % | STD - passing % | % avg | % avg | MTD$_{avg}$ |
| 16 | 100 | 100 | ≥ 4,0% | 22 - 30% | ≥ 1,2 mm | 16 | 100 | 100 | 100 | ± 1 | 6,4 ± 0,1 | 5,6 ± 1,4 | 1,3 ± 0,1 |
| 14 | | | | | | 14 | 100 | 100 | 98 | ± 2 | | | |
| 12,5 | 100 | 80 | | | | 12,5 | 100 | 95 | 95 | ± 2 | | | |
| 10 | 80 | 55 |  | | | 10 | 100 | 80 | 85 | ± 3 |  | | |
| 8 | | | | | | 8 | 80 | 60 | 65 | ± 3 | | | |
| 6,3 | 48 | 28 | | | | 6,3 | 60 | 43 | 45 | ± 3 | | | |
| 4 | 28 | 14 | | | | 4 | 28 | 22 | 25 | ± 2 | | | |
| 2 | 21 | 10 | | | | 2 | 22 | 18 | 19 | ± 1 | | | |
| 1 | 14 | 6 | | | | 1 | | | 16 | ± 1 | | | |
| 0,500 | | | | | | 0,500 | 19 | 15 | 14 | ± 1 | | | |
| 0,250 | | | | | | 0,250 | | | 13 | ± 1 | | | |
| 0,125 | | | | | | 0,125 | | | 11 | ± 1 | | | |
| 0,063 | 5 | 2 | | | | 0,063 | 11 | 8 | 8,7 | ± 1,1 | | | |

Table 4. Macrotexture Information (MPD)

| Highway | Min. (mm) | Max. (mm) | Mean (mm) |
|---|---|---|---|
| A | 0,5 | 1,4 | 0,8 |
| B | 0,6 | 2,3 | 1,3 |
| C | 1,7 | 3,6 | 2,5 |

### *Statistical Pass-By method (SPB)*

The Statistical Pass-By method (SPB) is a standardised 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, it is possible to obtain a quantitative classification of road pavement surfaces related to road traffic noise to satisfy the necessities expressed by road infrastructure managers, designers, contractors, pavement manufacturers, and other parties interested in predicting and controlling road traffic noise.

To determine the sound pressure levels that characterise a given pavement surface (wearing course), a reference speed for light and heavy vehicles is adopted. 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 highways, 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 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, at each vehicle pass-by, the maximum A-weighted sound pressure level is recorded, the speed and the vehicle type (light, heavy dual-axle, and heavy multi-axle vehicles). After the passage of at the least 100 light vehicles and 80 heavy vehicles, 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 resulting SPB Indicator (SPBI) 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 per si, 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.

### *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 ($L_{CPX}$). In this study, only the tyre representative of light vehicles (P) was considered.

The measurements were taken along the three sections for reference speeds of 50 km/h, 80 km/h, and 100 km/h, although, in the latter case, they were not carried out in all sections tested.

## Presentation and analysis of the results for the SPB method

### *Measured Noise Level on each Highway*

Table 5 shows the results obtained by the SPB method on the three highway sections, before and after replacing the wearing courses. The comparison of the SPBI shows a significant reduction of 3 and 4 dB(A), respectively on the highway sections A and B, which was similar for light and heavy vehicles.

Highway A provided consistently lower tyre-road noise values. This performance must be further investigated. One possible cause might be the applicability of the SPB method concerning the geometric requirements. The north of Portugal is characterized by high road slops, consequently, high embankments, short shoulders and recovery areas. Before the intervention, Highway C, on porous asphalt provided the same noise level as Highway B, on asphalt concrete, which shows that it had lost most of the absorption capacity that characterizes this type of mixture. The analysis of the noise spectra will help explain these remarks.

### *Spectrum Analysis*

Several mechanisms and factors determine the sound spectra resulting from tyre-road contact, the main ones being vibrations promoted by the pavement texture in the tyres and the pavement maintenance state (for frequencies lower than about 1000 Hz), and the air movements resulting from the interaction of the tyre tread with the irregularities of the pavement (for frequencies higher than about 1000 Hz) and by the sound absorption (Bühlmann and Ziegler, 2012).

Figures 1-3 show the sound spectra for each highway.

Table 5. Results obtained by SPB testing

| **Highway** | **Interven** | **Vehicle class** | **% Light/Heavy vehicle** | **Average $L_{max}$ dB(A)** | **Standard sound signal deviation dB(A)** | **Standard speed deviation (km/h)** | **Average speed (km/h)** | **$L_{veh}$ (dB(A) (120km/h and 90km/h)** | **SPBI dB(A)** |
|---|---|---|---|---|---|---|---|---|---|
| A | **Before** | Light | 95% | 77 | 3,7 | 17,7 | 108 | 78 | 78 |
| | | Heavy | 5% | 80 | 3,7 | 13,5 | 85 | 80 | |
| A | **After** | Light | 95% | 77 | 6,5 | 14,4 | 109 | 75 | 75 |
| | | Heavy | 5% | 78 | 1,8 | 12,3 | 88 | 77 | |
| B | **Before** | Light | 66% | 82 | 1,9 | 18,3 | 114 | 82 | 85 |
| | | Heavy | 34% | 86 | 1,2 | 4,5 | 87 | 87 | |
| B | **After** | Light | 67% | 82 | 1,3 | 17,9 | 122 | 82 | 86 |
| | | Heavy | 33% | 89 | 1,8 | 6,6 | 92 | 88 | |
| C | **Before** | Light | 93% | 87 | 4,5 | 13,7 | 124 | 86 | 86 |
| | | Heavy | 7% | 87 | 2,4 | 5,6 | 90 | 87 | |
| C | **After** | Light | 93% | 82 | 3,4 | 13,9 | 120 | 81 | 82 |
| | | Heavy | 7% | 84 | 3,6 | 8,3 | 94 | 82 | |

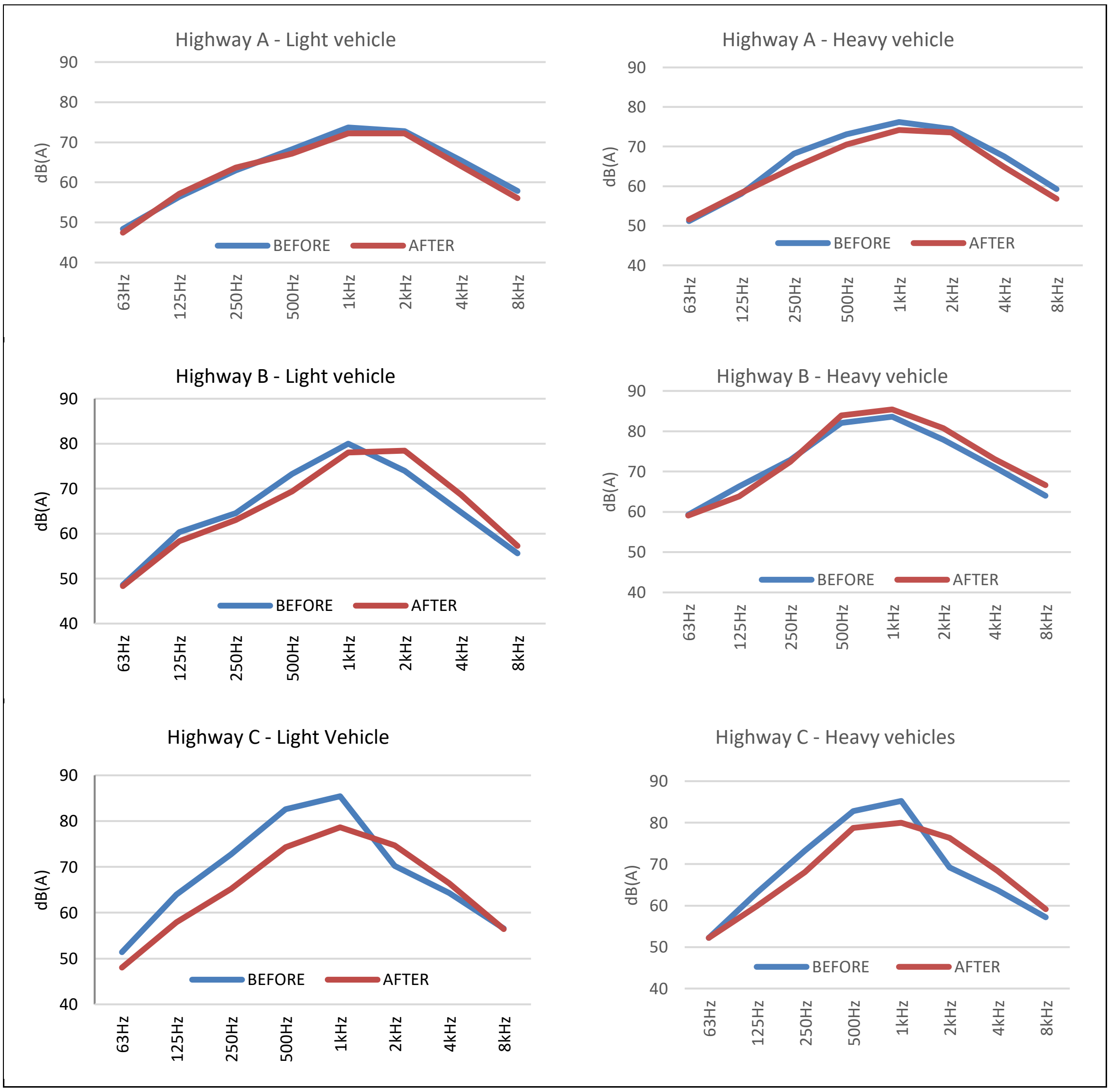


Fig.1. Sound level vs frequency (1/1 octave band).

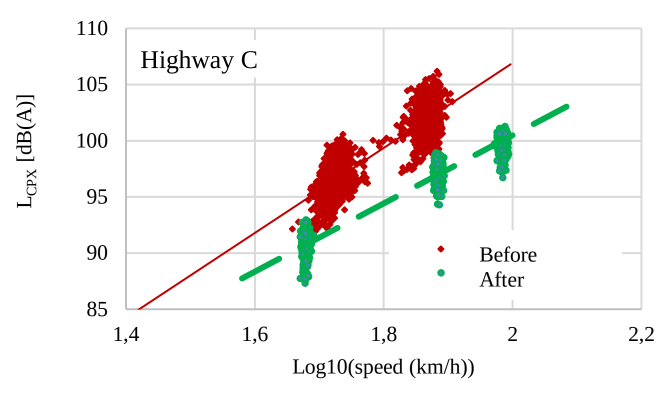
Before and after replacing the wearing course, the analysis of the frequency spectrum per octave band shows an identical behaviour for low frequencies, except for highway C where a decrease in sound pressure levels per frequency was observed for light vehicles. For high frequencies, on highway A the behaviour at low frequencies is also identical, while on highways B and C, there was an increase in the sound pressure levels per frequency, which was more accentuated for heavy vehicles.

## Presentation and analysis of the results for the CPX method

### *Measured Noise Level on each Highway*

The measured noise level is significantly affected by the test vehicle speed. For results comparison for the three defined speeds from the noise levels determined in each 20-metre segment and the corresponding speed, $L_{CPX}$ - log10(speed) regression lines were defined, whose slope (m) is used to correct the measured $L_{CPX}$ for a given reference speed. For the situations before and after the intervention, Figure 4 shows the obtained data and the fit lines. The figure also shows, for the three highways, the obtained regression line parameters, slope (m) and ordinate at the origin (b), and the coefficient of determination ($R^2$).

It can be observed that the parameter representing noise increase with speed changes significantly for highway C, indicating that the impact of the intervention in terms of noise reduction is higher at higher speeds. Highway B shows a similar trend to that of C. However, for highway A this trend is reversed.



| $L_{CPX} = m \times \log_{10}(speed)+b$ | | | |
|---|---|---|---|
| Highway - moment | m | b | $R^2$ |
| A-before | 35,3 | 34,4 | 0,92 |
| A-after | 38,0 | 26,4 | 0,97 |
| B-before | 35,9 | 32,5 | 0,96 |
| B-after | 32,1 | 37,4 | 0,96 |
| C-before | 37,8 | 31,3 | 0,74 |
| C-after | 30,4 | 39,8 | 0,96 |

Fig.4. $L_{CPX}$ at 50, 80 and 100 km/h in Highway C / Regression line coefficients for all highways.

All $L_{CPX}$ values were adjusted for the reference speeds (50, 80, and 100 km/h). Figure 5 shows the values obtained for the 80 km/h reference speed before and after intervention on highway C. In addition to facilitating the comparison of noise levels obtained along a section at different pavement life moments, this type of visualisation helps identify zones of homogeneous and heterogeneous behaviour, which can be related to performance explicative factors such as texture. In this section before the intervention, noise variability along it is notorious, reaching 7,6 dB(A).

After the intervention, besides the observed reduction of the average LCPX by 5 dB(A), the noise variability was also reduced to 5 dB(A). The coefficient of variation after the intervention reduced for each section, which indicates that tyre-road noise became more homogeneous and that the effect of the intervention in some locations is much higher than the average effect determined by the difference of the mean $L_{CPX}$. If $L_{CPX}$ per segment is considered, there are differences before-after intervention reaching 12 dB(A).

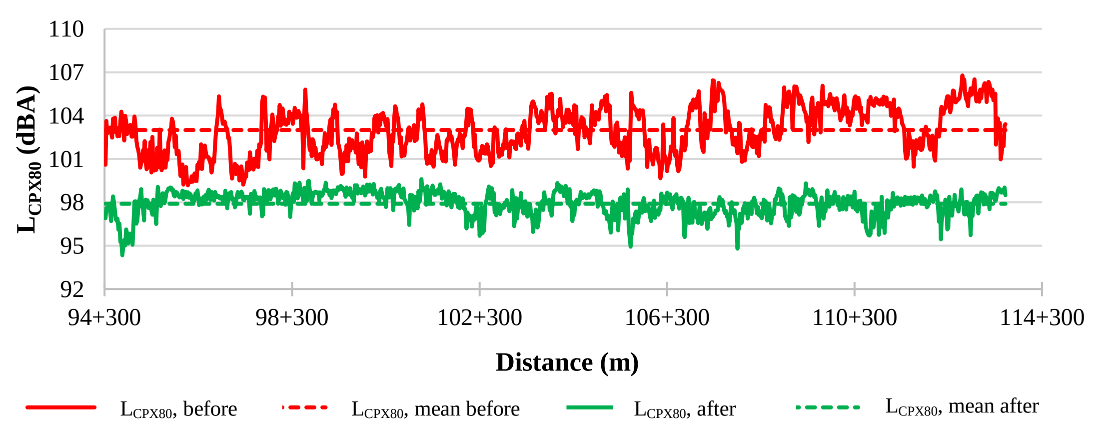


Fig.5. $L_{CPX}$ at 80 km/h in highway C before and after intervention (example).

For an overall evaluation of the effect of changing the wearing course in the three highway sections, the mean $L_{CPX}$ was determined at each reference speed in both traffic directions (see Figure 6). Highway C benefitted the most from the course change, while highway B presented only a small reduction.

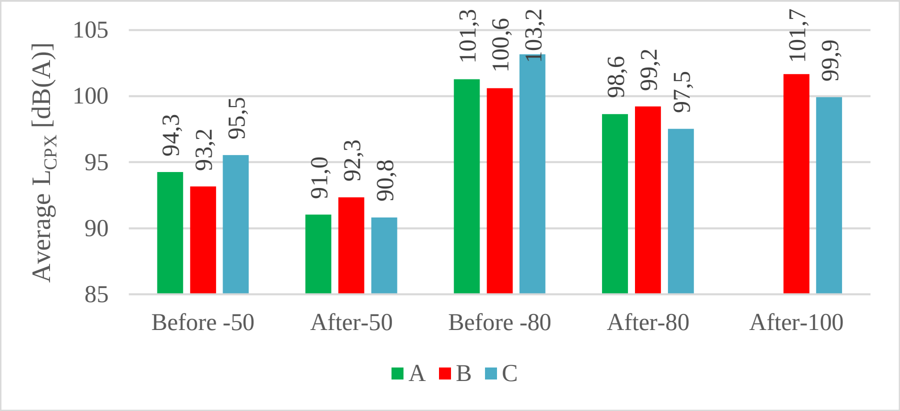


Fig.6. $L_{CPX}$ Noise Levels at 50, 80 and 100km/h in Highways A, B and C, before and after intervention.

***Spectrum Analysis***

Figure 7 presents the sound spectra for a speed of 80 km/h, per direction (C-crescent, D-decrescent), before and after the intervention, for the three highways, and for a speed of 100 km/h after intervention for highways B and C.

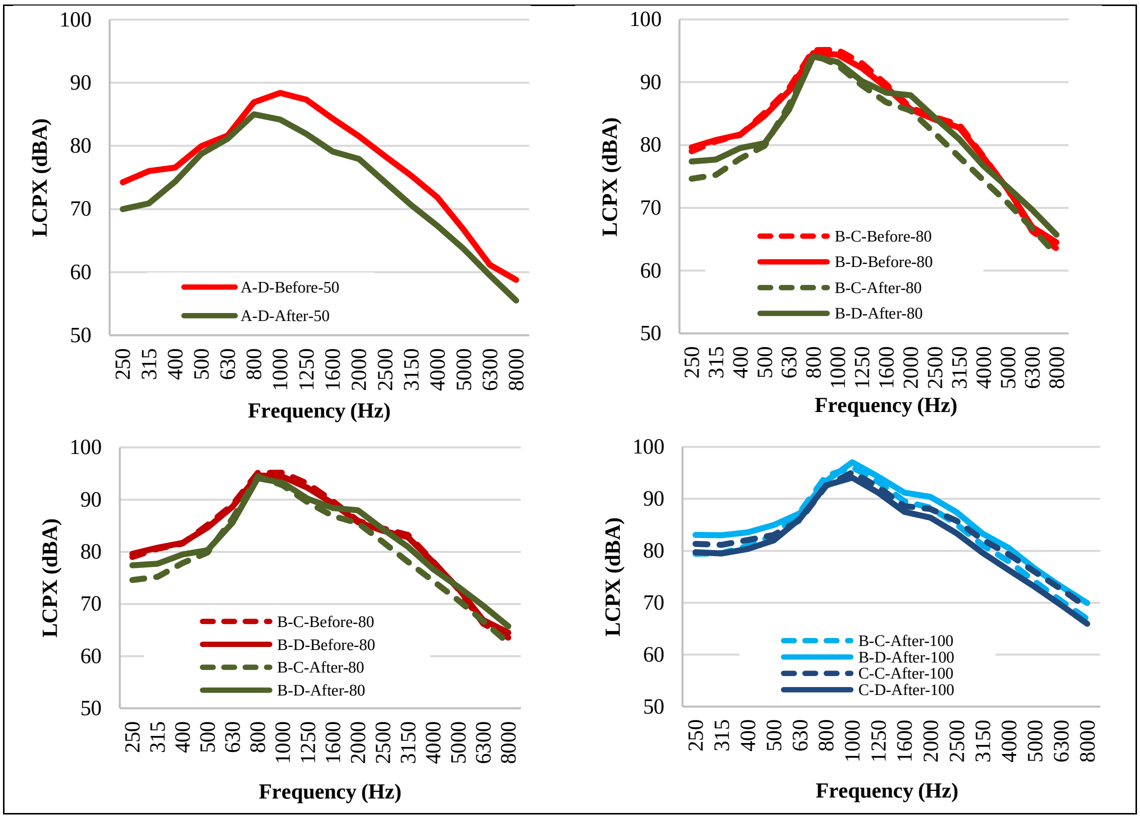


Fig.7. $L_{CPX}$ at 80 km/h in highways A, B and C, before and after intervention, and at 100 km/h in highways B and C, after intervention.

On highway A, the effect of changing the wearing course was predominant at high frequencies, meaning that noise reduction was essentially due to favourable air movements provided by the texture. This effect is opposite to that observed for highway C, where after the intervention there was a significant noise reduction at low frequencies and a small increase at high frequencies. The new wearing course provided a reduction in tyre vibrations and negatively affected the air movement mechanisms resulting from tyre-road interaction. The effect in the case of highway B was closer to that of highway A.

Considering the reference speed of 100 km/h, as it is closer to the operational speed in this type of road, it should be noted that the noise variation at each frequency, resulting from the intrinsic variability of construction conditions, was in average 4 dB(A).

## SPB and CPX method comparison

The two methods were able to provide data to determine the resulting noise change after the replacement of the existing wearing course by one of the SMA 12 type and also investigating the factors affecting it.

The results of both methods allow to establish the same hierarchy in terms of ordering the highways according to the level of noise reduction after replacement of the wearing course, specifically: highway C, highway A, and highway B.

Also, there is some similarity regarding the level of noise reduction after replacement of the wearing course of the three highways, obtained by both methods. Specifically, for light vehicles, there is a reduction of about 3 dB(A) on highway A, a reduction of 5 dB(A) on highway C, and a variation between - 1.4 dB(A) and + 1 dB(A) on highway B.

Overall, the results obtained by both methods on highways B and C confirm the noise difference of approximately 20 dB(A) for light vehicles, corroborating the relationship obtained in international studies [ROSANNE, 2016). Thus, in an expedite way the noise levels obtained by one methodology can be reasonably estimated in function of the values measured by the other.

Only in a more detailed analysis of noise level reduction by frequency ranges can be seen a greater dissonance between the two methods. In fact, the results of the CPX method indicate that replacement of the wearing course generates a greater reduction in noise levels at high frequencies in the case of highways A and B, and at low frequencies in the case of highway C. The results of the SPB method, in turn, indicate that wearing course replacement does not allow for a reduction in noise levels at high frequencies in any of the highways, and that it allows for a reduction at low frequencies in highway C. This observation is due to the effect of heavy vehicles which, in this analysis, are considered only in the SPB method, and to the effect of sound propagation.

## Conclusions

From the data obtained via the SPB and CPX methods, the effect in terms of noise reduction of the replacement of the existing wearing course by SMA 12 was assessed in three highways. While in two of them there was a noise reduction between 3 and 4 dB(A), in the other one the effect was negligible.

Both SPB and CPX methods point to similar global noise reduction levels caused by replacement of the wearing course. However, the more detailed analysis of noise reduction levels by frequency indicates some dissonance between the results obtained by the two methods, caused by the sound propagation effect in the results from the SPB method. Therefore, it seems that both methods can be used complementarily, since the SPB method allows for the observation of noise reduction levels in a wide range of vehicle types and considers a greater diversity of factors, and the CPX method allows for the characterisation of a long stretch of road in a short period of time.

For future studies, and for the SPB method, the need for a larger sample size was identified, given the assumptions associated with the test method. Also, to relate the observed noise reduction with variations of the wearing course characteristics, these must be evaluated after intervention through measurement in continuum, for comparison with the MPD values obtained prior to the intervention.

The analysis of the data resulting from the SPB and CPX methods suggests that these approaches can contribute to obtaining baseline data on pavement characteristics for predictive noise models. These data can be very useful for the obtaining of models better adjusted to existing conditions once being collected in situ and consequently more adapted to effective noise propagation (Anfosso-Ledee and Goubert, 2019). Therefore, the development of methodologies for obtaining pavement characterisation parameters for use in noise simulation models is envisaged as a future challenge, designing and outlining tests based on the SPB and CPX methods with this objective in mind, and considering the pavement typology used in the network operated by Brisa.

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