ACOUSTIC PERFORMANCE OF ROAD PAVEMENTS AND THE ROLE OF PAVEMENT CHARACTERISTICS ON THE BRISA MOTORWAY NETWORK

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Abstract

BRISA, Portugal's leading highway concessionaire, is committed to place sustainability at the core of its road infrastructure management. In this context, BRISA has been investigating the acoustic impact of replacing end-of-life pavements, analysing both the immediate noise reduction and the long-term evolution of acoustic performance.

To this end, tyre–road noise has been monitored on several motorway sections using Close-Proximity (CPX) and Statistical Pass-By (SPB) methods. Measurements were conducted prior to pavement renewal and repeated periodically after.

The results show consistent reductions in traffic noise following pavement renewal. However, the acoustic performance does not evolve monotonically over time, exhibiting fluctuations as pavements age and their surface characteristics change.

These findings highlight the need for further research on the relationship between pavement surface properties and acoustic behaviour throughout the pavement life cycle. The outcomes of this work aim to support the refinement of predictive noise models, including improvements to the CNOSSOS' pavement database, and to contribute towards optimisation of both pavement design and maintenance strategies for reducing environmental noise, underscoring the critical role of pavement management in the development of quieter and more sustainable road networks.

Keywords: *pavement characteristics, CNOSSOS, tire-pavement noise, acoustic durability, pavement life cycle*

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1. Introduction

The long-term acoustic performance of asphalt pavements has become increasingly important as traffic noise mitigation strategies have shifted towards controlling noise at the source. Although low-noise pavements can substantially reduce tyre–road noise when newly constructed, these benefits inevitably diminish over their service life due to traffic loading, environmental exposure and material ageing. Consequently, recent research has focused on acoustic durability, i.e., the ability of a pavement to retain its noise-reducing performance over time, established through distinct tyre-road noise measurement methods [1-3].

The rate of acoustic deterioration depends strongly on pavement type because the governing ageing mechanisms differ. In porous asphalt (PA), the loss of acoustic performance is mainly caused by pore clogging, traffic-induced densification, binder ageing and ravelling, which reduce sound absorption and increase air-pumping noise. In contrast, dense asphalt concrete (AC), Stone Mastic Asphalt (SMA) and thin asphalt layers (TALs/VTACs) contain little interconnected porosity, and their acoustic ageing is primarily associated with macrotexture evolution and surface wear. For rubberized asphalt, deterioration is mainly related to gradual stiffening of the asphalt-rubber binder and texture evolution rather than pore clogging [2-3].

The literature consistently shows that porous asphalt provides the greatest initial noise reduction, typically 3–6 dB(A) relative to conventional dense asphalt, while double-layer porous systems may achieve 7–8 dB(A). Thin asphalt layers generally provide initial reductions of 2–4 dB(A), whereas SMA achieves 1–3 dB(A) and rubberized asphalt typically 3–5 dB(A), with rubberized porous mixtures reaching 6–8 dB(A) under favourable conditions [1,4-5]. However, these benefits evolve differently over time. Dense asphalt concrete exhibits the highest acoustic stability, with long-term increases generally limited to 0.1–0.5 dB(A) per year [6]. Although its initial acoustic performance is modest, AC maintains relatively constant noise levels because deterioration is governed mainly by gradual texture evolution rather than loss of porosity [6].

Thin asphalt layers (TALs/VTACs) represent one of the best compromises between initial acoustic performance and durability. Their optimized aggregate gradation and negative surface texture reduce tyre vibration and air-pumping while relying less on interconnected porosity than porous asphalt. Consequently, their acoustic performance is much less affected by pore clogging and tends to deteriorate more gradually over time. Long-term monitoring has shown that thin asphalt layers retain a significant proportion of their initial noise-reducing performance throughout their service life and exhibit considerably better acoustic durability than porous asphalt, making them an attractive solution for urban and high-volume roads [1,3-4,7].

Stone Mastic Asphalt (SMA) provides an excellent balance between durability and acoustic performance. Initial tyre–road noise reductions are typically 1–3 dB(A) compared with conventional dense asphalt. Long-term field studies consistently show that SMA retains most of its initial acoustic benefit throughout its service life and undergoes considerably less acoustic ageing than porous asphalt, owing to the absence of interconnected pores and the greater stability of its surface texture [1]. Its stone-on-stone aggregate skeleton provides excellent mechanical durability and makes the surface considerably less sensitive to acoustic deterioration than porous mixtures [4].

In contrast, porous asphalt experiences the greatest acoustic deterioration despite providing the highest initial benefit. Most long-term monitoring studies report increases between 0.5 and 1.3 dB(A) per year. Overall, porous asphalt commonly loses 2–5 dB(A) of its initial acoustic advantage during its service life, meaning that a pavement initially providing a 5–6 dB(A) reduction may retain only 2–3 dB(A) after 8–10 years if no maintenance is performed. Nevertheless, even after considerable ageing, porous asphalt usually remains quieter than conventional dense asphalt [1,3].

Rubberized asphalt appears to offer one of the most favourable compromises between initial performance and acoustic durability [8]. Crumb rubber increases the viscoelastic damping of the mixture, reducing vibration transmission at the tyre–road interface while improving resistance to ravelling. Long-term CPX monitoring has shown that rubberized pavements maintain their noise-reducing performance better than many conventional low-noise surfaces [2].

Field studies consistently demonstrate that tyre–road noise is strongly correlated with pavement characteristics such as macrotexture, permeability and air-void structure, supporting the integration of acoustic indicators into pavement management systems [3,6]. Furthermore, such correlations help to explain the variability inherent to each type of mixture, which, together with climatic conditions, justify region-specific studies.

In this context, the aim of this investigation was to compare the tyre-road noise measured by two different methods, the close proximity method (CPX) and the statistical pass-by method, on a set of pavements constructed at the Brisa motorway network immediately after construction and over time.

The ultimate aim of the investigation is to characterize the acoustic evolution and durability of the pavement to support maintenance decisions.

2. Experimental approach

The experimental approach is grounded in the measurement of tyre road noise in eleven road sections, comprising five types of asphalt surfaces: gap-graded asphalt (GGA10 and GGA14), stone mastic asphalt (SMA12), porous asphalt (PA12), and microaglomerate (msurf). The number indicates the maximum aggregate size in mm.

The CPX measurements were carried out at 100 km/h over the full length, in accordance with ISO 11819-2 [9]. The extension of the section is variable, ranging from 2 km to nearly 10 km

The SPB measurements were carried out at a single location in accordance with ISO 11819-1 [10].

The sequence of measurements followed the company's maintenance plan for the baseline assessment (a few weeks after construction), and subsequent measurements were intended to be taken on an annual basis. As only five sections were monitored two or more times, this reduced set of sections was used to assess the evolution of the tyre-road noise with time and traffic.

3. Baseline assessment

3.1 CPX method

Figure 1 presents the tyre–pavement noise levels ($L_{CPX}100$) measured on the investigated pavement surfaces. Considerable differences were observed among the surface types, with $L_{CPX}100$ values ranging from 98.5 to 106.4 dB(A), corresponding to a maximum difference of 7.9 dB(A).

The porous asphalt (PA12) exhibited the lowest noise level, with an $L_{CPX}100$ of 98.5 dB(A), confirming its superior acoustic performance due to its interconnected air void structure. Among the dense asphalt mixtures, SMA12 provided relatively low noise levels, ranging from 99.8 to 101.6 dB(A). The difference between the two SMA sections (1.8 dB(A)) suggests that local conditions and construction quality may influence the acoustic performance despite the use of the same mixture.

The GGA10 sections showed intermediate acoustic behaviour, with noise levels of 100.0 and 101.3 dB(A). In contrast, the GGA14 sections exhibited the largest variability, with values ranging from 98.8 to 104.1 dB(A). A spread of more than 5 dB(A) indicates that factors other than nominal aggregate size, such as surface texture and construction practices, have a substantial influence on tyre–road noise generation.

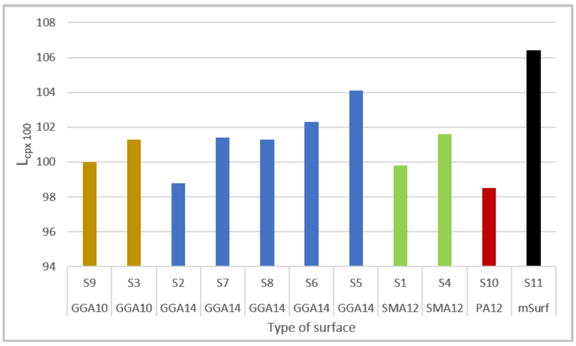

Figure 1. L_{CPX} a few weeks after construction.

3.2 SPB method

Figure 2 presents the initial Statistical Pass-By Index (SPBI) values measured shortly after pavement construction. The ranking obtained with the SPB method generally agrees with the CPX measurements, confirming that pavement surface characteristics strongly influence traffic noise under real traffic conditions. Porous asphalt exhibited the lowest noise levels, whereas the denser surfaces generally produced higher SPBI values. Nevertheless, the variability between sections of the same pavement type is greater than expected, particularly for SMA12, suggesting that local factors such as traffic composition and speed, pavement construction quality, and surrounding conditions also influence the measured pass-by noise. Although the absolute values obtained by SPB cannot be directly compared with CPX because the methods characterize different acoustic phenomena, both techniques consistently identify the quieter pavement surfaces.

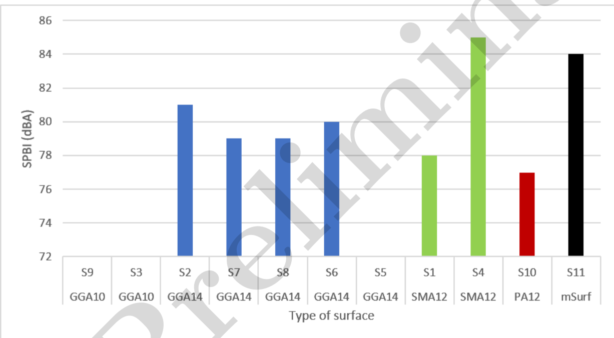

Figure 2. SPBI a few weeks after construction.

4. Evolution with time and traffic

4.1 CPX method

Table 1 identifies the motorway sections and characterizes them in terms of type, age, and the volume of traffic at the time of the CPX measurements. Table 1 shows that all monitored sections experienced an increase in tyre–road noise over time, although the deterioration rate differed considerably among pavement types. The annual increase ranged from practically negligible values (-0.08 dB(A)/year for section S4 during the first monitoring period) to approximately 1.0 dB(A)/year for section S1 and 0.90 dB(A)/year for GGA10 (S9). Most deterioration rates remained below 1 dB(A)/year, which is consistent with values reported in the literature for dense asphalt surfaces.

SMA12 generally exhibited the best acoustic durability. Section S4 remained almost acoustically stable during the first monitoring interval and showed only a moderate increase during the following period, while section S1 presented a faster deterioration despite having the same pavement type. This behaviour indicates that factors other than traffic loading, like local environmental conditions or construction variability, may significantly affect acoustic performance and durability.

The two GGA14 sections showed very similar deterioration rates (0.49 and 0.55 dB(A)/year), indicating relatively consistent long-term behavior. In contrast, GGA10 presented the highest deterioration rate (0.90 dB(A)/year), suggesting that this mixture may be more susceptible to texture evolution and surface wear. No clear relationship between deterioration rate and traffic volume can be established from the limited dataset, as sections subjected to similar or even lower traffic exhibited substantially different acoustic evolution.

4.2 SPB method

Table 2 summarizes the motorway sections considered in the SPB analysis, including pavement type, measurement date, time interval between surveys and annual daily traffic (ADT) at the time of measurement. The SPBI results show substantially greater temporal variability than the CPX measurements. Although some sections exhibited an increase in SPBI between successive surveys, others showed stable or lower values. This variability is particularly evident for the GGA14 sections, for which both positive and negative changes were observed between successive surveys.

For section S1 (SMA12), the SPBI decreased from 78 to 77 dB(A) between May 2023 and July 2024, corresponding to an annualized change of -0.92 dB(A)/year, and remained stable at 77 dB(A) in July 2026. Section S4 (SMA12) increased from 85 to 86 dB(A) between February 2022 and May 2023, corresponding to 0.86 dB(A)/year, but subsequently decreased to 83 dB(A) in September 2024 and remained unchanged in August 2025. These results indicate that the acoustic evolution of the two SMA12 sections was not consistent, with both increases and decreases in SPBI observed over time.

The GGA14 sections also exhibited substantial variability. Section S7 increased from 79 to 84 dB(A) between August 2023 and November 2024, corresponding to an annualized change of 4.29 dB(A)/year, but subsequently decreased to 82 dB(A) in August 2025, corresponding to -3.00 dB(A)/year. In contrast, section S8 increased by 1 dB(A) over a 10-month interval, corresponding to 1.20 dB(A)/year, while section S2 decreased by 1 dB(A) over the same time interval, corresponding to -1.20 dB(A)/year. The different trends observed for these three GGA14 sections indicate that the temporal evolution measured by SPB cannot be attributed to pavement type alone. The GGA10 section S11 exhibited an increase in SPBI from 84 to 85 dB(A) over a seven-month interval, corresponding to an annualized change of 1.71 dB(A)/year. This represents the highest positive annualized change observed among the most recent SPB measurements, although the relatively short monitoring period does not allow this value to be interpreted as a definitive long-term deterioration rate.

Table 1. Site identification and noise evolution indicators for the CPX method.

Site ID	Type of surface	$L_{CPX}100$ (dBA)	Date	Time lag (month)	$L_{CPX}100$/month (dBA/month)	$L_{CPX}100$/year (dBA/year)	ADT (Vehicles)
S1	SMA12	99.8	10/02/2022		-	-	
S1	SMA12	101.1	04/05/2023	14.9	0.09	1.04	160832
S4	SMA12	101.6	02/03/2022		-	-	
S4	SMA12	101.5	04/05/2023	14.3	-0.01	-0.08	93916
S4	SMA12	102.3	25/11/2025	31.2	0.03	0.31	216814
S7	GGA14	101.4	26/11/2024		-	-	
S7	GGA14	102.2	03/07/2026	19.5	0.04	0.49	258082
S8	GGA14	101.3	26/11/2024		-	-	
S8	GGA14	102.2	03/07/2026	19.5	0.05	0.55	213251
S9	GGA10	100	28/05/2025		-	-	
S9	GGA10	101	03/07/2026	13.4	0.07	0.90	1178618

Table 2. Site identification and noise evolution indicators for the SPB method.

Site ID	Type of surface	SPBI(dBA)	Date	Time lag (month)	SPBI/month (dBA/month)	SPBI/year dBA/year)	AADT (Vehicles)
S1	SMA12	78	19/05/2023				
S1	SMA12	77	03/07/2024	13	-0,08	-0,92	385957
S1	SMA12	77	07/07/2026	24	0,00	0,00	1109040
S4	SMA12	85	28/02/2022				
S4	SMA12	86	09/05/2023	14	0,07	0,86	630770
S4	SMA12	83	16/09/2024	16	-0,19	-2,25	728816
S4	SMA12	83	25/08/2025	11	0,00	0,00	504834
S7	GGA14	79	31/08/2023				
S7	GGA14	84	26/11/2024	14	0,36	4,29	638708
S7	GGA14	82	19/08/2025	8	-0,25	-3,00	367104
S8	GGA14	79	19/08/2025				
S8	GGA14	80	07/07/2026	10	0,10	1,20	462100
S2	GGA14	81	19/08/2025				
S2	GGA14	80	06/07/2026	10	-0,10	-1,20	109840
S11	GGA10	84	27/11/2025				
S11	GGA10	85	07/07/2026	7	0,14	1,71	323463

Overall, the SPB results do not show a consistent monotonic increase in noise levels with pavement age. Instead, the measurements reveal considerable short- and medium-term variability, with both positive and negative changes observed for the same pavement type and, in the case of GGA14, even over comparable monitoring periods. This behaviour highlights the influence of factors other than pavement ageing, including traffic composition, vehicle speed distribution, meteorological conditions and local measurement conditions.

5. Discussion and conclusions

This study investigated the initial acoustic performance and early acoustic evolution of asphalt pavement surfaces on the Brisa motorway network using complementary Close-Proximity (CPX) and Statistical Pass-By (SPB) measurements.

The baseline results demonstrate clear differences in acoustic performance between pavement surfaces. Porous asphalt exhibited the lowest CPX noise level, while the other pavement surfaces showed higher and more variable noise levels. The differences observed between sections with the same nominal pavement type also indicate that pavement type alone does not fully determine acoustic performance. Surface characteristics, construction variability and local conditions may have a significant influence on tyre–road noise.

The longitudinal CPX results indicate a generally gradual increase in tyre–road noise during the monitoring period. Most annualized CPX evolution rates remained below 1 dB(A)/year. The monitored SMA12 sections generally exhibited favorable acoustic durability, although differences were observed between sections with the same pavement type. The GGA14 sections showed relatively similar CPX evolution rates, while the highest observed CPX evolution rate was obtained for the monitored GGA10 section. Given the limited number of monitored sections and the relatively short observation periods, these results should be considered as site-specific observations rather than generalized deterioration rates for the corresponding pavement mixtures.

In contrast, the SPB results exhibited substantially greater temporal variability, with both positive and negative changes observed between successive surveys. This variability was particularly evident for the GGA14 sections, for which the observed annualized changes ranged from -1.20 to +1.20 dB(A)/year for S2 and S8, respectively, while S7 showed a strong increase followed by a decrease in the subsequent survey. The SMA12 sections also exhibited different temporal trends, ranging from practically stable behavior to substantial short-term variations. These results indicate that the evolution observed in SPB measurements cannot be attributed to pavement ageing or pavement type alone. The substantial variations observed between successive SPB surveys highlight the influence of factors other than pavement characteristics, including traffic composition, vehicle speed distribution, meteorological conditions and other local measurement conditions. Consequently, individual annualized changes in SPBI should be interpreted with caution and should not be considered direct measures of pavement acoustic deterioration, particularly when based on relatively short monitoring intervals. Longer monitoring periods and repeated measurements under comparable traffic and meteorological conditions are required to identify robust long-term trends in SPB measurements.

The available data do not indicate a clear relationship between acoustic evolution and the traffic volume measured at the time of each survey. This does not exclude the potential influence of traffic loading on pavement acoustic ageing, but highlights the importance of considering cumulative traffic exposure, pavement age and environmental conditions in future analyses.

The comparison of CPX and SPB measurements demonstrates the complementary nature of the two methods. CPX provides a more controlled assessment of tyre–road interaction and, in the present dataset, showed more consistent temporal trends for evaluating changes in pavement acoustic performance. SPB provides valuable information on the acoustic performance of road sections under actual traffic conditions, but is more sensitive to variations in traffic and environmental conditions. The two methods should therefore be regarded as complementary rather than interchangeable.

Overall, the results demonstrate the value of long-term acoustic monitoring to support pavement management and traffic noise assessment. Continued monitoring of the investigated sections, combined with information on pavement age, cumulative traffic exposure, surface characteristics and environmental conditions, will be essential for establishing more robust models of pavement acoustic ageing. Such datasets may contribute to optimizing pavement maintenance strategies and improving the representation of pavement acoustic performance in traffic noise prediction models, including CNOSSOS, throughout the pavement life cycle.

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