# Noise comparison of different types of pavement inside highway tunnels

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ABSTRACT: To mitigate noise pollution in highway tunnels and improve their acoustic environment, this study conducted on-site noise measurements in two tunnels, using open-area pavement as a control group, to analyze and compare the noise characteristics of different pavement types. Three pavement types were evaluated: dense-graded asphalt concrete (DAC), single-layer porous asphalt (PA), and double-layer PA. The results indicate that roadside noise levels inside tunnels are significantly higher than those in open areas, with an average increase of over 10 dBA. Noise attenuation performance is poorer in long tunnels. For PA pavements, roadside noise levels are significantly reduced, with an average decrease of over 3.5 dBA. PA pavements also exhibit faster noise attenuation. The application of PA pavements can effectively enhance the acoustic environment within tunnels.

## 1 INTRODUCTION

Noise pollution has become the second most significant environmental factor affecting human health. In particular, road traffic noise has severe impacts on the physical and mental well-being of drivers, passengers, and nearby residents [Foraster et al. 2016, Lee et al. 2019]. Current research on traffic noise pollution mainly focuses on residents along highways, while studies on its effects on primary road users—drivers and passengers—remain relatively scarce [Petri et al. 2021, Gilani & Mir 2021].

In tunnels, sound waves are easily reflected by the arched tunnel walls, leading to a larger reflective surface compared to open areas. As a result, noise levels inside tunnels are significantly higher than those outside [Zhang et al. 2020]. Compared to short tunnels, long tunnels have longer noise propagation paths, making dissipation more difficult and thus amplifying the impact of noise [Qin et al. 2023, Jiang et al. 2022]. Most tunnels constructed in China lack sound-absorbing and noise-reducing treatments. Under such conditions, noise waves undergo multiple reflections on the tunnel walls, and direct and reverberant sounds repeatedly overlap, resulting in elevated noise levels [Zhao et al. 2022, Lokhande et al. 2023].

The noise in tunnels primarily originates from traffic noise, which is a combination of noise from vehicle engines and noise generated by the interaction between tires and the pavement [Mikhailenko et al. 2022]. By optimizing pavement materials, noise generated from tire-pavement interaction can be reduced. Pavement type plays a crucial role in mitigating tire-pavement noise, and low-noise asphalt pavements have been employed to reduce traffic noise [Leng et al. 2019].

Low-noise asphalt pavements are generally classified into two categories: porous asphalt (PA) pavement and dense-graded asphalt concrete (DAC) pavement. However, few studies have systematically compared the noise characteristics of different pavement types in tunnels of varying lengths.

## 2 EXPERIMENTAL DESIGN

### 2.1 *Basic Information on the Tunnels*

Two tunnels, Dahongling No.1 Tunnel and Dahongling No.2 Tunnel, were selected for this study and will be referred to as No.1 Tunnel and No.2 Tunnel, respectively, in subsequent descriptions. Both tunnels are unidirectional with two lanes. No.1 Tunnel is a short tunnel with a length of approximately 120 meters, whereas No.2 Tunnel is a long tunnel, extending about 5000 meters. The surface layer in No.1 Tunnel consists of dense-graded asphalt concrete (DAC) with a nominal maximum aggregate size (NMAS) of 13.2 mm, referred to as DAC-13. In No.2 Tunnel, three types of surface layers were examined: DAC-13, single-layered porous asphalt (PA) pavement, and double-layered PA pavement, both with an NMAS of 13.2 mm, referred to as PA-13.

Additionally, as a control group, the pavement in the open area located in the connecting section between No.1 Tunnel and No.2 Tunnel was also investigated. Figure 1 provides a detailed schematic of the pavement structures in both tunnels and the open area.

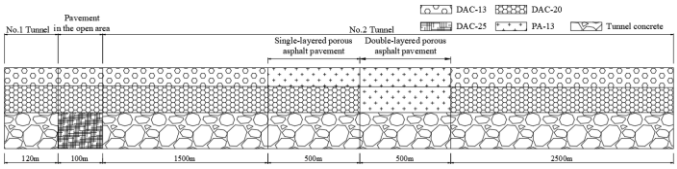


Figure 1. Schematic representation of the pavement structure in the two tunnels.

## 2.2 *Noise Measurement Methods*

(1) Roadside Noise Measurement

Roadside noise levels were measured using a multifunctional sound level meter. Following the Statistical Pass-By (SPB) method, measurements were conducted both in the inspection lanes within the tunnels and outside the road barriers in open areas. The sound level meter was mounted on a tripod at a height of 1.2 meters above the inspection lane surface, approximately at the height of the human ear. Since the test was conducted in a controlled environment without traffic flow, the recorded noise exclusively resulted from a single passing vehicle.

(2) Longitudinal Noise Attenuation Measurement

To evaluate longitudinal noise attenuation, a microphone was positioned along the tunnel centerline, capturing noise levels at distances of 30 m, 60 m, 90 m, 120 m, and 150 m from the noise source. At each measurement point, two microphone heights were used: 1.2 meters and 2.6 meters. During the test, the noise source remained stable to ensure consistency in measurements. A linear fitting was applied to the collected data, with the slope of the fitted equation representing the longitudinal noise attenuation rate.

# 3 NOISE COMPARISON ANALYSIS

## 3.1 *Noise in Tunnels of Different Lengths*

(1) Roadside noise

The overall roadside noise levels on DAC-13 pavement were measured at speeds of 60 km/h, 80 km/h, and 100 km/h in the inspection lanes of No.1 Tunnel and No.2 Tunnel, as well as in the open-area section serving as a control group. The results are presented in Figure 2.

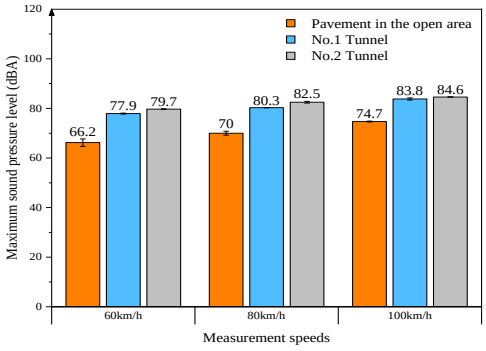


Figure 2. Comparison of roadside noise levels measured in two tunnels under different driving speeds.

As shown in Figure 2, at a speed of 60 km/h, the average noise levels in the open-area section, No.1 Tunnel, and No.2 Tunnel were 66.2 dBA, 77.9 dBA, and 79.7 dBA, respectively. At 80 km/h, the corresponding average noise levels were 70.0 dBA, 80.3 dBA, and 82.5 dBA, while at 100 km/h, they were 74.7 dBA, 83.8 dBA, and 84.6 dBA. Compared to the roadside noise levels in the open-area section, the roadside noise levels in the inspection lanes of tunnels exhibited a significant increase, exceeding 10 dBA on average, which can be attributed to the effects of reverberation.

Furthermore, the roadside noise increase in No.2 Tunnel was more pronounced than in No.1 Tunnel, with an approximate 2 dBA difference. This may be due to the more significant reverberation effects in the longer tunnel. For the same DAC-13 pavement, the roadside noise levels in the inspection lanes of the same tunnel increased with higher measurement speeds.

(2) Longitudinal Noise Attenuation

Figure 3 illustrates the noise level attenuation characteristics of DAC-13 pavement within a 150-meter range from the noise source in both tunnels, measured at 30-meter intervals. The fitted results are also included, with the slope of the fitted curve used to assess the longitudinal noise attenuation characteristics.

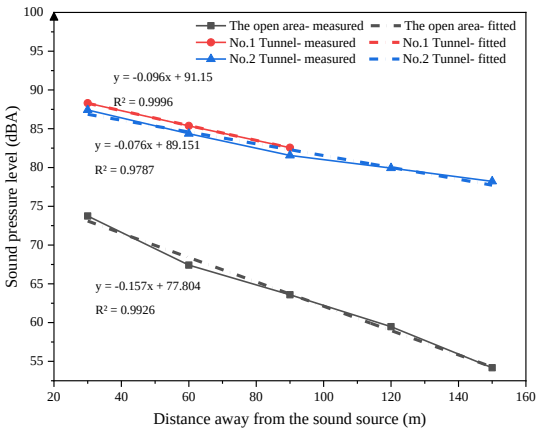


Figure 3. Longitudinal noise attenuation characteristics observed in the two tunnels.

As shown in Figure 3, the longitudinal noise attenuation rates for the open-area section, No.1 Tunnel, and No.2 Tunnel were 0.16 dBA/m, 0.10 dBA/m, and 0.08 dBA/m, respectively. The highest attenuation rate was observed in the open-area section, while the lowest was found in No.2 Tunnel. This indicates that longer tunnels exhibit more pronounced noise reverberation effects and lower noise attenuation rates. In longer tunnels, noise dissipation occurs differently, with a more noticeable reverberation effect.

## 3.2 *Noise on Different Pavement Types*

(1) Roadside noise

As shown in Figure 4, the overall roadside noise levels on DAC, single-layer PA, and double-layer PA pavements in No.2 Tunnel were measured at speeds of 60 km/h, 80 km/h, and 100 km/h.

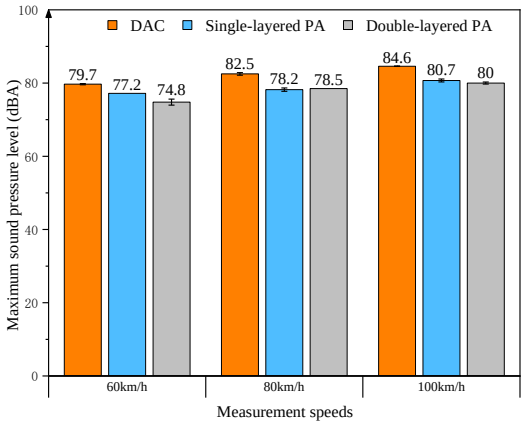


Figure 4. Roadside noise levels for different pavement types in No.2 Tunnel.

From Figure 4, it can be observed that at a speed of 60 km/h, the overall roadside noise levels in the No.2 Tunnel were 79.7 dBA on the DAC, 77.2 dBA on the single-layered PA pavement, and 74.8 dBA on the double-layered PA pavement. Compared to DAC, PA pavements exhibited lower roadside noise levels. The presence of numerous interconnected pores in PA pavement allows it to absorb sound effectively. Additionally, aerodynamic noise generated at the tire-road contact area and noise propagating outward from the source are primarily absorbed by the porous surface layer. As a result, the roadside noise levels in the inspection lanes of PA pavement sections were significantly reduced, with an average reduction of more than 3.5 dBA.

The noise reduction effect of double-layer PA pavement was more significant than that of single-layer PA pavement, with roadside noise levels in the inspection lane reduced by an additional 1 dBA. These results indicate that PA pavement is more effective in reducing roadside noise levels in long tunnel inspection lanes, with double-layer PA pavement providing superior noise reduction performance.

(2) Longitudinal noise attenuation

The longitudinal noise attenuation characteristics of DAC, single-layer PA, and double-layer PA pavements were measured in No.2 Tunnel to determine the noise attenuation patterns of the three pavement types. By performing linear fitting on noise levels along the longitudinal direction, the noise attenuation rates in the tunnel were obtained. The attenuation curves and fitted results are shown in Figure 5.

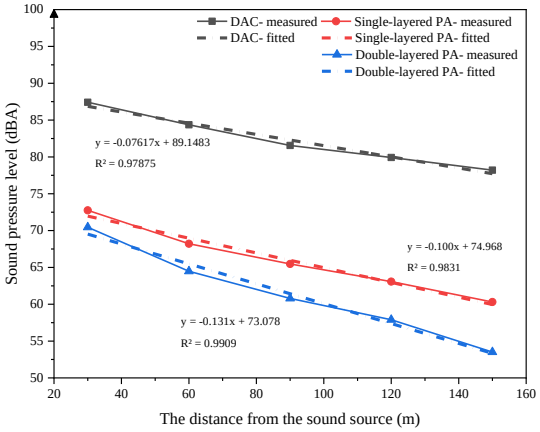


Figure 5. Longitudinal noise attenuation characteristics for different pavement types.

Based on the noise attenuation curves and the slopes of the fitted results, it is evident that there were significant differences in longitudinal noise attenuation rates among the three pavement types. The attenuation rates for DAC, single-layer PA, and double-layer PA pavements were 0.08 dBA/m, 0.10 dBA/m, and 0.13 dBA/m, respectively. This indicates that DAC exhibited the lowest longitudinal noise attenuation rate, while double-layer PA pavement had the highest attenuation rate. Therefore, PA pavement contributes to improved longitudinal noise attenuation, reducing noise levels within the tunnel and enhancing the acoustic environment.

## 4 CONCLUSIONS

This study conducted a field investigation on the noise characteristics of two tunnels, including roadside noise and noise attenuation properties. The noise characteristics inside and outside the tunnels were analyzed for the same pavement type. Additionally, the impact of pavement type on noise characteristics was examined within the same tunnel. Based on the test results and analysis, the following conclusions were drawn:

(1) For the same pavement type (DAC-13), roadside noise levels inside the tunnel were significantly higher than those in open areas, with an average increase of more than 10 dBA. Considering the reverberation effect, roadside noise can be used to characterize tunnel noise characteristics.

(2) For DAC pavement, the longitudinal noise attenuation rates in the two tunnels were 0.10 dBA/m and 0.08 dBA/m, respectively. The longitudinal noise attenuation rates indicate a significant reverberation effect within the tunnel.

(3) The roadside noise levels in the inspection lanes of PA pavement sections were significantly reduced, with an average reduction of more than 3.5 dBA. The longitudinal noise attenuation rate of PA pavement was also higher. This suggests that PA

pavement, with its large pore structure, can significantly improve the acoustic environment inside tunnels, and double-layer PA pavement contributes to even better noise reduction performance.

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