DOI: 10.61782/fa.2025.0536

FORUM ACUSTICUM EURONOISE 2025

LOW-HEIGHT NOISE BARRIERS FOR RAILWAYS: MEASUREMENT STANDARDIZATION AND METAMATERIALS APPLICATION FOR NOISE REDUCTION

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ABSTRACT

The present work is part of a LIFE project to develop a measurement standard to assess the acoustic performance of low-height noise barriers for railways. Low-height noise barriers (LHNB) present a cost-effective and space-efficient solution to mitigate railway noise, especially in urban and densely populated areas. However, the lack of standardized methods to evaluate their performance challenges their effective implementation. This project addresses these challenges by developing a robust measurement protocol for real-world railway operating conditions. Additionally, the study explores innovative strategies to enhance the absorption performance of these barriers through the integration of metamaterials. Metamaterials, with their ability to achieve tailored acoustic properties, offer promising solutions for maximizing noise attenuation while maintaining compact barrier designs. The research investigates advanced geometrical configurations by combining different resonators to optimize sound absorption across a broad frequency spectrum (100-5000 Hz). Preliminary results indicate significant improvements in noise reduction performance, validating the potential of metamaterial-enhanced barriers. The outcomes of this project will provide critical insights into sustainable noise management for railways, contributing to quieter and more livable urban environments while supporting European Union policy objectives on environmental noise reduction.

Keywords: *noise mitigation, low-height noise barrier, measurements, metamaterials, resonators.*

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1. INTRODUCTION

Railway noise pollution is a growing concern, especially in urban areas where proximity to tracks worsens its impact. Sources include rolling noise, aerodynamic noise, and structural vibrations [1]. Long-term exposure is linked to health issues such as sleep disturbances and cardiovascular diseases [2].
Traditional noise barriers are effective but have spatial, financial, and aesthetic drawbacks. Low-height noise barriers (LHNBs) offer a cost-effective alternative for urban settings, though their acoustic performance lacks standardized evaluation methods [3]. Unlike full-height barriers, LHNBs reduce noise differently, focusing on source-level mitigation.
Within a LIFE project, this study aims to develop a standardized measurement protocol for assessing LHNB effectiveness under real-world conditions and integrate metamaterials to enhance noise absorption while maintaining compact designs. Metamaterials, with tailored acoustic properties, optimize sound absorption across 100–5000 Hz [4].
By advancing evaluation methodologies and leveraging innovative materials, this research supports sustainable railway noise management, aiding policymakers and engineers in implementing effective, space-efficient solutions aligned with EU environmental noise directives [5].

2. THE STANDARDIZATION OF THE MEASUREMENT METHOD

Currently, a method for measuring the acoustic performance of low-height noise barriers does not exist. A study is currently in progress aimed at adapting the European standard EN 1793-6 (also known as "Adrienne") [6], which defines the standard measurement method for measuring sound insulation of highway and railway noise barriers [7], to low-height noise barriers as well.

Figure 1. Insertion Loss: a) measurement of impulse response with the barrier, no obstacles nearby; b) measurement of free-field impulse response; c) setup with reflective surface simulating train body; d) measurement of impulse response with barrier and reflective surface.

The EN 1793-6 standard was conceived for sound insulation measurements on barriers with appropriate dimensions, usually at least 3-4 m high. Two sets of impulse responses are measured using a sound source (positioned on the sound source side at the height of 2 m from the ground and 1 m from the noise barrier) and a 9-microphone grid (positioned on the other side of the barrier at the height of 2 m from the ground and 0.25 m from the noise barrier): one set is measured with the barrier interposed and one in free-field, at the exact relative distances, as described in detail in [6] and [8]. An MLS signal was used to measure impulse response [9]. By selecting data from the two measurement sets and by performing the logarithmic ratio of the transmitted power spectra to the free-field power spectra, the so-called Sound Insulation Index can be obtained averaged over all 9 microphones [6].
This method can be adapted to measure the Insertion Loss of LHNBs. However, as shown in Figure 1, the small size of the barrier and the reduced height on the ground of the microphone and the sound source pose a challenge: the sound reflection on the ground disrupts the measurement. It can be partially reduced using an ultra-directive microphone; however, the low barrier height shortens the data analysis selection window in the time domain and, consequently, a minimum valid frequency analysis of 400 Hz. Figure 1 shows the measurement setup: the microphone and sound source are placed 0.4 m from the noise barrier, both at a height above the ground of 0.21 m. The noise barrier had a height of 0.56 m and a thickness (at the height of the microphone and sound source) of 0.12 m. Figure 1 a) shows the barrier measurement configuration, and Figure 1 b) shows the free-field measurement. Figure 1 c) shows a measurement setup that involves placing the barrier near a highly reflective surface to simulate the train facade, visible in the graphical mock-up in Figure 1 d), in which the sound source is placed in the position corresponding to a train wheel.

3. INTEGRATION OF METAMATERIALS FOR ENHANCED ABSORPTION

As an LHNB is installed close to the track, reducing the rail-wheel noise bouncing between the train body and the noise barrier is essential. Otherwise, it overcomes the LHNB, reducing its efficacy. The proposed metamaterial solution integrates Helmholtz resonators and Fabry-Pérot channels onto the surface of an existing LHNB manufactured by Kraiburg Strail to enhance its absorption performance across a broad frequency spectrum. The design is tailored to achieve an absorption coefficient of at least 0.8 over the 100–5000 Hz range, despite railway noise energy being most concentrated between 500–4000 Hz, as indicated by EN 16272-3-2 [10].
Neck-embedded Helmholtz resonators are incorporated into the barrier surface to address the lower frequency range (100–1700 Hz). These resonators trap and dissipate low-frequency energy by exploiting localized resonance effects [11]. Beyond 1700 Hz, Fabry-Pérot channels enhance absorption at higher frequencies by leveraging quarter-wavelength resonance phenomena [12]. Combining these two metamaterial elements ensures broadband noise attenuation while maintaining a compact barrier profile.
Given the geometrical constraints imposed by the low-height Strail barrier, both perfect and imperfect coupling mechanisms have been exploited to maximize performance. The design carefully balances the interaction between resonators and Fabry-Pérot channels to achieve optimal impedance matching with the incident sound waves, thereby enhancing absorption efficiency across the entire target spectrum. The structural integration of these elements does not compromise the mechanical integrity of the barrier, making it a viable solution for real-world railway applications. The metasurface covering the barrier is subdivided into different bricks, each related to a given frequency range.
The acoustic performance of each individual metamaterial brick composing the total barrier surface has been

assessed under normal incidence conditions using an impedance tube [13]. These laboratory tests provide precise absorption coefficient measurements, allowing fine-tuning resonator geometries to optimize real-world performance.

4. RESULTS AND REMARKS

4.1 Measurements of Insertion Loss

The first results from the adaptation of the Adrienne method to LHNBs in the measurement configurations shown in Figure 1, are shown in Figure 2; here, the test barrier is placed away from nearby obstacles (Figure 1 a) and b)) and near a reflective surface, to simulate the reflecting body of the train (Figure 1 c) and d)). The measurements in the two configurations are similar at mid and high frequencies, showing good repeatability of the measurement method, while they differ somewhat at lower frequencies. Studies are underway to reduce soil's effect further and to evaluate the intrinsic effectiveness of the LHNB better.

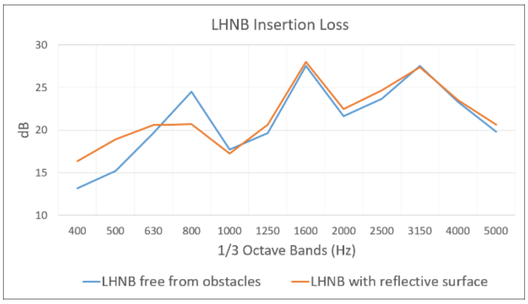

Figure 2. Insertion Loss measurement of the low-height noise barrier shown in Figure 1.

4.2 Metamaterial optimization

This section shows the main results for three "bricks" (sound absorbing units) incorporating imperfect and perfect coupled neck-embedded Helmholtz resonators (NEHR) and a Fabry-Pérot (FP) channel brick. Figure 3 shows the results of brick 1, composed of FP channels. The resonance peaks of the FP channels bricks are designed to keep them away from each other due to the low porosity of the brick (only 6 channels for each brick). The optimal results for FP channels are obtained for high porosity values [14].

Figure 4 shows the results of bricks brick 2, tuned in the 150-220 Hz frequency range and composed by 9 imperfect NEHRs (top), brick 5 tuned in the 550-1050 Hz range and composed by 20 perfect NEHRs (bottom). The imperfect coupling of the NEHRs in brick 2 allows this design to achieve a high absorption performance regardless of the geometrical constraints of the surface.

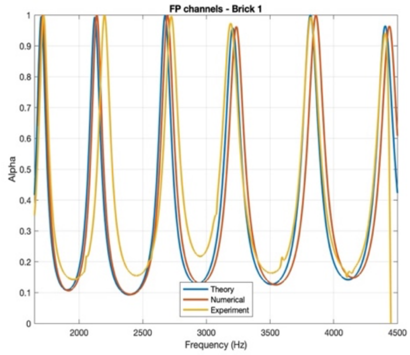

Figure 3. Results for brick 1, including perfect FP channels.

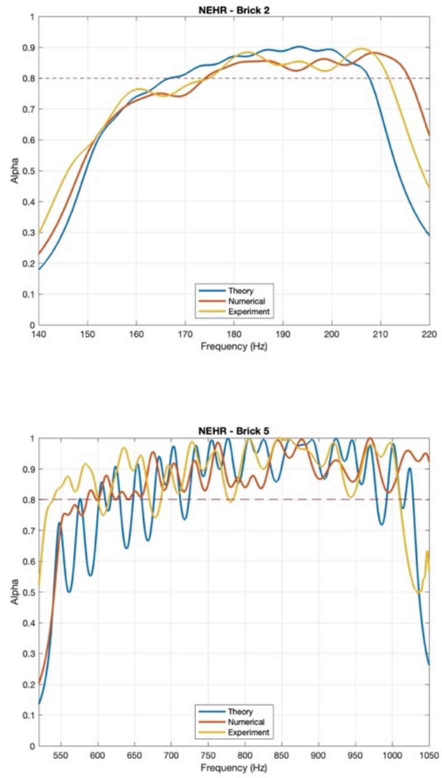

Figure 4. Results for brick 2, including 9 imperfect NEHRs (top) and brick 5, including 20 perfect NEHRs (bottom).

5. CONCLUSIONS

This study highlights the importance of standardizing measurement protocols for low-height railway noise barriers and explores the potential of metamaterials to enhance their performance. By establishing a reliable assessment framework and leveraging advanced acoustic materials, the project contributes to more effective noise reduction solutions. The integration of metamaterials represents a breakthrough in sustainable urban noise management, supporting European Union initiatives for quieter and more livable urban environments.

FUNDING

The project is co-funded by the European Union under the LIFE 2021-2027 *Environment and Climate Action Program*.

Co-funded by the European Union

LIFESILENT

REFERENCES

[1] Thompson, D. (2008). *Railway noise and vibration: mechanisms, modelling and means of control*. Elsevier.

[2] Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., & Stansfeld, S. (2014). Auditory and non-auditory effects of noise on health. *The lancet*, *383*(9925), 1325-1332.

[3] De Coensel, B., Botteldooren, D., De Muer, T., Berglund, B., Nilsson, M. E., & Lercher, P. (2009). A model for the perception of environmental sound based on notice-events. *The Journal of the Acoustical Society of America*, *126*(2), 656-665.

[4] Ma, G., & Sheng, P. (2016). Acoustic metamaterials: From local resonances to broad horizons. *Science advances*, *2*(2), e1501595.

[5] European Environment Agency. (2020). *Environmental noise in Europe — 2020. EEA Report No 22/2019*.

[6] EN 1793-6:2018/A1:2021: Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 6: Intrinsic characteristics - In situ values of airborne sound insulation under direct sound field conditions.

[7] Garai M., Guidorzi P., *In situ measurements of the intrinsic characteristics of the acoustic barriers installed along a new high speed railway line*, Noise Control Eng. J., ***56*(5)**, (2008), pp. 342-355.

[8] Guidorzi P., Garai M., *Repeatability of the European Standardized Method for Measuring Sound Reflection and Sound Insulation of Noise Barriers*, Environments, ***10*(8)** (2023), 139.

[9] Borish, J.; Angell, J. B. *An Efficient Algorithm for Measuring the Impulse Response Using Pseudorandom Noise*. J. Audio Eng. Soc., **31** (1983), pp. 478-488.

[10] EN 16272-3-2 (2023) - Railway applications - Infrastructure - Noise barriers and related devices acting on airborne sound propagation - Test method for determining the acoustic performance - Part 3-2: Normalized railway noise spectrum and single number ratings for direct field applications.

[11] Huang, S., Fang, X., Wang, X., Assouar, B., Cheng, Q., & Li, Y. (2019). Acoustic perfect absorbers via Helmholtz resonators with embedded apertures. *The Journal of the Acoustical Society of America*, *145*(1), 254-262.

[12] Liu, C., Yang, Z., Liu, X., Wu, J. H., & Ma, F. (2023). Ultra-broadband acoustic absorption with inhomogeneous high-order Fabry–Pérot resonances. *APL Materials*, *11*(10).

[13] ISO 10534-2 (2023). Acoustics–Determination of Acoustic Properties in Impedance Tubes–Part 2: Two-microphone Technique for Normal Sound Absorption Coefficient and Normal Surface Impedance.

[14] Yang, M., Chen, S., Fu, C., & Sheng, P. (2017). Optimal sound-absorbing structures. *Materials Horizons*, **4(4)**, 673-680.