DOI: 10.61782/fa.2025.0636

NUMERICAL STUDY OF A STEPPED DIRECTIONAL BARRIER FOR URBAN NOISE CONTROL

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ABSTRACT

Acoustic barriers are structures used to block or reduce noise propagation, improving people's quality of life. Barriers installed to mitigate traffic noise traditionally consist of continuously installed acoustic panels. In contrast, this work proposes the development of a directional barrier consisting of discrete cylindrical elements of stepped height distributed in the form of a sonic crystal. The barrier is designed to suppress transversely especially the frequency of 1000 Hz, the frequency at which the sound peak of rolling noise occurs. In order to test the sound effect of this barrier, numerical simulations of acoustic propagation are performed using FEM/BEM. The final objective aims to develop a sound barrier for application in urban environments that fulfils a dual application: mitigating noise pollution, but allowing a certain directivity of the noise from the transit of a vehicle to act as an acoustic warning element for pedestrians.

Keywords: *noise barrier, tyre road noise, sonic crystal, electric vehicle, traffic noise.*

1. INTRODUCTION

Noise emission generated by road traffic is one of the main sources of noise in urban and interurban environments. The noise emitted by a vehicle is generated by different sub-sources, commonly grouped into three categories: noise generated by the engine and traction system, noise produced by the interaction between tyre and road surface -tyre/road noise-, and aerodynamic noise. The gradual introduction of hybrid-electric and pure electric vehicles in road traffic can contribute to improving noise environments in cities by reducing engine noise, whereas tyre/road noise emission remains. However, the low detectability of the new generation of vehicles, mainly at low speeds - i.e. sound pressure levels below 56 dB at 10 km/h [1] - is of great concern for the most vulnerable groups [2] such as pedestrians, especially children and elderly people and people with blindness or low vision [3], cyclists or scooter users, as well as drivers of other vehicles [4]. Therefore, the coexistence of both types of vehicles (ICE vehicles and electric vehicles) will require technical solutions that allow adequate noise control in urban environments.

The use of acoustic barriers as a corrective measure for noise generated by road traffic has been used for decades [5-7]. Classical noise barriers, understood as continuous flat elements whose noise control mechanism is mainly based on reflection, have a series of drawbacks, some of which are caused precisely by the reflected sound [8,9]. This has led to the evolution of barrier designs through different solutions, either based on their material composition with the incorporation of absorbent materials, or based on their geometric definition with the inclusion of elements that disperse the reflected sound, for example through the use of sonic crystals [10,11].

Sonic crystals are materials formed by a regular distribution of repeated basic elements that allow the waves impinging on them with a certain frequency to suffer a destructive interference. Currently, the optimization of this type of materials is focused on different lines [12], such as the inclusion of resonances within their elements to analyze the interaction of both phenomena [13-15], the design of the geometry of the section of the discrete elements that form

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the barrier [16-18], the configuration of the position of the elements within the barrier [19-21], the composition of the materials of the elements that form the barrier [22-25], or the height of the elements [26].

The diffraction of sound waves that occurs at the upper edge of the barriers is one of the main factors that reduce their performance, and one of the main lines of work in the optimization of classical barriers [8]. However, this aspect has also been considered in other barrier proposals, such as in [27] where the effect of diffraction at the edge of a sonic crystal-based barrier was analyzed, observing the possibility of varying its attenuation level by modifying the design of the upper edge of the barrier. In [28] the effect of diffraction was also considered, working with a barrier design based on sonic crystals made up of nested elements.

Therefore, this paper presents a preliminary study of a low height stepped directional acoustic barrier (SDAB) system. The purpose of the design of this barrier is to create an interference in the propagation of sound in the transverse direction, but at the same time to allow sound transmission at a certain angle in both the horizontal and vertical planes. Thus, the stepped directional acoustic barrier SDAB is based on a two-dimensional sonic crystal of circular elements of 0.125 m diameter arranged as a three-row square Bravais grid. Each of these rows has been assigned a different height: 0.4, 0.7 and 1 m. In this way, a three-dimensional barrier of staggered cylindrical elements has been achieved, where the elements with the lowest height are located on the emitter's side. The barrier is designed to mainly block the propagation of the 1000 Hz frequency in its transverse direction, the frequency at which the highest peak sound energy is produced in the tyre/road noise emission. Given that the rolling sound emission occurs at a very low height, hence the low height of the barrier elements. The grid parameter “a” has been set according to Bragg's law at 0.17 m, as half the wavelength of the interest frequency transmitted by the air.

The study has been based on the numerical modelling of a set composed by a point sound emitter, located at a distance of twice the parameter “a” from the axis of the first cylindrical dispersing element of the barrier. The objective of the work will be to study the ability of the SDAB barrier to reduce the sound propagation in the transverse direction, while at the same time allowing the sound transmission to reach a receiving area located towards the end of the barrier. Fig. 1 shows the source assembly in front of the SDAB, at the center of the barrier. The figure shows the area to be protected from sound transmission - the protected area - in a transverse direction to the barrier, as well as the area where it is desired that the barrier allows sound transmission - the receiving area-.

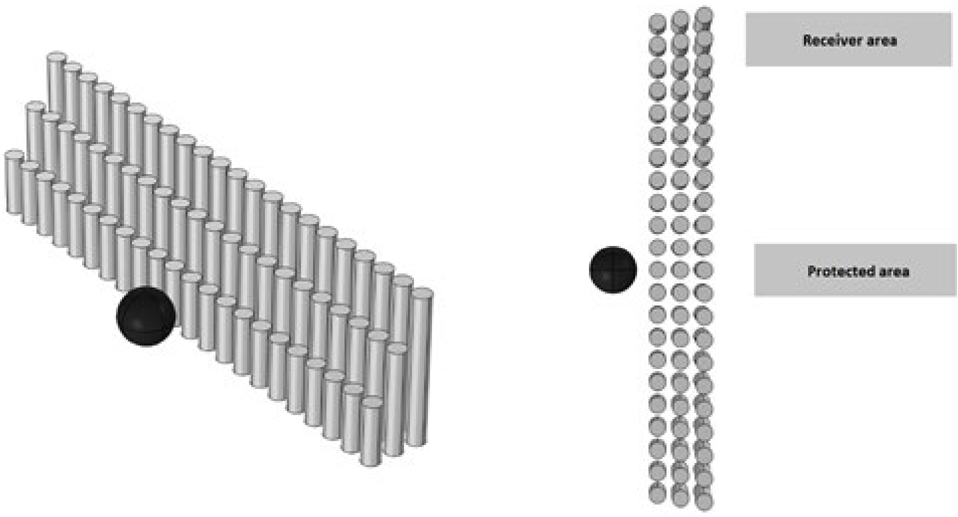

Figure 1. Noise source and SDAB barrier set. Left: isometric view. Right: plan view.

2. SIMULATION METHODOLOGY

The model developed to study the effect of the SDAB barrier on the acoustic propagation of an emitter, has been implemented in the COMSOL Multiphysics software. It is a BEM model where a sound source is placed in front of the acoustic barrier in an open field. Fig. 2 shows the geometry of the barrier as well as a detailed grid layout. The advantage of the BEM methodology is that it does not need to discretize the air volume, which is computationally advantageous for calculating sound propagation in open spaces. In this preliminary study, the emitter has been defined as a static omnidirectional sound source, located in front of the central area of the barrier. For this purpose, a point monopole has been placed at a height of 0.25 m, same height as the center of a commercial dodecahedral sound source, and separated by a distance of twice the parameter "a" from the axis of the first cylindrical dispersing element. To simulate the omnidirectional sound source, this monopole has been placed inside a 0.36 m diameter air sphere whose interior has been discretized by FEM. For the study, a barrier of 22 cylindrical elements for each of the rows has been used, giving a total barrier length of about 4 m. The surface of the sphere serves as a connection between the FEM environment and the BEM environment used for the study of acoustic propagation by imposing a continuity in the generated sound pressure field. The sides and top caps of the cylindrical elements of the barrier are established as fully reflective surfaces. In turn, the effect of the ground is modelled as a plane which is also considered as fully reflective.

3. RESULTS

The numerical model implemented in COMSOL Multiphysics has been run in a stationary analysis at the frequency of 1000 Hz with a sound source power of 5 W. Fig. 3.a) shows the effect of the directional SDAB barrier on the sound propagation of the acoustic field generated by the omnidirectional source. Additionally, the sound field produced by a conventional continuous flat barrier of rectangular geometry, 1 m high, placed at the same distance from the source as the highest row of cylindrical elements, see Fig. 3.b), has been simulated.

In the vertical plane of both simulations in Fig. 3 (lower images), it can be seen how the SDAB barrier is able to reduce, more effectively than the conventional barrier, the sound propagation from a distance of 1 m in the transverse direction of the barrier. In addition, the conventional barrier reflects, to a greater extent than the SDAB barrier, the sound field produced on the source side, instead of scattering it. In the horizontal plane (images above), there is also a different behavior between the two types of barriers. While the conventional barrier blocks the sound propagation similarly along its entire length, the SDAB barrier is more effective in the transverse direction, for which the distance between cylinders presents a destructive interference for the 1000 Hz wavelength. As the angle of incidence increases, the distance between elements increases, allowing more sound propagation.

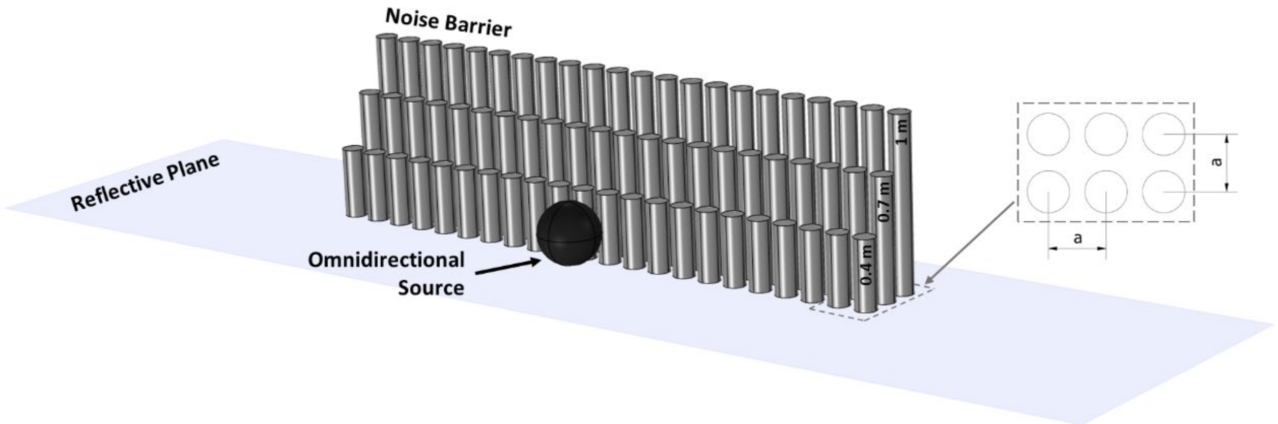

Figure 2. Geometric characteristics of the SDAB acoustic barrier and modelling in COMSOL Multiphysics.

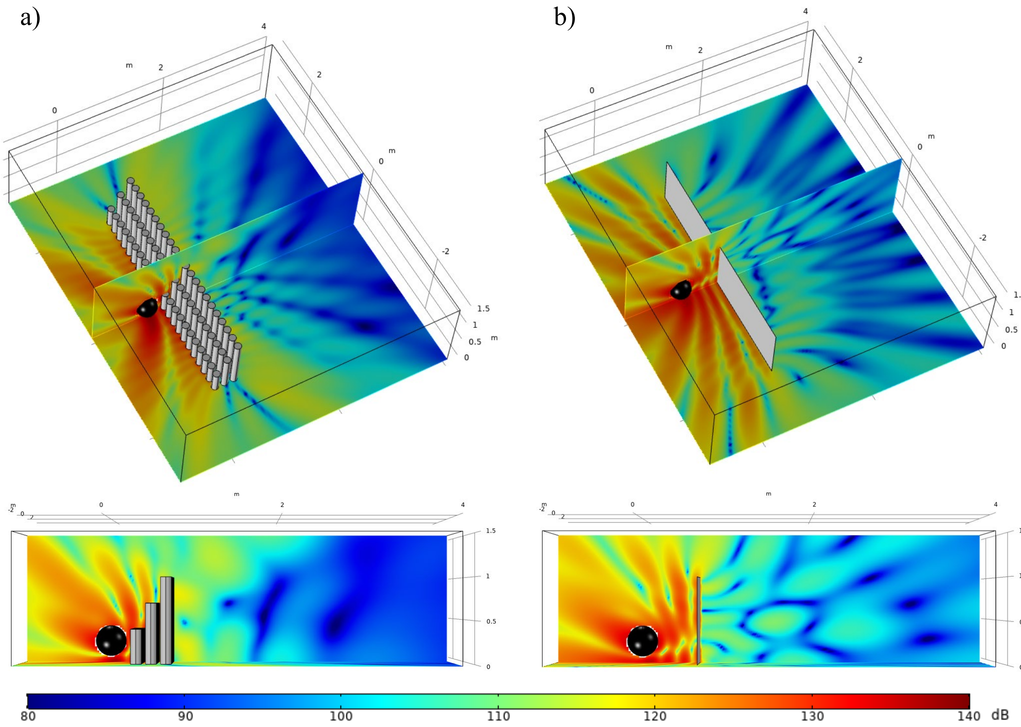

Figure 3. Sound Pressure Level of the simulated sound field at 1000 Hz: a). Directional barrier with cylindrical elements. b). Conventional rectangular barrier.

To better quantify the propagation in the horizontal plane, Fig. 4 shows a polar plot of the Sound Pressure Level, evaluated over a circumference of 4 m radius, centered on the source at 1.2 m height, thus lying above both barriers. In the transverse direction, at 0°, a receiver at a height of 1.2 m would perceive 90 dB for the SDAB barrier and 95 dB for the traditional barrier. The SDAB barrier is more effective than the rectangular barrier up to an angle of 50°, where it has a lobe of greater acoustic propagation. A difference of 5 dB can also be quantified at 180° due to the higher reflection of the traditional barrier towards the source itself.

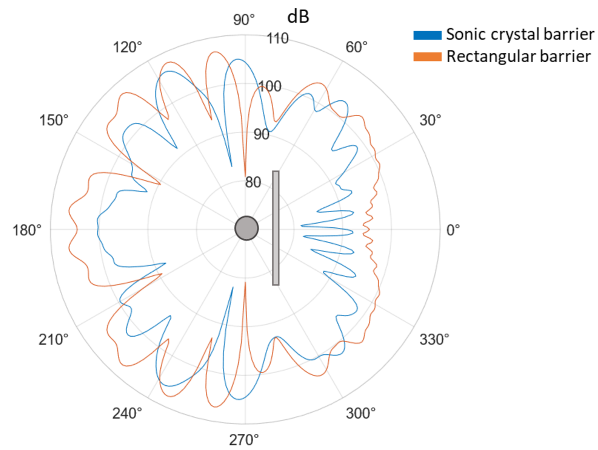

Figure 4. Polar plot of the Sound Pressure Level of the simulated sound field at 1000 Hz, at a height of 1.2 m and with an evaluation radius of 4 m.

4. CONCLUSIONS AND FURTHER WORK

The SDAB stepped acoustic barrier presented in this work has been designed in order to favor sound directivity at a frequency of 1000 Hz. In the horizontal plane, greater directivity has been achieved at an angle of 50º with respect to the transverse direction of the barrier, while it is reduced in the direction of 0º. In turn, in the vertical plane, the stepped barrier produces a more effective attenuation below the angle formed by its stepped elements. In this sense, the group is working on the experimental validation of a prototype SDAB stepped barrier, as shown in Fig. 5. This figure has been obtained using an acoustic camera that allows the sound field generated by the source, with an emission of 1000 Hz, and located at a distance of 4 m, to be seen graphically.

The behavior of the barrier at other frequencies is also being studied experimentally by obtaining the Insertion Loss in different positions in space. The final objective will be to achieve three-dimensional directivity by placing the barrier in the proximity of an urban traffic flow.

5. ACKNOWLEDGMENTS

This work has been supported by the Conselleria de Educación, Cultura, Universidades y Empleo, de la Generalitat Valenciana (GVA), by means of the research call “Convocatoria de Subvenciones a grupos de investigación emergentes – Convocatoria GE 2023” - project CIGE/2022/1.

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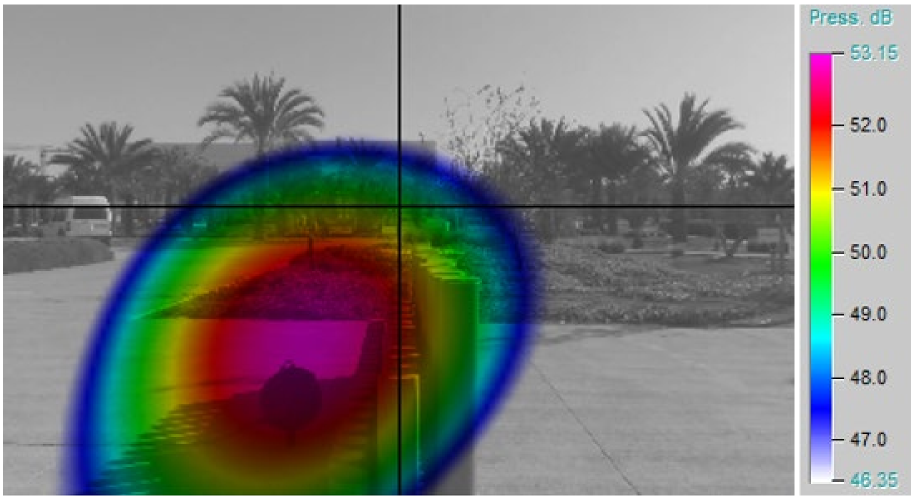

Figure 5. Acoustic camera study of the effect on sound propagation of a prototype SDAB barrier.

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