Design and technological adaptation of an acoustic screen based on Sonic Crystals to place it in real environments

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Summary

Sonic Crystals are new heterogeneous materials formed by a crystalline array of scatterers that are embedded in a host material with different physical properties, being one of them a fluid. The great variety of physical properties of these materials in the control of the acoustic waves transmission has given rise to the development of numerous high technological level devices. One of the main properties of Sonic Crystals is the existence of Band gaps, defined as ranges of frequencies whose propagation through the Sonic Crystal is forbidden. This new acoustic wave control mechanism is based on the well-known Bragg interference due to a multiple scattering process. Based on this property, a new generation of technologically advanced noise reducing devices has been developed. One of them are the Sonic Crystal Acoustic Screens (SCAS), a family of advanced acoustic screens with many advantages over the classical screens normally used in environmental acoustics. Several models of SCAS have been proposed by different research groups with excellent noise control capabilities, able to compete acoustically with the classic screens usually formed by continuous walls. However, there is still no SCAS ready to be commercialized and installed. In this work we present a new SCAS designed with a double purpose: (i) to achieve a high level of acoustic protection and (ii) to follow the market guidelines so that SCAS can be competitive with the classical screens in some non-acoustic aspects. To do this, a multidisciplinary team has been formed to design a new device from both acoustic and non-acoustic points of view. The result obtained, commercially called “Cristalofnoise”, is the first SCAS ready to be commercialized and installed.

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1. Introduction

Environmental noise, considering as disturbing sound generated by human activity such as that produced by transport, industry or leisure-related activities, is one of the main environmental problems in industrialized countries, [1], generating risk situations related to health, such as stress, fatigue, sleep disorders, cardiovascular problems, hearing loss, etc. [2], [3].

According to EU published regulations, European citizens should not be exposed to noise levels above 55 dB(A) at night, nor should they be exposed to noise levels above 65 dB(A) during the day. Despite these published limit values, according to the EU-Eurostat, 20% of European citizens endure higher levels during daytime and 30% of the European citizens endure higher values during night-time. The health problems that can be caused by these excessive noise levels generate significant health costs of around 0.35% of European GDP (Gross Domestic Product).

Generally, environmental noise can be mitigated acting in one of its three propagation phases: at the source of noise, in the transmission phase, or at the receiver. When talking about reducing noise generated by transport infrastructures, the most commonly adopted solution at the transmission stage is the use of. Acoustic barriers (AB), defined as devices composed by continuous flat walls that are interposed between the noise source (transport infrastructure) and the receiver (urban areas), are the most often performed action [4]. Figure 1 shows schematically how these AB work. The noise is mostly reflected to the source; some energy, however, is transmitted through the barrier, and other part is diffracted by the barrier edge.

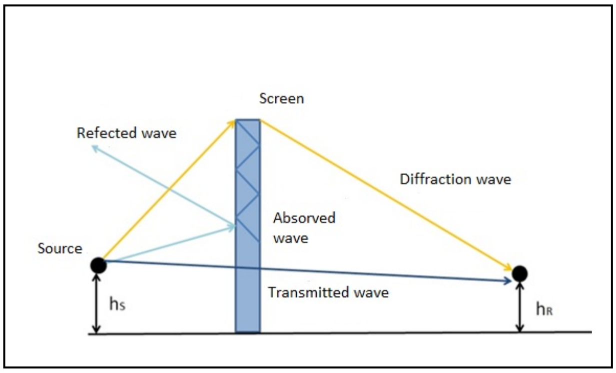

Figure 1. Operation diagram of AB.

Although the installation of these AB is the commonly adopted solution by transport infrastructures managers to reduce the noise problem, their installation carries certain disadvantages: i) AB do not offer specific protection for each type of noise, providing the same solution for all situations; ii) AB are made up by large continuous flat walls that produce communication problems and rejection of neighbors, due to the isolation and landscape rupture caused by their location; (iii) sometimes it is necessary the use of large volumes of foundations due to the significant wind loads supported by AB. These disadvantages mean that the installation of classical AB, in some sites, may be inappropriate.

On the other hand, the discovery of new materials in the last decade has made possible the development of new noise reducing devices. Sonic crystals (SC), defined as heterogeneous materials formed by arrangements of acoustic scatterers embedded in air [5] is one of them. They could be used to design a new kind of AB for transport infrastructures.

SC provide a new noise control mechanism based on a physical principle called "Bragg's interference" due to the multiple scattering process [6]. This phenomenon produces some ranges of frequencies, called band gaps, where the propagation of the waves is forbidden. This mechanism can be used on noise reducing devices [7], [8]. The first AB designed using this physical principle were proposed theoretically by Kushwaha in 1997 [9], and the first prototype was designed and built by Sánchez Pérez et al. in 2002 [10]. These new barriers are usually named Sonic Crystals Acoustic Screens (SCAS)

These first SCAS prototypes used multiple scattering as the only noise control mechanism to reduce the transmission of noise. However, to improve the attenuation capacity of SCAS, other noise control mechanisms were incorporated in the design of the scatterers [11]. These new scatterers were called multiphysical scatterers due to the introduction of other noise control mechanisms, as absorbent materials and resonant cavities, in their design. As a consequence, an improvement in the attenuation level of these devices was achieved, making these new SCAS acoustically competitive.

A prototype was designed and manufactured to certify the acoustic efficiency of the new SCAS. An approved laboratory carried out two tests for determining the acoustic performance of these noise reducing devices for road infrastructures, according with the acoustical standardization tests described at UNE 1793-1 [12] and UNE 1793-2 [13]. These standards describe the test methods for determining intrinsic characteristics of sound absorption and of airborne sound insulation. The results allowed the acoustic characterization of SCAS, classifying them into categories A3 for absorption and B2 for airborne noise insulation [14].

On the other hand, some laboratory experiments in wind tunnel were carried out to estimate the reduction of the wind efforts transmitted to the foundation in SCAS compared with AB. The obtained results showed that there is an average around 42% of reduction of both the drag efforts and overturning moments [15]. This structural aspect highlight (i) the possibility of reducing the required foundation and (ii), to make possible the use of SCAS in places where the installation of classical AB is not possible due to the high transmitted loads, such as viaducts.

2. Adaptation of the screens to market requirements for their installation in road

After the good results obtained in the acoustic standardization tests, which demonstrated the acoustic competitiveness of SCAS, and to achieve an improved product adapted to the business requirements, the research team undertook the challenge of obtaining new designs. These new designs should be more open and present smaller SCAS width occupancy in the roadside margins, maintaining similar results of acoustic performance.

Thus, a new theoretical SCAS design was proposed to achieve a more attractive product for marketing, based on the following premises:

- **Reduction of SCAS width**. It was proposed that the new SCAS should not have excessive width, offering occupancy areas on the margin of road infrastructures similar to classical AB. In the approved acoustic standardization SCAS designs, this width was around 75 cm.
- **Increasing of the screen permeability to wind and visual.** A more transparency to wind and visual SCAS design was proposed to offer the market more visually attractive screens. Transparency is determined by the screen filling factor, which in previous SCAS designs were around 36% in triangular arrangement, which provides less visibility through the devices.
- **Use of recycled materials in manufacturing**. The use of plastic material was proposed for the construction of the scatterers, and the use of polyester from recycled PET as acoustic absorber. The previous SCAS designs used metallic material and high-density rock wool.
- **Maintaining of acoustic performance**. The previous SCAS designs were classified as B2 in the standardized test to determinate the single-number ratio of airborne sound insulation performance (DL_R). The new SCAS design has to offer the same airborne noise insulation level.

3. Numerical model

In order to improve the SCAS design taking into account the previous premises, a numerical model, based on the Finite Elements Method (FEM), was developed. This model reproduces the situation of a transmission chamber with the test conditions described in standard UNE 1793-2 [13] for road traffic noise reducing devices, which describes the test method for determining acoustic performance (part 2, intrinsic characteristics of airborne sound insulation under diffuse sound field conditions). In order to improve the model and reduce computational time a two-dimensional (2D) model was developed. A diagram of this model is presented in Figure 2. The simulations were carried out in the frequencies range corresponding to the normalized traffic noise spectrum (100-5000 Hz), defined in UNE 1793-3[16].

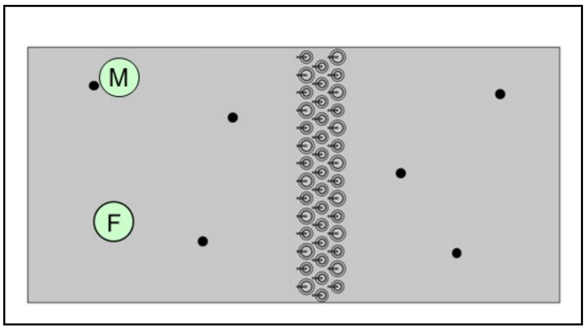

Figure 2. Diagram of the 2D test model in transmission chamber simulated with FEM.

For the adjustment and validation of this numerical model, the acoustic behavior of the previous approved standardization SCAS was simulated, using the experimental data obtained in the standardization tests.

Also, the Delany-Bazley-Miki model was used for the simulation of acoustical absorbing materials, using the commercial COMSOL Multiphysics software. The reasons for this use were, on the one hand the high accuracy and coincidence of the simulated results with the available experimental data; and on the other hand for the simplicity of the model, which requires only one parameter for the description of the absorbent material used. Previously, to verify the suitability of the model, different results obtained with other models, as the Attenborough model or the Johnson-Campoux-Allard model, were compared. The comparison of these numerical models is shown in Figure 3.

It can be seen that the method selected does not differ too much from the Attenborough model, so its use was approved.

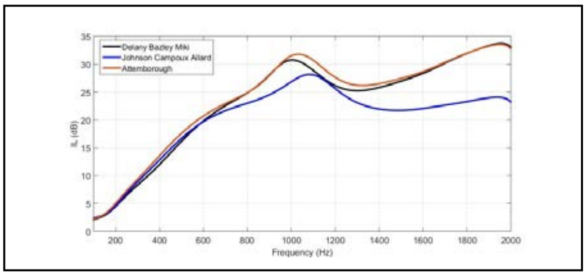

Figure 3. Result of the comparison of numerical models for acoustical absorbing materials.

4. Results.

Using the validated model based on FEM in 2D, the standardization test was modelled according to UNE 1793-2 [13] to analyze the acoustic behavior of several proposed SCAS that met the premises listed earlier in this communication. The proposals were based on the use of a square arrangement of scatterers, on a change in the absorbent materials used and on a change in resonators working frequencies. In all proposed cases, the acoustic insulation capabilities were analyzed and the value of the DL_R index was calculated.

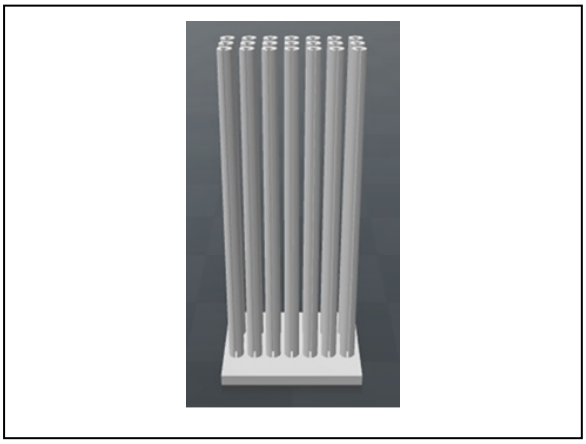

Figure 4. Example of an acoustic screen that meets the design requirements considered.

With the data obtained from simulations, a new SCAS design was chosen with the following characteristics: i) occupancy width of less than 50 cm, ii) a very high visual permeability (60%), and despite this, iii) a noise control capacity such that they can continue to be classified as B2 with respect to their airborne noise insulation according to UNE 1793-2[13]. The results of the design is shown in Figure 4.

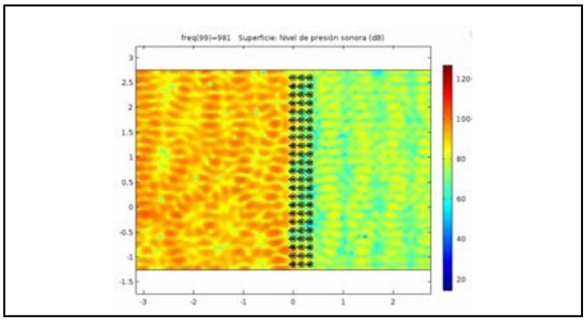

Figure 5. Simulated sound pressure level for 981 Hz.

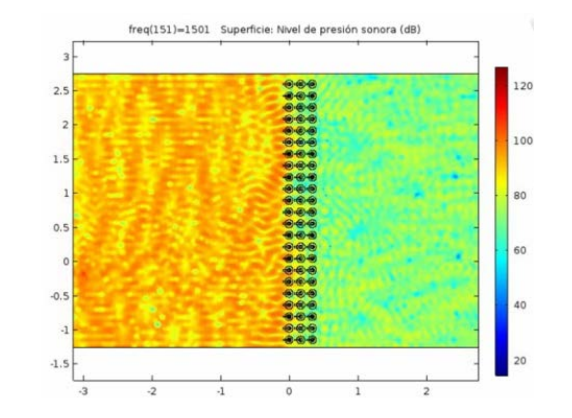

Figure 6. Simulated sound pressure level for a frequency of 1501 Hz.

Figures 5 and 6 show two examples of simulations where sound pressure attenuation is observed in the reception area of the simulated transmission chamber for a frequency of 981 Hz and 1501 Hz.

Finally, figure 7 shows a comparison of the attenuation capability of the previous approved acoustic standardization SCAS (shown in black) respect to the new SCAS proposed (shown in blue). The "insertion loss" index, defined as the difference in sound pressure at a fixed point without and with the device, has been used for this purpose. The figure shows the loss of noise attenuation capability assumed. The improvement in marketable design (more transparent and narrower) is achieved at the expense of loss of noise attenuation capacity.

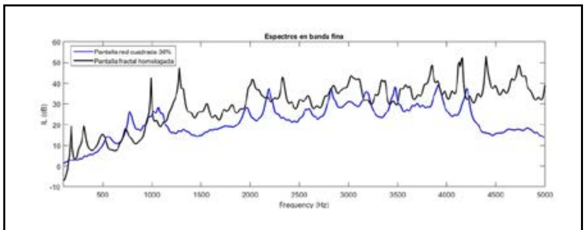

Figure 7. “Insertion loss” obtained in the entire frequency range of the standard traffic noise spectrum (from 100 to 5000 Hz) for the two simulated SCAS (the previous approved one and the recommended in the new design).

5. Conclusions.

In this work a new SCAS design with high attenuation properties, the lowest possible thickness and most possible permeable has been presented, which represents a new concept of AB. While classical AB currently on the market base their effectiveness on the installation of continuous flat walls without gaps, the new SCAS presented in this communication offer certain advantages such as being lighter, open, visually permeable and also permeable to wind and water. In addition, the required foundations for installation are reduced, presenting higher versatility. Furthermore, these new devices introduce the possibility of "tuning" the screen to the type of noise to attenuate, being able to offer solutions on demand. Visually speaking, they can gain greater acceptance from neighbors of dwellings protected. In addition, these new SCAS represent an important technological advance in the field of acoustics and, despite their permeability, they have demonstrated a competitive acoustic effectiveness respect to classical AB with greater volumetric dimensions.

It can be concluded that the new SCAS are ready to be used in noise reducing devices to control the annoying traffic noise of road infrastructures and compete with the classical AB currently on the market.

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