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NOISE CONTROL FOR A BETTER ENVIRONMENT

Simple method to predict the performance of Noise Barriers

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ABSTRACT

Noise barriers are usually classified attending to their intrinsic acoustic characteristics. This is standardized by the European standard EN 1793-2 [1], **in which a single parameter, DL_R, is defined in order to assign four different levels of insulation. However, the final performance of a noise barrier, quantified by the so-called Insertion Loss, *IL*, is not only dependent on the insulation provided by the noise barrier, but it is as well affected by geometrical aspects and the acoustic characteristic of the environment where these noise-reducing devices are placed. In this work, we explore the relationship between the Insertion Loss and the Acoustic Insulation by means of numerical methods. Moreover, we propose a simple way to predict the Insertion Loss from a numerical simulation in which this parameter is obtained for a completely rigid noise barrier.**

Keywords: Noise barriers, Performance, Numerical Simulation
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1. INTRODUCTION

Traffic noise caused by vehicles is nowadays one of the most important and annoying problems all over the world and one of the main sources of environmental noise. This kind of noise has worsened significantly in recent years, mainly due to the increase of population mobility and high traffic density on the roads. In general, this sound pollution level depends on the noise generated by the vehicle engines, but also on the road surface, which depends on the speed of the vehicles and the type of pavement on the infrastructure.

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The most commonly used solution to mitigate the effects of road traffic noise during transmission is the placement of noise barriers, also known as noise reduction devices (DRRs) in the European standards. Classical noise barriers, usually formed by continuous flat walls, are located between the noise source (transport infrastructure) and the receiver (adjacent dwellings or other sensitive receivers).

Noise screens are commonly classified attending to its acoustic insulation [1-2]. The parameter used to evaluate the acoustic insulation performance is the so-called DL_R defined as a weighted average of the sound reduction index R_i for each one third octave band that takes into account both the sound source spectra (traffic noise) and the listener sensitivity (dBA). The sub index i is the index of each one third octave band. Namely, it is expressed by:

$$DL_R = -10log\left|\frac{\sum_{i=1}^{18} 10^{0.1\,L_i}10^{-0.1\,R_i}}{\sum_{i=1}^{18} 10^{0.1\,L_i}}\right| \text{(dBA)} \qquad (1)$$

where L_i are the values of the normalized traffic noise spectrum, given by the standard EN 1793-3 [3] and R_i are the one third octave band values of the sound reduction index of the noise barrier, defined in the standard EN1793-2 [1].

However, the final performance of the screen is not only dependent on the acoustic insulation but also on the particular geometry (shape of the ground, position of the sound source and listeners and shape of the noise barrier). To acoustically characterize the final performance of a noise barrier, we have developed a simulation scheme based on the Finite Difference Time Domain, FDTD, numerical technique. For further details see [4].

2. PROPOSED MODEL

In this section we will describe a simple method to obtain the Insertion Loss of a noise barrier without requiring specific measurements or a complete vibroacoustic simulation of the behaviour of the screen.

To do so we have first developed an acoustic simulation scheme using FDTD schematically illustrated in Fig. 1, hereafter referred to as XZ simulation. In order to avoid unwanted numerical reflections in the considered rectangular calculation domain, a Perfectly Matched Layer (PML) [5] is located at 3 of the 4 domain boundaries. Take into account that the sound can be reflected on the ground, which is considered as being perfectly reflective. With these boundary conditions, the numerical domain is excited by a plane wave travelling from left to right. The measurements have been recorded at the microphones, located at the shadow area of a classical noise barrier. This FDTD scheme assumes that all the propagation domain is air, except the ground that is completely stiff, and the screen that allows the partial propagation of sound though it. In this respect, the screen is characterized by a frequency dependent factor τ_i, commonly known as the sound transmission coefficient that is related to the sound reduction index by the expression:

$$R_i = 10log\left(\frac{1}{\tau_i}\right) \qquad (2)$$

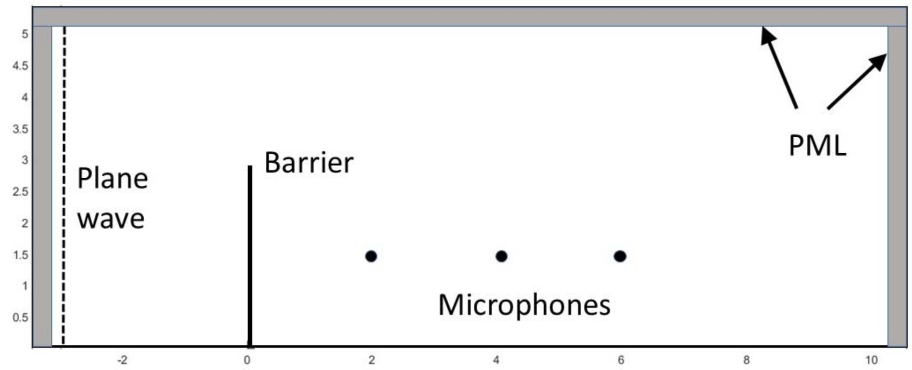

Figure 1: FDTD simulation scheme. XZ simulation.

The effect of the screen can be understood following the Huygens–Fresnel-Kirchhoff principle (see Fig. 2). Energy from the plane wave impinging the noise barrier can pass through the screen or can pass over it. Both contributions will arrive to each measurement position. If we call ε_i to the portion of the energy that arrives to a particular measurement position, traveling above the screen, the portion that travels through the screen will be $(1-\varepsilon_i)\cdot \tau_i$, being τ_i the transmission coefficient that can be directly derived from the sound reduction index, R_i. Then, if no reflections are considered, the frequency dependent Insertion Loss can be written as:

$$IL_i = -10\log[(1-\varepsilon_i)\tau_i + \varepsilon_i] \tag{3}$$

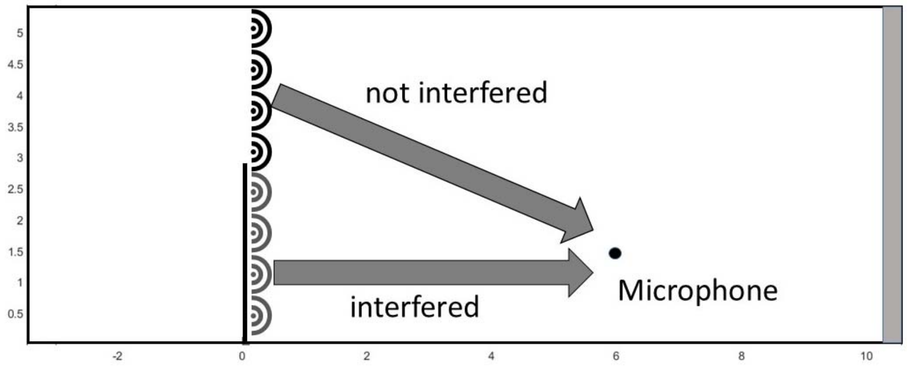

Figure 2: Application of the Huygens–Fresnel-Kirchhoff principle.

Notice that we are assuming incoherence between the sound not interfered by the screen and the one that goes through it. This is valid taking into account that all the measures are averaged in one third octave bands. The portion of energy not interfered by the noise barrier, ε_i, can be obtained from the numerical simulation of the particular geometry under study forcing the screen to be completely rigid.

As a result, the final performance of a noise screen can be obtained by knowing the reduction index R_i (commonly provided by the manufacturer) and the particular value of ε□ that can be obtained from the simulation of the limit case in which the noise barrier is completely stiff. In other words, there is no need to perform a vibroacoustic simulation of the screen that takes into account the transmission of sound through the material or materials it is made of. Notice that, for that particular case, ε_i can be easily obtained with common numerical methods (such as FDTD, BEM or MFS), given that the partial insulation of the screen is not needed.

3. RESULTS

The results of the numerical simulations carried out are illustrated in Fig. 3, for the case of the model shown in Fig. 1 (conventional noise barrier). For clarity, Fig. 3 includes only four representative values of R (6, 12, 18 dB and the perfectly rigid case), with constant values of R_i assigned at all one third octave bands.

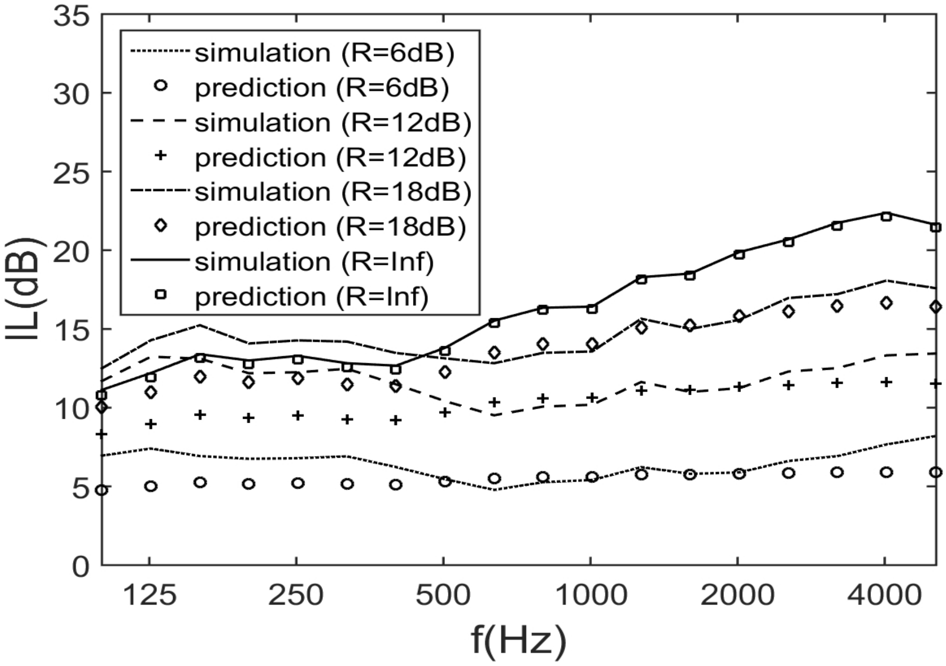

Figure 3: Values of IL index, predicted using Eq.2 and simulated with the FDTD model, as a function of the frequency, for different values of R.

In Fig. 3, the results of the *IL* index as a function of the frequency for different values of R_i are shown, considering for each case the same value of *R* for all the analysed frequencies. The first thing one can see is the good agreement between the values obtained by means of the numerical simulation and by the simple model proposed in this paper (Eq. 2). The agreement is not so good in the low frequency range where the assumption of incoherence is less likely to be entirely correct. However, the most interesting conclusion is the smaller values of *IL* when compared with the corresponding *R* values. This result is logical taking into account that the parameter *IL* not only considers the transmitted wave but also the diffracted wave, which reduced considerably the performance of the noise barrier. Moreover, if an infinite value of *R* is considered, *IL* index saturates, with an *IL* value around 20 dBA for higher frequencies. This means that, no matter how much the acoustic insulation of a noise barrier is increased (thus decreasing the transmission through them) their final performance, given by *IL*, saturates. This is more clearly seen in Fig. 4, where the relationship between the global *IL* and DL_R indexes is represented. The dashed line represents the global insulation of the noise barrier, given by DL_R index. The continuous line indicates the variation in the global *IL* index with the increasing of the acoustic insulation (DL_R). Again, one can see the saturation in the global acoustic performance of the noise barrier around 15 dBA although the DL_R value increases. That means that the final performance of the noise barrier should be estimated with the global *IL* index.

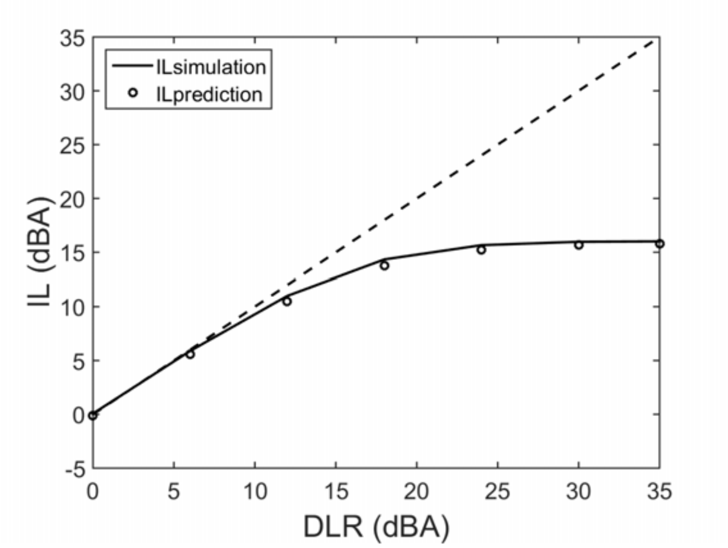

Figure 4: Relationship between global IL and DL_R indexes. Black dashed line indicates the ideal behaviour of a noise barrier if diffraction at the upper edge is not considered (infinite height). Continuous line represents the variation of IL index as a function of DL_R index. Dots represent the global IL index obtained by the simple method proposed in this work (Eq. 2).

In the next section we will validate the proposed model by applying it to a particular kind of noise barriers in which the full simulation of its behaviour does not require vibroacoustics simulations.

4. APPLICATION TO NOISE BARRIERS BASED ON SONIC CRYSTALS

In the last few years, several authors have demonstrated the applicability of sonic crystals as noise barriers with the additional advantage of being almost transparent to winds and water [6]. Figure 5 illustrates a prototype of this kind of noise barriers. Sonic crystals are defined as heterogeneous materials formed by arrangements of acoustic scatterers, commonly cylinders, embedded in air and organized in a regular lattice with a minimum distance between scatterers called lattice constant. These open screens present a new wave control mechanism due to the structuring of the scatterers, which provides the existence of bandgaps, defined as ranges of frequency where the propagation of waves is forbidden, and as a result can be used as noise barriers.

Figure 5. Noise barrier based on sonic crystals.

In order to check if the proposed model is valid we have used the transmission coefficients obtained from a classical 2D numerical simulation of the sound propagation through the sonic crystal (in the plane XY, see Fig. 6). This has been combined with Eq. 2, using the values of ε_i obtained from the XZ simulation commented in the previous section for the case of infinite acoustic insulation. To validate the results we have compared them with the ones obtained from a full 3D simulation (see Fig. 6). The results are summarized in Fig. 7. Again, for the sake of clarity, only three representative values of the diameter of the cylinders constituting the sonic crystal are used. The presented cases are the following: scatterers diameter (d) equal to 50%, 75% and 90% of the lattice constant. The lattice constant (lc = 0.17m) was chosen to make the first band gap appear around 1K Hz, which is the more relevant band according to [3].

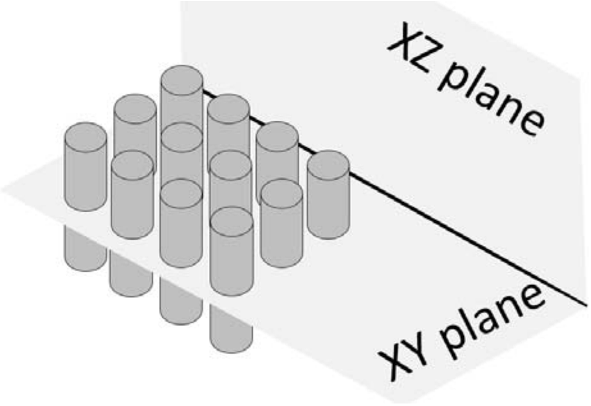

Figure 6. Schematic view of the simulations.

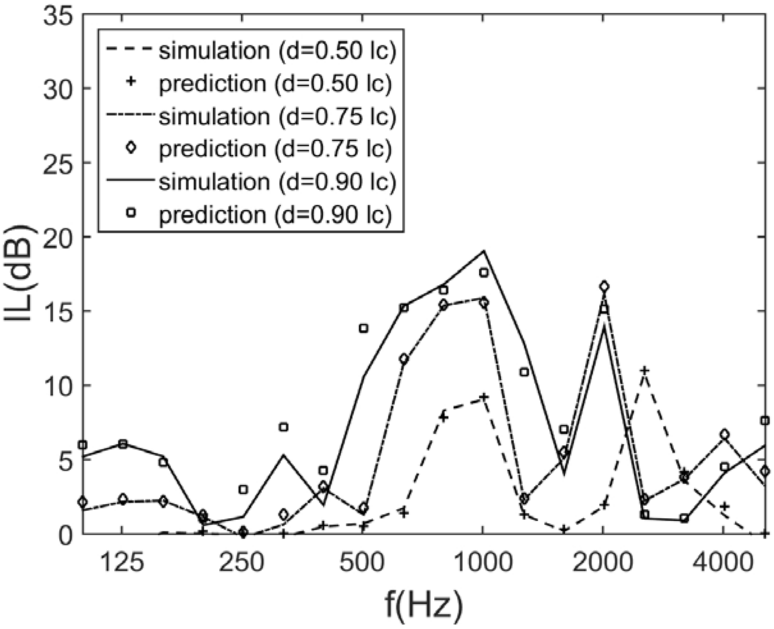

Figure 7.Values of IL index of sonic crystals with different scatter diameters. Continuous lines correspond to 3D numerical simulations. Doted lines correspond to predictions used in the model proposed in this paper.

From the results illustrated in Fig. 7 we can conclude that the agreement is nearly perfect for medium and high frequencies. In the range of low frequencies, as commented before, the effects of coherence between the sound interfered an non interfered worse the results. This is more noticeable when the acoustic insulation increases.

5. CONCLUSIONS

In this paper we have explored the relationship between two of the indexes more extended in the characterization of the final performance of Acoustic Barriers, Insertion Loss (*IL*) and the airborne sound insulation assessment index (DL_R). We have demonstrated, through the numerical results obtained by means of a simulation model developed by us, that the Insertion Loss can be obtained by a simple model in which only a simple acoustic simulation is needed, assuming that the sound reduction index in one third octave bands is known.

6. ACKNOWLEDGEMENTS

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