Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 78 (2015) 134 – 139

Energy Procedia

*6th International Building Physics Conference, IBPC 2015

Acoustic measurements on a sonic crystals barrier

Federica Morandi[a*], Marco Miniaci[b], Paolo Guidorzi[a], Alessandro Marzani[b], Massimo Garai[a]

[a] Department of Industrial Engineering, University of Bologna, Italy
[b] Department of Civil, Chemical, Environmental and Materials Engineering, University of Bologna, Italy

Abstract

This paper describes the measurements carried out over a sonic crystal at normal incidence according to EN 1793-6, which allows to cancel ground reflection and edge diffraction by applying suitable windowing techniques. The sample was made of hollow PVC pipes with an outer diameter of 160 mm arranged in a square lattice with lattice constant 0.2 m. FE predictions were computed in order to verify the experimental campaign. A good match between simulations and measurements was found in the first sonic Bragg band gap. As expected, increasing the number of rows does not translate into a shift of the Bragg band gap but into an increase of the insulation properties.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

Keywords: Sonic crystals; EN1793-6; noise barrier; band gaps

1. Introduction

Sonic crystals are periodic arrays of scatterers immersed in a fluid. For certain combinations of angle of incidence and wavelength, these arrays display stop band properties, i.e. the sound transmission is forbidden in selected frequency ranges. The great interest that focused the research to study sonic crystal in recent years is due to the fact that these light-weight structures allow a sensitive sound insulation over a selected frequency range and result thus as a

* Corresponding author: Tel: +39 051 2090567
E-mail address: federica.morandi6@unibo.it

1876-6102
Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.128

challenging and promising field in noise control. In particular, a significant portion of literature has focused on the case of rigid cylinders immersed in air, which allows a two-dimensional simplification of the problem.

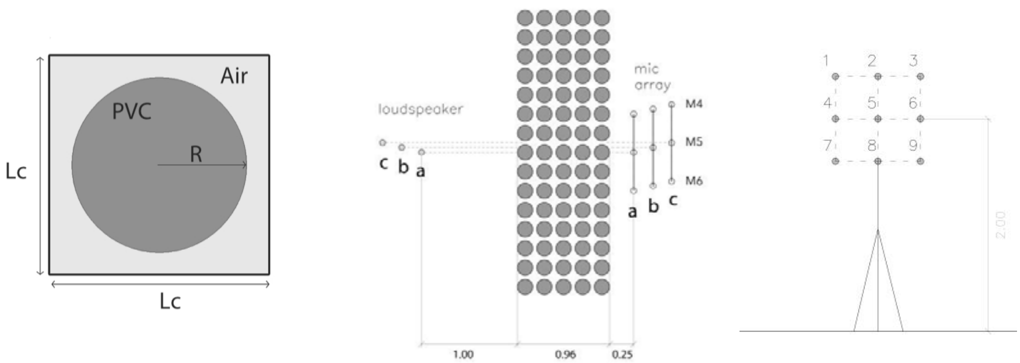
The first measurements that revealed the insulation properties of sonic crystals were conducted over the sculpture by Eusebio Sempere located outside the Juan March Foundation in Madrid [1]. A flourishing literature has followed immediately, analysing the phenomenon with different lattice structures. Among this wide literature, some references are reported in order to trace the evolution of the measurement techniques on sonic crystals. Most of the measurements are carried out in anechoic chambers [2, 3, 4] and over samples constrained in width, thus computing an attenuation value which comprises transmission and edge diffraction effects. In order to render negligible the contribution of the diffracted field from the edges, in many cases the microphone was placed very close to the sample [4]. Two significant exceptions to this measurement method are [5, 6]. In [5] the impulse responses are windowed in order to minimize the reverberation effects, which were evident for the free-field measurements. A window of 6 ms is used, but since the rods were 1 m long, diffraction effects were taken into consideration. In [6] measurements were conducted over a 1.1×7.2 m sample. The width of the sample was kept large in order to minimize the edge diffraction and measurements were performed in open air.

In this paper, measurements are performed to test a sonic crystal sample at normal incidence according to the EN 1793-6 standard [7]. The width and height of the sample determined the characteristics of a time window that was used to cancel ground reflection and edge diffraction, thus computing the transmitted sound component only.

2. Measurement setup

In the Acoustics Laboratories of the University of Bologna a sonic crystal sample was installed consisting of hollow polyvinyl chloride (PVC) pipes with an outer radius of 0.08 m. The cylinders were arranged in a square lattice with lattice constant 0.20 m, returning a filling fraction of 0.50. With the given lattice constant, the sonic Bragg frequencies for normal incidence are integer multiples of f_{Bragg} = 858 Hz. A parametric study was carried out varying the receivers' positions and the number of rows constituting the lattice.

A schematic draft of the measurement setup is shown in Fig. 1, together with the unit cell under study. The main front of the sample consisted of 15 unit cells, resulting in a total width of 3.0 m, and the height of the cylinders was 3.0 m. The depth of the sample varied from 2 to 5 rows of cylinders, i.e. from 0.36 to 0.96 m.



(a) (b) (c)

Fig. 1. Measurement setup. (a) Unit cell with L_c=0.20 m and ff=0.50. (b) Setup for insulation measurements on a 15x5 sonic crystal. (c) Array of 9 microphones spaced 0.40 m apart with the relative nomenclature.

The sample was tested for normal incidence according to EN 1793-6 [7]; the loudspeaker was placed at a distance of 1 m from the sample and a grid of 9 microphones spaced apart by 0.4 m was set at a distance of 0.25 m from the last row of cylinders, on the side of the sample opposite to the sound source. The central microphone of the grid (M5) always faced the sound source and was shifted along the width of the sample, keeping the same source-sample and sample-receiver distances. Three configurations were considered, drafted in Fig. 1b. In configuration a, the source and the receiver face the central cylinder of the array; in configuration c the source and the receiver are aligned to the space between two adjacent cylinders and configuration b lies in between these two.

The sound insulation values are given by the dB-ratio of the spectra of measurements with and without the barrier. As anticipated in the introduction, before computing the FFT the impulse responses were suitably windowed using the Adrienne time window [7] in order to cancel the ground reflection and the edge diffraction. Sound insulation returns then only the transmitted component of the sound pressure field.

3. Analysis of the results

Fig. 2 shows the attenuation measured at microphone position M5 (central microphone of the grid) for sonic crystals made of 2, 3, 4 and 5 rows of 15 cylinders. The source and receiver positions were aligned to the central cylinder as show in Fig. 1 - configuration (a). Positive sound insulation values are found at sonic Bragg frequency; even with two rows of cylinders, sound insulation assumes an average value of 10 dB over the frequency range 550-1,000 Hz and it increases by increasing the number of rows. Some anomalies are found for the 5-rows case, where sound insulation values are smaller than expected. This might be due to the fact that the width of the window was kept constant for all measurements; thus increasing the depth of the sample, a smaller number of n-th order reflections are contained within it. The sound insulation assumes negative values at twice the Bragg frequency and returns positive albeit small immediately after.

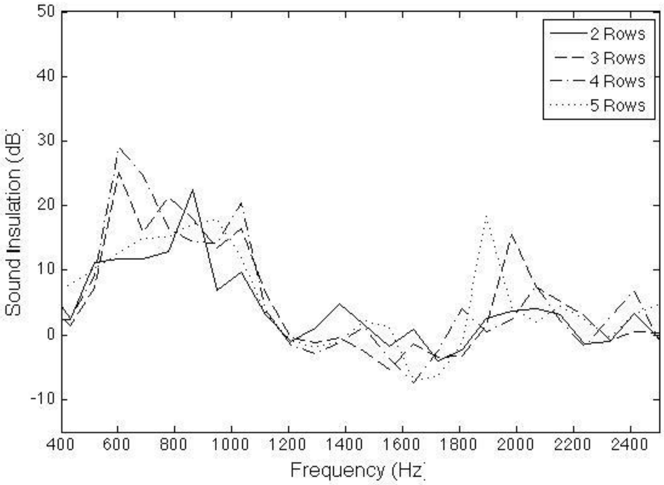
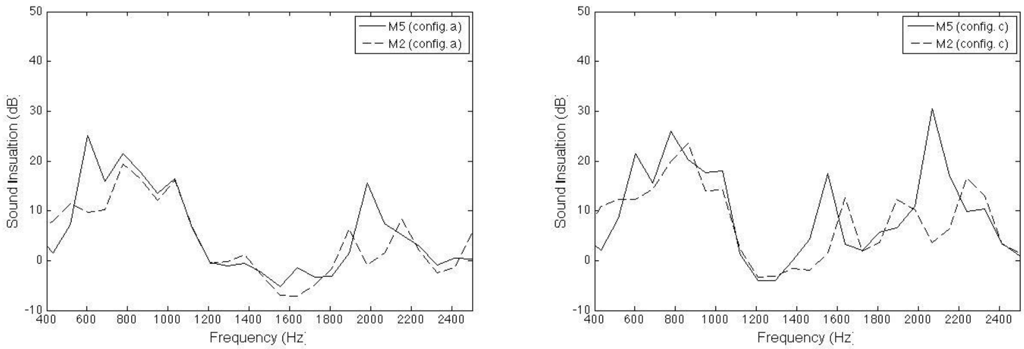


Fig. 2. Sound attenuation measured for 2, 3, 4, 5 rows of cylinders for configuration (a).



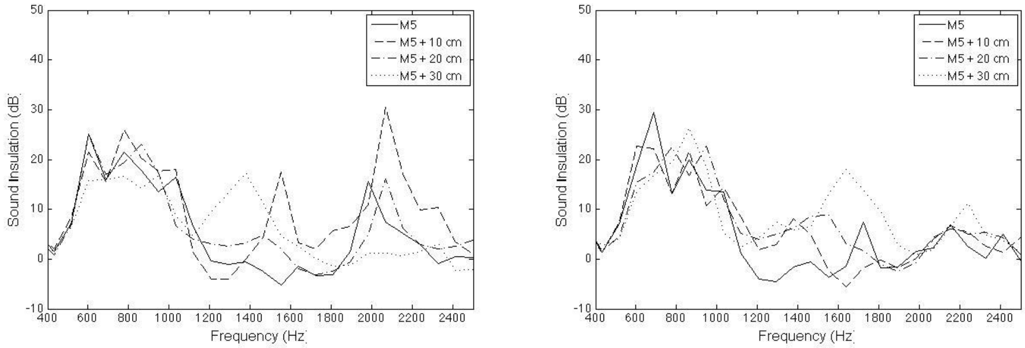
(a) (b)

Fig. 3. Sound attenuation measured along the vertical axis of the microphone grid for position 1 (a) and position 3 (b) for a 15x3 array.

Next, the behavior of the sample along the vertical direction is analyzed. The microphone grid sees the central microphone (M5) at the same height of the source, while microphone M2 lies 0.40 m below it. The sound insulation evaluated at points M2 and M5 is reported in Fig. 3 for a 15x3 sonic crystal. The results show that the behavior at the two measurement points is rather homogeneous in frequency both for configuration (a) and (c). In particular, there is an extraordinary match between the two trends within the range 1,000-1,400 Hz. Moreover, it is possible to notice that for measurement configuration (a), sound insulation at twice the Bragg frequency is slightly negative. Configuration (c) shows a pronounced decrease in sound insulation around 1,200-1,300 Hz and positive values are found again at $2\times f_{Bragg}$.

The sample is then analyzed by shifting the microphone parallel to the sample, starting from the central position M5 and moving aside with a step of 0.10 m. The results are shown in Fig. 4 for two configurations: with the grid spaced from the sample by 0.25 m (a) and by 0.50 m (b).

Again, the sound insulation values are not affected by the shift in position at the first Bragg band gap but start to diverge immediately after. For case (a) there is no recognizable trend shared Often in literature the results are averaged over the different measurement positions to determine a reference sound insulation value.



(a) (b)

Fig. 4. Sound attenuation measured along the longitudinal axis of the microphone grid. The microphone position is shifted from M5 towards M4, with a spacing of 0.10 m. The receiver kept the same distance from the sample. i.e. 0.25 m (a) and 0.50 m (b).

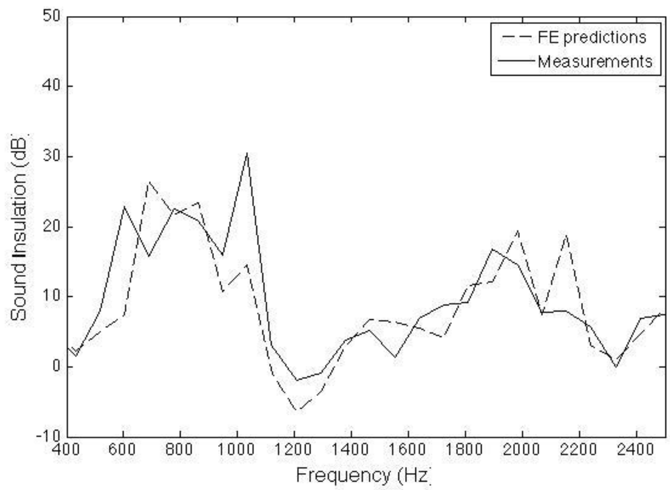


Fig. 5. Measured and predicted attenuation values at microphone position M5 for a 15x3 sonic crystal (configuration a).

For case (b), spaced 0.50 m from the sample, the behavior at high frequencies finds a convergence between the measurements. Due to the windowing procedure, necessary to isolate the transmitted component only, it becomes difficult to evaluate the behavior of the sample in the far field and also these measurements might be subject to errors related to the choice of the window.

The measurements were supported by finite elements (FE) analyses performed with the commercial software Comsol Multiphysics©. The domain was discretized in two dimensions and a point source determined the incident field. Neumann boundary conditions were applied to the cylinders and the boundaries of the domain were modelled using Perfectly Matched Layers in order to simulate Sommerfeld's radiation conditions. Fig. 5 shows the measured and predicted values computed at microphone position M5 for a 15x3 sonic crystal. FE predictions capture quite narrowly both the trend of the measured data and the local values, suggesting to consider the use of this method reliable for determining the a priori behavior of a sonic crystal.

4. Conclusions

In this paper a sonic crystal was investigated with the measurement setup used for sound insulation measurement according to the EN 1793-6 standard. This implies that the measured impulse responses are windowed in order to cancel ground reflection and edge diffraction. The measurement method required a sample of conspicuous dimensions, which was installed in the Acoustics Laboratories of the University of Bologna. The investigation was lead with a parametric approach, which was rendered possible by varying the positions of the receivers as well as the arrangement of the crystal. Measurement positions lying on the same vertical and horizontal axis were compared and discussed. Varying the number of rows comprised in the crystal, it was shown that the stop band properties are enhanced in the first sonic Bragg bang gap. It was also shown that in the first sonic Bragg band gap the results of the different measurement positions remain unchanged, while the behavior at higher frequencies depends dramatically on the measurement position. Shifting the microphones far away from the sample, i.e. getting close to the far field, a more homogeneous field is found, but concerns due to the windowing procedure arise.

References

[1] R. Mártinez-Sala, J. Sancho, J. V. Sánchez, V. Gomez, J. Llinares, F. Meseguer. Sound attenuation by sculpture. Nature 1995;378.

[2] J. V. Sánchez-Pérez, D. Caballero, R. Mártinez-Sala, C. Rubio, J. Sánchez-Dehesa, F. Meseguer, J. Llinare, F. Gálvez. Sound attenuation by a two-dimensional array of rigid cylinders. Phys. Rev. Lett. 1998;80;5325.

[3] O. Umnova, K. Attenborough, C. M. Linton. Effects of porous covering on sound attenuation by periodic arrays of cylinders. J. Acoust. Soc. Am. 2006:119;1.

[4] C. Lagarrigue, J. P. Groby, V. Tournat. Sustainable sonic crystal made of resonating bamboo rods. J. Acoust. Soc. Am. 2012:133;1.

[5] W. M. Robertson, J. F. Rudy III. Measurement of acoustic Stop band in two-dimensional periodic scattering arrays. J. Acoust. Soc. Am. 1998;104 (2).

[6] J. V. Sánchez-Pérez, C. Rubio, R. Mártinez-Sala, R. Sanchez-Grandia, V. Gomez. Acoustic barriers based on periodic arrays of scattererers. Appl. Phys. Lett. 2002;81; 5240.

[7] EN 1793-6. Road traffic noise reduction devices – test method for determining the acoustic performance. Part 6: Intrinsic characteristics – in situ values of airborne sound insulation under direct sound field conditions, 2012.