E3S Web of Conferences 32, 01024 (2018) https://doi.org/10.1051/e3sconf/20183201024
EENVIRO 2017

Urban sound energy reduction by means of sound barriers

Vlad Iordache**and Mihai Vlad* Ionita

Research Center CAMBI, Technical University of Civil Engineering of Bucharest, Romania

Abstract. *In urban environment, various heating ventilation and air conditioning appliances designed to maintain indoor comfort become urban acoustic pollution vectors due to the sound energy produced by these equipment. The acoustic barriers are the recommended method for the sound energy reduction in urban environment. The current sizing method of these acoustic barriers is too difficult and it is not practical for any 3D location of the noisy equipment and reception point. In this study we will develop based on the same method a new simplified tool for acoustic barriers sizing, maintaining the same precision characteristic to the classical method. Abacuses for acoustic barriers sizing are built that can be used for different 3D locations of the source and the reception points, for several frequencies and several acoustic barrier heights. The study case presented in the article represents a confirmation for the rapidity and ease of use of these abacuses in the design of the acoustic barriers.*

1 Introduction

The noise protection represents today one of the main design requirements in order to meet international LEED and BREAM standards as well as the Romanian Ministry of Development design option F requirement. Today, several types of building services equipment (chillers, heat pumps, compressor, VRVs, Rooftops, and others) alongside their role in preserving the indoor comfort of the serviced building, they become sound pollution vectors and sometimes leading to the violation of the noise protection requirements in urban environment [1]

The sound energy emitted by the equipment in the environment and leads to an increase of the acoustic pressure above the background value. The higher the acoustic pressure in a specific reception point the higher the sound energy arrived in that reception point. The amount of energy arrived at the reception point depends on the length of the sound wave propagation path: the further the reception point, the smaller the energy arrived, the smaller the acoustic pressure and finally the smaller the acoustic pressure level.

Therefore, engineers and architects strive to find solutions to reduce the sound energy arrived at specific locations in the urban environment and consequently reduce the noise level at that location. The installation acoustic barriers in-between the noise generation equipment and the reception point represents a noise protection solution. The design of these acoustic barriers consists in determining the position, length and height of this acoustic barrier. The height of the acoustic barrier is a design element that is most often done using the Maekawa diagram [2]. Although, other theories have been developed depending on the type of relief, the shape of the acoustic barrier [3], its thickness or the presence of an inclined cover [4] [5] as well as the type of noise source (point or line) [6], however Makawa Diagram remains today the most widely used method.

This acoustic barrier sizing procedure based on Maekawa's theory represents a method hardly exploitable by engineers and architects due to the complexity of calculations required to be performed for the entire spectrum according to national noise protection requirements [7]. In this study we propose a new and simplified method for the sizing of an acoustic barrier, method based on the same theory. This new design tool will lead, in a faster and easier way, to the same results. Today there are no simplified calculation abacuses for this sizing procedure neither in international norms nor in research literature. The aim of this study is to produce several abacuses in order to rapidly determine the correct height for these acoustic barriers. These abacuses should be relevant to different 3D geometries and different locations of the reception point (that is intended to be protected).

The paper presents the method for the construction of the abacus for the rapid calculation of acoustic barrier for all frequencies and a study case that aims to understand the applicability and the ease of the new design method.

2. Method

In this paragraph we will present the analyzed geometry and the method used for the construction of the calculation abacus for fast noise level decrease.

The analyzed geometry at urban level (**Fig. 1**) consists of three different elements:

- a noise source (chiller, pump, fan or other noisy equipment) that will be considered in our analysis as a stationary noise source, placed at 1 m above the ground;
- an acoustic barrier located at 1m away from the noise source. Its height is from the ground level up to the design height. Such an acoustic barrier should exceed the altitude of the noise source. In this study we aim to examine five different heights for the acoustic barrier:

* Corresponding author: viordach@yahoo.com

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).

a) 1m representing the lower limit, b) 2m, c) 3m, d) 4m and e) 5m. From a structural viewpoint, the barrier has a specific mass greater than 10 kg/m^2, so that the main sound wave is the diffracted wave (the wave passing around the acoustic barrier) and not the wave perpendicular on the acoustic barrier crossing the barrier.

- the area protected by the acoustic barrier is the area behind this acoustic barrier that is not directly visible from the noise source (the shaded area in Figure 1). For any point in this area, the sound wave generated by the noise source suffers is diffracted at the top of the acoustic barrier. In this study, we analyze five different heights of the acoustic barrier (five different geometries) and for each height the protected area will be different.

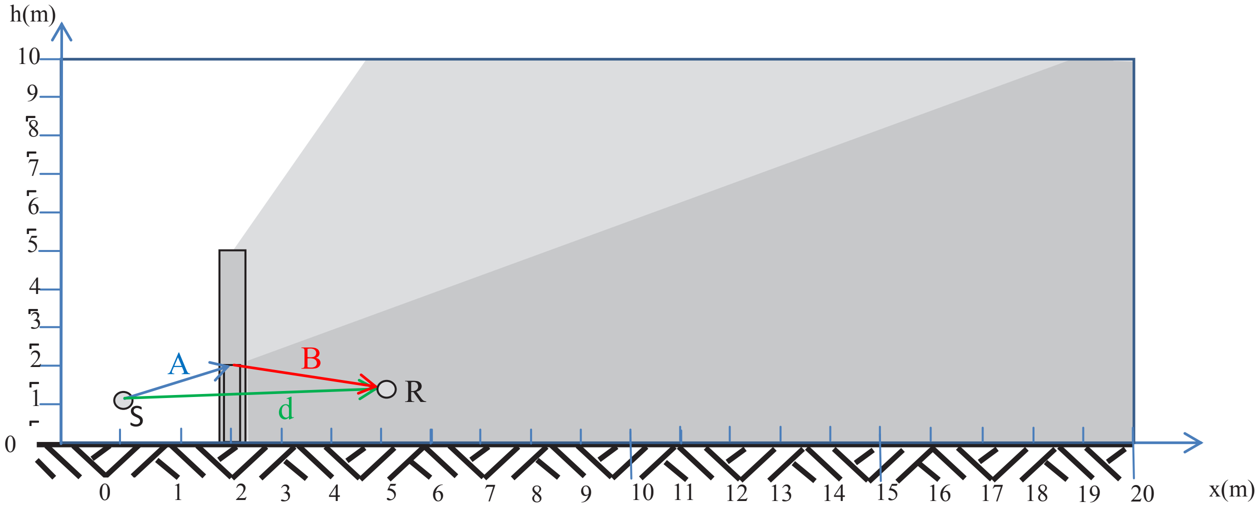

Fig.1. 2D geometry for two acoustic barrier heights (2m and 5m) and the corresponding protected area

When no acoustic barrier is mounted the noise level in the protected area is due to the sound wave propagated directly from the noise source (S) to the reception point (R), covering a distance d (m) (**Fig. 1**). After the installation of the acoustic barrier, the noise level is due to the diffracted wave, (the wave generated by the noise source (S), and passing around the acoustic barrier at its highest point to reach the receiver point (R). Thus, the new distance covered by the diffracted sound wave, A+B (m), where A (m) is the distance from the source to the highest point of barrier and B (m) is the distance from the highest point of the barrier to the receiver, is longer than if there were no acoustic barrier.

To determine the sound energy decrease due to a certain acoustic barrier, firstly we determine the Fresnel's number N (-) (Equation 1) [8].

$$N = 2 \cdot \frac{A + B - d}{\lambda}, \qquad (1)$$

where λ *(m)* is the sound wave length, (variable with the frequency). Further, the Maekawa theory will lead to assessment of the noise level attenuation in the reception point ΔLp *(dB),* compared to the case when there was no acoustic barrier, as a function of the Fresnel's number, N.

In urban environment the noise source is an HVAC equipment that generates sound energy on all frequencies of the audible spectrum. Thus the Fresnel's number and further the noise level attenuation are different from one frequency to another.

The urban noise protection norms in Romania [7] set sound pressure level maximum limit values for each frequency at both the street level [1] and the building facade level [9]. Thus the sizing of this type of urban acoustic barriers should simultaneously fulfill all the requirements for all the frequencies.

Therefore, the sizing of an acoustic barrier during the design phase becomes a highly complex procedure given the 3D geometry of the environment where sound wave propagates and the analysis that should be carried out for all frequencies.

This higher complexity of the calculation procedure has negative consequences upon the design solution. We wish to generate a new tool for acoustic barrier sizing for architects and engineers. The purpose of this study is to generate abacuses for rapid calculation of noise attenuation at the receiving point and this new tool will represent an essential advancement in this field.

3. Results

The calculation method presented in the previous paragraph was applied for each geometric configuration (each panel height). The receiver point was placed between 1m to 20m behind the acoustic barrier (1m horizontal grid spacing) and between the ground level to 10m height (0.5m vertical grid spacing). For all these reception points, the calculation method was applied, calculating the parameters: distance *A*, distance *B*, distance *d*, distance difference δ, Fresnel's number *N*, and noise attenuation ΔLp, for each frequency. For these receiver positions inside this grid where the receiver is

* Corresponding author: viordach@yahoo.com

not protected by the acoustic barrier (outside the shaded area), a zero noise attenuation value was imposed (negative Fresnel's number is irrelevant for our application).

In order to obtain the abacuses for rapid calculation of the noise level attenuation, these attenuations were calculated for each receptor position inside the matrix, each height of the acoustic barrier and each frequency: 125Hz and 250Hz (low frequencies), 500Hz and 1000Hz (median frequencies) and 2000Hz and 4000Hz (high frequencies).

In **Fig. 2**, corresponding to the 125 Hz frequency, we can compare the effect of the five heights of acoustic barriers. We considered the HVAC equipment of a house representing the noise source while the facade of the closest building (block of flats) is the receptor. In-between the two buildings, at 2m from the noise source the acoustic barriers are placed. In the case of the 1m height barrier (**Fig. 2**a), the protected area is the narrowest and therefore such an acoustic barrier is appropriate for receiver points placed on the ground or below ground level (depending on the relief). The protection provided by this 1m height barrier is 5-6 dB at ground level, representing a low noise protection.

For the 2m height barrier (**Fig. 2**b), the protected area is larger and the attenuation of ground level noise is approximately 8-10 dB. For the 3m height barrier (**Fig. 2**c), the protected area is wider, and the attenuation of ground level noise is 12-15 dB. For the 4m high barrier, the attenuation of the ground level noise increases to 14-17 dB, and for the 5m barrier height it reaches 16-19 dB.

As a general trend it is noted that the higher the height of the barrier the larger the protected area and the higher the noise level attenuation.

The minimum values of the sound level attenuation (about 5dB) are found on the separation line between the area protected by the acoustic barrier (shaded area in Figure 1) and the unprotected area. Above this separation line, the attenuation rapidly descends to 0dB (zone corresponding to negative Fresnel's number). In our study we considered the effect of the acoustic barrier is considered to be null.

The location where the sound level attenuation is highest is in the immediate vicinity of the barrier behind it. At this location, for the 1 m high barrier the attenuation is 7dB, while for the 5 m barrier the attenuation reaches 20dB.

If we consider a reception point at a horizontal distance of 20m from the noise source and at a height of 5m (located on the first floor of the block of flats) it is observed that the 1m height barrier does not provide any protection whatever the frequency. But the 2m barrier provides a 6.3dB sound level attenuation at 125Hz (**Fig. 2**b), a 3m barrier assures a 10dB attenuation, a 4m barrier assures an attenuation of 13dB, and the 5m barrier provides a 15dB attenuation.

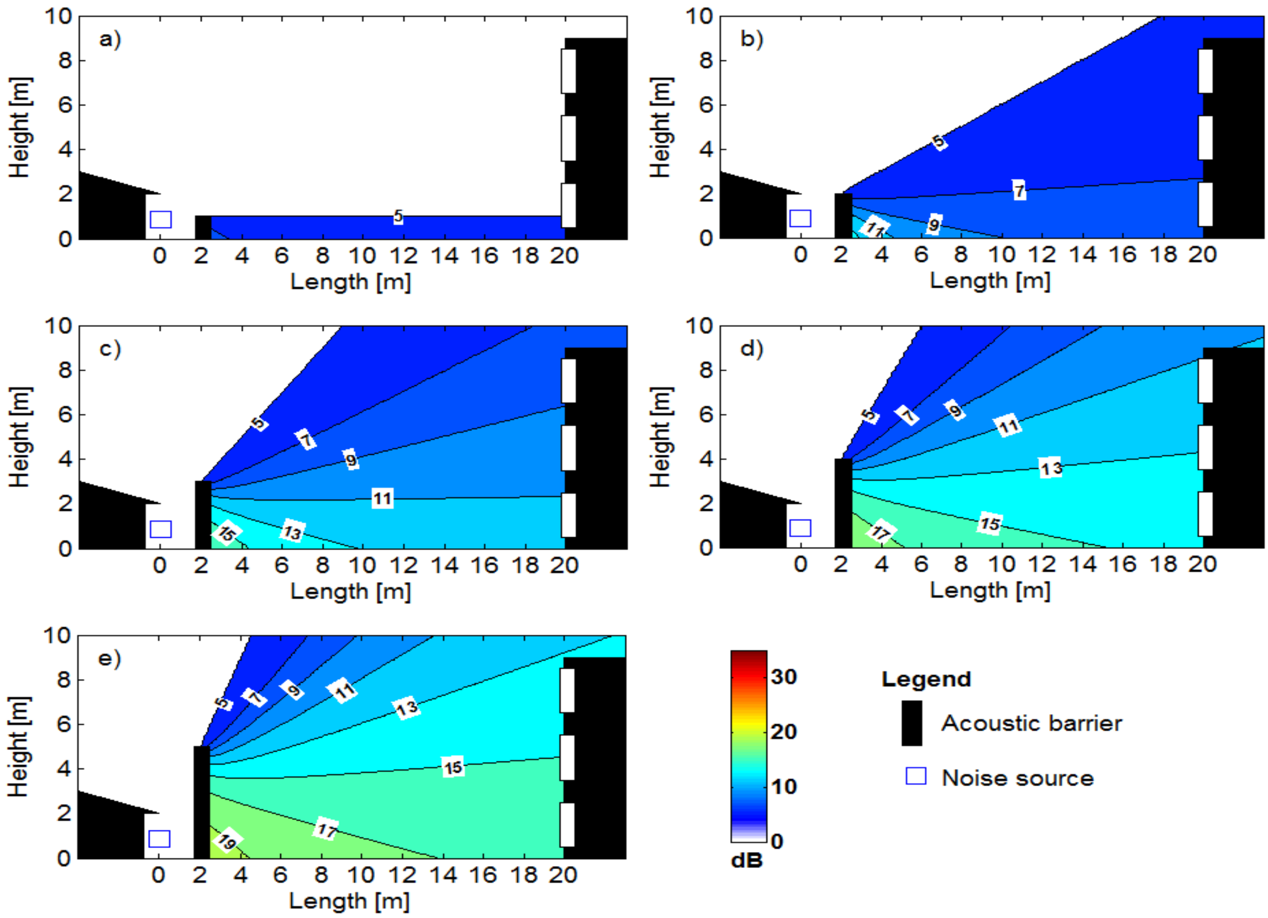

Fig. 2. Noise level attenuation at 125 Hz for an acoustic barrier height of: a) 1m; b) 2m; c) 3m; d) 4m; e) 5m

* Corresponding author: viordach@yahoo.com

https://doi.org/10.1051/e3sconf/20183201024

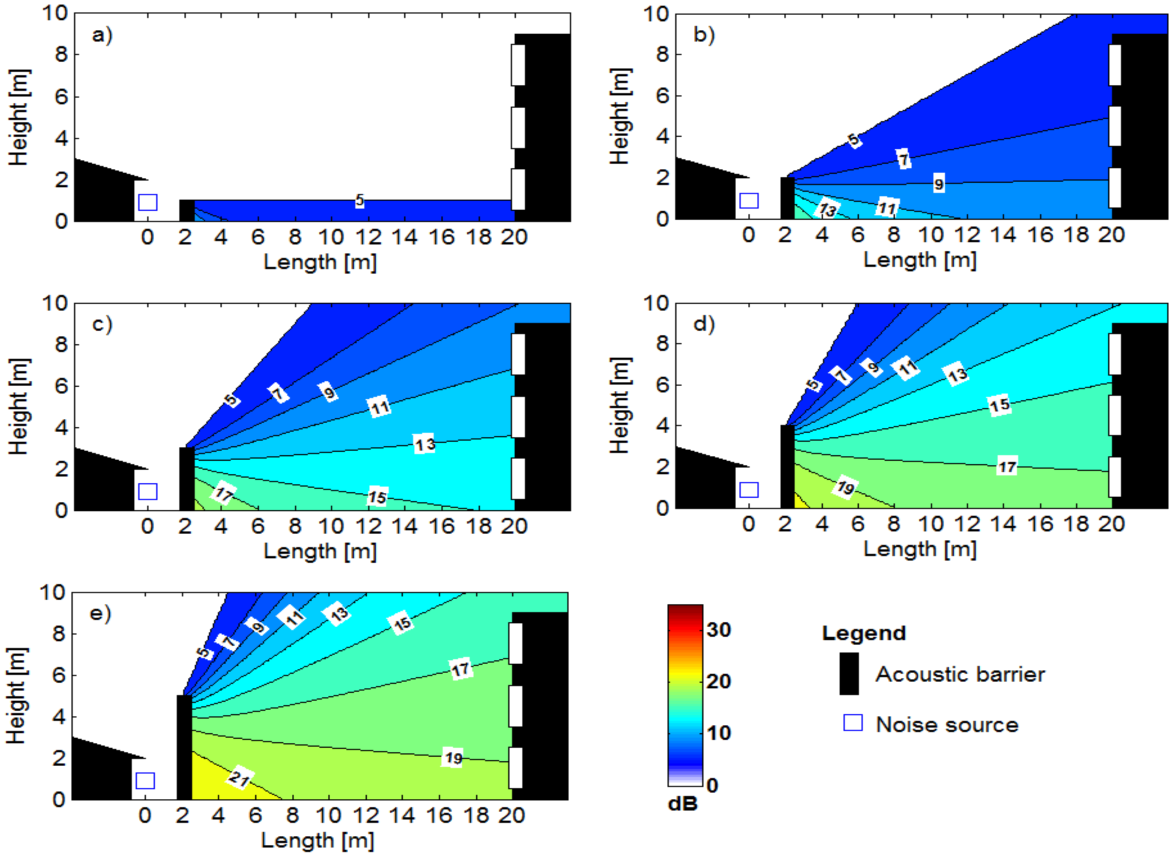

Fig. 3. Noise level attenuation at 250 Hz for an acoustic barrier height of: a) 1m; b) 2m; c) 3m; d) 4m; e) 5m

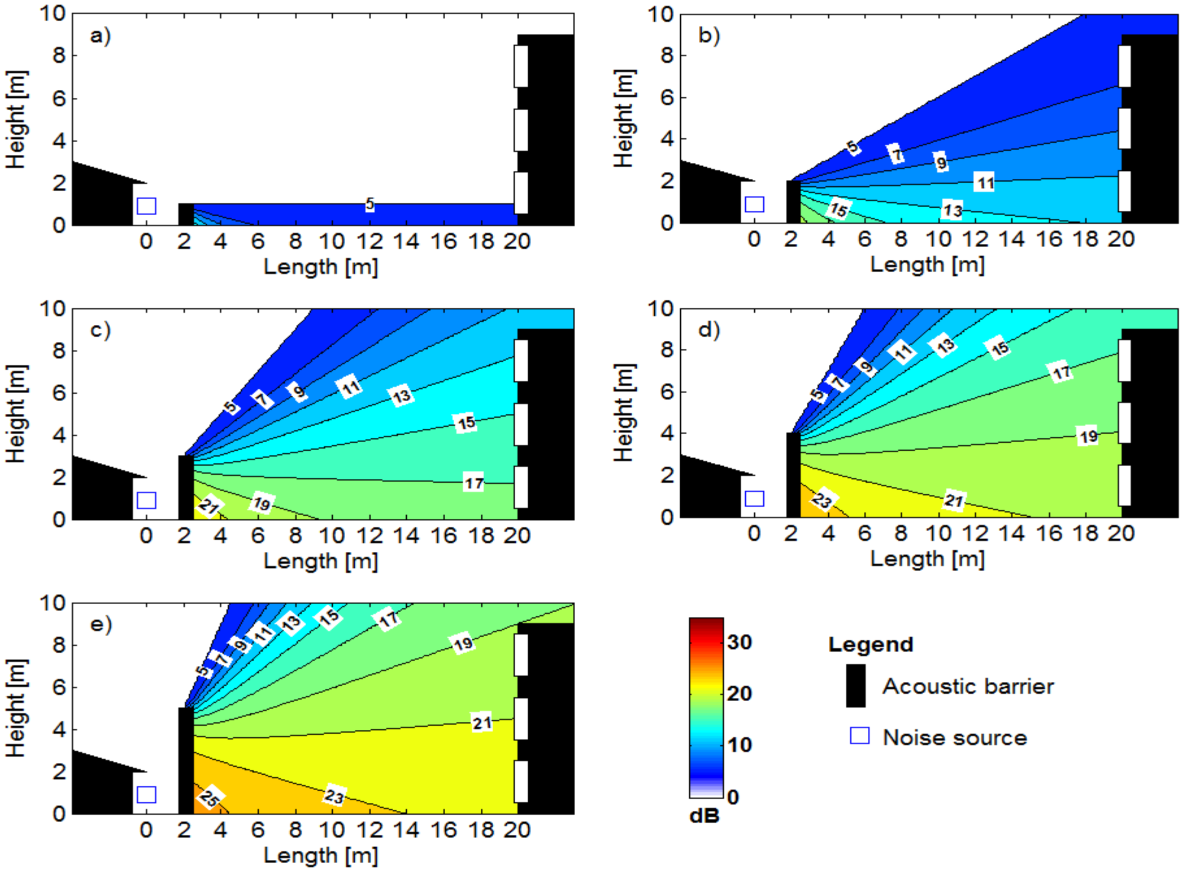

Fig. 4. Noise level attenuation at 500 Hz for an acoustic barrier height of: a) 1m; b) 2m; c) 3m; d) 4m; e) 5m

* Corresponding author: viordach@yahoo.com

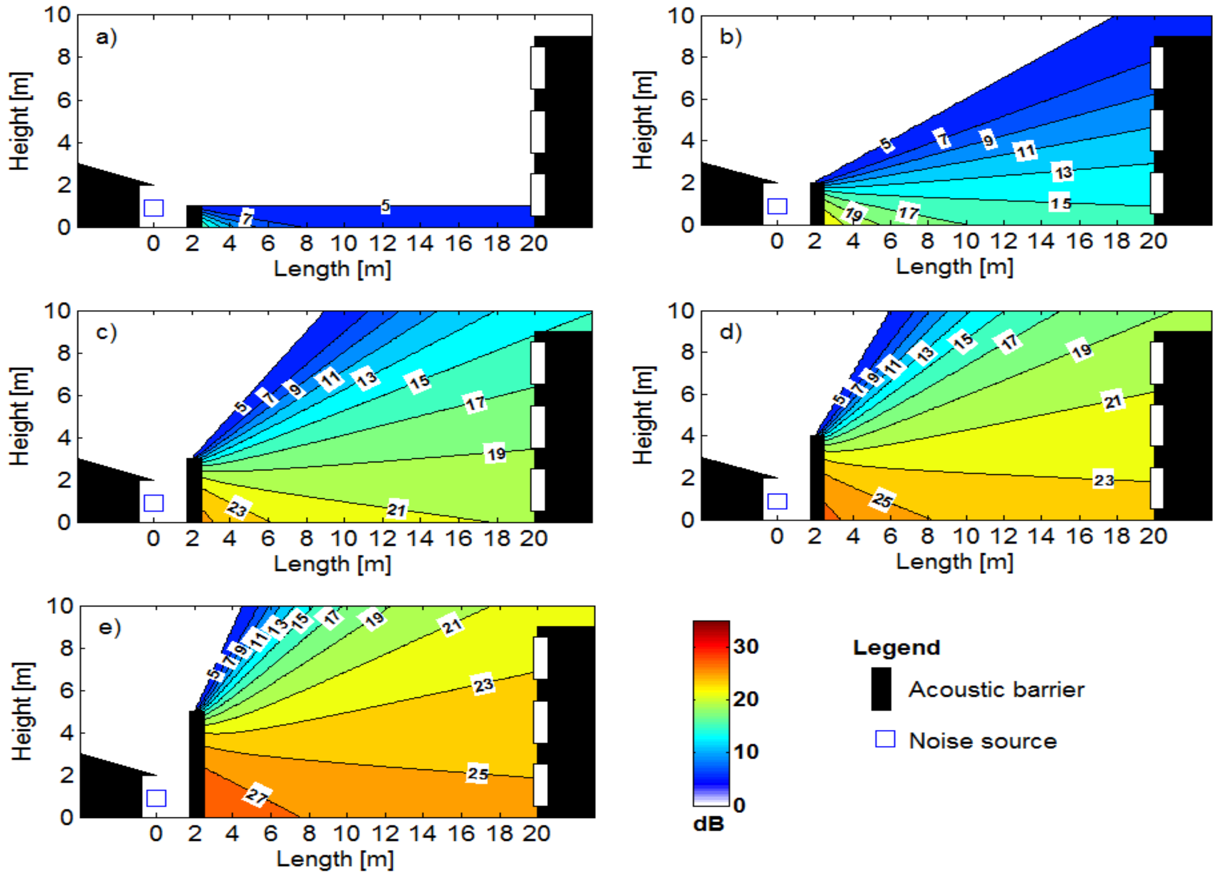

Fig. 5. Noise level attenuation at 1000 Hz for an acoustic barrier height of: a) 1m; b) 2m; c) 3m; d) 4m; e) 5m

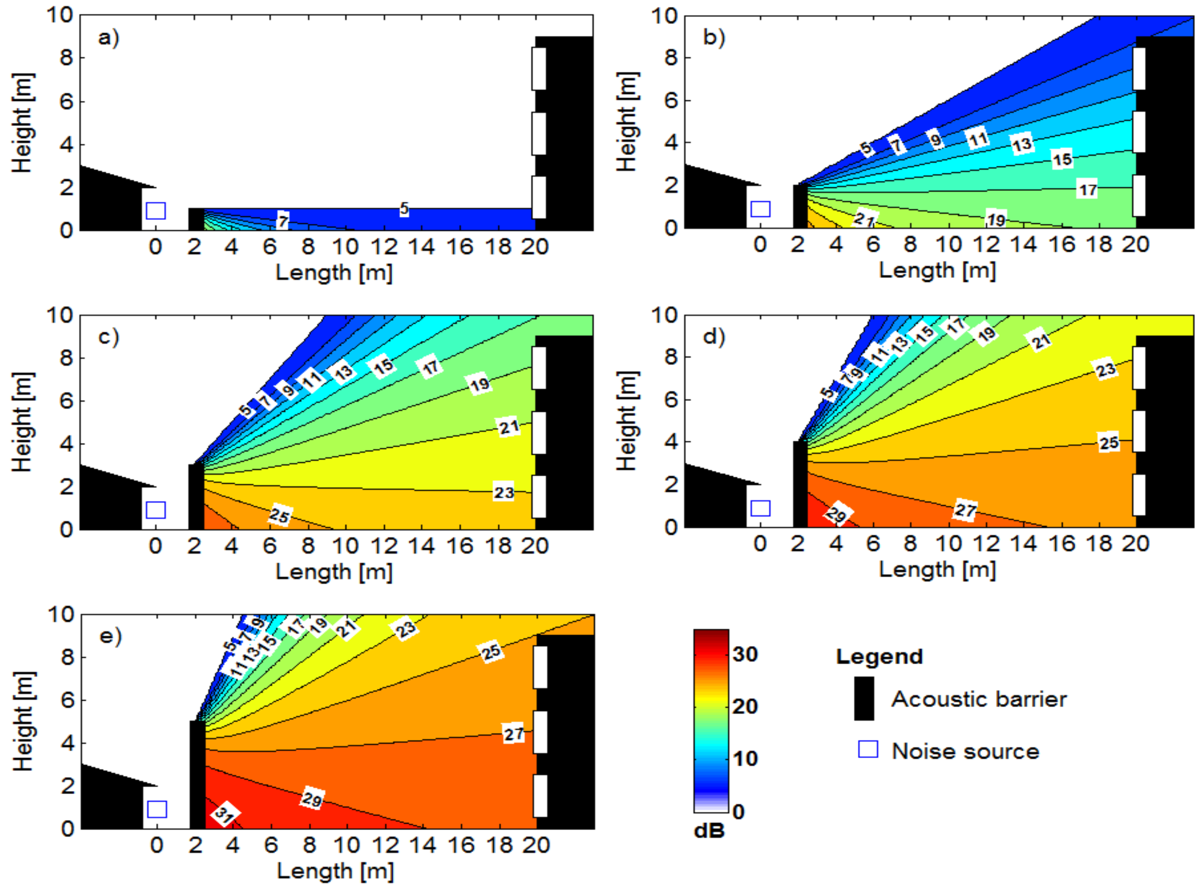

Fig. 6. Noise level attenuation at 2000 Hz for an acoustic barrier height of: a) 1m; b) 2m; c) 3m; d) 4m; e) 5m

* Corresponding author: viordach@yahoo.com

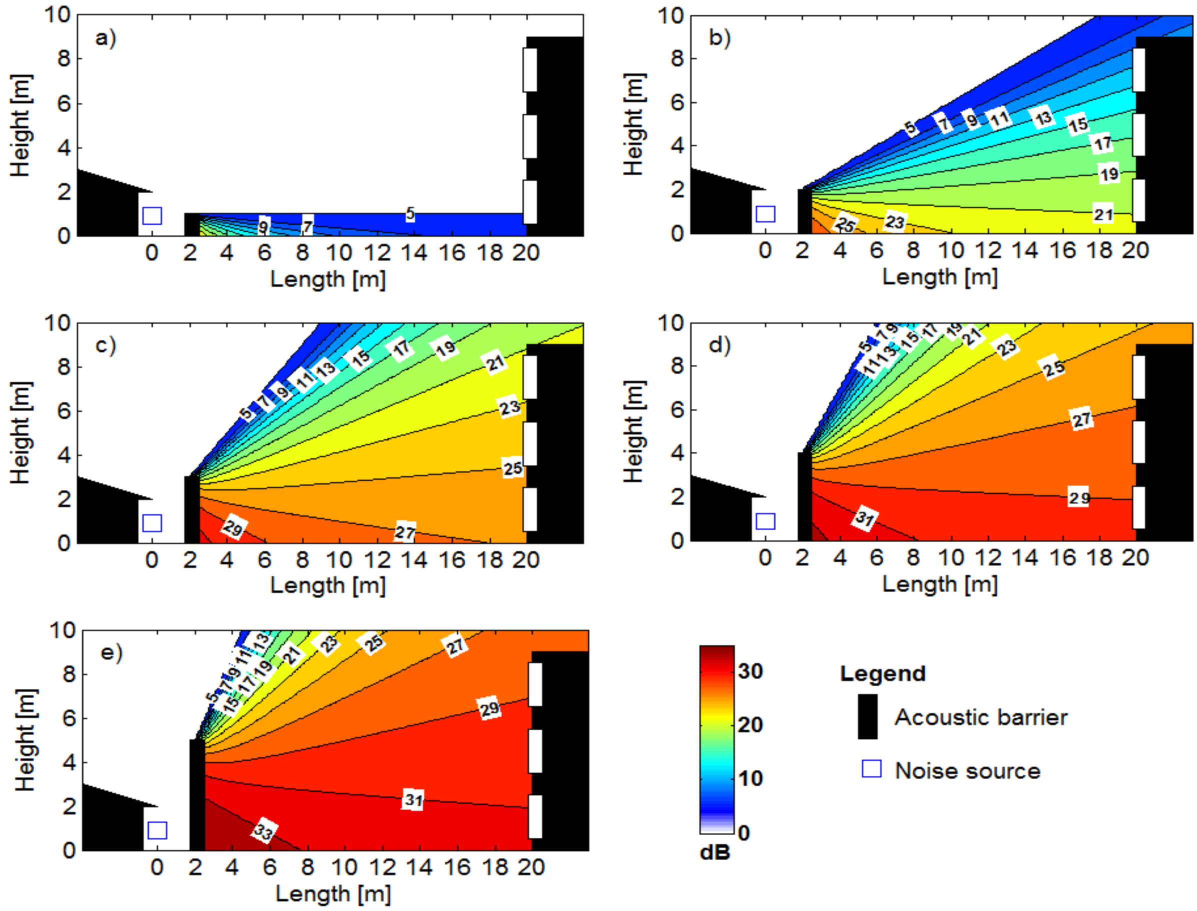

Fig. 7. Noise level attenuation at 4000 Hz for an acoustic barrier height of: a) 1m; b) 2m; c) 3m; d) 4m; e) 5m

In **Fig. 3**, corresponding to the 250Hz frequency, the same general tendency is observed: the higher the barrier height, the higher the protected area and the higher the sound level attenuation. The maximum attenuation corresponding to the 5m height acoustic barrier is about 23dB, higher than the maximum attenuation corresponding to the 125 Hz frequency (20dB). For a receiver located 18 m behind the acoustic barrier and 2 m high, the 2m height barrier sound level attenuation at 250 Hz is about 7.5 dB.

In **Fig.4 - 7**, corresponding to frequencies 500Hz, 1000Hz, 2000Hz and 4000Hz respectively, the same general tendency is observed: the higher the barrier height, the higher the protected area and the higher the sound level attenuation. The maximum attenuation is met behind the acoustic barrier for all frequencies.

Moreover, the sound level attenuation is variable as a function of the frequency: the higher the frequency the higher the attenuation. Thus, for 4000Hz the highest attenuation is about 34dB compared to only 20dB corresponding to 125Hz.

4. Study case

This chapter exemplifies how these simplified abacuses can be used to correctly design the height of an acoustic barrier. We shall consider the case of a rooftop ventilation equipment placed of the flat roof of an office building (marked "OB" in **Fig. 8**), which represents the sound source (marked with "S" in **Fig. 8**) placed at 2m from the office building attic. The reception point (marked with R in **Fig. 8**) is represented by the window of the nearby apartment building (marked "AB" in **Fig. 8**) where the façade maximum allowed noise level is 45 dB at 1000Hz. The distance between the rooftop and the analyzed window is 10m and the acoustic pressure level on the façade of the apartment building is 59.5dB, thus it is 14.5 dB over the maximum allowable limit. We note the higher the distance between the receiver and the sound source, the smaller the noise level in the receiver point. This is due to the dispersion of the sound energy emitted by the rooftop all-around into a sphere shape and thus the further the reception point from the source the higher the surface area of the sphere where the energy is dispersed (**Fig. 8**a).

An acoustic barrier would be installed close to the attic of the office building (blue line in **Fig. 8**) at 2m away from the noise source and at 8 m from the reception point. This barrier would alter this spherical energy dispersion behind the acoustic barrier.

We will consider the initial height of the acoustic barrier to be 1m. Thus for a 1000Hz frequency we will use the abacus in **Fig. 5**a and the sound level attenuation is about 6dB. Consequently, the noise level after the installation of the acoustic barrier is about 54dB (**Fig. 8**b). The attenuation on the façade of the apartment building is variable (lower acoustic pressure levels for lower floors of the apartment building façade), but for our reception point the noise protection condition is not fulfilled. For the case of the 2m height acoustic barrier

* Corresponding author: viordach@yahoo.com

(attenuation abacus in **Fig. 5**b) the attenuation is 15 dB, and thus the acoustic prresure level is 44.5dB (**Fig. 8**c) and the maximum limit condition is fulfilled.

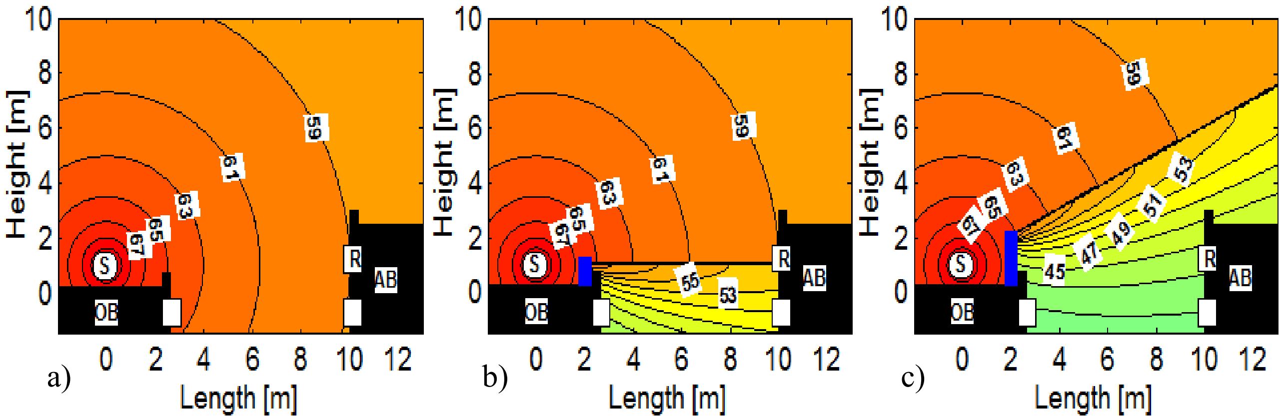

Fig. 8. Noise level comparison at 1000 Hz betwen three situations: a) no acoustic barrier, b) acoustic barrier height 1m, c) acoustic barrier height 2m

5. Conclusions

The Maekawa method of calculating the noise attenuation characteristic of an acoustic barrier has been applied to several receptor positions in the shaded area. The results were used to create simplified abacuses for the sizing of the acoustic barrier height. The abacuses were built for five types of barrier heights from 1m to 5 m and for different frequencies from 125 to 4000 Hz.

The study case proves that these abacuses essentially contribute to simplifying the height sizing calculation of an acoustic barrier while maintaining the same precision as the classical method.

Moreover, this study also represents a validation of this approach in order to achieve other simplifying methods for other geometries and special cases where the classical method can also become difficult to apply.

Acknowledgement

This study is supported by Romanian Authority for Scientific Research and Innovation, CNCS/CCCDI - UEFISCDI, through research project PN-III-P2-2.1-PED-2016-1951.

References

[1] SR 10009:2017 - Acustică. Limite admisibile ale nivelului de zgomot din mediul ambiant.

[2] Z. Maekawa, "A simple estimation method for noise reduction by various shaped barriers," *Revista de Acustica,* vol. XXI, pp. 32-37, 1990.

[3] K. W. W. H. Kasess CH, "Deriving correction functions to model the efficiency of noise barriers with complex shapes using boundary element simulations.," *Applied Acoustics,* vol. 102, pp. 88-99, 2016.

[4] U. J. Kurze and G. S. Anderson, "Sound attenuation by barriers," *Applied Acoustics,* vol. 4, no. 1, pp. 35-53, 1971.

[5] Y. M. Lam, "Using Maekawa's chart to calculate finite length barrier insertion loss," *Applied Acoustics,* vol. 42, no. 1, pp. 29-40, 1994.

[6] Z. Maekawa, "Noise reduction by screens," *Applied Acoustics,* vol. 1, no. 3, pp. 157-173, 1968.

[7] "Normativ C125:2012 - Normativ privind acustica în constructii şi zone urbane".

[8] R. Peng and L. Tang, "Narrowing effect of focused polychromatic laser with small Fresnel number," *Optics Communications,* pp. 2707-2710, 2011.

[9] "SR 6161-1:2008 Acustica în construcţii. Partea 1: Măsurarea nivelului de zgomot în construcţii civile. Metode de măsurare".

* Corresponding author: viordach@yahoo.com