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## Calculations of low height noise barriers efficiency by using Boundary Element Method and optimisation algorithms

Marine Baulac<sup>a</sup>, Arnaud Guillou<sup>b,a</sup>, Jérôme Defrance<sup>a</sup> and Philippe Jean<sup>a</sup>

<sup>a</sup>CSTB, 24 rue Joseph Fourier, 38400 Saint-Martin-d'Hères, France

<sup>b</sup>Institut National de Métrologie (LNE-INM/Cnam), 61 rue du Landy, 93210 La Plaine Saint Denis, France  
marine.baulac@cstb.fr

Nowadays, roads and railways are often quoted as the most annoying source of noise for the living environment. This problem of ground transportation noise is present in extra-urban environments as well as in town centres. Traditional noise barriers are in many cases not suited for acoustic protection in urban areas mainly because of their height.

Previous studies have shown a significant efficiency of low height noise protections (kind of urban furniture) for the decreasing of noise levels in semi-opened areas like city parks, places, large avenues. However, the simulations of low height noise protections requires specific numerical codes since ray tracing methods are not suited for barriers lower than around 2m.

This paper proposes a way to implement an approach with allow to simulate low height noise protections in engineering calculation methods. This can be done by creating a database using a Boundary Element Method numerical code combined with optimisation algorithms. Work is still in progress since only 2D configurations are considered at the moment.

## 1 Introduction on low height noise protections

Noise is one of the first bother in people's mind. Cities try to have more and quieter areas in order to offer a better way of life for their residents but it is most of time hard to protect pedestrians (pavements, gardens...) without too imposing protections which would not be aesthetic and without too expensive protections. Here, low height absorbers are proposed to reduce the impact of road traffic noise on pedestrians. This kind of protection improves the environmental quality of life in urban areas. The global idea for low height noise protections is represented on Fig.1.

Previous studies [1, 2] have shown that low height protections (one meter high) can lead to a significant efficiency for pedestrian behind the protection. Those protections are not often used since their efficiency needs a specific numerical code to be calculated; engineering methods cannot lead to accurate values for the efficiency of such protections. Here it is proposed to find approximated functions to evaluate the efficiency of those noise devices.

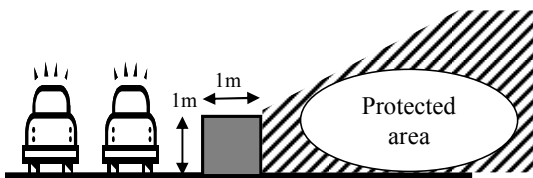


Fig.1 Geometrical configuration for 2D-BEM calculations.

## 2 Numerical simulations

The approximated functions would be found by minimising the difference with some reference results. Those results which are considered as the reference are calculated using a numerical code based on the boundary element method.

### 2.1 Boundary Element Method

The Boundary Element Method (BEM) which relies on the Integral Equation theory has been developed in the 60s and has been since extensively used [3]. Two families of boundary element methods can be distinguished: direct and indirect formulations. The direct formulation relies on the use of the Helmholtz integral equation where the unknown

functions are pressure and velocity, while the indirect one is based on an integral formulation assuming that the sound field scattered by a boundary can be represented by a linear combination of a distribution of monopoles (a simple-layer potential) and a distribution of dipoles (a double-layer potential). References [3, 4, 5, 6, 7] [3] are suggested for more details on the method.

In this work, the numerical simulations of outdoor sound propagation have been carried out with MICADO. It is a 2D, 2D½ and 3D BEM numerical code based on the direct formulation. It has been developed with a variational approach by Jean [5] at CSTB. In the 2D version used here, the geometry of the problem is bi-dimensional: the source is an infinite linear coherent source and all the obstacles remain unchanged and infinite along a direction perpendicular to the vertical section plane (as shown in Fig.2). The BEM is a powerful tool in acoustical predictions for complex topologies and geometries in a homogeneous atmosphere. In this work, the meteorological effects can be neglected since the distances considered are shorter than around one hundred meters. However, this method can be very time consuming, for optimization purpose, depending on some parameters among which the frequency and on the length of boundaries to mesh. A compromise has to be found between accurate results and reasonable calculation times.

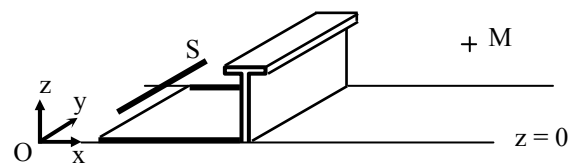


Fig.2 Geometrical configuration for 2D-BEM calculations.

### 2.2 Efficiency

In this paper, it is the Insertion Loss  $IL$  which is calculated. The insertion loss  $IL_{\Delta f}$  for each third octave band  $\Delta f$  writes:

$$IL_{\Delta f} = 10 \log_{10} \left( \frac{|p_{low\ absorbers}(\Delta f)|^2}{|p_{reference}(\Delta f)|^2} \right) \quad (1)$$

where  $p_{low\ absorbers}(\Delta f)$  is the acoustic pressure for the configuration with the low height protection in the third octave band  $\Delta f$  and  $p_{reference}(\Delta f)$  is the acoustic

pressure for the reference configuration without the low height protection in the third octave band  $\Delta f$ .

The global insertion loss  $IL_A$  in dB(A) is determined by the following equation:

$$IL_A = 10 \log_{10} \left( \frac{\sum_{\Delta f} 10^{\frac{LwA_{\Delta f} + EA_{low\ absorbers, \Delta f}}{10}}}{\sum_{\Delta f} 10^{\frac{LwA_{\Delta f} + EA_{reference, \Delta f}}{10}}} \right) \quad (2)$$

where  $EA_{low\ absorbers, \Delta f}$  is the excess attenuation (referred to free field free of ground) calculated in the configuration with the low absorbers and for the third octave band  $\Delta f$ , and  $EA_{reference, \Delta f}$  is the excess attenuation calculated for the reference configuration without the low absorbers and for the third octave band  $\Delta f$ .  $LwA_{\Delta f}$  is the road traffic noise sound power level in third octave bands ( $\Delta f$ ) given in Fig.3 and calculated from the standard EN1793-3:1997 [9]. It is important to notice that the choice of the road traffic noise spectrum has a significant influence on the results.

When the insertion loss is negative, the insertion of a protection in the geometrical configuration improves the acoustical situation, the noise level is reduced. The objective is to obtain an insertion loss as low as possible.

In numerical simulations, the surface impedance of the absorbent material is determined by the Delany and Bazley's semi-empirical model [8]. The parameter of this model is the effective flow resistivity  $\sigma$  expressed in  $\text{kPa s m}^{-2}$ . Absorbent materials in numerical simulations are always considered to be 0.1 m thick and to have a rigid-backing. As a consequence, the value of the effective flow resistivity for the relation between materials used in the scale model experiments and values taken in numerical simulations for comparisons will be sought considering a thickness  $h = 0.1 \text{ m}$  for numerical simulations.

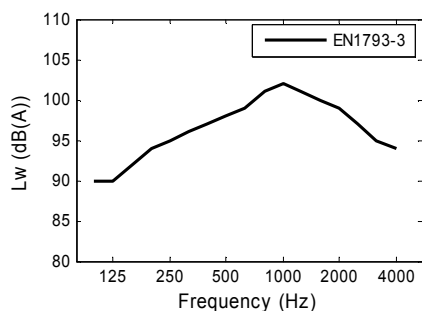


Fig.3 Road traffic noise spectrum calculated according to EN1793-3:1997 standard.

### 3 Approximation with analytical functions and optimization

The aim is to find an approximate function to have the efficiency of a low height protection depending on the

distance between the protection and the receiver and for a given height (from 1 to 6 meter high). This could be done in each third octave band but it is chosen here to consider global values of efficiency in dB(A). The source is located at 0.5 m above the ground (rolling noise and engine noise combined).

#### 3.1 Analytical functions

The analytical approximate function has been created regarding the shape of the graphs giving the efficiency of the protections depending on the distance between the protection and the receiver. It writes:

$$F_{app} = a[h, s]e^{(b[h, s]x)} + c[h, s]x.e^{(d[h, s]x)} + e[h, s]x + f[h, s] \quad (3)$$

where  $x$  is the distance between the protection and the receiver and  $a$ ,  $b$ ,  $c$ ,  $d$ ,  $e$  and  $f$  are constant coefficients depending on the height  $h$  and on the source location  $s$  and to be calculated by optimisation. For each height from 1 to 6 meter high, values of coefficients  $a$ ,  $b$ ,  $c$ ,  $d$ ,  $e$  and  $f$  are calculated by minimising the cost function given in the next section.

#### 3.2 Optimisation algorithm

The aim of this work is the optimization of several parameters simultaneously therefore the optimization algorithm has to be performing in such conditions. In addition, it is necessary to avoid any local search and to ensure a global optimization. Those constraints induced the choice of an evolutionary algorithm to perform the optimization in this work.

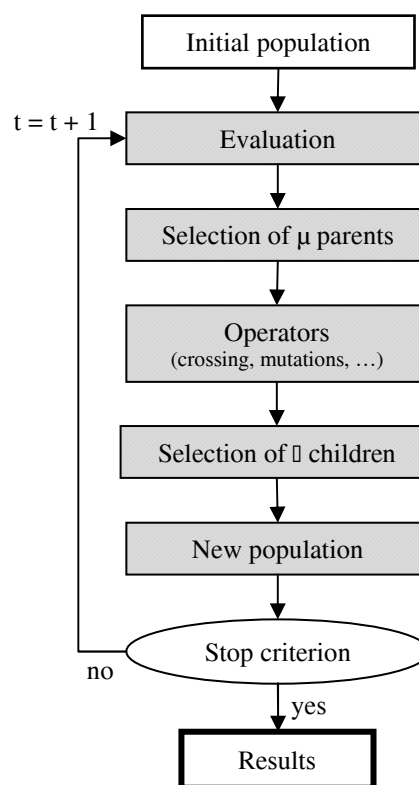


Fig.4 Principle of an evolutionary algorithm.

The basic idea for evolutionary algorithms is to imitate the natural process of biological evolution (Darwinism). In this work, it has been chosen to use an genetic algorithm [10, 11] (which is one of the four kinds of evolutionary algorithms). The successive steps for such an algorithm are presented in Fig.4. The main characteristics of evolutionary algorithms are:

- A memorization of results with the population of elements
- An operator insuring evolution of the population (crossovers)
- A randomized creation of elements which allows the algorithm to explore new region of the study domain (mutations)
- A stop criterion for the algorithm

The cost function to minimize is given by:

$$Cost\_func = \sum_{x=0m}^{x=50m} |F_{app}(x) - IL_A(h, x)| \quad (4)$$

where  $x$  is the distance between the protection and the receiver,  $F_{app}$  is the approximated function and  $IL_A$  is the reference insertion loss calculated with the MICADO code for the right height  $h$  considered.

The smaller is the value of  $Cost\_func$  the best is the approximation.

## 4 Results

Many calculations have been carried out for several shapes of the protections and for several source locations. The results have shown that for the global efficiency, the influence of the shape of the protection is negligible (but in octave band, this hypothesis becomes wrong, differences are significant especially for low frequencies). For the sources, it has been shown that for a configuration with two sources, it was possible to consider an equivalent configuration with a single source.

### 4.1 Configuration

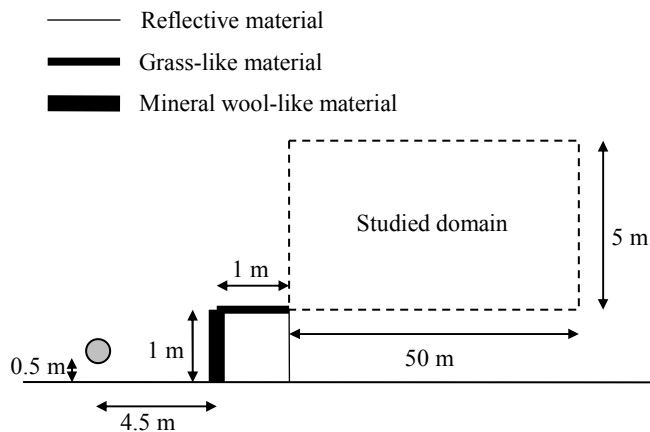


Fig.5 Principle of an evolutionary algorithm.

For the results presented here, the calculations have been carried out for a simple shape: a cube 1\*1 m with mineral-

wool-like materials on the face regarding the sources, grass-like material on the top surface and rigid material on the third face (see Fig.5). There is only one source for those calculations in order to have a quite simple configuration; it is located 0.5 m above the ground and 4.5 m away before the protection.

### 4.2 Comparison between approximation and reference results

In this section results from the reference numerical code MICADO and results coming from the analytical function which coefficient have been determined by minimizing the difference with the reference are compared. In Fig.6 the insertion loss in dB(A) is represented depending on the distance between the protection and the receiver. This is done for three heights: 2, 3 and 4 m. In thin solid lines it is the reference results from MICADO and in thick dashed lines it is the approximated function.

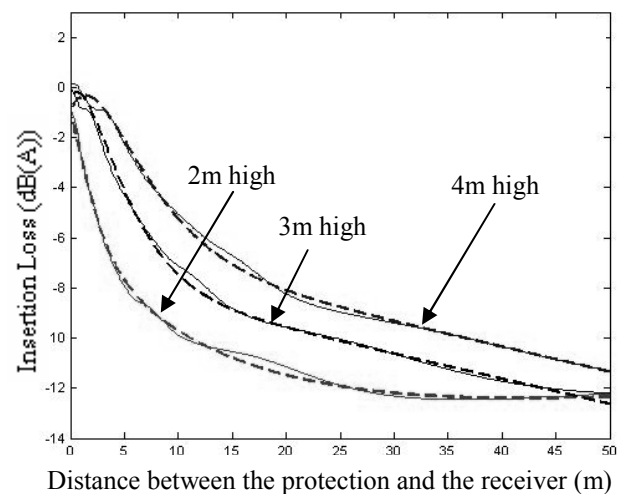


Fig.6 Insertion loss in dB(A), calculated with MICADO (thin solid lines) and with the approximated function (thick dashed lines), depending on the distance between the protection and the receiver.

Differences between the references values of efficiency and the approximated values are smaller than 1 dB(A) and for a distance higher than 2 m they are smaller than 0.5 dB(A).

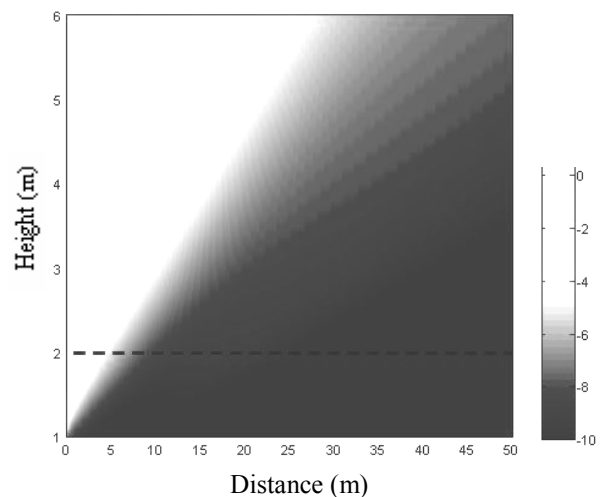


Fig.7 Noise map of the Insertion Loss in dB(A) calculated with MICADO.

Figs.7 and 8 are noise maps of the insertion loss in dB(A). Fig.7 has been calculated with the reference numerical code MICADO. Fig.8 has been calculated with the analytical function which coefficients have been determined after minimizing the difference with the reference. The dotted line represent the average pedestrian's ear position: 2 m high. This helps to see that the efficiency is significant in this area with such protections.

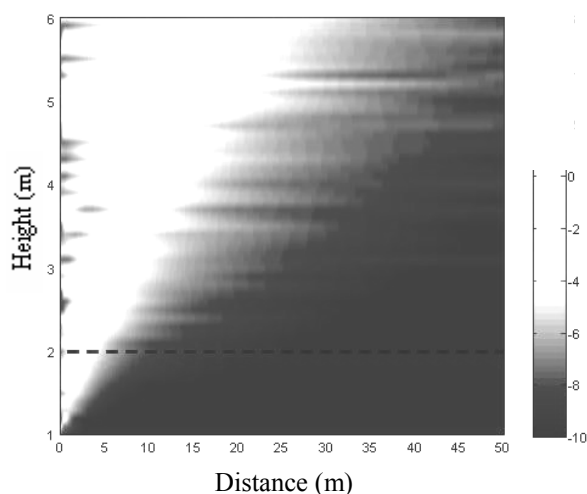


Fig.8 Noise map of the Insertion Loss in dB(A) calculated with the approximated function.

The comparison between Figs.7 and 8 shows that the approximated method leads to good results. There are differences between the two noise maps but on the whole the results are really comparable.

## 5 Conclusion

This work has shown the feasibility of evaluating the efficiency of low height protections with an analytical function determined by optimization and comparison with the reference results. This is an encouraging point since this analytical function could be implemented in engineering methods in order to have such protections taken into account.

Work is still in progress since at the moment the analytical function is only determined for a given height for the receiver. Further work could lead to a determination of the coefficient depending on the height and then to have a more global analytical function.

Finally, there are two limits of the present work that could be surpassed. Firstly only the global efficiency in dB(A) has been considered, the same kind of work could be done in each octave band or third octave band. Secondly only 2D configurations have been considered whereas engineering methods consider 3D configuration. Further work has to be done to have the 3D efficiency with an analytical function and then to implement it in engineering methods.

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