ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

OPTIMIZATION OF PERFORMANCE OF T-SHAPED BARRIERS WITH REACTIVE TOP SURFACES

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Abstract

In this study, the aim is to optimize the acoustical efficiency of T-shaped noise barriers the top of which is covered with a series of wells. This research work uses a multi-criteria optimisation method in order to find the best noise barrier profile. Numerical simulations of the acoustical propagation are achieved by use of a 2D Boundary Element Method (BEM) code. The optimization part is carried out with a global and direct evolutionary optimization method: a genetic algorithm. The parameters to optimize are the shape of the protection (the depths of the wells on the crowning). The cost function to maximize is defined through a mean value of the acoustical efficiency of the protection compared to a reference configuration, averaged on several receiver points. Final results show significant optimized values of parameters for efficient protections in order to improve classical noise barriers. Work is still in progress in order to optimize wells' depths on other shapes of barrier tops.

INTRODUCTION

Transportation noise is one of the main bother in people's mind. That is why noise barriers are so much studied. Simplest ones are straight and rigid; however they have sometimes an additional shape above it. Crownings added at the top of noise barriers allow to improve the barrier performance without increasing its overall height. Many different shapes of crownings have been proposed and studied by acousticians to increase the acoustical efficiency of barriers. Complete reviews on noise barriers and crownings can be found in Watts [15] and Ekici [5].

The performance of non-straight top edge for noise barriers has already been studied. But here, a systematic research is proposed. The purpose is to use an optimization method to directly determine the optimal depths of some wells on the top edge of the barrier; and thus to obtain a noise barrier with a maximum efficiency. The function to be optimized (called the cost function or the fitness function) is the average efficiency of the barrier compared with a reference configuration in a specified zone to be protected. The optimization variables are the well depths on the top surface. The reference configuration is the capped barrier without any well. This study is limited to T-shaped barriers but there are many other applications. The objective of this paper is to show that this kind of optimisation allows a noticeable improvement of the performance of the acoustic protection.

ACOUSTIC SIMULATIONS: BOUNDARY ELEMENT METHOD

The numerical simulations of outdoor sound propagation have been carried out with MICADO. It is a Boundary Element Method (BEM) numerical code based on the direct formulation working either in 2D, 2.5D or 3D. It has been developed with a variational approach by Jean [11] at CSTB. The 2D version is here employed. 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. The BEM is a powerful tool in acoustical predictions for complex topologies and geometries in a homogeneous atmosphere. The meteorological effects can be neglected since the distances considered here are smaller 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.

THE OPTIMIZATION METHOD: EVOLUTIONARY ALGORITHMS

It is necessary to use a direct optimization method since the function to optimize (called cost function or fitness and defined in a next section) is not derivative. 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 three constraints (not easily derivative, simultaneous optimization of several parameters and global search) induced the choice of an evolutionary algorithm to perform the optimization in this work.

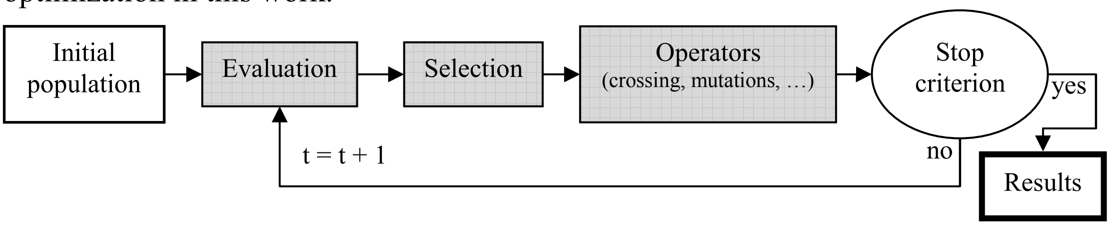


Figure 1 – Principle of an evolutionary algorithm

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 [7, 9] (which is one of the four kinds of evolutionary algorithms). The successive steps for such an algorithm are presented in Figure 1. 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

PROBLEM AND GEOMETRY

Existing Results About T-Shaped And Reactive Barriers

This work focuses on T-shaped barriers (one of the simplest crowning) which have been studied for example by Hothersall in [10] and by Defrance in [2]. Roughly, gains of the order of 2-3 dB(A) for this kind of crowning can be obtained depending on the barrier height, the cap width, the surface impedance and the source receiver configuration. Some non-straight top edge profiles are considered in order to increase the efficiency: noise barriers with quadratic residue diffusers [13], random edge barriers [8, 12, 14], and reactive barriers [6]. Here the aim is to improve the efficiency of a T-shaped barrier without increasing its height or its width. A T-shaped barrier is already more efficient than a straight one. Here, the optimization allows another improvement of 2-3 dB(A).

Sources

The objective of this paper is to demonstrate the possibility of using optimization methods in the aim of improving noise barriers performance. Therefore, the simplest source configuration has been chosen: one single source. The source considered in this paper represents the rolling noise; it is located on the ground 8 m away from the base of the barrier (see Figure 2). Since the acoustical simulations are carried out with a 2D BEM numerical code, the source is represented by an infinite coherent source line.

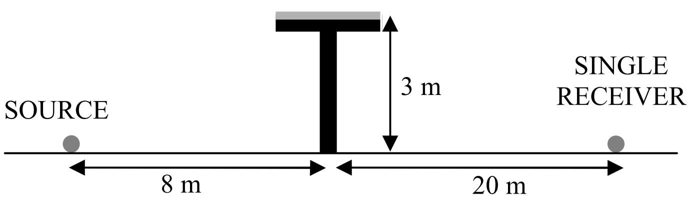


Figure 2 – Single receiver configuration

The ground is chosen perfectly reflective in order to reduce calculation times but a ground with a specific surface impedance could have been considered and even optimized.

Geometry Of The Noise Barrier

The noise barriers studied in this work are T-shaped barriers with wells at their tops (as shown in Figure 3). The number of wells and their depths can vary. Moreover, there are two kinds of materials covering the noise protection: one is perfectly reflective from an acoustical point of view; the other is absorbent. The impedance model used to describe absorbent materials is the two-parameter semi empirical Delany and Bazley model [3]. Those two parameters are the thickness h of the absorbent material expressed in meters and the flow resistivity σ expressed in kPa s m^{-2}.

The reference configuration used for all calculations is a 3 m high (overall height) and 1.5 m wide T-shaped barrier. The top surface of the crowning is covered with a 0.1 m thick layer of a mineral wool like material. The crowning thickness is 0.3 m including the absorbent material. This reference configuration is detailed in Figure 3.

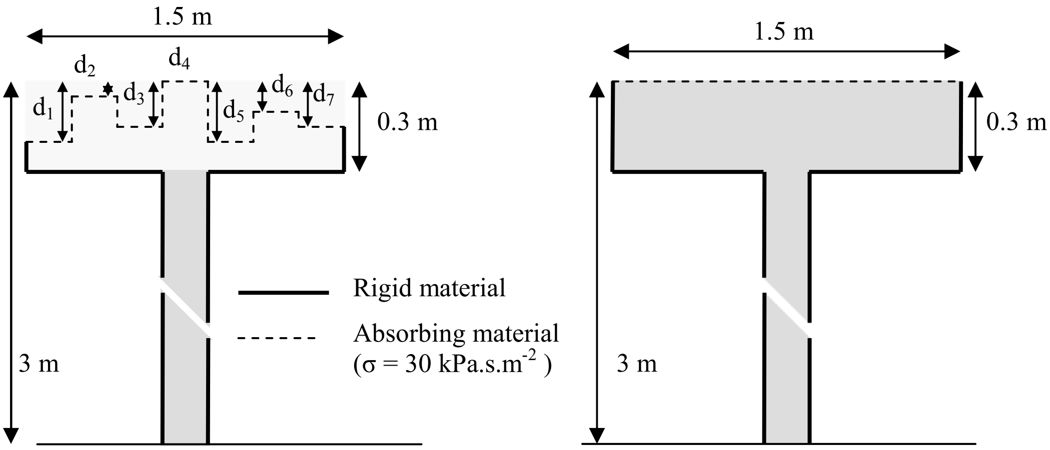


Figure 3 – Configuration of the barrier to optimize (left graph) and reference T-shaped barrier (right graph)

The configuration of the barrier to optimize and the varying parameters are given in Figure 3. The varying parameters are the depths of the wells represented on the graph by $d_1 \ldots d_7$. In the following parts, the vector of the depths is named $Depths$ and $Depths = (d_1,...,d_n)$ where n is the number of wells ($n = 7$ in Figure 3). Because of the geometry of the barriers considered in this work, the depths d_i are restricted to the interval [0.0 m; 0.25 m] and are determined with a precision of 0.01 m. The impedance of the absorbent material considered is defined by the Delany and Bazley model by $\sigma = 30\ kPa.s.m^{-2}$ and $h = 0.1\ m$ which corresponds to mineral wool like material. The flow resistivity is specified in this work but it could have been another parameter to optimize.

Cost Function And Receivers

The cost function is the name for the function which has to be maximized or minimized in the optimization problem, here the genetic algorithm search the global maximum of the cost function. In our case, the objective is to have an efficiency of the crowning as high as possible for a given source-receiver configuration. The cost function is the result of BEM calculations of the efficiency of the crowning. This global efficiency Eff_{global} is given with a precision of 0.1 dB and writes:

$$Eff_{global}(n, d_i, \sigma, h) = 10\log_{10}\left(\frac{\sum_{\Delta f} 10^{\frac{LwA(\Delta f) + EA_{\Delta f,\ T-shaped}}{10}}}{\sum_{\Delta f} 10^{\frac{LwA(\Delta f) + EA_{\Delta f,\ wells}(n, d_i, \sigma, h)}{10}}} \right) \tag{1}$$

where $EA_{\Delta f,\ wells}$ is the excess attenuation for the T-shaped barrier with varying well depths (referred to free field) in the third octave band Δf and $EA_{\Delta f,\ T-shaped}$ is the excess attenuation for the reference T-shaped barrier (with a straight top surface) of the same overall height (3 m) in the third octave band Δf. $LwA(\Delta f)$ is the road traffic noise spectrum in third octave bands (Δf) calculated with the EN 1793-3:1997 regulation [1]. The choice of the spectrum has a great influence on the global efficiency in dB(A).

It is quite obvious that this cost function is not derivative. This is why it has been chosen to use a direct optimization method presented in section 2. This cost function is highly dependent on the position and the number of sources and receivers.

The configuration has a single receiver point as shown in Figure 2. The receiver is located on the reflective ground in order to avoid any reflection on it, and is 20 m away from the base of the barrier.

Usually road traffic noise studies simulate the outdoor sound propagation up to 5000 Hz. However, the higher the frequency, the longer BEM calculations, and optimizations methods commonly require a high number of evaluations of the cost function. A compromise is to consider the frequency range 100-2500 Hz which is acceptable because those are the frequencies where the road traffic noise is the most important. Moreover, the objective of this work is more to show the method than to study exact cases.

RESULTS AND DISCUSSION

In this last section, results of optimization (in third octave bands and in the whole frequency range considered) are given for several cases. Then, a map of the efficiency of one of the optimal barrier is given.

Optimization In Each Third Octave Band Between 100 And 630 Hz

Because of time consuming calculations, optimization in separated third octave bands has been carried out only from 100 to 630 Hz bands. The results are recapped in Table 1. The first column gives the third octave band considered, the next ones give results for $n = 3$ and $n = 5$, n being the number of wells on the top edge. In each case the optimal value of the efficiency in dB is also given.

Table 1 – Results for optimization in each third octave band from 100 to 630 Hz

	$n = 3$		$n = 5$	
Δf (Hz)	$Depths_{opt}$ (m)	Eff_{opt} (dB)	$Depths_{opt}$ (m)	Eff_{opt} (dB)
100	0.25 0.25 0.25	0.7	0.25 0.25 0.25 0.25 0.25	0.7
125	0.25 0.25 0.25	1.1	0.25 0.25 0.25 0.25 0.25	1.1
160	0.25 0.25 0.25	1.4	0.0 0.25 0.0 0.25 0.0	2.6
200	0.0 0.25 0.0	1.6	0.0 0.25 0.0 0.25 0.0	3.9
250	0.0 0.25 0.0	1.8	0.0 0.25 0.0 0.24 0.0	3.3
315	0.25 0.0 0.25	2.0	0.09 0.25 0.0 0.25 0.07	3.1
400	0.25 0.02 0.25	2.6	0.25 0.00 0.25 0.23 0.0	3.8
500	0.0 0.18 0.0	1.7	0.1 0.21 0.0 0.15 0.0	2.6
630	0.25 0.13 0.0	2.2	0.25 0.1 0.22 0.14 0.0	3.1

Firstly, the results show that the optimal depths are highly dependent on the frequency. Secondly, for third octave band frequencies higher than 125 Hz, the larger the number of wells, the better the efficiency; as confirmed in the next section.

Global Optimization

Table 2 – Results for global optimization in the frequency range 100-2500 Hz

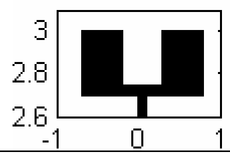
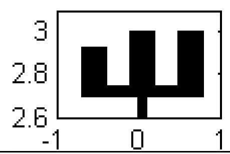
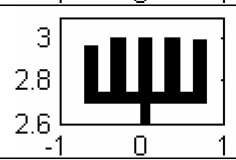
	$Depths_{opt}$ (m)	Optimal shape	Eff_{opt} (dB(A))
$n = 3$	0.0 0.25 0.0		**1.2**
$n = 5$	0.07 0.25 0.0 0.25 0.0		**2.0**
$n = 9$	0.04 0.25 0.0 0.25 0.0 0.25 0.0 0.25 0.01		**2.7**

Table 2 gives the results for the global optimization where the efficiency is calculated in the frequency range 100-2500 Hz. The optimal shapes are represented in the third column and the optimal efficiencies are given in the last one.

The optimal efficiency increases with the number of wells on the top edge. It reaches up to 2.7 dB(A) when 9 wells are considered on the top surface. It appears that the best shape is an alternation between deep wells and shallow ones.

Other calculations confirmed the fact the larger the number of wells on the top surface, the higher the efficiency. However, the optimization for 9 wells needs already several days of calculations (on a Pentium 4 - 2.66 GHz); as a consequence, optimization with a higher value of number of wells is not achievable (the higher the number of wells, the longer the surface to mesh, the higher the calculation time).

Efficiency maps

In this last paragraph, the efficiency of the optimal T-shaped barrier with 9 wells on the top compared with the reference T-shaped is presented in Figure 4. The map is 110 m wide and 30 m high. The barrier is located at 0 on the x-axis and the source is located on the ground at -8 m on the x-axis. The lighter the area, the higher the efficiency (the color bar on the right of the map gives details for grey levels and values of efficiency)

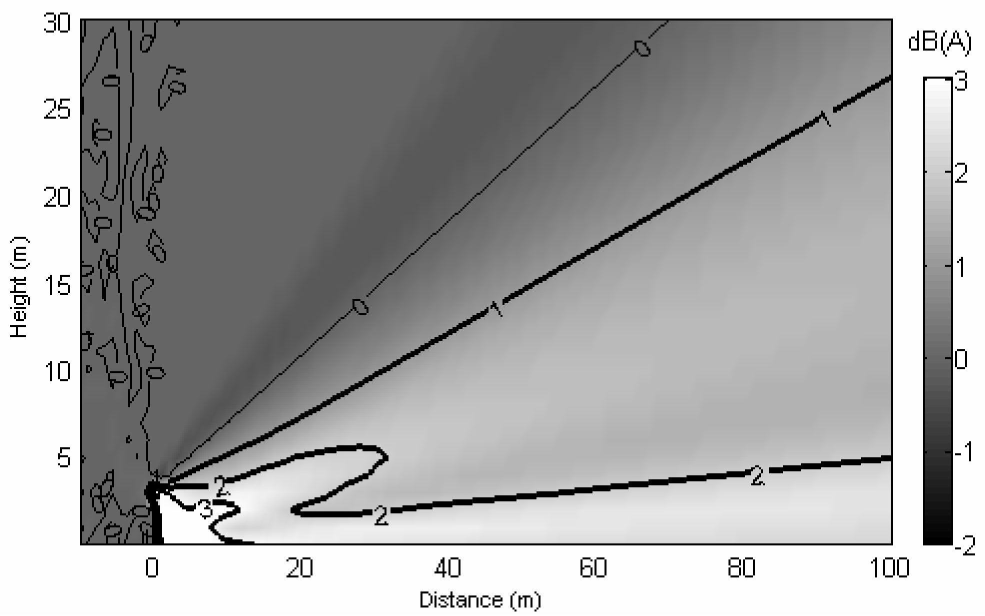


Figure 4 – Map of efficiency in the optimal case with n = 9

There is a zone of very slight degradation (darkest part) but the loss of efficiency is smaller than 1 dB(A) and the area of degradation is very restricted. On the whole, one can see an improvement of the efficiency in the shadow zone. The increase is up to 3 dB(A) but is around 1 to 2 dB(A) in the major part. The improvement is significant in the whole area beside the barrier.

CONCLUSIONS

An evolutionary optimization method coupled with a BEM 2D code has been presented with application to non-straight top edge above T-shaped barriers. The results show that the efficiency of such barriers is highly frequency dependent; and the global efficiency of such barriers increases with the number of wells considered on the top surface. The global efficiency compared with a straight top surface T-shaped barrier reaches up to 2-3 dB(A) for 5 to 9 wells (for a given source-receiver configuration).

Only 2D calculations have been performed because of prohibitive calculation time for 3D calculations. A compromise could have been the use of BEM 2D1/2 method proposed by Duhamel [4] but optimization algorithms induces many acoustical simulations therefore it would have been too time consuming over again.

Work is still in progress in order to apply this approach on other cap shapes; and scale measurements are also planed in order to have 3D results.

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