A METHODOLOGY FOR OPTIMUM DESIGN OF Y-SHAPE NOISE BARRIERS

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ABSTRACT

A method for designing optimum shape Y-noise barriers is performed using a 2D-boundary element method modelling and evolutionary computation. The model assumes an infinite, coherent line source of sound, parallel to an infinite noise barrier of uniform cross section and surface covering along its length, where a maximum limit to the effective height of the barrier designs is imposed. The study is carried out in frequency domain. The proposed fitness function to minimize is the sum of squared differences corresponding to the insertion loss (IL) throughout a set of frequencies belonging to the one-third octave band spectra (fourteen values are taken into account) of two barriers: the candidate Y-barrier design and a reference noise barrier design (a simple barrier with higher effective height than the maximum constrained value of the design). Shape optimization is accomplished by forcing the design to fit a IL reference curve corresponding to a higher effective height simple barrier and to obtain a Y-shape design whose IL curve performance fits this reference. The obtained results succeed in accomplishing the imposed requirements. Results are detailed in terms of IL values and barrier shape designs, numerically and graphically.

INTRODUCTION

Shape optimization has been performed in recent years applied to various fields of engineering, such as aeronautics [4][11] or solid mechanics [1] using evolutionary optimization. Here we propose to apply shape optimization to the design of Y-shape noise barriers using the boundary element method (BEM) for modelling of sound propagation and a steady-state genetic algorithm for optimization.

The BEM has been applied to sound propagation successfully. Concretely, to estimate the efficiency of noise barriers with complex shapes, the BEM has been used from the 80s, see e.g. (Seznec, 1980)[13], (Hothersall, 1991)[6] and (Crombie & Hothersall, 1994)[2]. In recent years, design of noise barriers has been taken into account using BEM: In (Peplow, 2005)[12] a BEM is used to model a cutting over a road-side noise barrier, and the effects of depth of the cutting and the profile of the associated noise barrier considering a traffic noise spectrum are studied. In (Monazzam and Lam, 2005) [10] different noise barrier shapes are modelled and analysed using a 2D BEM, whose insertion loss is evaluated. They include T-, Arrow-, Cylindrical and Y-shape profiles, and the inclusion of quadratic residue diffuser (QRD) is considered for traffic noise. Ishizuka and Fujiwara, 2004 [7] studied the performance of including absorbing and soft edges in different noise barriers shapes using BEM considering six different receiver positions, concluding their high impact in the barrier efficiency. Defrance and Jean, 2003 [3] used 2D and 2D1/2 BEM simulations to study the efficiency of T-shaped absorbing cap with road traffic noise conditions. Suh et al, 2002 [14] use a commercial BEM code to analyse traffic noise barriers, using it as accuracy tester of diffraction-based models and as basis of a new barrier performance metric. They propose to substitute the insertion loss by the propagating sound power calculated on a recovery plane in the barrier shadow. Watts, 2002 [15] analyses barrier designs to reduce road traffic noise, comparing BEM numerical results and full scale tested measure values, both resulting in agreement magnitudes and therefore in BEM model validation through a wide variety of barrier shapes. Martin and Hothersall, 2002 [9] model outdoor sound propagation from road traffic using BEM and considering both coherent and incoherent line sources of sound in different road and barrier types. The BEM model considered and implemented in this paper is fully detailed in Maeso and Aznarez, 2005 [8]. The structure of the paper is as follows: The optimum design methodology is presented in the next section, followed by the results and ending with the conclusions and references.

METHODOLOGY: GENETIC ALGORITHMS AND BOUNDARY ELEMENTS

The proposed methodology is based on coupling genetic algorithms and boundary elements, and it is schematically represented in Fig.1. The genetic algorithm generates a population of solution candidates operating in a transformed domain which are evaluated by a BEM software in a standard cartesian domain in order to evaluate their fitness function (FF) or cost function. This cycle continues performing crossover, mutation and selection based in the FF value until the population converges or the optimum is reached.

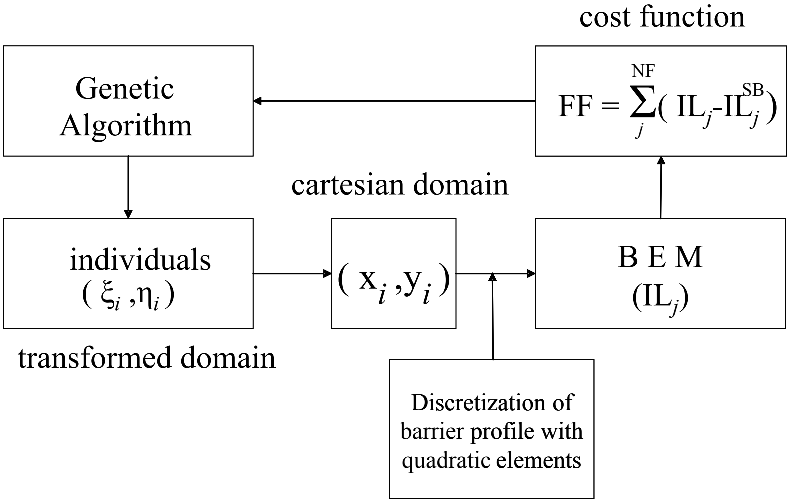

Figure 1. Optimization procedure by coupling GA and BEM.

The cost function which has to be minimized is:

$$FF = \sum_{i}^{NFreq} \left(IL_i - IL_i^{SB} \right)^2 \qquad \text{(Eq. 1)}$$

where:

IL_i : insertion loss in the third octave band centre frequency for the barrier profile evaluated

IL_i^{SB} : insertion loss in the third octave band centre frequency for a straight barrier of height h^{SB}

This general methodology was previously described in [5]. It solves an inverse problem, where the IL curve at certain frequencies is known (IL-reference, here it is IL-SB) and it allows to obtain its corresponding barrier design. In [5] was shown the capability to increase a certain percentage the acoustic efficiency of a certain Y-shape barrier taken as original design and obtaining the shape designs corresponding to 15 and 30% improved IL values corresponding to five different frequencies. Here the approach is different, as we consider as IL-curve of reference, the values of a straight barrier of given effective height, which is higher than the maximum effective height of the searched Y-shape barrier. The proposed procedure allows determining the barrier profile with a closer IL spectrum.

The configuration studied in this paper is shown in Fig 2. It is a bi-dimensional problem which assumes an infinite, coherent mono-frequency source of sound, situated parallel to an infinite noise barrier of uniform cross section situated on a flat plane (ground). This ground and all the surfaces of the barrier are perfectly reflecting. In the present research all the evaluated barrier profiles have the maximum effective height constrained to the value of h = 3 m. They were formed with three arms, different slope and a fixed thickness of t = 0.1 m. The barrier projection to the ground is constant in all cases (b = 1 m). In this general configuration, common T-, Y- and arrow-profile barriers are included. The source configuration is one single source placed in the ground surface (d = 10m). The analyzed barrier profile is determined from 3 points defined in transformed domain (Figure 3), where the coordinates ξ_1 and ξ_3 were established 'a priori' (-0.5 and 0.5, respectively).

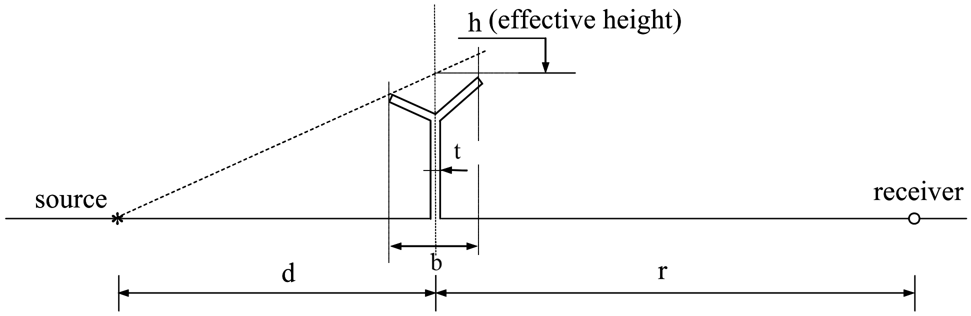

Figure 2. Two-dimensional configuration studied. Generic geometry of Y-shaped noise barrier

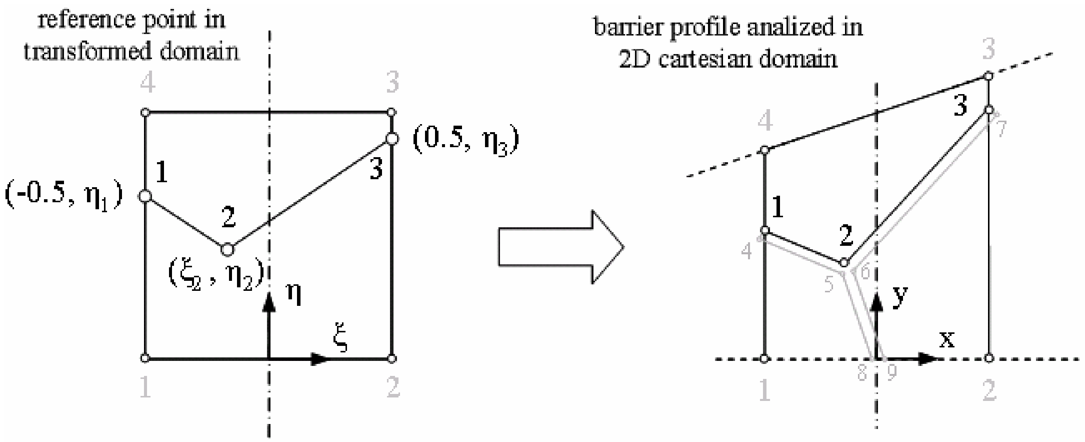

Figure 3. Process to obtain the barrier profile

The coordinates *x, y* of points 1,2 and 3 are easily obtained. The cartesian coordinates of the rest of the corners of the barrier (4,5,6,7,8,9) represented in Figure 3, can be calculated using simple geometric operations, considering that each arm thickness is perpendicular to its length. With this geometry and for a given source position, the boundary element program calculates the acoustic pressure at the receiver position. In the cost function, IL and IL^{SB} are calculated at the receiver (r = 50m in the ground surface) using a BEM code with quadratic elements. With the formulation implemented only the barrier surface is discretized with these elements, since the used fundamental solution satisfies the boundary conditions on the ground surface. A maximum element length not bigger than λ / 4 (being λ the wavelength) is necessary to obtain an appropriate solution accuracy. This approach has an interesting interpretation as we will see in the results: it is possible to obtain Y-shaped barriers of maximum effective height of 3 meters with the same efficiency than straight barriers of greater height, and therefore diminishing their visual impact.

RESULTS

Four independent runs of the evolutionary optimization design were executed in each case. Among them the best result is selected. A population size of 100 individuals and 3% mutation rate were used in a Gray coded steady-state genetic algorithm with uniform crossover and the stop criterion was set to forty thousand evaluations. The best obtained results are shown in figures 4 and 5, where both the Reference IL curve and best fitted solution are represented for the 3.5 m and 4.0 effective height straight barriers, respectively. In the x axis the third octave centre spectra frequency is represented in Hertz in logarithmic scale. In the y axis the IL is represented in dbA units. Also the IL detailed numerical results are shown in Table 2, where the fitness function best values of each case are also included. Both shapes are shown in figure 6, including the depicted effective height line in blue. The corresponding coordinates in transformed space of these configurations can also be read in Table 1. In figure 6, the values of insertion loss of the Y-shape barrier designs for a standard road traffic spectrum are also represented (ILT): -13.42 and -14.57 dbA, respectively.

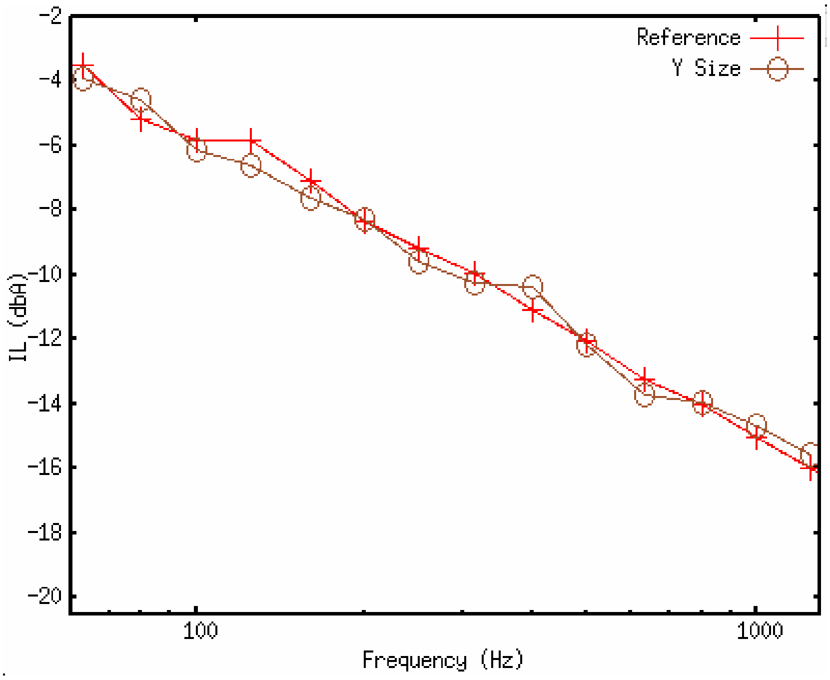

Figure 4.-Frequencies following 3.5 Effective Height IL

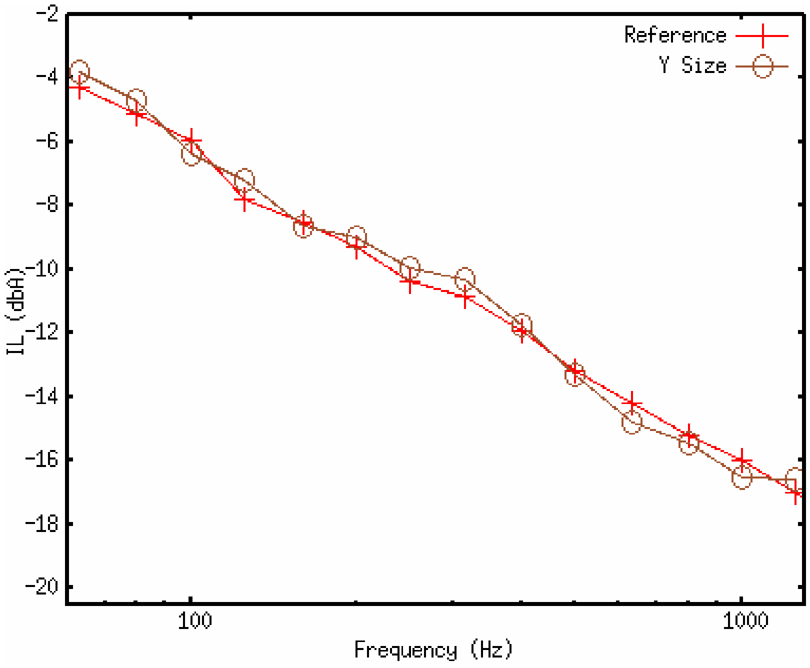

Figure 5.-Frequencies following 4.0 Effective Height IL

Table I.- Horizontal and vertical coordinates in transformed space

	ζ1	ε2	ζ2	ζ3
3.5 Y-Shape Best Solution	0.882812	0.496094	0.718750	0.996094
4.0 Y-Shape Best Solution	0.976562	0.496094	0.714844	0.996094

Table II.- Y Shape Numeric IL Results of References and Best Solutions (dbA)

Frequency (Hz)	Simple Barrier 3.5m Reference IL values	Best Y-shape Solution 3.5 IL values	Simple Barrier 4.0m Reference IL values	Best Y-shape Solution 4.0 IL values
63.0	-3.47827	-3.89252	-4.30565	-3.81325
80.0	-5.20635	-4.59891	-5.14532	-4.69032
100.0	-5.85963	-6.15130	-5.92462	-6.36817
125.0	-5.85963	-6.59997	-7.80653	-7.22457
160.0	-7.10648	-7.62218	-8.54042	-8.64346
200.0	-8.34382	-8.27600	-9.28958	-9.00032
250.0	-9.19604	-9.61944	-10.35201	-9.93707
315.0	-9.97212	10.24600	-10.85198	-10.34185
400.0	-11.09944	-10.36188	-11.93769	-11.73214
500.0	-12.04160	-12.15843	-13.16464	-13.31367
630.0	-13.25846	-13.69497	-14.17725	-14.77727
800.0	-14.03769	-13.95197	-15.18590	-15.47201
1000.0	-15.00996	-14.69737	-16.00739	-16.49941
1250.0	-16.00312	-15.57706	-17.03257	-16.59066
Fitness Function Value	---	2.2157	---	2.4553

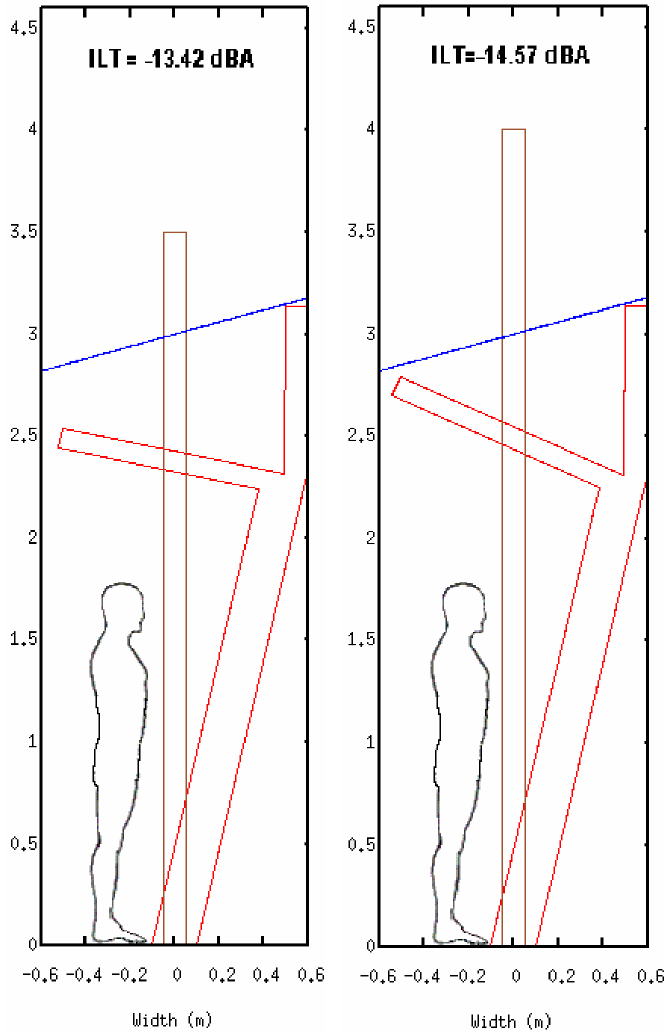

Figure 6.- Optimized Y-shape and reference simple barriers with proportional-size human figure

Results show the capability of the methodology presented to fit a certain IL curve. In table II the fitness function values are represented: 2.2157 and 2.4553, for the first (3.5 equivalent) and second (4.0 equivalent) designs respectively. The higher the straight barrier height equivalence we want to achieve, the harder for the evolutionary algorithm to obtain lower fitness function values. This shows the acoustic efficiency physical limitations due to a constrained maximum effective height in the Y-shape design. From the obtained shape designs (fig. 6) it is possible to observe that in the first case (left of fig. 6) it is achieved a barrier with equivalent efficiency as a straight barrier of 3.5 m by displacing its topology towards to the receiver direction (to the right). In this case the left arm function is less relevant acoustically speaking. From this shape, it is possible to obtain an equivalent configuration to a 4 m. straight barrier when the left arm heightens to the maximum effective height line of reference (in blue) as can be seen in the right part of figure 6. It should be remarked that we are not searching the barrier with higher efficiency, but the barrier with greatest fitting to the corresponding reference curve. This methodology allows to obtain a physical image of the acoustic barrier efficiency relating it with the efficiency of a common straight barrier.

CONCLUSIONS

A methodology for optimum design of Y-shape noise barriers has been presented with successful results. It is based in the BEM modelling coupled with evolutionary computation for optimization, solving an inverse problem consisting in obtain the barrier shape design that corresponds to a known IL curve at a certain number of frequencies. Here it is applied to obtain Y-shape barriers with constrained maximum effective height (3.0 m) lower than two cases of straight barriers (3.5 and 4.0 meters height) with the same acoustic efficiency.

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