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Improving the Design of M-Shape Noise Barriers using the Boundary Element Method and Evolutionary Algorithms

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Abstract

Shape optimum design of M-shaped noise barriers is carried out using BEM for modelling and evolutionary algorithms for optimization. The sound level is calculated being known: the source position, the receptor position, the barrier shape, and the sound frequency. The 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 of two barriers: the candidate M-barrier design and a reference noise barrier design (a simple barrier with higher effective height than the maximum constrained value of the design). The obtained results succeed in accomplishing the imposed requirements. Results are detailed in terms of IL values and barrier shape designs, numerically and graphically

Keywords: noise barriers, shape optimization, genetic algorithms, boundary element method.

1 Introduction

In this paper we propose to apply shape optimization to the design of M-shape noise barriers using the boundary element method (BEM) for modelling of sound propagation and a steady-state genetic algorithm for optimization. Shape optimization has been performed in recent years applied to various fields of engineering, such as aeronautics [1][2] or solid mechanics [3] using evolutionary optimization. Concretely, an article containing references about shape optimization in solid mechanics using BEM is Mackerle, 2003 [4] (where evolutionary optimization is considered as optimizer in some cases). A recent application of shape optimization using BEM and evolutionary computation applied to thermoelastic problems is in Bialecki et al., 2005 [5].

The BEM has been applied to sound propagation successfully. To estimate the efficiency of noise barriers with complex shapes, the BEM has been used from the 80s, see e.g. Seznec 1980 [6] and it is still a field of research interest. Therefore, examples of recent publications using BEM for noise barriers applications are Peplow, 2006 [7] and Anfosso & Dangla, 2006 [8]. The BEM model considered and implemented in this paper is fully detailed in [9]. 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.

2 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.

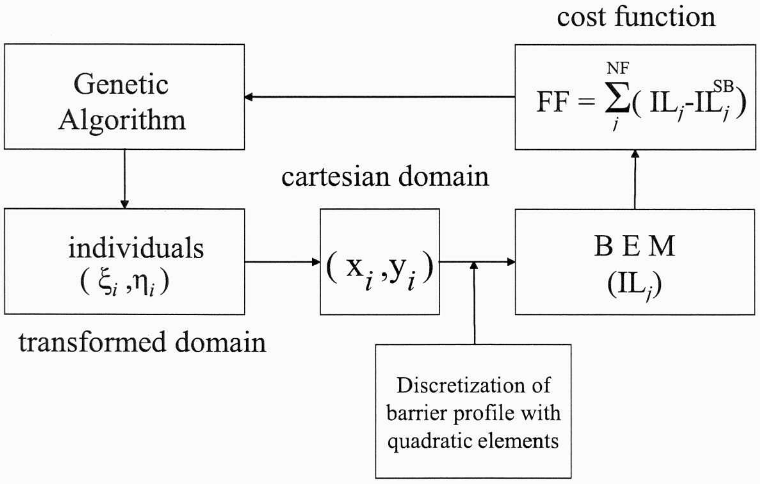

Figure 1: Optimization procedure by coupling GA and BEM.

The cost function which has to be minimized is:

$$FF = \sum_{j}^{NFreq} \left(IL_j - IL_j^{SB}\right)^2 \tag{1}$$

where:

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

IL_i^{SB} : insertion loss in the third octave band centre frequency for a simple-straight barrier of height h^{SB} (in this work 3.5 and 4.0 meters have been considered) and width of 0.2 m.

This general methodology was previously described in Greiner et al. [10]. 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 [10] 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 M-shape barrier. The proposed procedure allows determining the barrier profile with a closer IL spectrum.

Recently, other works have appeared that use also the coupling of BEM and evolutionary optimization to improve the design of noise barriers. Among them, the following are remarkable: Duhamel 2006 [11], Baulac et al. 2007 [12], Baulac et al. 2007 [13]. The methodology used in [11], provides geometry without practical applications, as the author recognizes in the paper. In [12] the top reactive surface of T-shaped barriers is optimized, and in [13] the shape of multiple edge-crowned barriers with three different screens is improved.

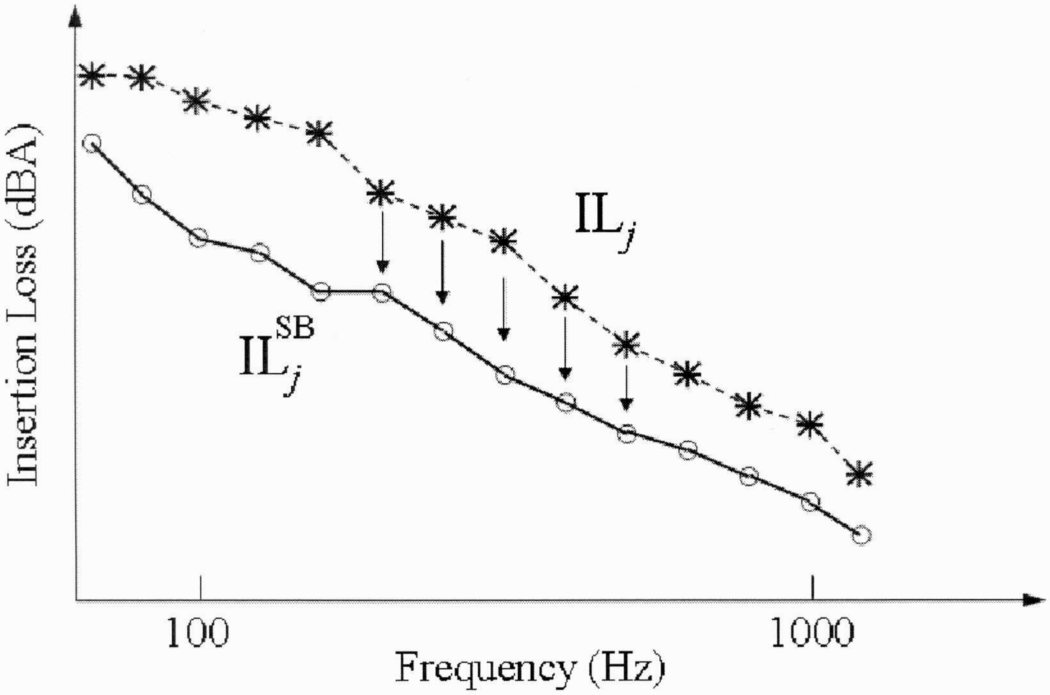

Figure 2: Fitness Function fitting procedure.

We use a different approach: our fitness function is capable to obtain the barrier design that fits a certain IL spectrum (see Figure 2), constrained by the acoustical limitations of the imposed maximum effective height. It is based in the optimization procedure used for shape optimization in other fields such as aeronautical engineering.

The configuration studied in this paper is shown in Fig 3. 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. Although the consideration of absorbing surfaces is included in our BEM modelling, it has been preferred here to study exclusively the geometric configurations without any other influence. In the present research all the evaluated barrier profiles have the maximum effective height constrained to the value of $h \leq 3$ m. They were formed with two vertical surfaces at the extremes and two slanting surfaces in the centre with arbitrary slope. The barrier projection to the ground is constant in all cases (b = 1 m). 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 4), where the coordinates ξ_1 and ξ_3 were established 'a priori' (-0.5 and 0.5, respectively). The four variables coded in the chromosome are the vertical coordinates of points 1,2 and 3 and the horizontal coordinate of point 2 (Figure 4).

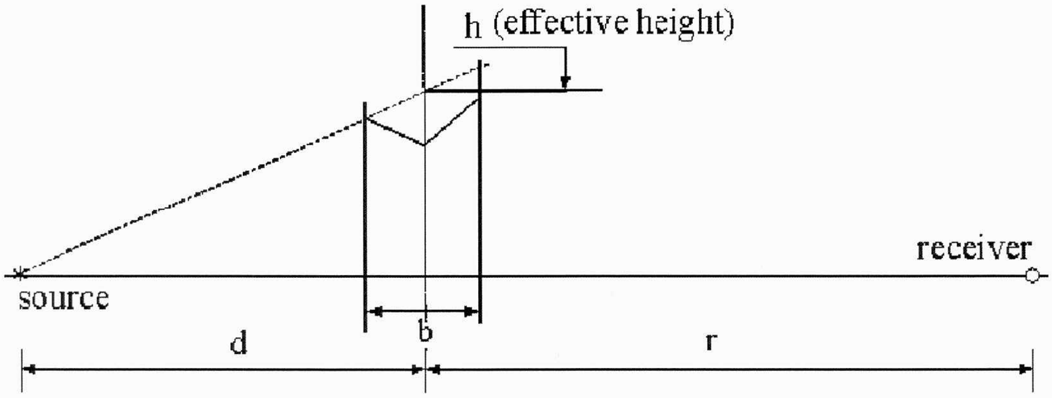

Figure 3: Two-dimensional configuration studied. Generic geometry of M-shaped noise barrier

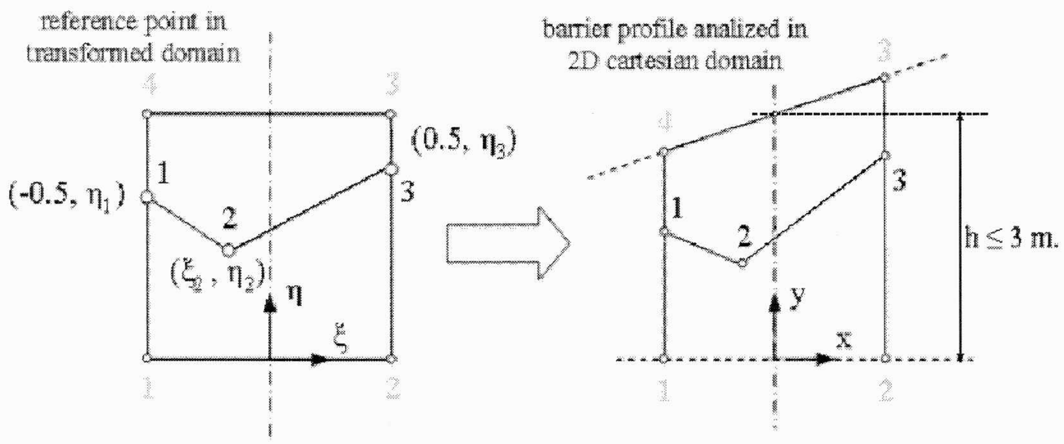

Figure 4: Process to obtain the barrier profile

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 represented in Figure 4, can be calculated using simple geometric operations. 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 = 50 m 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 considered. Further work is related with considerations about determining an appropriate element discretization size and its influence in the accuracy of the acoustics results (the greater the better) and in the required computational time to solve each candidate design (the greater the higher). A suitable accuracy should be balanced with an acceptable computational cost, affordable for the evolutionary search.

This approach has an interesting interpretation as we will see in the results: it is possible to obtain M-shaped barriers of maximum effective height not higher than 3 meters with the same efficiency than straight barriers of greater height, and therefore diminishing their visual impact.

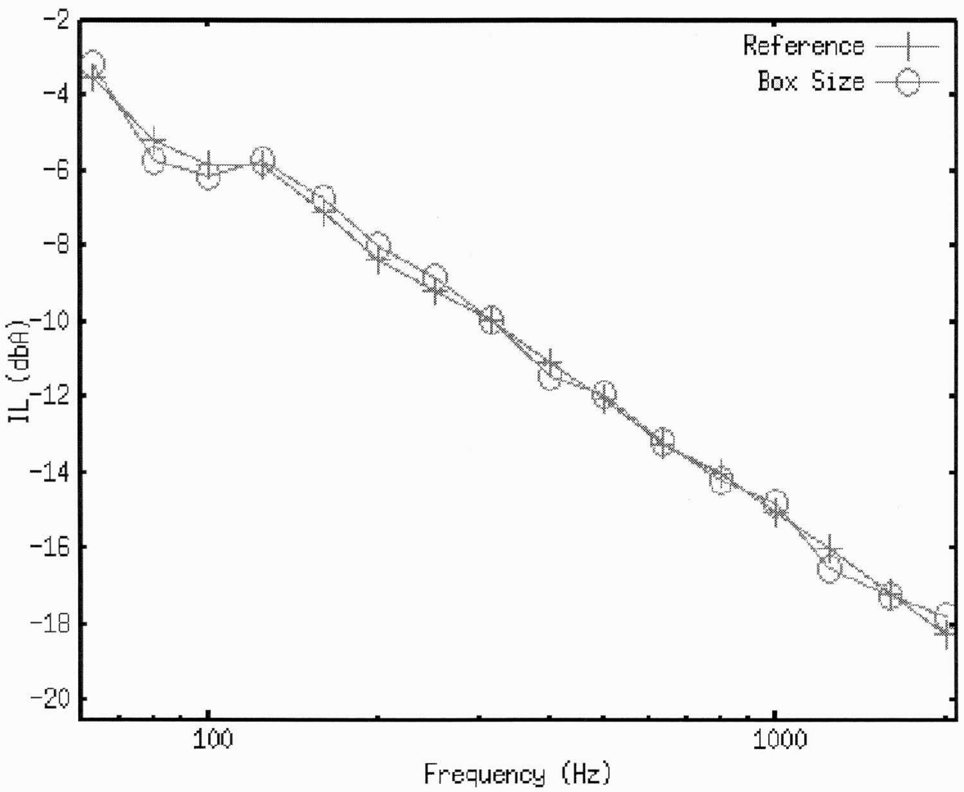

Figure 5: Frequencies following 3.5 Effective Height IL

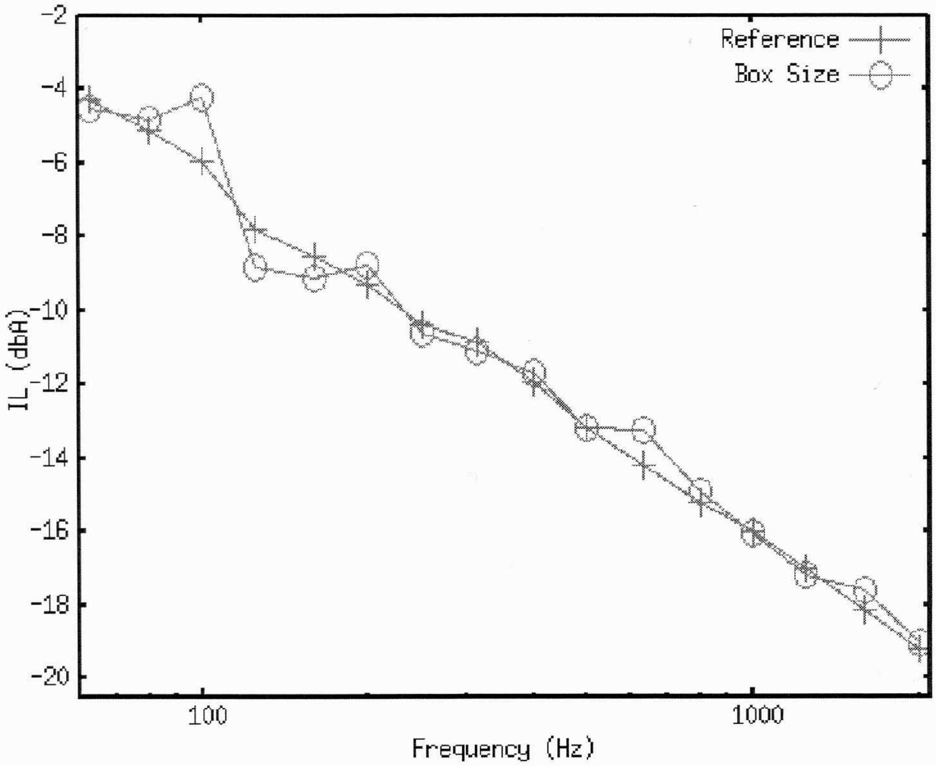

Figure 6: Frequencies following 4.0 Effective Height IL

3 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 5 and 6, 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 7, 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 7, the values of insertion loss of the M-shape barrier designs for a standard road traffic spectrum (shown in Table 3) are also represented (ILT): -13.15 and -14.04 dbA, respectively.

Results show the capability of the methodology presented to fit a certain IL curve. In Table 2 the fitness function values are represented: 2.0148 and 6.2091, for the first (3.5 m equivalent) and second (4.0 m 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 M-shape design. This methodology allows to obtain a physical image of the acoustic barrier efficiency relating it with the efficiency of a common straight barrier.

	$\zeta 1$	$\varepsilon 2$	$\zeta 2$	$\zeta 3$
3.5 M-Shape Best Solution	0.949219	-0.300781	0.093750	0.988281
4.0 M-Shape Best Solution	0.945312	0.382812	0.554688	0.980469

Table 1: Horizontal and vertical coordinates in transformed space

Frequency (Hz)	Simple Barrier 3.5m Reference IL values	Best M-shape Solution 3.5 IL values	Simple Barrier 4.0m Reference IL values	Best M-shape Solution 4.0 IL values
63.0	-3.47827	-3.14483	-4.30565	-4.52879
80.0	-5.20635	-5.69311	-5.14532	-4.80667
100.0	-5.85963	-6.16044	-5.92462	-4.22913
125.0	-5.85963	-5.71415	-7.80653	-8.81051
160.0	-7.10648	-6.72956	-8.54042	-9.12363
200.0	-8.34382	-7.99256	-9.28958	-8.78597
250.0	-9.19604	-8.82618	-10.35201	-10.62813
315.0	-9.97212	-9.93762	-10.85198	-11.11340
400.0	-11.09944	-11.44789	-11.93769	-11.66064
500.0	-12.04160	-11.94114	-13.16464	-13.20191
630.0	-13.25846	-13.20330	-14.17725	-13.23626
800.0	-14.03769	-14.21650	-15.18590	-14.90411
1000.0	-15.00996	-14.79197	-16.00739	-16.03275
1250.0	-16.00312	-16.50758	-17.03257	-17.19500
1600.0	-17.18088	-17.22080	-18.13375	-17.58326
2000.0	-18.25275	-17.80913	-19.24577	-19.02095
Fitness Function Value	---	2.0148	---	6.20911

Table 2: M Shape Numeric IL Results of References and Best Solutions (dbA)

From the obtained shape designs (fig. 7) it is possible to observe that in the first case (left of fig. 7) it is achieved a barrier with equivalent efficiency as a straight barrier of 3.5 m. In the second case (right of fig. 7) it is achieved a barrier with equivalent efficiency as a straight barrier of 4.0 m. 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.

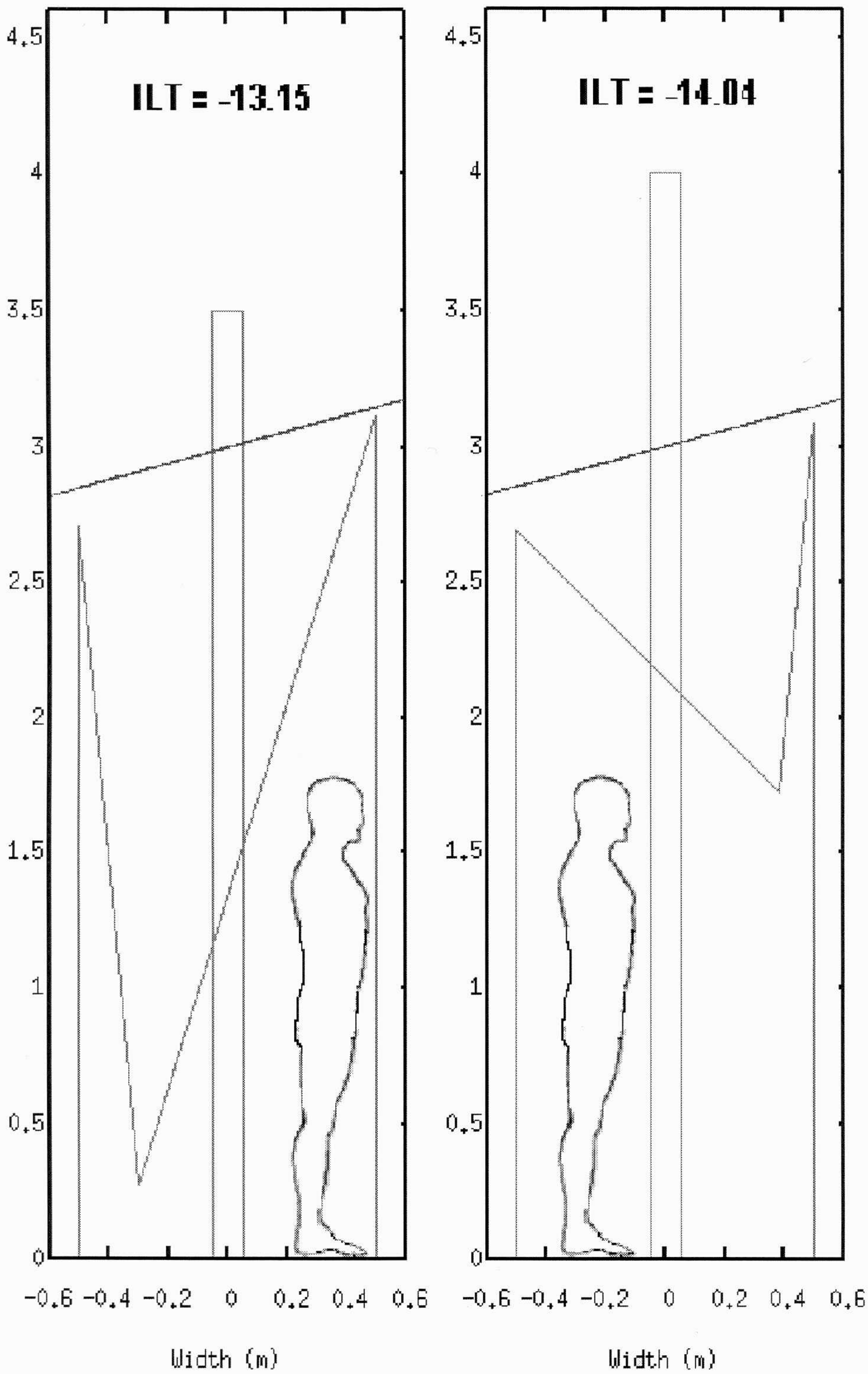

Figure 7: Optimized M-shape and reference simple barriers with proportional-size human figure

Frequency (Hz)	Sound Pressure Level (dBA)
63	75.3
80	80.0
100	83.3
125	85.7
160	88.2
200	89.8
250	91.0
315	91.7
400	92.9
500	94.5
630	95.9
800	97.0
1000	98.1
1250	98.2
1600	98.0
2000	96.2
2500	93.8
3150	91.6
4000	89.0

Table 4: Standard Road Traffic Noise Spectrum

4 Conclusions

A methodology for optimum design of M-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 M-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. Lower environmental and visual impact respect to the highway costumers are achieved.

References

[1] B. Galván, D. Greiner, J. Periaux, M. Sefrioui, G. Winter, "Parallel Evolutionary Computation for Solving Complex Optimization Problems: A Review and some Nozzle Applications", Parallel Computational Fluid Dynamics, Eds: K. Matsuno et al, 573-604, 2003.

[2] A. Oyama, M. S. Liou, S. Obayashi, “Transonic axial-flow blade optimization: Evolutionary algorithms / 3D-Navier-Stokes solver”, Journal of Propulsion and Power, 20-4, 612-619, 2004.
[3] W. Annichiarico, M. Cerrolaza. “Structural shape optimization 3D finite-element models based on genetic algorithms and geometric modeling”, Finite Elements in Analysis and Design 37-5, 403-15, 2001.
[4] J. Mackerle, “Topology and shape optimization of structures using FEM and BEM a bibliography (1999-2001)”, Finite Elements in Analysis and Design, 39 (3), 243-253, 2003.
[5] R. A. Bialecki, T. Burczynski, A. Dlugosz, W. Kus, Z. Ostrowski, “Evolutionary shape optimization of thermoelastic bodies exchanging heat by convection and radiation”, Computer Methods in Applied Mechanics and Engineering, 194 (17), 1839-1859, 2005.
[6] R. Seznec, “Diffraction of sound around barriers: use of boundary elements technique”, Journal of Sound and Vibration, 73, 195-209, 1980.
[7] A.T. Peplow, “On the efficiency of screens near roadside cuttings”, Journal of Sound and Vibration, 298 (4-5), 982-1000, 2006.
[8] F. Anfosso, P. Dangla, “Sound propagation above a porous road surface by Boundary Element Method”, Road Materials and Pavement Design, 7 (3), 289-312, 2006.
[9] O. Maeso, J. J. Aznárez, “Strategies for reduction of acoustic impact near highways; an application of BEM”, University of Las Palmas of GC, Civil Engineering Dept. Report, (in Spanish), 2005.
[10] D. Greiner, J.J. Aznárez, O. Maeso and G. Winter, "Shape Design of Noise Barriers Using Evolutionary Optimization and Boundary Elements", in Proceedings of the Fifth International Conference on Engineering Computational Technology, B.H.V. Topping, G. Montero and R. Montenegro, (Editors), Civil-Comp Press, Stirlingshire, United Kingdom, paper 43, 2006.
[11] D. Duhamel, “Shape optimization of noise barriers using genetic algorithms”, Journal of Sound and Vibration, 297, 432-443, 2006.
[12] M. Baulac, J. Defrance, P. Jean, “Optimization of multiple edge barriers with genetic algorithms coupled with a Nelder-Mead local search”, Journal of Sound and Vibration 300 (1-2), 71-87, 2007.
[13] M. Baulac, J. Defrance, P. Jean, “Optimization with genetic algorithm of acoustic performance of T-shaped noise barriers with a reactive top surface”, Applied Acoustics, doi:10.1016/j.apacoust.2006.11.002, 2007, (in press).