Engineering Analysis with Boundary Elements 63 (2016) 49–60

Contents lists available at ScienceDirect

Engineering Analysis with Boundary Elements

journal homepage: www.elsevier.com/locate/enganabound

Shape design optimization of road acoustic barriers featuring top-edge devices by using genetic algorithms and boundary elements

R. Toledo*, J.J. Aznárez, D. Greiner, O. Maeso

Instituto Universitario de Sistemas Inteligentes y Aplicaciones Numéricas en Ingeniería (SIANI), Campus Universitario de Tafira, Universidad de Las Palmas de Gran Canaria, Spain

A R T I C L E I N F O

Article history:
Received 6 July 2015
Received in revised form
7 October 2015
Accepted 31 October 2015
Available online 21 November 2015

Keywords:
Noise barriers
Very thin bodies
Shape optimization
Genetic Algorithms
Dual Boundary Element Formulation

A B S T R A C T

This paper presents a Boundary Elements (BE) approach for the efficiency improvement of road acoustic barriers, more specifically, for the shape design optimization of top-edge devices in the search for the best designs in terms of screening performance, usually represented by the *insertion loss* (IL). With this aim, a procedure coupling BE with Evolutionary Algorithm is proposed in pursuing barrier configurations with ever higher IL. The complexity normally associated with such designs raises the need to consider some geometric simplifications in order to ease the shape optimization processes. In this way, the overall barrier configuration is modeled as both thickness and null-thickness bodies (the boundary thickness is neglected), as representatives of very thin elements. Such an idealization requires a Dual Boundary Element formulation that allows the problem to be solved. The procedure is applied to 2 D problems and numerical results are presented on the basis of simulations on noise barriers with three different top designs. It is a quite simple process that makes use of well-known both formulations and procedures. The improvements observed in the designs obtained invite to further studies in the same line on devices with similar applications.

1. Introduction

The inclusion of sound barriers for abating the negative effects of road traffic noise near residential areas is a broadly used strategy. Considerable research works and studies focused on sound diffraction around barriers have been conducted in the past two decades, specifically in the prediction of the performance and the development of more efficient designs. Among all of the different theoretical methods proposed concerning the issue, the Boundary Element Method (BEM) has been broadly used for its indubitable benefits in the analysis of exterior sound propagation problems [1–6]. More specifically, a comprehensive, up-to-date revision of the application of this technique in the assessment of the screening behavior on various barrier designs in different scenarios can be consulted in [7]. Some of these research works focus on both the application and the potential of the standard BEM formulation for the aforementioned cases. Others deal with the incorporation of some geometric changes on classic, widely used barrier configurations (such as **Y**-, **T**-, **M**- and arrow-shaped barriers, multiple-edge screens, etc.) and the assessment of their influence on the acoustic performance. In this line, with the purpose of searching designs more and more acoustically efficient, the shape optimization methods (extensively used in other engineering fields [8]), are presented as valuable application tools. Such is the case of Evolutionary Algorithms (EA) and, in particular, Genetic Algorithms (GA), which coupled with BEM have been successfully implemented in the design optimization of noise barriers in exterior acoustic problems within the SIANI Institute, where this work is developed [9–13]. Some other notably contributions concerning the issue can be found in the bibliography. For instance, with a markedly academic nature, Duhamel [14] performs the optimization of a noise barrier starting off with a prismatic, volumetric structure built of equally sized bricks to lead to the final optimized shapes with non-inner holes and fillings. As a result, some bricks remain from the original prismatic configuration, while others are removed according to the patterns established by the process. Other interesting works present a more practical approach. In this line, Baulac et al. [15] propose an original optimization method for bi-dimensional multiple-edge noise barriers based on the adjusting of both some geometric parameters and the impedance values of some boundaries. The same authors study the performance of **T**-shaped barriers featuring a reactive surface on the top [16]. Still on the same practical approach, Grubeša et al. [17] broaden these methodologies into a three-dimensional analysis involving a multi-objective optimization of both the acoustic performance and the economic feasibility

* Corresponding author.
E-mail address: rtoledo@siani.es (R. Toledo).

http://dx.doi.org/10.1016/j.enganabound.2015.10.011
0955-7997/

of noise barriers made of varying cross-section modules. Concerning the authors of this work, a mono- and a multi-objective optimization process for bi-dimensional problems, following a procedure in the line of the one introduced here, can be consulted in Greiner et al. [11].

In relation to the previous work done [13], this paper deals with an improved, more advanced procedure that allows the shape design optimization of more complex road barrier designs to be easily accomplished. In [13] a Dual BEM formulation coupled with a GA for the analysis and optimization of very thin noise barriers is introduced. Concerning the work here presented, the scope of the Dual code is broaden to cope with the analysis of generic volumetric barriers featuring, in addition, very thin elements. In this respect, the Dual BE approach developed in this work addresses this issue more properly, allowing a versatile, robust, general methodology that may cover any type of 2 D acoustic optimization problem by both (1) mitigating the fictitious eigenfrequencies associated with the inner domain of volumetric structures and (2) assuming the idealization of very thin elements as *single-wire* bodies, greatly facilitating the geometric definition of the barrier. Under the framework of the coupled use of this code and GAs, improved designs of top edge devices are proposed in a way, to the authors' knowledge, not covered so far in the bibliography concerning the issue. As an application, numerical results on the basis of three models with complex top designs featuring both thick and very thin bodies (idealized as null-thickness type) are performed. The use of the Dual BEM formulation in both works are justified in the sense that is the most appropriate strategy to address the proposed problems numerically, as reported by Hong and Chen [18], Krishnasamy et al. [19], de Lacerda et al. [20], Chen and Chen [21], Chen and Hong [22], Wu [23], Chen et al. [24] and Tadeu et al. [25]. Above all, the null-thickness idealization greatly eases the geometric definition of complex configurations with no substantial influence on the acoustic performance for the considered thickness of very thin bodies [20].

Two-dimensional sound propagation hypotheses are considered, i.e., an infinite, coherent mono-frequency source of sound and a noise barrier with no geometric variation that stands on a flat plane (ground) of uniform admittance. The problem is performed in the frequency domain with the usual assumptions (Helmholtz equation): the medium (air) is modeled as homogeneous, elastic and isotropic with no viscosity, under small disturbances and initially at rest with no wind effects. Expression of the objective function to be maximized throughout the shape optimization process is written in terms of this response.

The work is structured as follows: after this introduction, in Section 2 a detailed description of the top barrier designs to be studied is provided, including a brief state of the art, the scattering and the screening properties as well as the use and implementation of well- and diffuser-based top designs in exterior acoustic problems. In Section 3, the modeling and discretization by implementation of a Dual BEM formulation is described. Section 4 deals with the shape optimization procedure. Finally, Section 5 shows results and discussion, and Section 6 covers the conclusions of the paper.

2. Diffuser-based top designs in exterior acoustic problems

For their unquestioned benefits for scattering sound field, the use of diffusers has been the subject of many reviews and studies in indoor acoustic projects. Among them, those based on sequence number series (such as Maximum Length Sequence (MLS), Quadratic Residue Diffuser (QRD), Primitive Roots Diffuser (PMR), etc.) have gained prominence for their excellent scattering properties, characterized by an approximately flat power spectral density. As the power spectrum and surface scattering are closely related [26–28], the far field scattering can be approximately predicted by taking the Fourier transform of the surface reflection coefficients (in this case, a series of wells that could be modeled as a flat surface of varying impedance). In short, any numerical sequence featuring good auto-correlation properties (in other words, the auto-correlation function of the reflection coefficients of the surface is a delta function) presents a Fourier transform with a flat power spectral density, meaning that such a surface exhibits an even scattering distribution of sound.

Despite the indoor-oriented application of well-based designs, the use of such devices on noise barriers in exterior acoustic problems has evidenced a good performance when compared with both a vertical screen and other top configurations. Some noteworthy works concerning the use of diffusers installed on the barrier top can be found in the literature. Such is the case of those based on mathematical number sequence, such as Quadratic Residue Diffusers (QRDs) [29–32] and Primitive Roots Difussers (PRDs) [33]. Other designs featuring elaborated configurations eligible for either some kind of scattering or screening behavior can be found in [34,35] (see Fig. 1).

All the aforementioned works address the problem with the standard BEM formulation, considering the real geometry of the barrier comprised of thick and very thin elements. Despite their remarkable contribution, no shape design optimizations are performed in the referenced works. In this regard, the methodology here presented proposes a general procedure that aims at optimizing the shape design of edge-modified road acoustic barriers

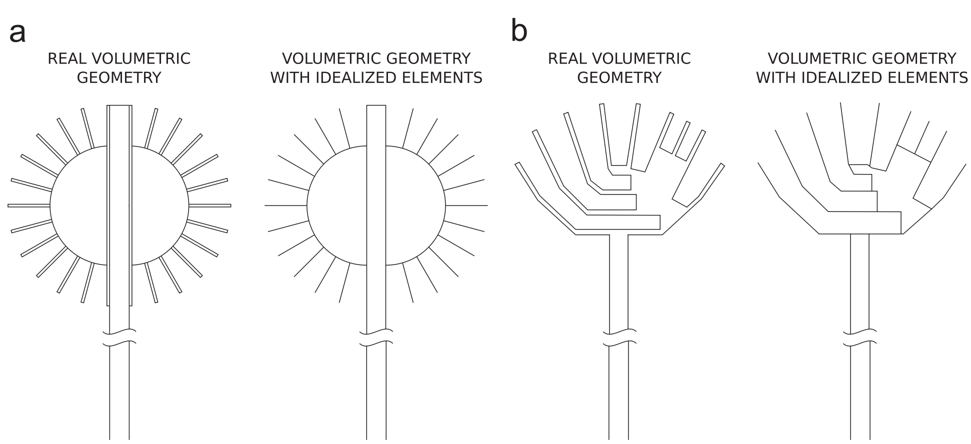

Fig. 1. Examples of complex designs eligible for undergoing geometric idealizations. (a) Waterwheel-top barrier from Okubo and Fujiwara [34]. (b) Complex barrier-top featuring wells with different lengths and paths [35].