Available online at www.sciencedirect.com
ScienceDirect
Applied Acoustics 69 (2008) 93–109
applied acoustics
www.elsevier.com/locate/apacoust

Performance of T-shape barriers with top surface covered with absorptive quadratic residue diffusers

M.R. Monazzam, Y.W. Lam *

Acoustics Research Centre, School of Computing, Science and Engineering, University of Salford, Salford M5 4WT, UK

Received 22 April 2005; received in revised form 15 September 2006; accepted 19 October 2006
Available online 1 February 2007

Abstract

A previous paper [Applied Acoustics 66 (2005) 709–730] has shown that adding a quadratic residue diffuser (QRD) to the top of a T-shape barrier can provide better barrier performance than an equivalent purely absorptive barrier. In here, we extend the study to look at the performance when a QRD is made absorptive. This paper presents an investigation on the acoustic performance of a few welled-diffusers with different absorption ability on top of a T-shape noise barrier. The absorption properties of the diffusers are modified with different sequences, by filling the wells with fiberglass, by covering the well entrance with wire meshes, and by putting perforated sheet either on the top surface or inside the wells. A 2D Boundary Element Method (BEM) is used to calculate the barrier insertion loss. The numerical and experimental results on diffuser barriers with rigid and absorptive covers are compared. Among the tested models the best method of treating diffuser barriers with absorbent agents in the QRD is found to be a perorated sheet on top or inside the diffuser wells. It is found that increasing the absorption ability of QRD by fiberglass or high resistance wire meshes has negative effect on the efficiency of a QRD barrier. It is shown that, if the increase in absorption destroys the effect of resonance in wells, it will also have negative effect on the insertion loss performance of the QRD edge barrier.

Keywords: Noise barriers; Absorptive diffusers

1. Introduction

Traffic noise barriers are the most common solution for controlling unwanted noise from expressways and other outdoor noise sources. A number of methods have been suggested to improve their effectiveness without increasing their height. The barrier edge is known to act as an imaginary source for a diffracted field at the back of the barrier [1]. Control of sound pressure at the barrier's edges therefore reduces this imaginary source and decreases the diffracted field at the rear of the barrier. Previous works found that employing a weakly absorbing upper surface to a T-shape profile barrier could not improve the efficiency of the barrier significantly, while more strongly absorbent surface gave increasingly higher improvements [2]. Covering a T-shape barrier with a layer of mineral wool type absorbent material (flow resistivity $\sigma = 20{,}000\ \mathrm{Ns\,m^{-4}}$ and thickness $T = 0.1$ m) could improve the performance of a single rigid barrier by 2.5 dB according to Hothersall et al. [3].

In order to give more suppression of the sound pressure, Fujiwara [4] introduced a barrier with an "acoustically soft surface", where sound pressure is much less than that of an absorptive surface. Although improvement over a wide frequency range was not obtained, the efficiency of the "soft" barrier increased by more than 10 dB in the frequency range where the surface pressure was minimised. It is also worth noting that, providing such a soft surface with wide range frequency effect is very difficult. Fujiwara tried to introduce a practical "Cylindrical edge barrier" for practical use [1].

Utilising quadratic residue diffuser (QRD) on different barrier profiles is also investigated by the authors, where

* Corresponding author. Tel.: +44 161 295 5684; fax: +44 161 295 5427.
E-mail address: y.w.lam@salford.ac.uk (Y.W. Lam).

0003-682X/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apacoust.2006.10.006

the best shape for using the device was found to be a T-shape profile with a 400 Hz design frequency [5]. It was found that a 400 Hz frequency designed T-shape QRD barrier could increase the efficiency beyond its equivalent absorbent T-shape barrier by up to 3.5 dB(A) on a rigid ground. The highest improvement was achieved in the far field at heights between 6 and 8 m above the ground. Although QRD is well known as a diffuser that spreads sound in many directions with very low loss in energy, there are also a few studies showing that they can also work as an absorbent device. Commins, Auletta and Suner [6] experimentally investigated the absorption characteristics of a Schroeder diffuser. They showed that by slopping the bottom of the diffuser wells, the absorption could be reduced. Fujiwara and Miyajima [7] in an experimental investigation found a high absorption coefficient on a Schroeder diffuser particularly at frequencies lower than the design frequency. Kuttruff [8] later confirmed the high absorption of the diffuser at low frequencies. The reason behind this unexpected absorption was thought to be strong interaction between elements, that each of them being tuned to a different resonant frequency. More investigation both experimental and numerical on the reasons for the very high absorption ability of Schroeder diffuser (QRD) was done by Fujiwara [9]. At the same time an analytical solution for the absorption coefficient of a welled diffuser was also introduced by Mechel [10].

Wu et al. [11] introduced an optimised QRD absorber and they verified the effectiveness of a resistive layer at the well opening for increased absorption. They obtained very high absorption performance from a Schroeder diffuser. They also introduced a type of profiled absorber in another investigation [12] which could extend the absorption at low frequencies whilst preserving the absorption at mid frequencies. However there is yet no application of QRD as an absorbent in environmental noise control.

This paper investigates the effect of a new set of barrier types using various welled diffusers with different absorption properties on the top surface of a T-shape barrier. In this report the performance of noise barriers with welled diffusers and QRD profiles with either wire mesh, perforated sheet or fibreglass, is calculated using a two-dimensional boundary element method. Insertion loss spectra at 1/15-octave centre frequencies are calculated. The results are compared with absorptive as well as a selected plain QRD top surface T-shape barrier on rigid ground to show when it is efficient to add absorption to a QRD in barrier applications.

2. Schroeder diffusers

Depth sequence diffusers were introduced by Schroeder in the 1970 [13,14]. The most common of them is the Quadratic Residue Diffuser (QRD). They are periodic surface structures with rigid construction that are intended to reduce specular sound reflection by scattering the incident sound energy in to a wide range of directions. The elements of the construction are wells with the same width separated by thin fins. In this case the well depth sequence for a QRD is determined by the quadratic residue sequence, which is a mathematical sequence based on a prime number, N. The nth term in the sequence is given by $n^2 \bmod N$. Ideally a QRD should produce a uniform scattered field at its design frequency. Primitive root sequence is one more example of a mathematical sequence providing another kind of Schroeder diffuser known as primitive root diffuser (PRD).

3. Absorption by Schroeder diffusers

Schroeder diffuser can absorb sound energy mainly because of (i) high energy flows from wells in resonance to wells out of resonance, and (ii) quarter wave resonant absorption in the wells, particularly in narrow wells. In an investigation Fujiwara [9] looked at the possible reasons behind the absorption ability of Schroeder diffusers. Quadratic residue sequence diffuser was found to have lower absorption ability than random and regular sequence diffuser over the entire tested frequency range (Fig. 6 of Ref. [9]). Moreover, in his numerical prediction, which had fairly good agreement with experimental result, it was shown that QRD with higher prime number ($N = 11$) got more absorption coefficient than one with $N = 7$. Finally he concluded that even if the inner surface of a QRD is ideally smooth the absorption coefficient was as high as 0.3 in the frequency range below the design frequency. Furthermore absorption coefficients were found to be very frequency dependent and very sharp absorption peaks were observed at the resonance frequencies of the coupled wells.

An optimised well sequence was shown to have better absorption ability than a QRD and random structure diffusers according to Wu et al. [11]. Both Kuttruff [8] and Wu et al. [11] tried to show the importance of the surface covering of a QRD in increasing the absorption ability of the device. There is energy flow between wells of the diffuser promoted by pressure gradients, which are caused by wells being in resonance and wells not in resonance. Therefore high particle velocity around the front face of a Schroeder diffuser occurs, and a resistance cloth covering will cause excess absorption as might be expected if resistive material is placed in a region of high particle energy flow.

Wu et al. [11] showed the dramatic effects of covering a QRD with wire mesh, which made huge increases in the absorption coefficient of constant slit diffusers, QR diffusers, and an optimised QR diffuser. In another investigation a new idea of improving absorption coefficient of QR diffuser was raised by Wu et al. [12]. It was proved both experimentally and theoretically that not only covering the surface of QR diffusers by a perforated sheet is effective in increasing the absorption ability of the structure, but also having a variably positioned perforated sheet in the well introduces extra degree of freedom that produces a good broad band absorption coefficient for QR diffusers. These means of increasing the absorption property of a QRD, and their effect on barrier performance will be tested here.