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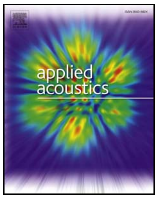

Research on the well at the top edge of noise barrier

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ABSTRACT

Wells mounted on the top edge of barrier could improve the noise reduction effect of the barrier. In order to research the characteristics of the well, the 2D boundary element method (BEM) was adopted, the insertion loss (*IL*) of different type of barriers were calculated, the effect of well was analysed. Results showed that, almost 1.5 dBA of the *IL* is aroused by the reflect sound of the well. So, it is important to improve the sound field inside the well to improve the noise reduction effect of the barrier. The sound field inside the well depends on the sound diffraction effect, therefore, the characteristics of sound field diffracted by a single edge was analysed by the geometrical theory of diffraction (GTD) method. Then the effect of well width on the noise reduction effect was discussed according to the sound diffraction loss. To verify the discussion conclusions, the noise reduction effect of barrier with different width of well was simulated and compared. In addition, experiments were also carried out in a semi-anechoic chamber using full-scale models. Both the experimental and simulation results show that, to play a better role of the well, the well width should be greater than $1/\sqrt{3}$ of the well depth.

1. Introduction

Noise pollution from transportation is still a major environmental concern, to mitigate the impact of sound on roadside communities, noise barriers need to be employed in an appropriate place [1,2]. Over the last years, noise barriers have been widely studied [3–7], to improve the barrier performance without increasing its overall height significantly, the edge-modified barriers are widely used nowadays. And many different kinds of top device have been proposed and studied by acousticians [8–12].

Barriers with complex shapes of top devices attracted a lot of attention, Monazzam.M.R and Lam.Y.W investigated the acoustic performance of noise barriers with quadratic residue diffuser (QRD) tops using a 2D BEM, and found that insertion loss produced by utilizing QRD on different barrier profiles varies significantly with frequency and is strongly dependent on the design frequency of the QRD [13]. Naderzadeh Mahdiyeh et al. investigated the performance of noise barriers treated with different diffusers with/without a perforated sheet using a 2D BEM, found that the diffuser performance improved by treating the diffuser with perforated sheets either on the top surface or inside the wells [14].

Okubo.T and Fujiwara.K investigated a noise barrier with a Waterwheel cylinder installed on the edge of it, which can be viewed as a soft surface cylinder. According to their research, the Waterwheel cylinder improves the sound shielding efficiency of a noise barrier, and the improvement is strongly frequency dependent [15]. Fujiwara Kyoji investigated the acoustic performance of rectangular, T-shaped and cylindrical edged noise barriers with rigid, absorbing and soft surfaces with BEM, found that a uniform series of wells in the upper surface of a T-shaped barrier produce *IL* values equal to those of a soft surface over a significant range of frequencies [16]. Baulac Marine applied an evolutionary optimization method to optimize the acoustical efficiency of T-shaped noise barriers whose top is covered with a series of wells, 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 [17].

Indeed, many meaningful conclusions have been gained by such studies, however, there are still much left to be explored, such as the design of the parameters of the well. In the present paper, the *ILs* of barrier with different types of wells on its top was calculated by the method of BEM firstly. And results show that, the reflected sound of the well would improve the noise reduction effect by almost 1.5 dBA. Then, to investigate the sound field inside the well, GTD method was adopted to investigate the diffraction effect by a single edge. At last, the effect of well width on the noise reduction effect of barrier is investigated. According to the research, to get better performance, the width of the well should larger than $1/\sqrt{3}$ of the depth of the well, and experimental results done in a semi-anechoic chamber verified that. Section 2 of this paper first reviews the theories of 2D BEM, and then Section 3 describes the simulation models, calculation results and discusses the effect of the well. Section 4 analyses the characteristics of the diffraction of sound, researches the effect of the width of the well. Section 5 describes the

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details of the experiments as well as discusses the results of the experiments. Finally, we summarize the results and discuss our findings in the conclusion.

2. The BEM model

The BEM is considered an effective tool to predict the acoustic efficiency of different barrier models [18]. Numerous applications of BEM for prediction of acoustic performance of noise barriers have shown the good accuracy of this method. The three-dimensional simulations require much more computational resources and calculation time, and the barrier can be assumed to be of infinite length and to have constant acoustical properties over its length, so the two-dimensional method is widely used. For the two-dimensional analyses, the barrier lies on a reflective ground, the line source of sound is parallel to the barrier, located at r_0, the receiver located at r. The sound pressure $p(r,r_0)$ at the receiver satisfies the following integral equation [19]:

$$\varepsilon(r)p(r,r_0) = G(r_0,r) - \int_S \left(\frac{\partial G(r_s,r)}{\partial n(r_s)} + jk\beta(r_s)G(r_s,r)\right)p(r_s,r_0)ds(r_s) \tag{1}$$

where $\beta(r_s)$ denotes the normalized surface admittance at point r_s on the barrier surface S,$ds(r_s)$ denotes the arc length of the barrier surface S at point r_s,$\partial/\partial n(r_s)$ denotes the normal derivative at r_s,k denotes the wave number. $\varepsilon(r)$ takes the value 1 when r lies anywhere in the propagating medium except on S;$\varepsilon(r) = 1/2$ if r is a point on S which is not a corner point. If r is a corner point then $\varepsilon(r) = \Omega/(2\pi)$, where $\Omega$is the angle in the medium subtended by the two tangents to the boundary at r. $G(r,r_0)$ is the solution to the problem in the absence of the barrier, can be written as:

$$G(r,r_0) = -\frac{i}{4}\{H_0^{(1)}(k\,|r_0-r|) + H_0^{(1)}(k\,|r_0'-r|)\} \tag{2}$$

where r_0' denotes the image of the source in the ground and $H_0^{(1)}$ denotes the Hankel function of the first kind of zero order.

To solve Eq. (1) numerically, the barrier surface S was divided into a number of straight line elements S_1,S_2,... , S_N, and r_n denotes the midpoint of S_n for $n = 1,2,...,N$. By the approximation that $p(r,r_0)$ is constant and equal to $p(r_n,r_0)$ for r on S_n, Eq. (1) is reduced to

$$\varepsilon(r)p(r,r_0) = G(r_0,r) - \sum_{n=1}^{N} p(r_n,r_0)\int_{S_n}\left(\frac{\partial G(r_s,r)}{\partial n(r_s)} + jk\beta(r_s)G(r_s,r)\right)ds(r_s) \tag{3}$$

By setting $r = r_m$ for $m = 1,2,...,N$ in Eq. (3), a set of N linear equations is obtained in the unknowns $p(r_1,r_0)$,$p(r_2,r_0)$,...,$p(r_N,r_0)$. After solving these equations, the sound pressure at any point r, can be calculated by substituting the pressure at the midpoint of each element into Eq. (3).

3. The BEM simulations

In order to investigate the noise reduction effect of the well, several different types of barrier models were established as shown in Fig. 1. Model *a* is barrier with no well, model *b* is barrier with one well, model *c* is barrier with five wells, model *d* is barrier with five deep wells. Each model are same in height and width, height of the model is 2.17 m, width of the model is 0.56 m, the depth of the well of model *b* and model *c* is 0.17 m, the width of the well of model *c* and model *d* is 0.1 m.

In the modeling process, the source is considered to be linear and aligned parallel to the barrier, located at 1.3 m away from the center of the barrier, 1 m above the ground. Receiver point located at the other side, 2 m away from the center of the barrier, 1.5 m above the ground. Both ground and the surfaces of the barrier are all considered as rigid. The range of frequencies considered in the BEM models was from 200 Hz to 5000 Hz, which encompasses the most important frequencies in the traffic noise spectrum. The values of *ILs* calculated are shown in Fig. 2 and the 1/3 octave band SPLs (Sound Pressure Level) at the receiver point are shown in Fig. 3.

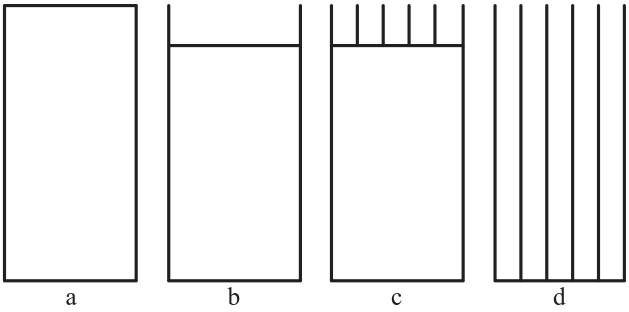

Fig. 1. Different types of barriers. (a) Barrier with no well; (b) Barrier with one well; (c) Barrier with multi-well; (d) Barrier with deep multi-well.

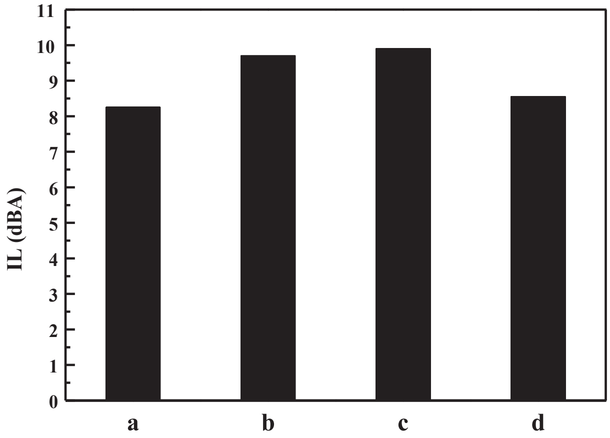

Fig. 2. *ILs* of simulation models.

For barrier with well on its top, its noise reduction effect includes two contributions, the effect of multi-edge diffraction and the effect of the reflected sound of the well. So, the noise reduction effect of the barrier $E_{barrier}$ can be expressed as $E_{barrier} = E_{md} + E_r$. Where E_{md} is the effect aroused by the multi-edge diffraction, E_r is the effect aroused by the reflected sound of the well. To investigate the beneficial methods which would improve the noise reduction effect of the barrier further, mainly through improve the effect of the reflected sound, This paper is mainly concern on the effect of the reflected sound.

Fig. 2 shows that model *b* is more efficiency than model *a*. The difference in noise reduction effect is great between barrier with and without well, the well can improve the value of *IL* by almost 1.5 dBA compared to barrier with same height and width. And Fig. 3(a) shows that barrier with well has better performance in most frequency range from 315 Hz to 4000 Hz. The depth of the well in model *b* is 0.17 m, equal to a quarter of the wavelength at 500 Hz, but it is clear that, besides 500 Hz, well is also helpful in other frequency range.

The difference of model *b* and model *c* is the number of the well, the width of the well in other words. Fig. 2 shows that the difference of performance of model *b* and *c* is small. Fig. 3(b) shows that barrier with one well is more effective in the frequency range over 2500 Hz. Barrier with multi-well does not show a better noise reduction effect, this may because the top edge of the multi-well is flat, the sound abatement caused by multi diffraction is small, and the narrow wells weakened the sound abatement of high frequency noise.

Compare to model *c*, model *d* has deep wells, which means there is no sound reflecting from the bottom of the well. It is clear that deep well has poor performance according to Figs. 2 and 3(c), barrier with deep well has similarly performance with barrier with no well. The difference of noise reduction effect of model *c* and model *d* is almost

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