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SOUND BARRIERS FROM MICRO-PERFORATED PANEL ABSORBERS WITH SUB-CAVITIES AT DIFFERENT DEPTHS

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In this paper, insertion loss of sound barriers made from specially designed kinds of micro-perforated panel (MPP) absorbers are investigated to order to avoid the performance deterioration from multiple reflections between the parallel sound barriers. The MPP absorbers are designed having broad sound absorption spectra to cover the main energy spectrum of traffic noise to be blocked, through equipping MPP with sub-cavities at different depths designed by quadratic residue sequences. Insertion loss of the sound barriers above is numerically investigated through finite element modeling. Results show that, the presented sound barriers have distinct performance advantage over the conventional rigid sound barriers, especially for parallel barrier applications.

Keywords: multiple reflections, micro-perforated panel, insertion loss, finite element modeling

1. Introduction

Sound barrier is commonly seen in highways [1], railways [2] and factories, etc. Typically, a sound barrier is placed between a noise source and the noise-sensitive region to shield the nearby communities from noise. The direct components of the noise can be effectively blocked by the barrier's structure. Therefore, the primarily method to enhance the shielding effects of the barrier is to eliminate the diffracted sound emanating from the barrier's edges. Increasing the height of barrier is a simple way to improve the performance of it, especially at low frequency. But this way is not suitable in practical for its potential cost and safety issues [3]. Under the premise of not increasing the height of barrier, different barrier shapes including *T*-profiled, *Y*-profiled, cylindrical and jagged edge have been investigated [4-8].

However, when the barriers are placed on opposite sides of a source, such as the roadsides of a highway, degradation in performance caused by multiple reflections between the parallel barriers has been reported [9, 10]. To suppress the multiple reflections, absorption materials were proposed to apply on the inner surfaces of the barriers to absorb the sound energies, but the use of conventional porous and fibre sound absorption materials may bring extra environmental problems. A tilted barrier with a 10° slope was designed to redirect the sound wave upward, so the diffraction at the barrier top can be efficiently reduced [11]. Another solution that can redirect the sound waves downward to the ground was realized by the multiple wedges barrier [12], which also called the wave-trapping barrier for trapping the reflected waves by its semi-enclosed domain.

Barriers whose surfaces have inhomogeneous impedance were proposed by Wang et al [13]. Their results showed that the inhomogeneous impedance can change the behaviours of the sound when the sound was multi-reflected by the parallel barriers, and then confine the sound energies within the parallel barriers. Consequently, the degradation in performance of the parallel barriers has been improved. It was noted that the impedance inhomogeneity of the barriers can be approximately realized by a closely spaced array of progressively tuned hollow narrow tubes. In one period, the depths of the tubes are evaluated by a specified formula, which is similar with the quadratic residue diffuser (QRD), in spite of the depths of QRD wells are evaluated by a quadratic residue sequence [14]. The QRD is not only an effective diffuser, but also has absorption ability at low frequency reported by Fujiwara et al [15-16]. Besides, when a single micro-perforated panel (MPP) layer is applied on the opening of the QRD, a wide-band sound absorber called QRD-backed MPP absorber can be formed [17].

QRD-backed MPP absorber is actually made up of a single layer MPP and an array of sub-cavities with different depths. Its absorption characteristics, especially its absorption peaks, can be easily adjusted to the noise spectra through tuning the depth sequence of the sub-cavities. Not as the conventional porous and fibre sound materials, MPP absorber is a type of eco-friendly sound absorber that has been used in many applications [18-20]. In this paper, sound barriers made from specially designed kinds of MPP absorber are proposed to avoid the performance deterioration from multiple reflections between the parallel barriers. A finite element modeling procedure is implemented to investigate the insertion loss of the proposed parallel barriers and compared with the results of parallel barriers with rigid wall and porous material.

2. Finite element modeling

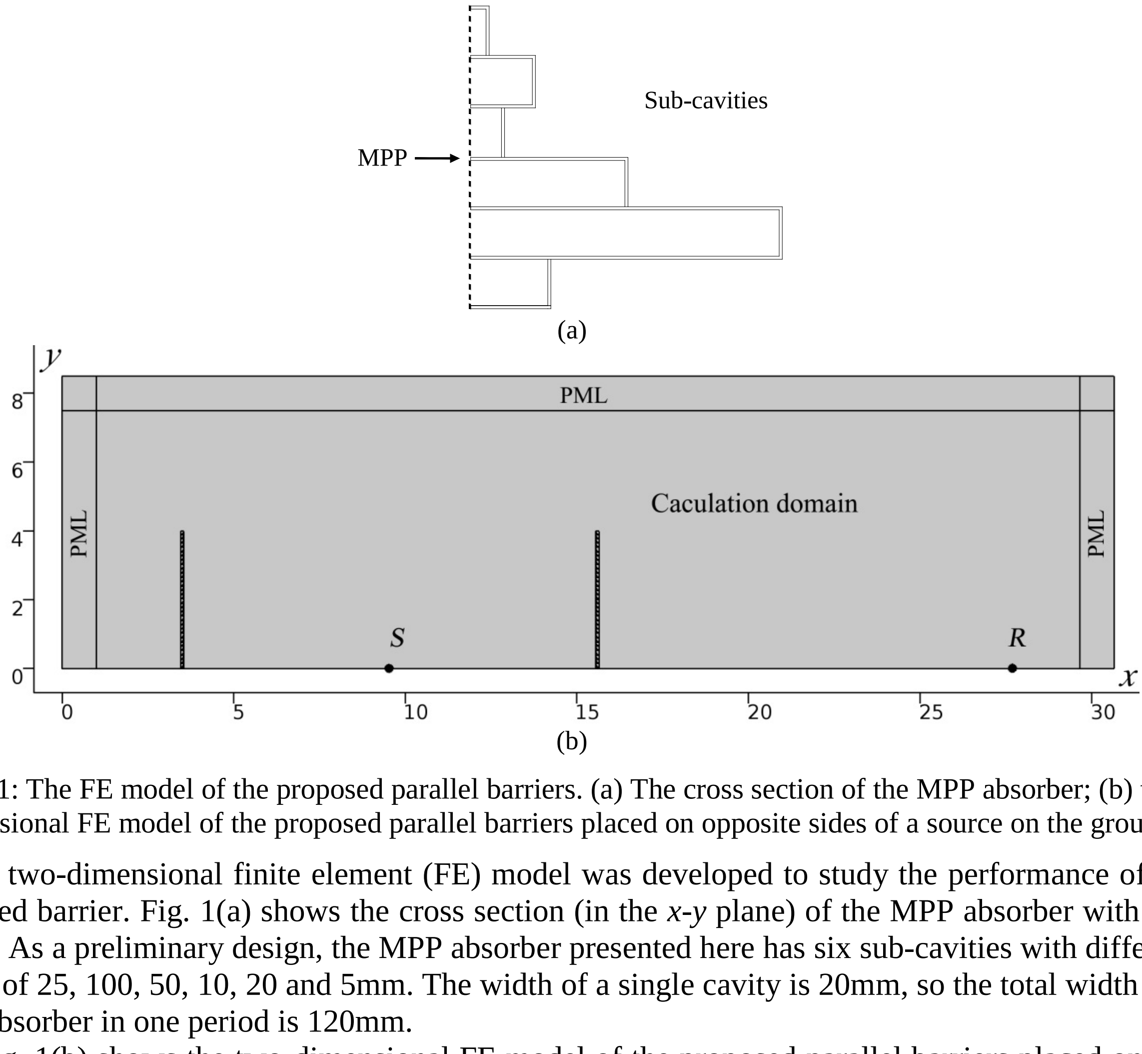

Figure 1: The FE model of the proposed parallel barriers. (a) The cross section of the MPP absorber; (b) two-dimensional FE model of the proposed parallel barriers placed on opposite sides of a source on the ground.

A two-dimensional finite element (FE) model was developed to study the performance of the proposed barrier. Fig. 1(a) shows the cross section (in the *x*-*y* plane) of the MPP absorber with one period. As a preliminary design, the MPP absorber presented here has six sub-cavities with different depths of 25, 100, 50, 10, 20 and 5mm. The width of a single cavity is 20mm, so the total width of a MPP absorber in one period is 120mm.

Fig. 1(b) shows the two-dimensional FE model of the proposed parallel barriers placed on opposite sides of a source on the ground. The modeling procedure is established by the commercial software COMSOL Multiphysics. Two acoustic domains are defined, the first domain is the calculation domain, which including the parallel barriers, ground, source *S* and receiver *R*. The height and width of the two barriers are 4.0m and 0.1m, respectively. The distance between the two barriers is 16.0m, the source *S* is located at the middle of the two barriers with a coordinate (in *x*-*y* plane) of (9.55, 0), 18.1m away is the receiver *R*. Each barrier consists of 34 stacked MPP absorbers and a single backed panel. The MPP is defined as an impedance surface, the relative (to the characteristic impedance of air) acoustic impedance of it is [21]:

$$z_{MPP} = r + j\omega m. \tag{1}$$

where r is the relative acoustic resistance, $j=\sqrt{-1}$ is the imaginary unit, $\omega = 2\pi f$ is the angular frequency, m is the relative acoustic mass. r and ωm can be calculated by:

$$r = \frac{32\eta t}{\sigma\rho_0 c d^2}k_r, \quad k_r = \left[1+\frac{k^2}{32}\right]^{1/2} + \frac{\sqrt{2}}{32}k\frac{d}{t}. \tag{2}$$

$$\omega m = \frac{\omega t}{\sigma c}k_m, \quad k_m = 1+\left[1+\frac{k^2}{2}\right]^{-1/2} + 0.85\frac{d}{t}. \tag{3}$$

where f is frequency, ρ_0 is the density of air, η is the viscosity coefficient of air, c is the sound speed in air; k_r is resistance coefficient, k_m is mass reactance coefficient; σ, d and t are the perforation ration, orifice diameter and panel thickness of MPP, respectively; k is the perforate constant of MPP, which can be obtained by a useful design formula:

$$k = d\sqrt{f/10}. \tag{4}$$

Other surfaces of the calculation domain, except for the MPP, are assumed to be rigid. The second domain is the perfectly matched layers (PMLs), which are artificial absorbing layers allowing sound waves to propagate out from the domain with minimal reflections [22]. In other words, the PMLs are used to simulate an infinitely extended sound field within a finite size domain for computing efficiency. As shown in Fig. 1(b), the PMLs are applied at the boundaries of the calculation domain. Triangular elements were used to discretize the acoustical domains. Under the rule that there should be more than six elements per wavelength at the highest frequency in the range considered, the maximum size of the triangular element was set to be 0.014m.

The performance of the sound barriers is defined as insertion loss (IL), which is given as:

$$IL = 20\log_{10}\left(\left|\frac{p_0}{p_1}\right|\right). \tag{5}$$

where p_0 and p_1 are the sound pressure at the receiver without and with the barriers installed, respectively.

3. Discussions

3.1 Model validation

As a preliminary validation of the FE modeling procedure above, the performance of a single barrier is simulated and compared with the results predicted by Kim's model [23], which is a theoretical method based on the geometrical theory of diffraction (GTD). The numerical model validated consists of a single rigid barrier placed between a source and a receiver; the height of the barrier is 2.0m, the source is located on the right side of the barrier with a height of 0.5m, the horizontal distance between the barrier and source is 2.0m. The receiver is located on the left side of the barrier with a mirror image position of the source. The calculated frequency range is from 10 to 4000Hz, with an interval of 10Hz. As shown in Fig. 5, the insertion loss of the single barrier predicted by the current FE model agrees well with the results predicted by Kim's model, which indicates that the FE modeling procedure presented here is accurate.

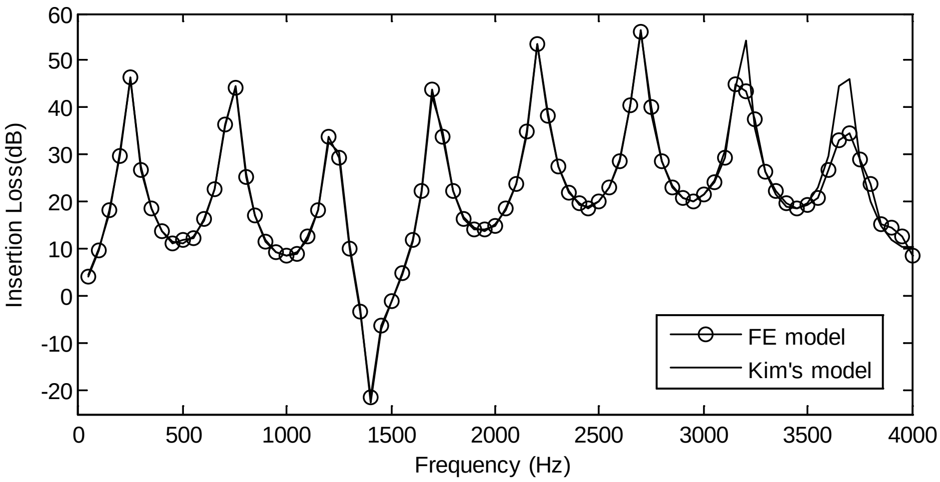

Figure 2: Comparison of the insertion loss of a single barrier predicted by the proposed FE model and Kim's model.

3.2 Results

Three numerical cases are employed to investigate the performance of parallel barriers, the different of them is the inner walls of the barriers are defined to have rigid, porous material and MPP absorber, respectively. The structure of the MPP absorber is shown in Fig. 1(a), the properties of the MPP are d=0.4mm, t=0.4mm, σ=1.8%. The thickness of the porous material is 40mm, and the flow-resistance of it is chosen to be 3000 Pa.s.m^2. As shown in Fig. 3, the sound absorption coefficient of the MPP absorber is predicted by the analytical method proposed in Ref. 17, while the absorption coefficient of the porous material is predicted by Delany and Bazley's model [24].

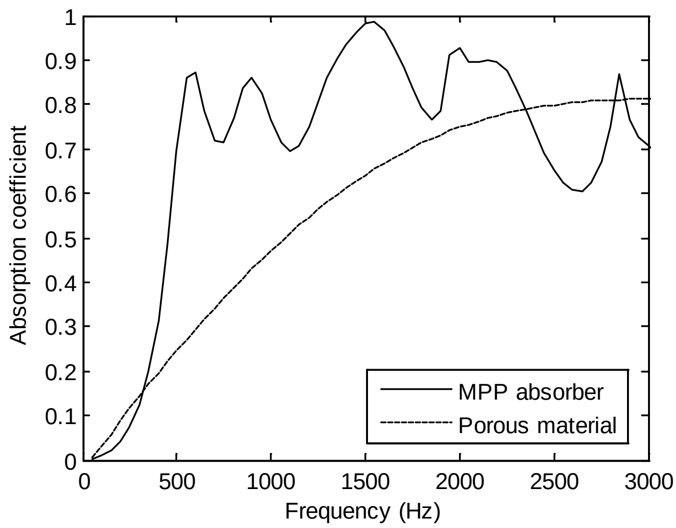

Figure 3: Sound absorption coefficients of the MPP absorber and porous material.

Fig. 4 shows the predicted insertion losses, in one-third octave band centre frequencies from 250Hz to 2000Hz, of the parallel barriers with rigid wall, porous material, and MPP absorber. It is shown that in the low frequency range, roughly below 500Hz, the insertion loss curves of the three cases agree well with each other, the differences between them are smaller than 2.5dB.This indicates that the improvements of insertion loss obtained by the absorption materials, both porous material and MPP absorber, are negligible in this frequency range. The reasons can be explained as follows. First, in the current model, the insertion losses below 500Hz are mainly dominated by the geometric configuration of the parallel barriers, which means the height of the barriers, the distance of the parallel barriers, and the location of the source and receiver are the key parameters that affect the performance of the parallel barriers. Second, as shown in Fig. 3, although the sound absorption coefficient of the MPP absorber at 500Hz is 0.7, but it drop sharply with the frequency decreasing. And the sound absorption coefficients of the porous material below 500Hz are even smaller than 0.25. Neither of them have satisfactory sound absorption ability in this frequency range.

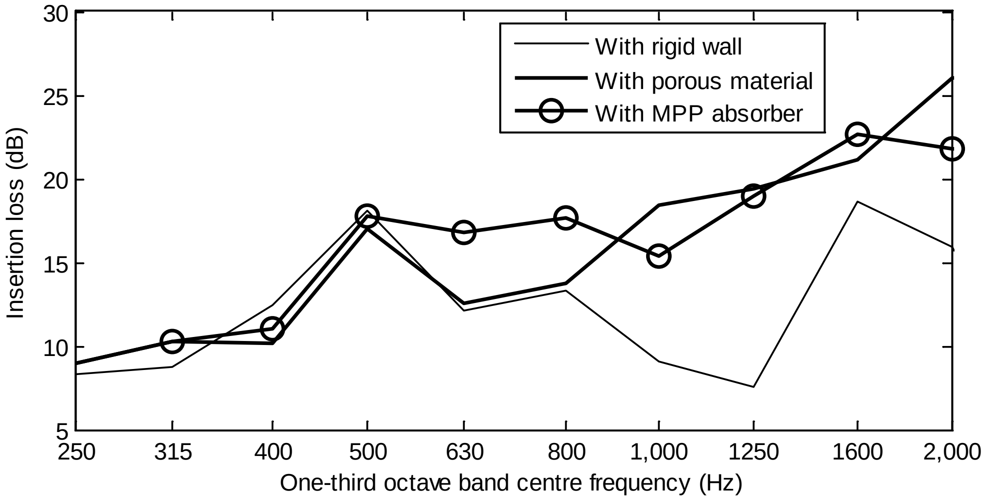

Figure 4: Comparison of the insertion loss of noise barrier with MPA wall and rigid wall.

In the frequency range of 500~800Hz, the improvement of insertion loss brought by the MPP absorber is observed. In comparison with the insertion losses of the parallel barriers with rigid wall and porous material, the MPP absorber provides an average improvement of around 5dB in this frequency range. This is because the average sound absorption coefficient of the MPP absorber is around 0.8, while the sound absorption coefficients of the porous absorber are still smaller than 0.5. It is also indicated that, the performance deterioration caused by the multiple reflections between the parallel barriers is emerging in high frequency range (above 500Hz). The way to avoid the reduction in performance is to apply a high-absorption layer on the inner faces of the parallel barriers. However, it is hard for porous material to achieve high-absorption in low frequency range for the limitation of material thickness. Therefore, the performance of the parallel barriers with porous material has little improvement in the frequency range of 500~800Hz.

Above 800Hz, the insertion loss of the barriers with rigid wall is consistently decreased until at 1250Hz, where an insertion loss dip is observed. While, the insertion losses of the parallel barriers with MPP absorber and porous material increased with the increasing frequency. As a result, at 1250Hz, the insertion losses of the barriers with MPP absorber and porous material are around 18.9dB while that for the rigid wall ones is 7.6dB, hence an optimal improvement of 11.3dB has been achieved. It is also shown that the improvements bought by MPP absorber and porous material are almost the same level above 800Hz, which indicates the absorption layer is effective to avoid the performance deterioration of the parallel barriers. But the porous material is unsuitable to be used in practical projects for its low-absorption ability at low frequency range and potential environmental problems such as the accumulation of dust and bacteria. The MPP absorber presented in this paper overcomes the above inherent vice of porous material. It is an eco-friendly sound absorber, and more importantly, its absorption spectra can be easily adjusted according to the needs of traffic noise, through tuning the depth sequence of the sub-cavities shown in Fig. 1(a).

4. Conclusions

To avoid the performance deterioration of the parallel barriers, a type of barriers made from specially designed kinds of MPP absorber were proposed in this paper. A FE modeling procedure was implemented and the accuracy of it was validated through an analytical model. The insertion loss of the parallel barriers with MPP absorber was numerically investigated and compared with those with rigid and porous material. The results indicated that in the current model, the performance of the parallel barriers below 500Hz is mainly dominated by the geometric configuration of the barriers; the absorption materials have little influences on the insertion losses of the parallel barriers. In the frequency from 500~800Hz, the MPP absorber provides an average improvement of around 5dB compared with the conventional rigid barriers, the performance deterioration of the parallel barriers has been improved. While, the improvements bought by porous material are quite small for its low absorption. Above 800Hz, both MPP absorber and porous material can efficiently avoid the performance deterioration of parallel barriers. But the porous material is unsuitable to be used in practical projects for its low-absorption ability at low frequency range and potential environmental issues.

Thus it is concluded that the use of specially designed MPP absorber presented in this paper is promising to improve the performance of sound barriers, especially parallel sound barriers. The influences of the parameters, including the properties of the MPP and the depth sequences of the sub-cavities, on the performance of sound barriers will be further investigated in future works.

REFERENCES

1 Hayek, S. I. Mathematical modeling of absorbent highway noise barriers, *Applied Acoustics*, **31**(1-3), 77-100, (1990).

2 Morgan, P. A., Hothersall, D. C., Chandler-Wilde, S. N. Influence of shape and absorbing surface—a numerical study of railway noise barriers, *Journal of Sound and Vibration*, **217**(3), 405-417, (1998).

3 May, D. N., Osman, N. M. Highway noise barriers: new shapes, *Journal of Sound and vibration*, **71**(1), 73-101, (1980).

4 Fan, R., Su, Z., Cheng, L. Modeling, analysis, and validation of an active T-shaped noise barrier, *The Journal of the Acoustical Society of America*, **134**(3), 1990-2003, (2013).

5 Voropayev, S. I., Ovenden, N. C., Fernando, H. J. S., et al. Finding optimal geometries for noise barrier tops using scaled experiments, *The Journal of the Acoustical Society of America*, **141**(2), 722-736, (2017).

6 Ishizuka, T., Fujiwara, K. Performance of noise barriers with various edge shapes and acoustical conditions. *Applied Acoustics*, **65**(2), 125-141, (2004).

7 Okubo, T., Fujiwara, K. Efficiency of a noise barrier with an acoustically soft cylindrical edge for practical use, *The Journal of the Acoustical Society of America*, **105**(6), 3326-3335, (1999).

8 Menounou, P., Ho, You. J. Experimental study of the diffracted sound field around jagged edge noise barriers, *The Journal of the Acoustical Society of America*, **116**(5), 2843-2854, (2004).

9 Bowlby, W., Cohn, L. F. A model for insertion loss degradation for parallel highway noise barriers, *The Journal of the Acoustical Society of America*, **80**(3), 855-868, (1986).

10 Watts, G. R., Godfrey, N. S. Effects on roadside noise levels of sound absorptive materials in noise barriers, *Applied Acoustics*, **58**(4), 385-402, (1999).

11 Monazzam, M. R., Fard, S. M. B. Impacts of different median barrier shapes on a roadside environmental noise screen, *Environmental Engineering Science*, **28**(6), 435-441, (2011).

12 Yang, C., Pan, J., Cheng, L. A mechanism study of sound wave-trapping barriers, *The Journal of the Acoustical Society of America*, **134**(3), 1960-1969, (2013).

13 Wang, X., Mao, D., Yu, W., et al. Sound barriers from materials of inhomogeneous impedance, *The Journal of the Acoustical Society of America*, **137**(6), 3190-3197, (2015).

14 Schroeder, M. R. Binaural dissimilarity and optimum ceilings for concert halls: More lateral sound diffusion, *The Journal of the Acoustical Society of America*, **65**(4), 958-963, (1979).

15 Fujiwara, K., Miyajima, T. Absorption characteristics of a practically constructed Shroeder diffuser of quadratic-residue type, *Applied Acoustics*, **35**(2), 149-152, (1992).

16 Fujiwara, K. A study on the sound absorption of a quadratic-residue type diffuser, *Acta Acustica united with Acustica*, **81**(4), 370-378, (1995).

17 Guo. W., Min, H. A compound micro-perforated panel sound absorber with partitioned cavities of different depths, *Energy Procedia*, **78**, 1617-1622, (2015).

18 Asdrubali, F., Pispola, G. Properties of transparent sound-absorbing panels for use in noise barriers, *The Journal of the Acoustical Society of America*, **121**(1), 214-221, (2007).

19 Soon-Hong, P. A design method of micro-perforated panel absorber at high sound pressure environment in launcher fairings, *Journal of Sound and Vibration*, **332**(3), 521-535, (2013).

20 Yu, X., Cheng, L., You, X. Hybrid silencers with micro-perforated panels and internal partitions, *The Journal of the Acoustical Society of America*, **137**(2), 951-962, (2015).

21 Maa, D. Y. Potential of microperforated panel absorber, *The Journal of the Acoustical Society of America*, **104**(5), 2861-2866, (1998).

22 Berenger, J. P. A perfectly matched layer for the absorption of electromagnetic waves, *Journal of computational physics*, **114**(2), 185-200, (1994).

23 Kim, H. S., Kim, J. S., Kang, H. J., et al. Sound diffraction by multiple wedges and thin screens, *Applied Acoustics*, **66**(9), 1102-1119, (2005).

24 Delany, M. E., Bazley, E. N. Acoustical properties of fibrous absorbent materials, *Applied Acoustics*, **3**(2), 105-116, (1970).