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Effect of absorption on the performance of diffusive T shape barriers

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ABSTRACT

Previous research [Applied Acoustics 66, pp.709-730, 2005] has shown that adding a cover based on a quadratic residue diffuser (QRD) design to the top of a T-shape barrier can provide significant improvement to the barrier performance. Such a design was adopted and successfully implemented in a railroad noise control project in Hong Kong [Internoise 2008 paper in08_0164]. The insertion loss performance of the production barrier was found to contain the predicted features of the diffusive barrier design, but the magnitude of the loss fell short of the prediction. Despite of this shortfall, it was still found to be significantly better than other alternative designs, and was subsequently chosen for the project. In this paper, we aim to determine the possible causes for this shortfall. The result should give guidance to how to avoid this reduction in performance so that the full potential of this diffusive barrier design can be achieved in future production products.

1. INTRODUCTION

It has been shown previously that adding a diffusive cover to the top of a T-shape barrier can significantly increase the insertion loss [1]. Numerical simulations and controlled laboratory experiments have shown that an increase of the order of 5-6 dB can be achieved within the operating frequency range of the diffusive element. Using a typical traffic noise spectrum, the broadband increase in insertion loss was calculated to be around 2.5 dB A-weighted. This improvement was found to be better than that could be achieved by putting a fibrous absorptive cover on to the T-top [2].

The success of the concept has led to the development of a commercial diffusive noise reducer barrier, which is now implemented along a railway line in Hong Kong [3]. Because of the nearby high-rise residential buildings, the barrier needs to have significantly better performance than typical rigid T-shape design. The diffusive barrier was judged to be the most effective among all the alternative designs. Despite this success, the actual insertion loss performance of the commercial barrier was found to be poorer than that predicted by simulation and by scaled model measurements. In order to improve future production, reasons for the reduced performance need to be determined. This paper describes the result of an investigation into the performance of the diffusive barrier.

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2. PERFORMANCE OF THE DIFFUSIVE BARRIER

A. Diffusive Design

The diffusive cover was based on a quadratic residue diffuser (QRD) design [4]. This is chosen because of the well established design principle of the QRD, and the proven diffusive performance of QRD in room acoustics. It is however noted that the determining factor for the performance of the diffusive cover on the top of a barrier is its ability to attenuate the propagation of sound along the top, and not necessarily its diffusion ability, although the two are closely related. Therefore further optimization of the design is possible by moving away from a standard QRD design. However, in this case, a standard 7-well QRD was used. The well sequence chosen is 2412413 with a maximum depth of 200mm. The design frequency f_r relates to the well depth d_n where n is an integer [5]:

$$d_n = \frac{c\left(n^2 \bmod N\right)}{N(2f_r)} \tag{1}$$

where N is an odd prime number and c the sound velocity.

The design range of the QRD is determined from the extremum wavelengths λ_{min} and λ_{max} [5]:

$$\lambda_{\max} \approx \frac{2Nd_{\max}}{n_{\max}}; \qquad \lambda_{\min} \approx 2w \tag{2}$$

Where w is the well width, d_{max} is the maximum well depth and n_{max} the maximum number from the sequence (n^2mod$N$). The commercial design is for a frequency range from 400 Hz to 1.6 kHz.

For commercial production, the diffusive cover was manufactured using aluminum panels which were bent into the required well shapes and depths.

B. Full Scale Test

Prior to implementation along the railway line, the performance of the production cover was measured in a full scale test in the premises of the manufacturing company. The test site arrangement is shown in Figure 1 (not to scale).

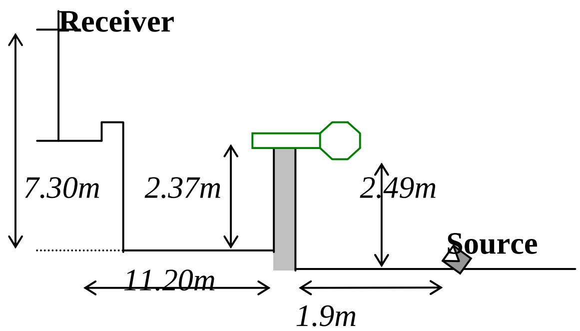

Figure 1 Test set-up for full-scale measurements.

The high up receiver location was chosen to reflect the high-rise residence buildings along the railway line. The sound pressure level at the receiver was measured with the diffusive cover, and with the top covered by a rigid panel to represent a corresponding rigid T-top with the same geometry. The difference in the sound pressure level therefore gives the extra attenuation provided by the diffusive cover over that of a rigid T-top. The measured result is compared with that predicted by a boundary element model [1] in Figure 2.

It is clear that the measured extra attenuation provided by the diffusive cover is lower than predicted. The measured values actually matched the predicted values well at the baseline levels, but the high peaks in the prediction are not realised in the measurement. This is particularly obvious in the 800 and 1.25k Hz 1/3 octave bands where improvements of only 4-5 dB is achieved in the actual performance compared to the predicted improvement of 10-15 dB. The BEM used in the prediction has been validated against laboratory measurements to an accuracy of around 1 dB in previous studies of diffusive barriers. It is therefore unlikely that the discrepancies seen here is due to errors in the prediction. Something else in the production unit is causing the reduction in performance.

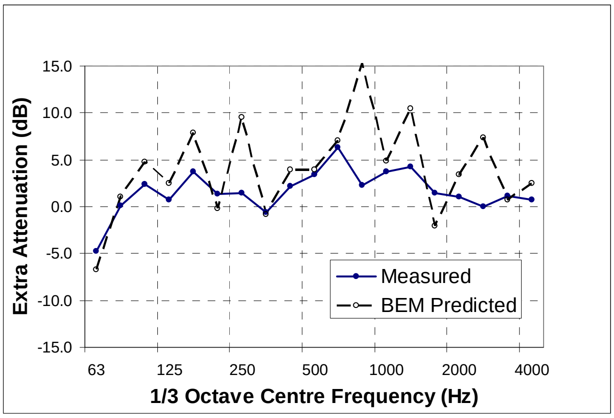

Figure 2 Measured and predicted extra attenuation provided by the diffusive cover at a high-up receiver.

C. Nearfield Test

Figure 2 is for a particular receiver location. It is therefore susceptible to receiver specific interference effects caused by ground and other nearby reflections. Previous research have shown that the performance of a diffusive cover for barrier applications can be characterised by the attenuation of the sound as it propagates from one end of the cover to the other [6]. It is therefore possible to determine the performance by measuring the attenuation at the edge of the cover. Such a nearfield measurement method has been developed [7] and applied to this diffuser. The measured extra attenuation relative to that of a rigid top is compared with that predicted by the BEM in Figure 3.

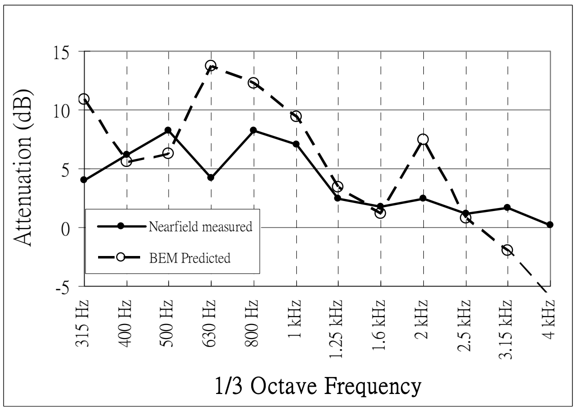

Figure 3 Measured and predicted nearfield extra attenuation provided by the diffusive cover.

It is again clear that the measured real attenuation does not have the strong peak values that are predicted by the numerical simulation.

3. EFECT OF ABSORPTION

A possible reason for the reduction of the peak values in the attenuation spectrum is increased absorption in the production unit. Indeed, research has shown that the addition of absorptive elements in the diffusive cover is detrimental to the performance of a diffusive barrier. The reason is that the attenuation of sound along the cover, which is responsible for the increase in insertion loss, is caused mainly by the impedance discontinuity created by the different wells [6]. This impedance discontinuity is enhanced by the resonances of the wells. Hence large resonances increase the performance of the diffusive cover. Indeed, the peaky nature of the predicted attenuation spectrum can be seen as indicative of this resonance behaviour. It is therefore not surprising to find that increasing the absorption inside the diffusive cover will degrade its performance. Figure 4 shows the predicted changes in the insertion loss when the diffusive cover of a T-shape barrier is stuffed with absorptive fibreglass. It can be seen that the large, peak insertion loss values were largely damped out. This behaviour is remarkably similar to what was found in the production diffusive cover (Figures 2 and 3). It seems that absorption could indeed be the reason for the differences between the performance of the production and laboratory diffusive barriers.

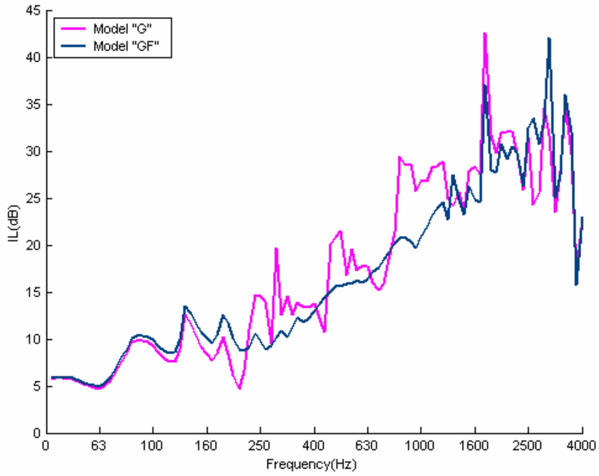

Figure 4 Effect of filling the wells of a QRD cover with absorptive fiberglass in a diffusive barrier.

To confirm this suggestion, the absorption coefficient of a sample of the production diffusive cover was measured using the reverberation room method. The result is shown in Figure 5.

The absorption coefficient of the production diffusive cover is over 0.6 between 160 Hz to 500 Hz, reaching about 0.7 – 0.8 between 315 to 400Hz, before dropping back to about 0.2 at higher frequencies. For the finished product, a perforated cover with 20% perforation was added for protection. This increases the absorption further to a maximum of 0.9 in the mid-frequency bands of 315 and 400 Hz. These values are substantially higher than that found in the scaled model barrier that was made with well varnished wood, which is of the order of 0.1. The absorption test clearly shows that the absorption in the production unit is much higher than expected, and supports the hypothesis that the degradation of performance is due to excess absorption in the production unit. The frequency range in which the absorption is high is from 100 to 630 Hz. This correlates well with the reduction of peak attenuation values shown in Figure 2 and 3 in this frequency range. The correlation is better with Figure 3 which shows the nearfield attenution result that is non-receiver specific. When compared with Figure 2, which is specific to a high receiver position, it is noted that the peak attenuation values in the 800 and 1000 Hz bands are also significantly reduced, while the measured absorption coefficient in those bands are only of the order of 0.2.

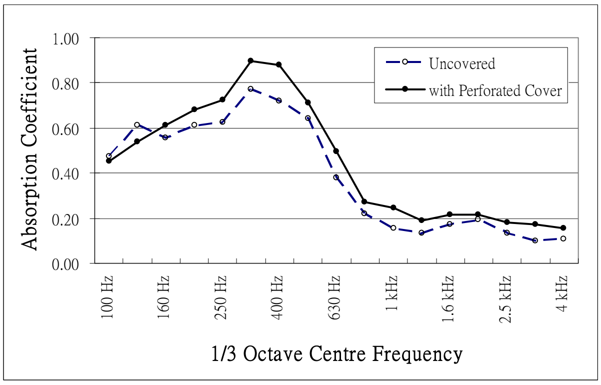

Figure 5 Absorption coefficient of a sample of the diffusive cover measured in a reverberant room.

The reason for the excess absorption in production unit is probably due to difficulties in sealing all leaks and gaps between the wells that were formed by bending aluminium panels. It was known that practically construction can give rise to substantial absorption in a QRD [8]. In addition, the thin aluminium panels are also prone to resonances of their own, producing resonant absorption. These together could explain the high absorption found in the production diffuser.

A series of modifications were performed on a sample of the production unit in an attempt to reduce the absorption. Unfortunately, with the constraints of the basic aluminium construction technique, it was not possible to reduce the absorption significantly. At the end, since the performance of the unit was already well within requirements, it was not considered cost-effective to make radical changes to further the investigation.

4. CONCLUSIONS

A commercial product using the diffusive T-shape barrier design was developed and tested. The performance was found to be less than predicted. In particular the peak attenuation values were found to be substantially reduced. An investigation was conducted to find the causes. Reverberation room measurements on a sample of the production unit has found that the sample has large absorption in the mid frequency range, from 100 to 630 Hz. This correlates well with the frequency range in which the performance of the diffusive cover was found to be reduced. The absorption coefficient, reaching a maximum of 0.9, is much higher than that found in scaled models that were made with well varnished wood. Previous research on the effect on adding absorption in a diffusive barrier has already shown that increasing absorption will reduce the peak values of the diffusive barrier. This is because the main attenuation mechanism of the diffusive cover comes from well resonances, which will be significantly reduced by large absorption. It is therefore concluded that the reduction in performance in the production unit is due to excess absorption in the unit. The cause of the absorption is thought to be due to leaks and gaps in the aluminium construction, and resonances of the thin aluminium panels. This investigation has shown that, to gain maximum performance from a diffusive barrier top, it is important to keep the absorption in the diffusive element as low as possible to avoid excessive damping of the air resonances in the wells.

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