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The insertion loss of thick barriers with rectangular and circular vertical edges

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ABSTRACT

A model study of a thick barrier of finite length on a hard reflecting ground is presented. One of the vertical edges is isolated so diffraction only occurs from the top edge and one of the side edges. The reference case is when the side edge angle is 90° (rectangular edge) which is compared to several cases with increasing angle from 90° to 180° (circular edge). In this paper the reference case is presented and compared with the 180° case. The measurements were conducted in a semi-anechoic chamber using a line source for the frequency range 250 Hz to 20 kHz. The barrier thickness was 150 mm which corresponds to a characteristic frequency of about 2 kHz. The measurement results show that the insertion loss is basically broadband. It increases with frequency and the rate of increase is relatively rapid at 2 kHz which is the characteristic frequency of the edge. However, there is a dip in the insertion loss at about 8 kHz for the circular edge.

INTRODUCTION

Traffic noise pollution is a widespread problem that affects people in cities around the world. This is especially true in highly congested cities as Hong Kong for example. Due to the limited land area that is available for housing development and infrastructure together with an increasing population has created many problem areas in Hong Kong. Existing guidelines dictates that the sound level 1 meter from a residential building facade should not exceed 70 dBA. In order to achieve this, several creative solutions must be employed. One common such is to use barriers to mitigate the traffic noise. Barriers have been used since the mid 20th century for traffic noise reduction and the most effective way to use barriers is to place them either close to the source or the receiver. The effectiveness of rigid thin barriers has been investigated thoroughly for the past half century. The main reason why so much focus has been put on barriers is due to the problem of diffraction. Maekawa's chart [1] has been a useful engineering tool for getting a rough estimation of barriers performance when taking diffraction into consideration. Several improvements have been made to the empirical solution provided by Maekawa, where on is by Pierce [2], who provided a solution for a wedge shaped barrier with arbitrary angle. Many theories and numerical prediction models have been presented but very few analytically exact solutions have been obtained. An exact 2D plane wave solution was presented by Sommerfeld [3] over a century ago, and a 3D point source solution by McDonald [4] about a decade and a half later. Macdonald's solution is often used for comparing and validating numerical solutions. However, it is not suitable for engineering purposes, which is why it is still of value to pursue an accurate but easily implemented prediction model for diffraction problems. Due to the complexity of diffraction problems concerning thick finite barriers, numerical 3D computer simulations do not provide a sufficiently accurate result, and are usually very time consuming. Consequently, an experimental investigation has been conducted of a thick finite barrier to determine the sound propagation around one of the vertical side edges. Two edge conditions were studied, where the base case was a rectangular edge and the other was a semi-circular edge. In order to obtain a result that agrees with traffic noise conditions, a line source was used.

MODEL STUDY

Line Source

In order to obtain a reliable result for traffic noise related experiments it is necessary to build a line source, which has to be carefully constructed. The first thing is to chose which type of point source to use, and in this study 100 tweeters (RS, TMQ-050006F1-10) were chosen as individual point sources, to form a 5m long line source. Other common options are spark sources, ultrasonic sources etc. However, loudspeakers are a comparatively inexpensive choice that shows satisfactory properties. Several important parameters have to be considered, such as the uniformity and directivity of the source as well as distance decay and the coherence. So as to obtain a source with adequate directivity a partial enclosure was built with a sufficiently small opening to allow diffraction of high frequencies. In figure 1, a photo of the line source can be seen.

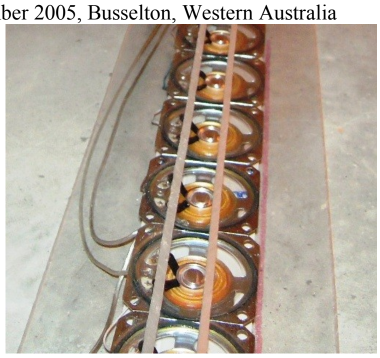

Figure 1. Photo of the enclosed line source

The speakers were attached to a wooden board and the enclosure was formed by two 8 mm thick PVC plastic panes fixed in 45 degree angle leaning towards the center of the line source, as can be seen in figure 1.

Thanks to the enclosure a quite uniform directivity was obtained and in figure 2, an example of the line source directivity can be seen for 4000 Hz. The directivity was measured at several locations along the line source, and the results varied marginally.

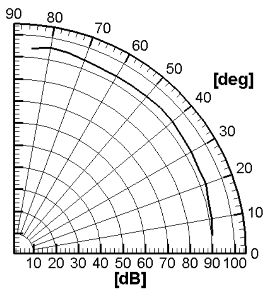

Figure 2. Polar plot of the directivity at 4000Hz

A more comprehensive analysis of the used line source is presented in another paper at a later time.

Model barrier

The barrier was built from ½ inch thick laminated plywood board, with the following dimensions: 1.5m height, 1.2m length and 0.15m width. The inside was filled with fibreglass insulation to reduce any standing waves and vibrations. The barrier width was chosen specifically since it corresponds to the wavelength at 2000 Hz, which was of interest for this particular study. Two cases were investigated where the first was with a regular 90 degree edge and the second with a rounded 180 degree edge. The rounded edge was constructed from steel plate and attached to the rectangular edge. The hollow space between the edges was filled with insulation.

Acquisition method

The experimental results were obtained by measuring the pressure differences with 36 Brüel & Kjaer type 4951 microphones. They were arranged in an array that consisted of three aluminium rods, 3m long placed vertically 0.5m apart, and on each rod 12 microphones were attached spaced out every 0.25m. The rods were firmly attached to a lightweight frame that was easily manoeuvrable. The microphones were connected to the Brüel & Kjaer PULSE™ Analyzer Platform (3560D), which is a portable multichannel data acquisition unit. The software used for the data logging was the Brüel & Kjaer PULSE time data recorder type 7708.

Experimental procedure

The experiment was performed in a semi-anechoic chamber, where the line source was connected to an amplifier and a Brüel & Kjaer random noise generator type 1405 that was set to produce white noise up to 20 kHz. To begin with the sound field was mapped without the barrier. This was done by moving the microphone array parallel to the line source along the chosen distances. In order to get a better analysis of how the sound field looked like close to the vertical edge a tighter measurement interval was chosen in that area. The next step was to position the barrier 1m from the line source with one edge isolated by the chamber wall. This was done to ensure diffraction only around the top and the other side edge of the barrier. Silicon was used for filling any gaps between the barrier and the floor to minimize sound leakage. The array was positioned at the same points as in previous measurement. Finally the barrier was modified and refitted with the rounded edge and another set of measurements were carried out. A layout of the chamber and experiment setup can be seen in figure 3.

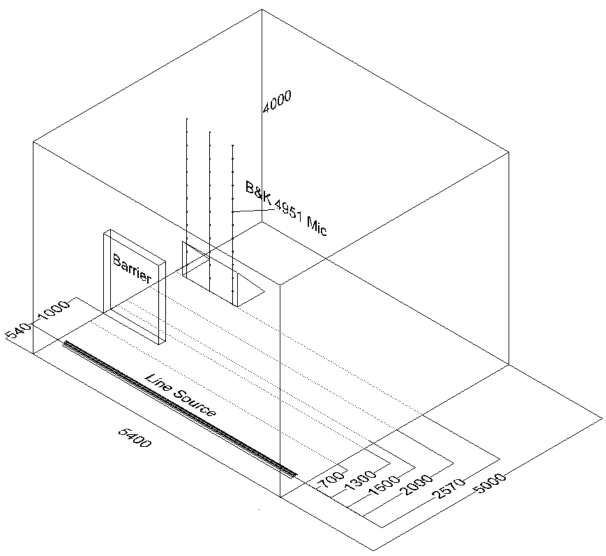

Figure 3. Layout of the semi-anechoic chamber and experiment setup

RESULTS

The acquired time data was processed by performing a 1/3 octave band spectrum analysis using MATLAB, and the insertion loss (referred to as IL hereafter) was calculated for both cases. A clear trend could be seen for both cases specifically that the IL was highest close to the ground, behind the barrier, and gradually decreased with distance from the ground. This was also the case at all frequencies. As a result of this a representative height was chosen, which was half the height of the barrier (0.75m above the ground), to compare the performance of both configurations. When analysing the results of the IL, an unexpected sharp dip was found at 8000Hz, which occurred at both cases and seemed to be uncorrelated to the measurement point location including distance from the barrier.

The dip occurred close to the ground, close to the barrier edges, and also at points in the middle of the barrier. A speculation is that the dip occurs due to ground interference. Consequently there were two frequencies of interest, specifically 2000Hz since the wavelength correlates to the barrier thickness and 8000Hz due to the dip. A number of other frequencies are presented in order to provide a better view of the results. The chosen frequencies have been plotted as contours at the representative height for both cases and also the difference in IL between the cases. The first column is the rectangular edge, the second is the rounded edge, and finally the third column shows the difference in IL with reference to the base case. Each column has a respective colorbar, where the scale is the same for the rectangular and rounded edge. The barrier is coloured grey in the plots and is seen from above. The area in front of the barrier is covered since it shows irrelevant data due to interpolation made by the software.

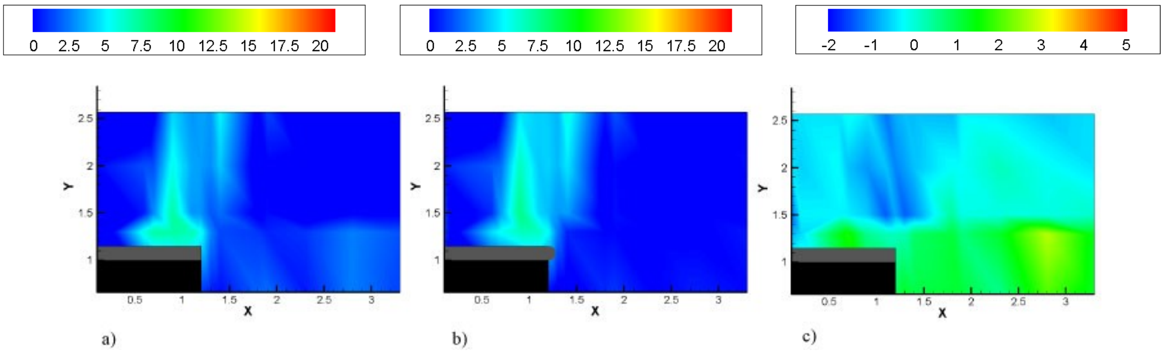

Figure 4. a) Rectangular edge – 500 Hz, b) Rounded edge – 500 Hz, c) Difference in IL between a) and b)

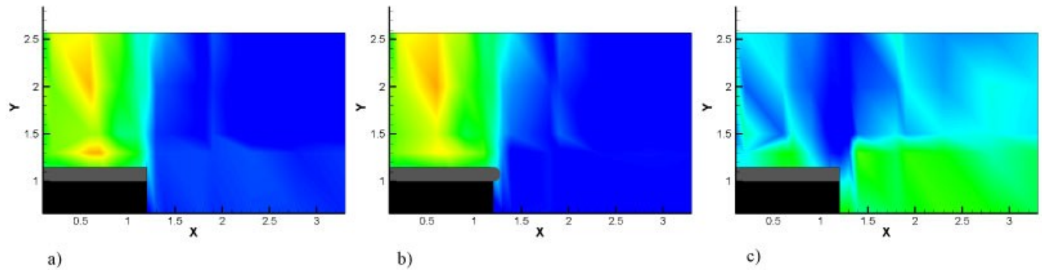

Figure 5. a) Rectangular edge – 2000 Hz, b) Rounded edge – 2000 Hz, c) Difference in IL between a) and b)

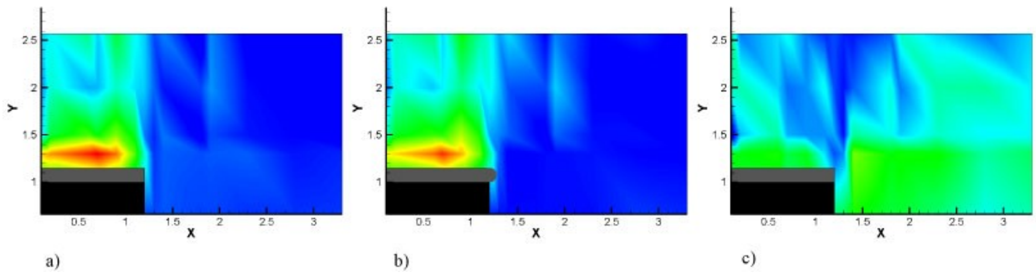

Figure 6. a) Rectangular edge – 4000 Hz, b) Rounded edge – 4000 Hz, c) Difference in IL between a) and b)

For the base case (rectangular edge) it is apparent that for low frequencies as shown in Figure 4a, the barrier does not provide much attenuation. However, the area closest behind the barrier has 10 dB IL which drops rapidly after just 0.4m. The same can be said for the rounded edge (Fig, 4b), with the small difference that the area of attenuation is slightly bigger further away from the barrier and smaller closer to the barrier. In Fig. 4c, the difference can be seen more clearly and it shows that the rounded case allows more diffraction close to the barrier but has slightly better shielding effect further away from the barrier. When the frequency is 2000Hz as shown in Fig. 5a to 5c, a much larger IL is found, as expected.

Although, probably due to the correlation between barrier thickness and wavelength at this specific frequency, one can see that the sound diffracts and leaks into the shadow zone close behind the barrier (Fig. 5a). And only in the middle is there a significant increase in IL (~17.5 dB) which stretches and broadens with distance from the barrier. The amount of diffraction close to the barrier is more significant for the rounded case (Fig 5b) which decreases the IL, but again covers a larger area with higher IL further away from the barrier, compared to Fig. 5a, which is also confirmed in Fig 5c. At 4000 Hz there is a considerable increase in IL (~20 dB) as can be seen in Fig. 6a, which covers a larger area close to the barrier. The same pattern is repeated as for 2000 Hz, when comparing the two cases which can be seen in Fig. 6b and 6c.

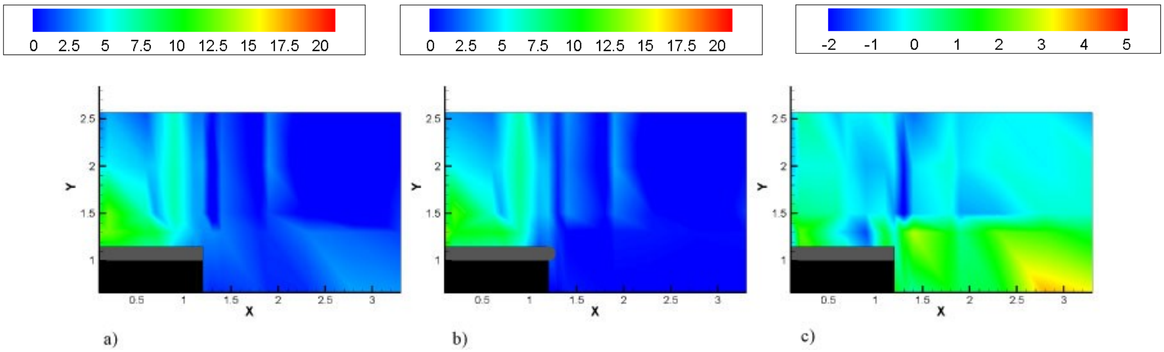

Figure 7. a) Rectangular edge – 8000 Hz, b) Rounded edge – 8000 Hz, c) Difference in IL between a) and b)

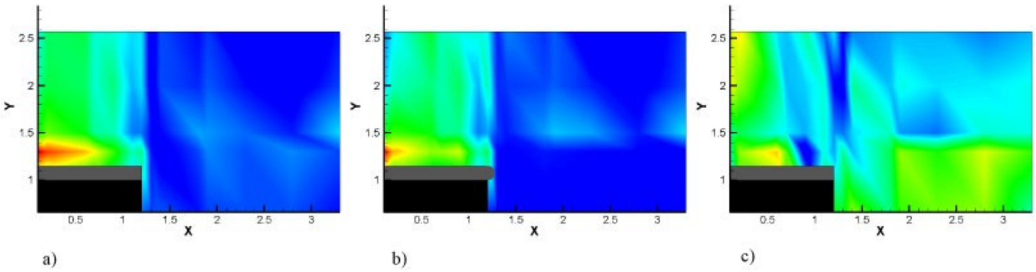

Figure 8. a) Rectangular edge – 10 kHz, b) Rounded edge – 10 kHz, c) Difference in IL between a) and b)

When studying the contours for 8000 Hz (Fig. 7a), where the dip in IL occur it can be seen that the IL has decreased significantly and has a maximum of about 9 dB. There are areas that have no IL at all close to the vertical edge and in the far field. The contour of the rounded case (Fig. 7b) has a similar shape but when looking at the difference in Fig. 7c one can see that the rounded edge provides slightly more IL than the base case closer to the vertical edge. For 10 kHz (Fig. 8a) we see a similar shape as earlier for 4000 Hz (Fig. 5a,b). However, the total IL is reduced in comparison, and the area close to the barrier is smaller. Still, when comparing the rounded case (Fig. 8b) with the base case a recognizable pattern is seen. The area close to the barrier is significantly smaller than for the rectangular case, with the exception of a small area close to the vertical edge.

CONCLUSION

In the study presented in this paper an experimental investigation was conducted on a thick finite barrier with two different edge configurations. The base case being a 90 degree rectangular edge and the other a semi-circular 180 degree edge.

A line source was constructed and used as the sound source in order to obtain relevant data related to traffic noise conditions. The insertion loss was attained by mapping the sound field without the barrier, and with the two barrier configurations.

Initial findings indicates that for the presented frequencies the rectangular edge has a higher insertion loss close to the barrier compared to the rounded edge, which seems to allow sound waves to diffract more easily. However, the opposite appears to be the case further away from the barrier, where the rounded edge provides a slightly higher degree of insertion loss.

The unexpected dip at 8000Hz may be present due to ground interference that is caused by the line sources semi-coherence, however, the exact cause is not know at this moment. Further investigations are required.

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REFERENCES

1 Z. Maekawa, "Noise Reduction by Screens" *Applied Acoustics*. **1**, 157–173 (1968)
2 A.D. Pierce, "Diffraction of sound around corners and over wide barriers" *J.Acoust. Soc. Am*. **55**, 941–955 (1974)
3 A. Sommerfeld, *Mathematical Theory of Diffraction* Trans. Nagem, R. J, Zampolli, M. and Sandri, G (Birkhäuser, Boston, 2004) pp. 317–374
4 H.M. MacDonald, "A Class of Diffraction Problems" *Proc.London.Math. Soc* **14**, 410–427 (1915)