WAVE TRAPPING BARRIERS

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Abstract

A noise barrier is an effective noise control device with many applications. However when installed in front of a noise source with a large reflective surface, its performance deteriorates. Multiple reflections of noise between the barrier and the source significantly reduce the insertion loss of the barrier. For instance, 15 dB insertion loss of a single noise barrier can be decreased to about 5 dB when multiple reflections occur. Absorptive treatment of the noise barrier can reduce the multiple reflections, but it is often not practical when used in an outdoor environment, especially for low-frequency noise. A wave-trapping barrier has been developed to solve the multiple-reflection problem. The surface of the wave trapping barrier facing the noise source is designed to effectively absorb low frequency noise and to control the direction of the multiple reflections. The internal surface of the barrier is made of perforated panel. When combined with the back cavity and absorptive lining in the cavity, the surface/cavity system behaves as a distributed Helmholtz absorber, which can be tuned to the frequency range of interest. The profile of the surface is designed such that the residue (reflected) noise is trapped between the barrier and noise source, so that the noise escape from the barrier top due to multiple reflections is minimized. This wave-trapping noise barrier has been designed and installed at a WA mining site. Its advantage over traditional noise barriers is demonstrated experimentally. A significant reduction of the noise from several large gear-boxes, especially for the low-frequency tonal components, is achieved.

Introduction

Noise barriers are the most common protection used in attenuating outdoor noise propagation. Their design and performance have been well documented [1] The performance of a noise barrier is described by the sound insertion loss IL, which is the decibel value of the ratio between sound pressure (at the receiving position) before and after the installation of the barrier. The theories to calculate a barrier's insertion loss are based on Huygen's principle and Kirchhoff's diffraction formulation [2]. There are also many approximate expressions of insertion loss for engineering estimations. Typically, Maekawa's asymptotic expression [3],

$$IL = 10\log_{10}(3+20N) \text{ (dB)} \tag{1}$$

describes the general features of reflective noise barriers, where $N = \frac{2}{\lambda}\delta$ is Fresnel's zone number, λ the wavelength, and δ is the difference in the path lengths between the source and receiver before and after the barrier installation. A close observation of Equation (1) shows that to increase the insertion loss in the low frequency range (where λ is large), δ has to be increased and hence the barrier height increased. However, there is always a practical limitation to the barrier's height. Therefore the question of how to increase the insertion loss of a barrier with a given height has been a challenge to researchers for decades.

Over the last decade, only some incremental progress has been made. This includes the study of the effect of various shapes of the top part of a barrier on its performance [4] and the use of active noise control to reduce the sound diffraction at the top [5]. However, few new and critical questions about the fundamentals of barrier acoustics were raised.

On the other hand, decreased performance has been reported in many engineering applications of parallel barriers [6] and for barriers installed in front of noise sources with large reflective surfaces. Watts reported that where reflective traffic noise barriers are placed on both sides of the highway, the performance of the reflective barriers is reduced (by 4 dB for his 2 m high barrier). A significant decrease is observed in insertion loss at low frequencies for a noise barrier when it was installed in front of large gearboxes at a WA mining site. For these two cases, the insertion losses are much less than that predicted by Equation (1). The reflected noise from the far side barrier or gearbox surfaces made a significant contribution to the noise level at the receiver location.

A simple solution to reduce such reflection is to add sound absorptive material on the barrier surface. However the required thickness of the absorptive material for low frequency noise will lead to an impractical, bulky and costly noise barrier. Moreover, existing absorptive materials are not suitable for long-term use outdoors and public concern about irritation of the human respiration system, due to fibers from porous material, has strengthened the case for using fibreless sound absorptive devices [7].

To overcome the effect of the reflection between the barrier and gearboxes, A new type of noise barrier named a "wave trapping barrier" (WTB) is developed. Figure 1 shows the concept of a WTB. The profile (as shown in Figure 1(b)) and sound absorption properties of the WTB are designed to retain the noise between the source and the barrier and to provide maximum sound absorption at the frequencies of concern. To achieve maximum sound absorption, Helmholtz resonance absorption was used to absorb the tonal components of the gearbox (Figure 2). The sound absorptive material in the acoustic cavity and the continuous change of the cavity depth are designed with a view to increasing the frequency range of sound absorption.

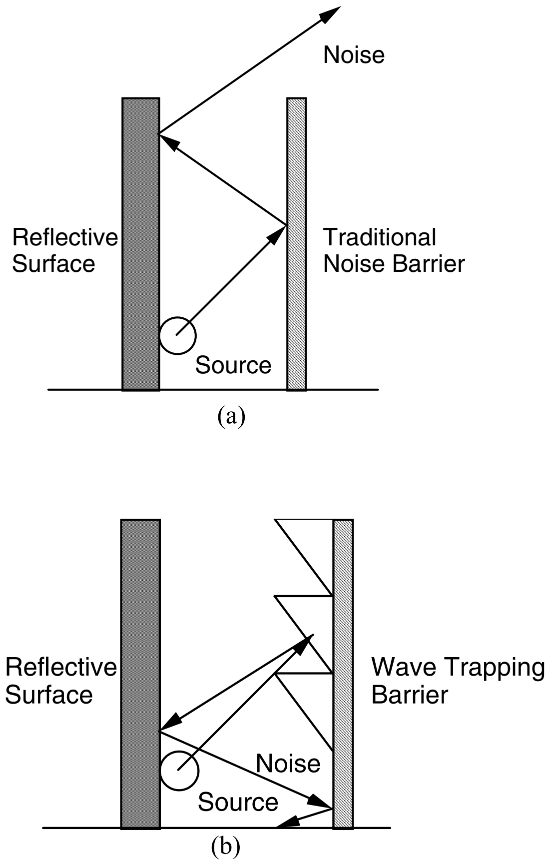


Figure 1. Illustration of (a) reflection problem between a traditional barrier and a reflective surface, (b) possible solution offered by the wave-trapping barrier.

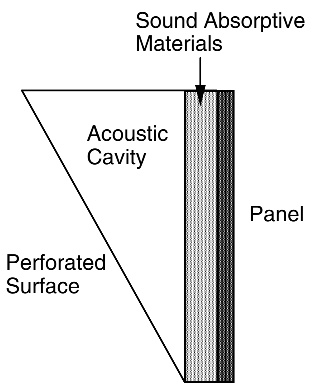


Figure 2. Illustration of resonance absorption of the WTB surface.

The design concept of a WTB was checked by a series of laboratory tests using scaled models and prototype WTB. Important design parameters, such as dimensions and shape of the acoustical cavity, perforation rate of the surface panel, and the thickness of the sound absorption materials within the cavity, were identified. Given the same height and absorption treatment, a comparison of the insertion loss between various traditional noise barriers with the WTB demonstrates that the WTB can produce higher insertion loss in the frequency ranges of interest.

Installation of a WTB

Based on the design concept and the results from laboratory experiments, a 5 m high WTB was designed and installed at a WA mining site to reduce the noise radiation from a gearbox drive station. The gearboxes at the station generate high level tonal noise, which significantly contributes to over 85dBA near the station area and about 38dBA (including tonal adjustment) at the residential area 1.5km north-west of the station. Figure 3 shows the relative locations of the residential area and the stations (including a nearby transfer station).

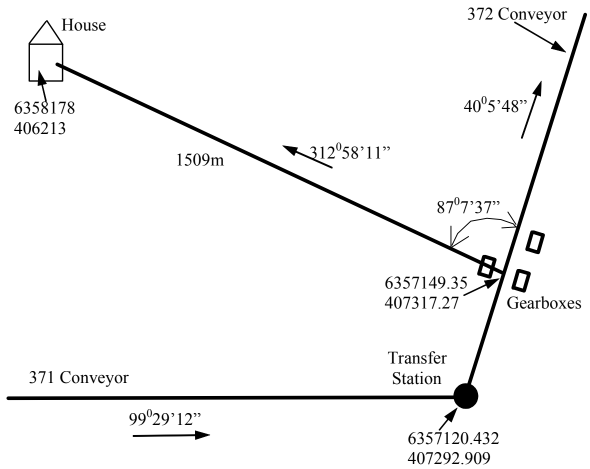


Figure 3. Schematic diagram of the transfer station and drive station.

The gearbox drive station (facing the residential area) is shown in Figure 4(a), where the gearboxes, motor drive and attached structures form a large reflective surface. Also shown in Figure 4 is the design of a "U" shaped barrier around the station.

Figure 4 (a)

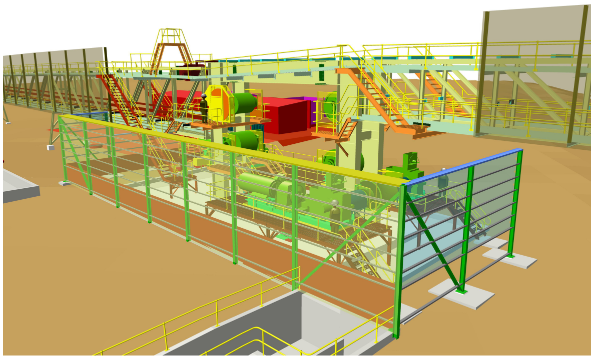


Figure 4 (b)

Figure 4. (a) Drive station before WT barrier installation, (b) A "U" shaped barrier design.

A series of pictures of the WTB at various stages of the installation is shown in Figure 5. At each stage, noise measurement was conducted at 12 locations selected within an $80m \times 60m$ range on the receiver side of the barrier (as shown in Figure 6) to evaluate the performance of the noise barrier.

Figure 5(a)

Figure 5(b)

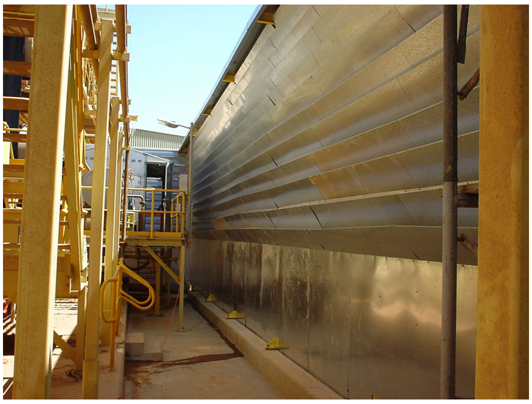


Figure 5(c)

Figure 5(d)

Figure 5. (a) Base panel of the WTBr, (b) Sound absorption material attached to the base panel, (c) WTB from inside, (d) WTB from outside.

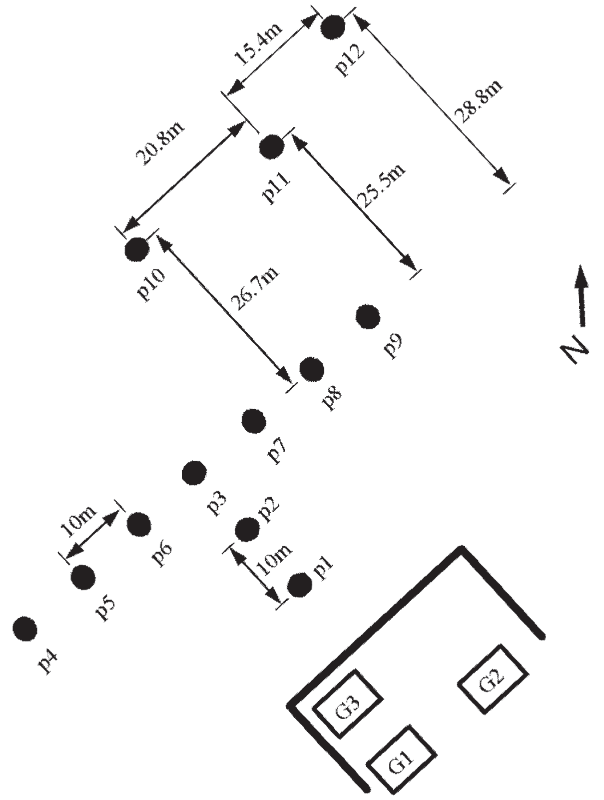


Figure 6. Schematic diagram of the measurement locations.

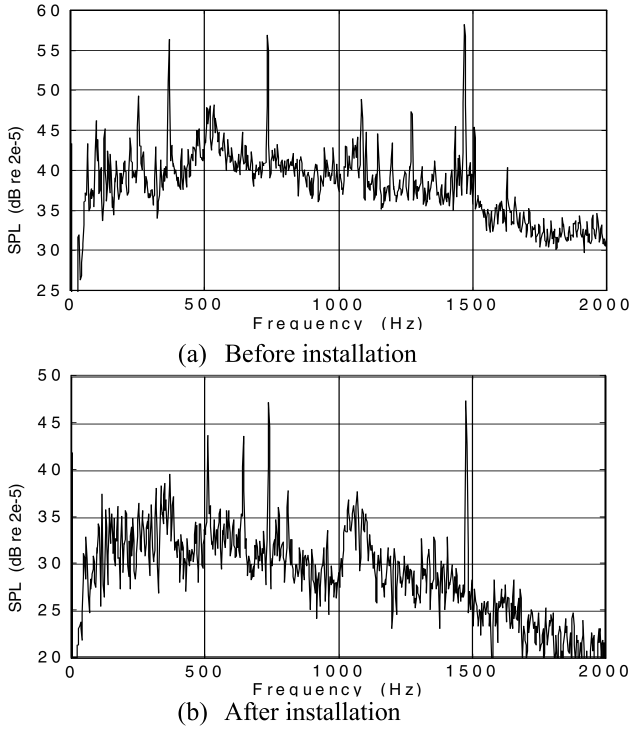
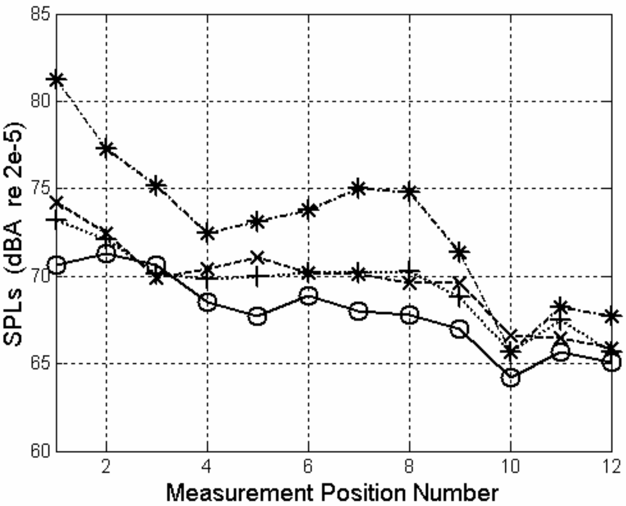


Figure 7. Sound pressure measured at p12 before and after the installation of the WTB.

Typical sound pressure measured at p12 before and after the installation of the WTB is shown in Figure 7. This location is about 70m from the noise source and 8m higher than the ground level, and the resident area can be seen from it. Peak frequencies in the sound field correlate to that from the noise and vibration measurement at the gearboxes. Before the installation, the sound pressure levels at these frequencies are much higher than the background noise (part of the background noise is radiated from the nearby transfer station, see Figure 3). After the installation of the WTB, a significant reduction of sound pressure at this location is observed. In particular, the tonal sound radiation in the low frequency range (below 500Hz) is eliminated, as the peak sound absorption of the Helmholtz resonators were designed in this frequency range.

The overall A-weighted sound pressure levels at all measurement positions are shown in Figure 8. In the shadow area (p1 and p2), a significant noise reduction about 10dBA was achieved. This indicates that the maintenance personnel in this area do not need to wear hearing protection ear muffs. The dBA noise reduction for each phase of the installation agrees with the measured tonal reduction. This confirmed that the reduction of tonal noise from the drive station has resulted in this overall noise reduction. However, the reduction of overall A-weighting SPL is relatively smaller than the tonal reduction (Table 1) especially in the far field area. This is due to the fact that the farfield noise is contributed by both the drive station and the transfer station. The reduction of the noise from one may not necessarily give a significant reduction of the overall noise. In the far field, after a significant reduction of tonal noise by the WT barrier, random noise radiated from the transfer station becomes the dominant contributor to the A-weighted sound pressure level.



Fugure 8: Sound pressure level at the 12 receiver' locations of Figure 6; (*: no barrier, x: reflective barrier, +: absorptive barrier, o: WTB).

Table 1. Measured sound pressure levels (dB re 20 micropascals) before ($^{b}L_{eqA}$) and after ($^{a}L_{eqA}$) WTB installation and the insertion loss (IL) at the tonal frequencies.

fre. / Pos. No.	367.5 Hz			510.0 Hz			735.0 Hz			1470.0 Hz		
	$^{b}L_{eqA}$	$^{a}L_{eqA}$	IL	$^{b}L_{eqA}$	$^{a}L_{eqA}$	IL	$^{b}L_{eqA}$	$^{a}L_{eqA}$	IL	$^{b}L_{eqA}$	$^{a}L_{eqA}$	IL
1	70.2	54.3	15.9	71.1	51.4	19.7	65.1	54.9	10.2	78.2	58.5	19.7
2	63.1	48.9	14.2	70.7	50.9	19.8	66.7	51.9	14.8	68.0	58.2	9.8
3	66.5	46.3	20.2	61.1	46.7	14.4	71.3	48.2	23.1	67.4	56.7	10.7
4	55.3	43.2	12.1	58.6	44.3	14.3	59.1	49.7	9.4	65.0	53.4	11.6
5	63.1	45.7	17.4	62.7	45.9	16.8	59.1	46.0	13.1	63.4	46.7	16.7
6	61.2	44.4	16.8	57.1	45.9	11.2	65.5	49.9	15.6	64.8	51.0	13.8
7	58.9	45.8	13.1	63.4	48.4	15.0	62.9	52.4	10.5	68.4	47.6	20.8
8	61.3	44.6	16.7	65.5	41.3	24.2	61.9	51.3	10.6	68.0	47.2	20.8
9	63.3	53.5	9.8	56.7	44.8	11.9	60.3	46.8	13.5	62.6	52.0	10.6
10	49.1	42.3	6.8	55.4	40.8	14.6	52.5	49.4	3.1	58.4	49.7	8.7
11	57.3	48.3	9.0	52.1	42.9	9.2	56.5	49.0	7.5	57.9	52.1	5.8
12	56.4	39.5	16.9	47.9	43.5	4.2	56.9	47.3	9.6	58.3	47.2	11.1

Conclusions

An innovative wave-trapping barrier (WTB) was developed and proved to be an effective device for environmental noise control. In areas near the drive station, the WTB provided more than 10dBA noise reduction. Before control treatment, the noise level exceeded the noise limit for hearing conservation of 85dBA. Use of noise control ear-mufflers had to be enforced. With the installation of the WTB, the noise level is more than 10dBA lower than the noise limit. As a result, ear-muffs are not needed and normal conversation in this area becomes possible.

The WTB provides a significant reduction of tonal noise (at 367.5Hz, 510Hz, 735Hz and 1470Hz) at far field locations (60m away from the barrier). Although the noise reduction varies with location of measurement, the tonal noise reduction from 3.1dB to 16.9dB was achieved. The location-averaged noise reduction is 11dB at 367.5Hz, 9.3dB at 510Hz, 6.7dB at 735Hz and 8.5dB at 1470Hz respectively.

The significant reduction of tonal noise at low frequencies may allow the lifting of the tonal noise penalty of 5dBA at the residential area 1.5km to the northwestern side of the drive station.

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