inter.noise 2010
noise and sustainability
13-16 June 2010 . Lisbon . Portugal
www.internoise2010.org

EFFECTIVENESS OF NOISE BARRIERS

Gilles A. Daigle

National Research Council Canada, Ottawa K1A 0R6
e-mail: {gilles.daigle@nrc.ca}

Abstract
Transportation activities are one of the most commonly occurring sources of noise outdoors. Noise levels from these transportation sources are not usually sufficiently high to cause permanent hearing loss in communities affected, but they may cause considerable annoyance and activity interference. For example, a large number of persons worldwide are exposed to outdoor time-average A-weighted sound levels greater than 65 dB. The use of barriers has proven an effective method of abating transportation noise. A recent I-INCE Working Party concluded that the most common values for insertion loss range between about 5 to 12 dB. Barrier height is of fundamental importance to the effectiveness of a barrier. Proximity of source/receiver relative to the barrier is also of fundamental importance to the insertion loss provided by a barrier. Sound-absorbing material may provide addition insertion loss. Parallel barriers can degrade the performance of the single barrier; however absorbent material can be used to recover some of the loss in performance. Finally, atmospheric effects can degrade the performance of a barrier and places an upper limit on the amount of insertion achieved outdoors. This lecture will review the various factors affecting the effectiveness of noise barrier.

Keywords: barriers, insertion loss, transportation noise, diffraction.

1   Introduction

The most effective noise control measures are those affected at the source, particularly by quieter designs, together with the application of careful land use planning measures in the community. In the case of motor vehicles, quieter engines, better air-intake and exhaust mufflers, quieter tires, and more recently, low noise road surfaces reduce the impact of traffic noise in communities along roadways. These advances have been directed by legislation in many countries in which the allowed maximum noise levels from road vehicles have been progressively reduced.
There are also many ways of modifying the transmission path to reduce the level of noise at the receiver. At the land use planning stage, the distance between source and receiver can be increased by setting aside sufficiently large areas of land along new roads and around

new airports. The receiver can also be screened from ground transportation noise by erecting noise barriers. Barriers are now in common use as a method of abating noise. They are used to reduce the noise from vehicle traffic, railways, and to some extent, to control noise from ground-based airport operations such as start of take-off roll. A large body of research work has been carried out aimed at understanding the diffraction of sound around barriers, predicting their performance and developing more efficient designs. This Lecture reviews the scientific basis for the performance afforded by noise barriers.

Barriers derive their performance by blocking the line-of-sight thus creating a sound shadow. Barrier performance is measured by its insertion loss defined as the difference in sound pressure level before and after the barrier is constructed

$$D_{IL} = L_p(\text{before}) - L_p(\text{after})$$

In some cases L_p(before) is not available and the insertion loss is approximated by some other measure. On order to better illustrate basic principle, this Lecture will also use sound pressure levels relative to free field in some cases.

Accurate prediction of barrier insertion loss must account for a wide variety of physical phenomena simultaneously. This is beyond the capabilities of many models and thus limits the accuracy of any prediction model. The accuracy of various models depend on how many physical mechanisms are included and to what level of detail they are considered. About 10 years ago, an I-INCE Working Party prepared a report [1] on the effectiveness of noise barrier. The report has a bibliography containing well over 100 references. This Lecture discusses the scientific evidence behind some of the conclusions found in the I-INCE report. After a discussion of basic principles, this Lecture will include a discussion of the effects of the ground, the effects of sound absorbing material on barrier performance, different barrier shapes, the degradation of performance in the case of parallel barriers, and the effects of the atmosphere.
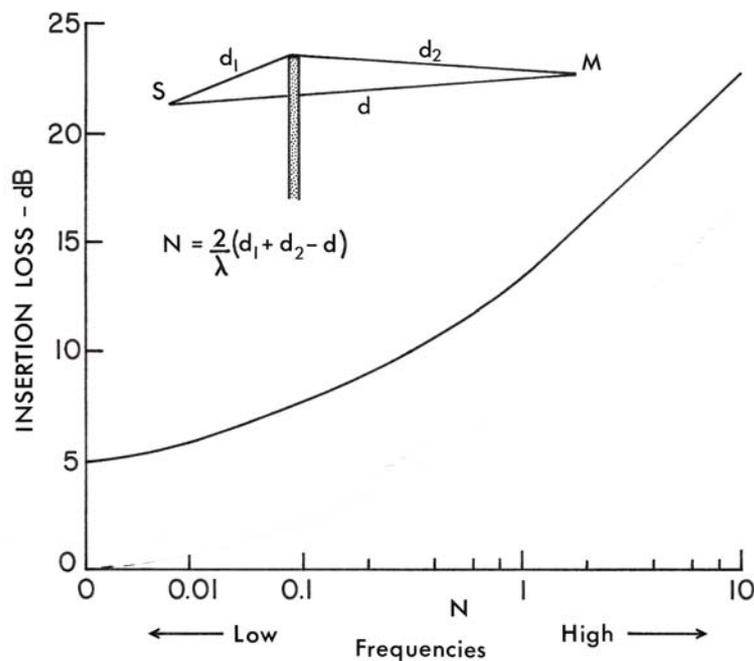
Figure 1 – Insertion loss of a thin screen

2

2   Basic principles and Maekawa's chart

A noise barrier can be defined as any solid obstacle that is relatively opaque to sound, that blocks the line-of-sight from sound source to receiver, thus creating a sound shadow. Since the dimensions of the barrier are usually of a similar order of magnitude as the wavelength of the sound, the shadow is not sharply defined. Significant sound energy propagates into the shadow region.

In its simplest form, the attenuation provided by a thin barrier represented by an infinite half-plane is calculated as a function of Fresnel number N as defined in Figure 1, where λ is the wavelength of the sound. The curve in Figure 1 is the insertion loss provided by a thin barrier as a function of Fresnel number. The curve shows that barrier height and the position of the source or receiver relative to the barrier is of fundamental importance to the insertion loss. Further, the curve also shows that the insertion loss decreases and the wavelength increases.

The curve in Figure 1 forms the basis for the well-known chart developed by Maekawa [2]. Maekawa conducted a series of experiments and empirically corrected the curve in Fig. 1 to account for the presence of the ground. Maekawa's original chart is shown by the solid curve in Figure 2. Note that Maekawa also adjusted the logarithmic scale so that the experimental curve becomes a solid straight line in the region $N < 1$. The remarkable agreement, on average, with a large body of measured field data and its simplicity of use has led to the widespread engineering use of the chart.
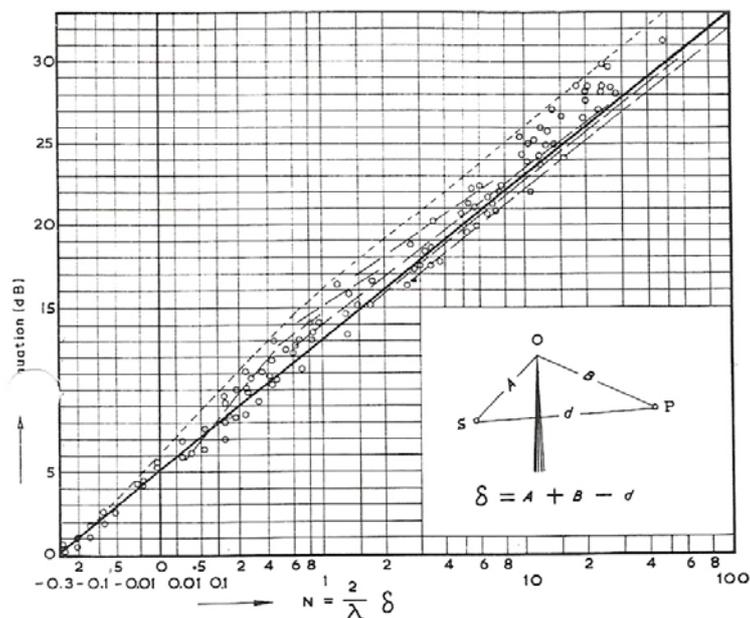
Figure 2 – Maekawa's chart (from Ref. 2)

3   Physical phenomena

3.1   Effect of the ground

Over the years, measurements have systematically yielded results that reveal in more detail the effects of the various physical phenomena than influence the effectiveness of noise barriers. For example, the points in Figure 3 represent the insertion loss of a line source
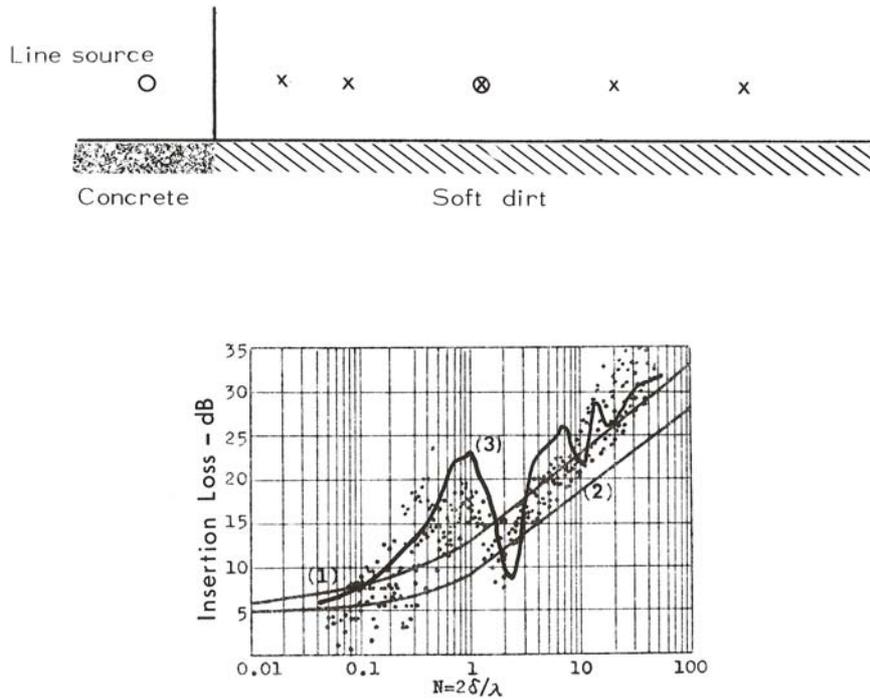
Figure 3 – Insertion of a line source above an acoustically hard surface measured by a microphone above a soft surface (from Ref. 3)

above an acoustically hard concrete surface measured by a microphone above a soft dirt surface. Curve 1 is from Maekawa's chart. Maekawa theory provides a good fit to the data on average, but the data show deviations about the curve.

If the geometry is examined more closely, a total of four paths can be identified: a) a direct diffracted field, b) a diffracted field due to the image receiver, c) a diffracted field due to the image source, and d) a diffracted field due to the image source and image receiver. The effects of interference between the four paths on the sound levels behind the barrier are shown in Figure 4. Thus Figure 4 shows a comparison between theoretical and measured results for three different combinations of ground surfaces for the same barrier and source, receiver configuration. The changes in the spectral shape of the diffracted field are clearly evident.

When the theory used in Figure 5 is extended to the case of a line source, Curve 3 in Figure 3 is obtained.
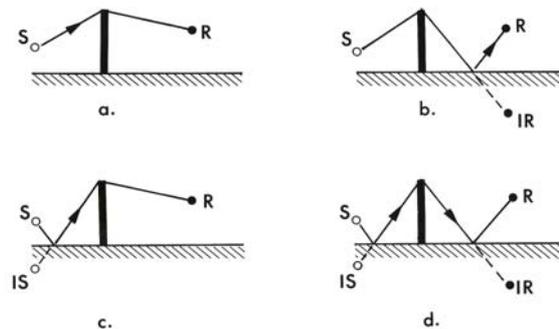
Figure 4 – Ray path over a screen in the presence of a ground surface
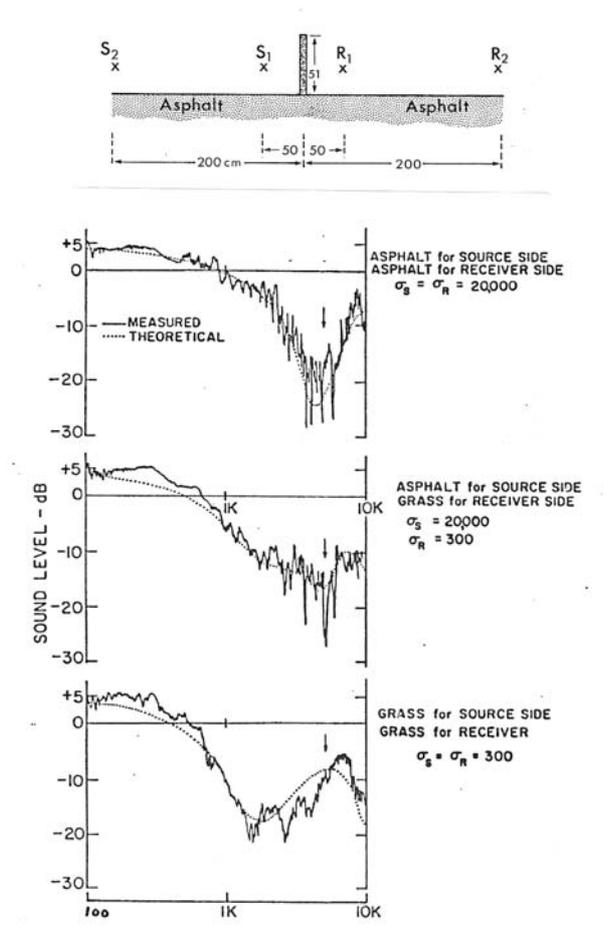
Figure 5 – Comparison between theoretical and measured results for three different combinations of ground surfaces (from Ref. 3)

3.2 Sound absorbing material

There is a body of evidence to suggest that the use of absorbing materials can enhance barrier performance. The information is based on the effects of absorbers on single barriers and parallel barriers.   As with all barrier problems it is very difficult to give a simple description of a particular effect since so many other parameters are involved. Nonetheless, the general principles can be described.

The measured points and calculated curves in Figure 6 were obtained from model experiments. The solid circles were measured when both sides of the screen are rigid. The open circles were obtained when the source side of the screed was covered with absorbing material. The open triangles were obtained when both the source side and receiver side of the screen were covered. Thus, this last results shows that if both sides are absorbing the effect is additive. Note that superimposed on the open circles, are a few open squares obtained when the receiver side only of the screen is covered with absorbing material.

From the results we note that the effectiveness of a porous absorber usually decreases as the frequency decreases. Further the effectiveness increases as the proximity of the source and/or receiver to the screed increases. Thus it is necessary for the source or the receiver to be close to the screen for this effect to be significant.

5
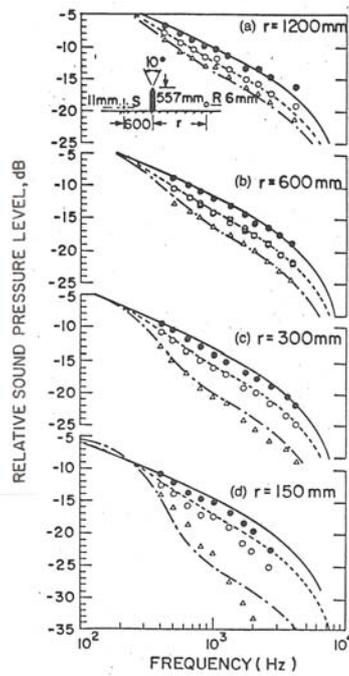
Figure 6 – Effect of covering the sides of a screen with absorbing material (from Ref. 4)

The full effect of an absorber on the diffracted path can be achieved by a strip at the top or sides of a barrier which has a width of one wavelength. For example, the field results shown in Figure 7 compares the sound levels behind a thin barrier alone with the sound levels obtained once an absorbing cylinder is installed on the top of the barrier.
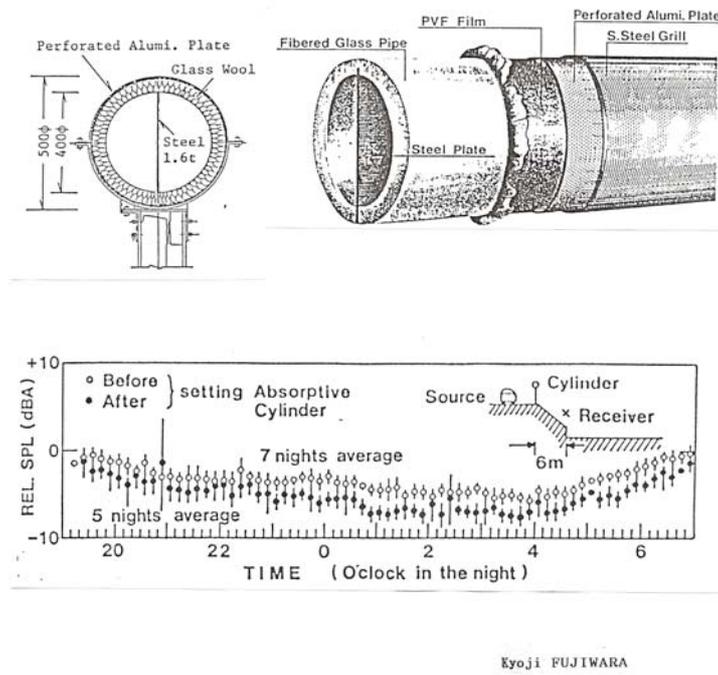
Figure 7 – Field results illustrating the effects of absorbing material on a screen (from Ref. 5)

3.3   Barrier shapes

Results in the literature have identified a wide range of noise barrier systems, some of which appear to be more effective in terms of acoustic performance than the simple plane reflective barrier widely used.   Shapes include wedge-shaped barriers, berms of various kinds, T-shaped and Y-shaped barriers, and arrow-profile barriers.   Many of these systems incorporate absorbing surfaces.   Resonant cavities have been used to produce 'soft' surfaces and some configurations are designed to promote destructive interference between waves following two different paths.   A problem that needs to be overcome with these designs is the narrow band of frequencies for which they are usually effective.

Studies have included computer modelling, laboratory experiments, and field measurements. The average improvement in insertion loss for the various designs 2 m high compared with simple plane reflective barriers of identical height ranges from 0.5 to 3.5 dB depending on detailed design.
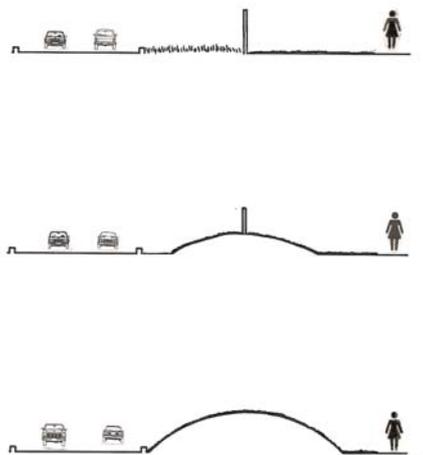
Figure 8 – Example showing possible barrier configuration

Numerical modelling of the efficiency of single noise barriers of various shapes confirms that barrier height (i.e., the path length difference effect) is of fundamental importance to the attenuation produced by a barrier. Also, the type of ground cover has a large effect upon the calculated insertion loss in the case of an earth berm.

The sketches in Figure 8 show three different barrier configurations commonly found in practice: a thin screen, a thin screen atop a berm, and earth berm. The results in Figure 9 shows a comparison of measurement obtained from model experiments in the case of similar configurations. In each three cases, the diffraction angle is maintained constant. The open circle were obtained above a berm covered with absorbing material (simulating an earth berm convered with grass for example). The solid curve was obtained when a small thin screen is placed on the top of the berm. Finally, the solid points were obtained when the height of the screen is significantly increased. This last case is comparable to the thin screed show in the top sketch of Figure 8.

3.4   Parallel barriers

An important application of absorption is in the case of parallel barriers. The attenuation provided by the barrier on one side of the source is degraded due to reflections from the reflective barrier on the opposite side [see Figure 10]. In the case of road traffic noise, results show that the degradation typically ranges from about 2 to as much as 7 dB.

Application of absorption over the road-facing side of the barrier restores the performance with a progressive improvement depending on the area covered.
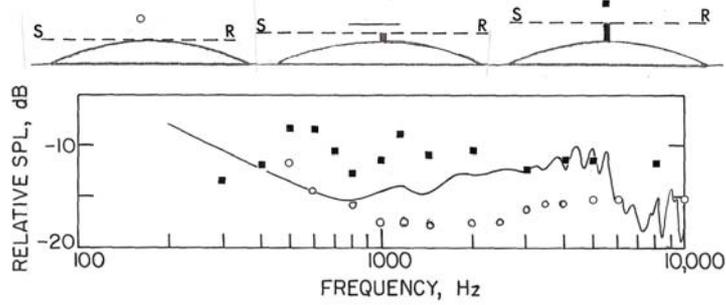
Figure 9 – Model experiments showing a comparison of results obtained in the case of three different barrier configurations (from Ref. 6).
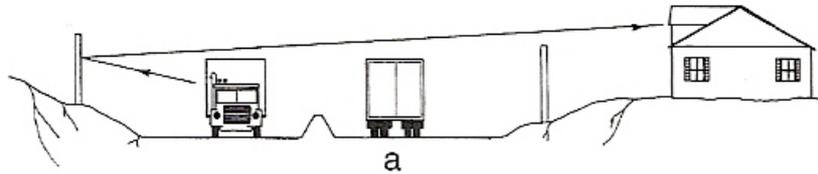
Figure 10 – The insertion loss provided by the barrier on one side of the source is degraded due to reflections from the reflective barrier on the opposite side.
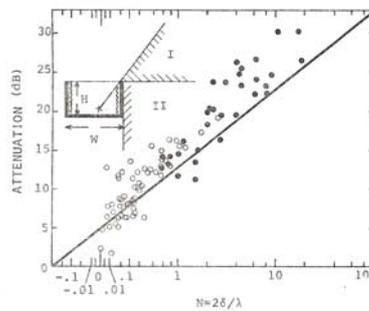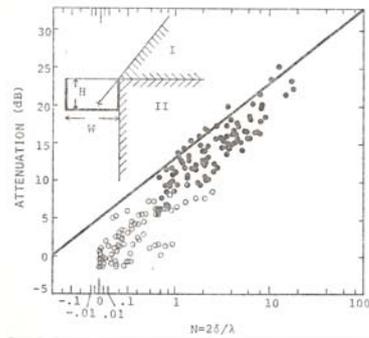
Figure 11 – Degradation in performance in the presence of parallel barriers (from Ref. 7)

This effect can be illustrated from some model experiments. The points in the top part of Figure 11 were obtained from a source located between two rigid parallel barriers. The open circles were obtained in Region I, while the solid circles were obtained in Region II. The solid curve is that of Maekawa's chart. The degradation in performance over the entire range of Fresnel numbers is clearly illustrated.

The points in the bottom part of Figure 11 were measured once both inside walls of the two screens were covered with absorbing material. These measured results are in better agreement with Maekawa's chart.
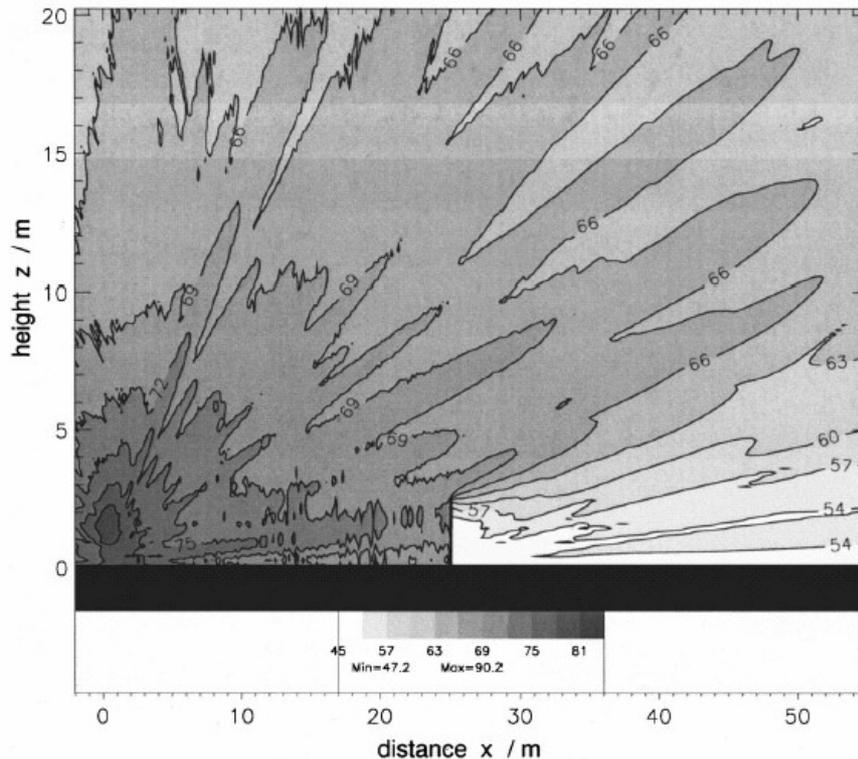
Figure 12 – Calculated sound pressure levels in the presence of a screen using a numerical model (from Ref. 8)

3.5   Atmospheric effects

Barrier performance is disturbed by other factors such as the atmosphere. Upward-curving sound paths, as in propagation upwind or during the temperature lapse characteristics of sunny days, do not reduce the acoustic performance of a barrier. However, it is generally recognized that downward-curving sound paths, as in propagation downwind or during the temperature inversions that are common at night, do reduce the insertion loss of a barrier. This reduction varies with wind speed, frequency and propagation distance.

Atmospheric turbulence scatters sound energy into the acoustic shadow behind a barrier. Therefore, turbulence is responsible for setting an upper limit to the amount of insertion loss that can be obtained from a given barrier configuration. For example, when the barrier noise reduction values are averaged and plotted against the design chart, close agreement is obtained until the predicted values exceed 20 dB. Thus barrier noise reduction tends to level off at around 20 to 25 dB.

Prediction of barrier performance in the presence of atmospheric effect requires sophisticated numerical models. An example of such a calculation is shown in Figure 8.

9

4 Conclusions

There is strong body of evidence to support the use of barriers as an effective method of abating transportation noise. The best descriptor of barrier performance is its insertion loss, which is the difference in the noise environment before and after the barrier is constructed. Barrier height and proximity of source and receiver are of fundamental importance to the attenuation produced by a barrier. In countries around the world typical barrier heights range between 2 and 6 m. The most common values for A-weighted insertion loss range between about 5 and 12 dB, but values between 3 and 25 dB are also often found. There is smaller body of evidence to support the use of absorbing material to improve the performance of barriers. Parallel vertical reflective barriers along both sides of a roadways may degrade performance.   The use of absorbing material is particularly important in this type of application.

References

[1] I-INCE report. Technical assessment of the effectiveness of noise walls, *Noise/News International*, Volume (7), 1999, pp137-161

[2] Maekawa, Z. Noise reduction by screens, *Applied Acoustics*, Volume(1), 1968, pp 157-173.

[3] Isei, T., Embleton, T.F.W., Piercy, J.E. Noise reduction by barriers on finite impedance ground, *Journal of the Acoustical Society of America,* Volume (67), 1980, pp 46-58

[4] L'Espérance, A. Nicolas, J. Daigle, G.A. Insertion loss of absorbent barriers on ground, *Journal of the Acoustical Society of America,* Volume 86, 1989, pp 1060-1064

[5] Fujiwara, K. Furuta, N. Sound shielding efficiency of a barrier with a cylinder at the edge, *Noise Control Engineering Journal,* Volume 37, 1991, pp 5-11

[6] Daigle, G.A. Nicolas, J. L'Espérance, A. Modification et analyse de l'efficacité de différents types d'écran routiers, *Actes INRETS*, Volume (28), 1990, pp 11.1-11.5

[7] Maekawa, Z. Shielding Highway Noise, *Noise Control Engineering Journal*, Volume (9), 1977, pp 38-44

[8] Blumrich, R. Heimann, D. A linearized Eulerian sound propagation model for studies of complex meteorological effects, *Journal of the Acoustical Society of America,* Volume (112), 2002, pp 446-455