Acoustics 2008
Geelong, Victoria, Australia 24 to 26 November 2008

Acoustics and Sustainability:

How should acoustics adapt to meet future demands?

Barriers to consistent results: the effects of weather

Michael Smith

Marshall Day Acoustics Pty Ltd, Adelaide, Australia

ABSTRACT

Calculating the attenuation provided by barriers and other screening elements is an essential part of practical noise control engineering. There are well-documented approaches to this problem, with noise propagation standards often specifying which approach to take. A noticeable exception is CONCAWE: the principal prediction method used in Australia. CONCAWE provides complex calculation methods for ground and meteorological effects, but not for barrier attenuation. The sound prediction software SoundPLAN uses the barrier attenuation algorithm from the General Prediction Method (GPM) in its implementation of CONCAWE. In Victoria, noise assessments are performed under neutral meteorological conditions, but the GPM assumes downwind propagation conditions. SoundPLAN therefore can under-predict the performance of the barrier. While predicting noise propagation under favourable conditions has merit, this paper discusses several barrier-attenuation algorithms and their suitability for modelling noise propagation in neutral meteorological conditions.

INTRODUCTION

Setting limits

Responsible authorities often specify a value on the amount of noise that industry is allowed to make. Policy is not about noise generation; it is the effect on the amenity at noise-sensitive locations that is important. Noise limits are therefore stipulated at these locations, typically the nearest residences.

Protection of amenity is a difficult concept. Different people have different sensitivities to noise. A reasonable definition could be a level at which *the majority of people are happy for the majority of the time*.

Noise criteria have been developed by the regulatory authorities based on research and trial and error. These criteria are generally considered an acceptable compromise between protection of amenity and economic growth.

Variability of conditions

The question of under what meteorological conditions to assess noise is an important one. Over a distance of 500m, it is possible for the noise level at a receiver to vary by 10dB in different conditions (Bies and Hansen, 2003).

Favourable conditions assist sound propagation, with *worst-case* referring to the most favourable of all conditions. *Neutral* conditions neither assist nor hinder propagation—not to be confused with *typical* conditions, which refers to the predominant weather conditions.

This question is relevant to both measuring and predictions. The Victorian EPA Document 280 states the following:

> Weather conditions can markedly affect the noise level received at a noise sensitive area. This is particularly important when the level is low and the distance between the noise sensitive area and the source exceeds 200 metres. When it is believed that the noise received at the noise sensitive area is affected by weather conditions, then a derived point may be used. It is advisable to use this point in all cases where the noise source is more than 500 metres from the noise sensitive area because weather conditions are likely to be the major source of variability in the noise level at this distance.

A derived point is one which is not at a noise sensitive location, but rather one at which noise from the source of interest can be reliably measured. Once the noise level at the derived point is known, an estimate can be made of the noise level at the noise-sensitive location. Two of the factors that need to be considered are shielding by noise barriers and the effect of meteorological corrections. In order to achieve a consistent approach, the question of what meteorological conditions to measure in must be addressed.

However, setting conservative noise limits and then using a *worst-case* propagation method may place an excessive burden on the noise emitter—typically industry. These questions are a matter of policy.

Propagation standards

Choosing an appropriate propagation method is key to a successful assessment. While it is desirable to perform an accurate prediction, there is a trade-off between accuracy, complexity, and sensitivity of the input parameters. Comparability with other work is also important, and standard methods have been developed, some of which have been specified for use in certain jurisdictions.

For a simple scenario over small distances and flat terrain, it may be appropriate to consider only geometric spreading, a hard/soft ground correction, and a 10dB *standard fence* barrier correction. Over larger distances, such a simple approach does not yield sufficiently accurate results.

Several standards are commonly used to predict noise propagation. They include:

- CONCAWE
- ISO9613-2
- NORD2000
- General Prediction method

CONCAWE does not include a barrier attenuation algorithm, but is an otherwise complete method, and is widely used in Australia. This paper will review barrier algorithms, from both adopted standards and published research, and discuss which is the most appropriate for use under neutral meteorological conditions.

HOW SOUND TRAVELS

Introduction

There are many different algorithms for predicting outdoor sound propagation. All models include the intrinsic reduction in intensity due to geometric spreading, plus additional terms to account for the *excess* attenuation due to meteorological effects, air absorption, ground attenuation, shielding due to houses, forests, and particularly relevant to this paper: barriers.

There are three approaches for modelling sound propagation. First, one can take a theoretical, physics-based approach. Alternatively, an empirical approach can be taken where a mathematical equation is fitted to measured data. The final option is to develop relatively simple algorithms based on theoretical considerations.

Diffraction

If sound travelled in a purely spherical manner, then a barrier blocking line-of-sight would completely stop any noise propagation, creating a perfect shadow zone. This does not happen, and it is well know that diffraction is the cause. Huygens' Principle is useful for understanding this phenomenon:

> Every point on a wave front can be considered as a source of tiny wavelets that spread out in the forward direction at the speed of the wave itself. The new wave front is the envelope of all the wavelets—that is, the tangent of them all.

The choice of symbols for dimensions is not constant across different standards. Figure 1 shows the relevant geometry with the variables that will be used in this paper. While different standards use different symbols, they all revolve around the *path difference*: the extra distance the sound wave travels due to the barrier. This path distance will be referred to as Δd .

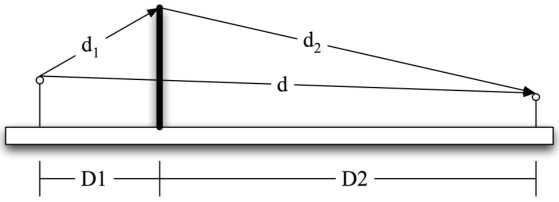

Figure 1. Barrier geometry

The reason that sound can propagate when line of sight is broken is due to diffraction over the edge. Many formulae for calculating the attenuation due to diffraction refer to the Fresnel Number, which is the path difference expressed as the number of half-wavelengths. This is detailed in Equation 1.

$$N = \frac{2}{\lambda}\Delta d \qquad (1)$$

Refraction

Meteorological conditions affect propagation. When vertical gradients of wind speed and temperature exist, refraction occurs. Upward refraction occurs during a conventional temperature lapse (where air temperature decreases with relative altitude) or upwind conditions; downward refraction is a consequence of temperature inversions or downwind conditions (Bies and Hansen, 2003).

Interaction

Barrier attenuation is reduced when the sound is refracted downward. This is because the sound curves over the barrier.

Barrier attenuation also interacts with ground attenuation; once a barrier is inserted, the angle at which the sound reflects off the ground changes, altering the manner in which the reflected wave re-combines with the direct wave at the receiver. The barrier attenuation algorithms must not be considered as a direct insertion loss. Ground attenuation is less affected if diffraction is occurs around the sides of a barrier.

Nelson (1987) suggests that downwind propagation typically leads to a 2-3dB reduction in barrier attenuation.

Assumptions

The methods described in this paper assume an infinitely long barrier, or one long enough such that leakage around the sides is insignificant. In addition, the barrier is assumed to be sufficiently massive that the path through the barrier does not contribute to the noise level at the receiver. Standard barriers are typically specified to have a surface density of at least $15kg/m^2$.

CONCAWE – THE PROBLEM

The CONCAWE method was developed for calculating the noise from petrochemical and petroleum plants and is described in Manning (1981). A key feature of this method is that it considers a large number of different meteorological conditions. The influencing factors are fundamentally air stability and wind speed, which are grouped into six meteorological categories labelled CAT1–CAT6. It is considered that CAT4 is neutral and that CAT6 is worst-case.

CONCAWE, however, does not include a barrier attenuation algorithm. To remain consistent with the intent of the standard, one must choose an algorithm which considers the meteorological conditions being modelled. CONCAWE states that the method of Maekawa may be used, with adjustments made for wind and temperature performed using the method described by Dejong and Stusnick (1976). In practice, consultants generally do not implement these corrections.

A REVIEW OF PROPAGATION ALGORITHMS

Maekawa

Many barrier corrections are based on the measurements performed by Maekawa (1965). Kurze (1971) fitted the following equation for the shadow zone of a barrier.

$$A_b = 20\log_{10}\left(\frac{\sqrt{2\pi N}}{\tanh(\sqrt{2\pi N})}\right) + 5 \qquad (2)$$

A commonly used simplification of the Maekawa prediction is provided in Equation 3, below.

$$A_b = 10\log_{10}\left(3 + 20N\right) \qquad (3)$$

ISO9613-2

ISO9613-2 entitled *Acoustics—Attenuation of sound during propagation outdoors* was developed to calculate noise propagation under favourable conditions. The standard provides the following:

$$D_z = 10\log_{10}\left(3 + \left(C_2 / \lambda\right) C_3 z K_{\text{met}}\right) \qquad (4)$$

For the case of single diffraction with a regular ground reflection, rewriting in terms of the Fresnel number and more familiar symbols:

$$A_b = 10\log_{10}\left(3 + 10 N K_{\text{met}}\right) \qquad (5)$$

The correction for favourable propagation conditions is provided for using the following term:

$$K_{met} = \exp\left(-\frac{1}{2000}\sqrt{\frac{d_1 d_2}{2\Delta d}}\right) \qquad (6)$$

It is not immediately obvious how this K_{met} term adjusts the barrier attenuation based on the inputs, although you will notice that it does not depend on what meteorological conditions are being modelled. This is consistent with the aim of ISO9613: modelling favourable propagation conditions. It is also not frequency dependent. Figure 2 shows the value of K_{met} for a range of barrier locations. It can be seen that K_{met} is lowest when the barrier is furthest from both source and receiver, or when the barrier height is low.

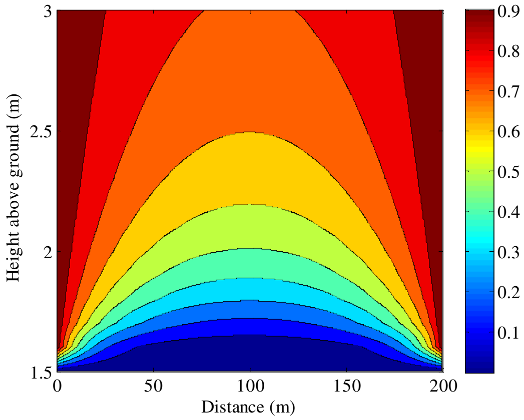

Figure 2. K_{met} for various barrier locations. Source located at 0m, receiver at 200m. Both 1.5m above ground

Note that K_{met} appears to vary from 0 to 1.

General Prediction Method (GPM)

The barrier attenuation algorithm from the General Prediction Method (GPM) is used by SoundPLAN for when implementing CONCAWE. Figure 3 provides a graphical description of terms used in its formulation. The method used is similar to *Nelson*, however the *direct* path is not treated a straight line; it follows a curved path. The GPM considers that the assumption of a straight direct path leads to an overestimate of the screening, thus introducing an adjustment to the height of the barrier.

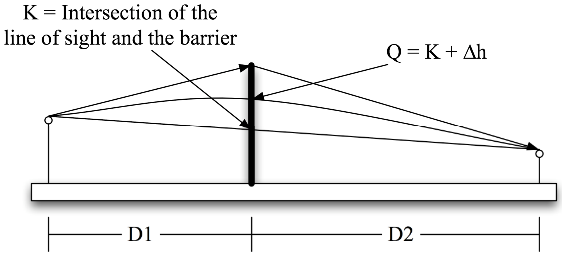

Figure 3. General Prediction Method Geometry

Equation 7 calculates the increase in height of this *virtual* intersection point Q. The consequence of this is that the path difference is reduced, achieving the desired decrease in barrier attenuation.

$$\Delta h = \frac{D_1 D_2}{16\left(D_1 + D_2\right)} \qquad (7)$$

The attenuation is then calculated with a Fresnel number N' based on the modified path difference.

$$A_b = 10\log_{10}\left(\frac{1}{3 + 20N'}\right) \qquad (8)$$

Nord2000

Nord2000 uses complex algorithms based on the wave nature of sound to estimate effects due to diffraction, refraction and reflection, and the interactions between these effects. Other methods discussed estimate the effects of refraction by adding various height corrections; Nord2000 implements refraction directly. While this may a useful step toward accurate estimation of these effects, the standard requires that the user enter the specific atmospheric conditions. Until accepted standard atmospheric conditions are agreed on for this method, this is not conducive for calculating long-term averages.

TEST CASES

This paper considers two different barrier configurations:

- barrier close to the source
- barrier distant from both the source and the receiver

Barriers close to receivers perform identically to those close to sources, and have not been discussed specifically in this paper.

The second type of barrier is not likely to be purpose-built, and could be thought of as an opportunistic barrier, such as a hill or a warehouse or other building that just happens to provide screening.

Barrier close to source or receiver

A 3m high barrier has been placed 5m from a source. Figure 2 shows the path difference at various distances away from the barrier. In this case, the correction provided to the path difference by the GPM is minimal.

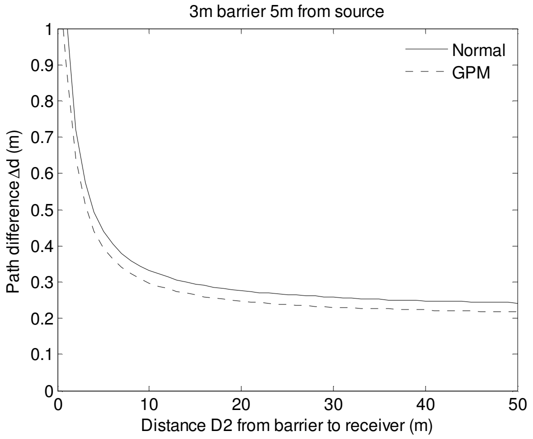

Figure 4. Path difference for a barrier close to the noise source

Also calculated is the octave band attenuation for each of the methods discussed. Figure 5 below shows the above case with the receiver at 20m from the source. The attenuation predicted by the simple method and the GPM are almost identical in this case.

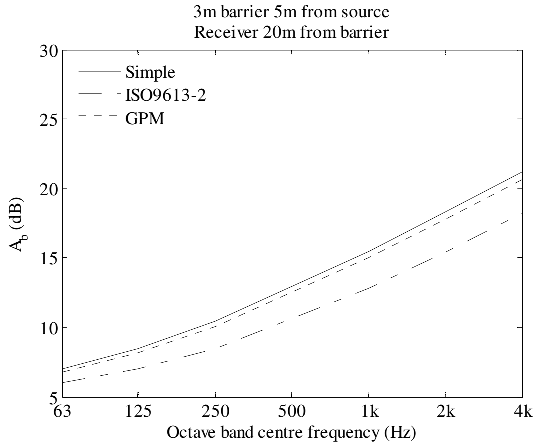

Figure 5. Attenuation 20m from barrier

Barrier distant from both source and receiver

For this situation, we will consider a 10m barrier located 400m away from a source. Figure 6 compares the *conventional* path difference with that used in the GPM. The difference is considerable.

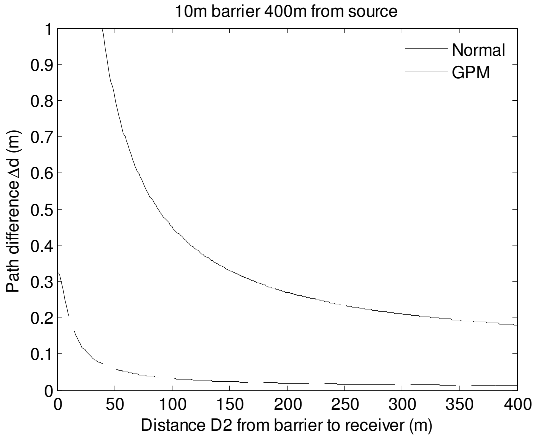

Figure 6. Path difference for opportunistic barrier

As the receiver becomes further from the barrier, the attenuation predicted by the GPM progressively diminishes. This is consistent with the curvature corrections provided by the GPM. Figures 7-10 illustrate this, showing the attenuation at different receiver locations, based on the 10m high barrier located 400m from the source.

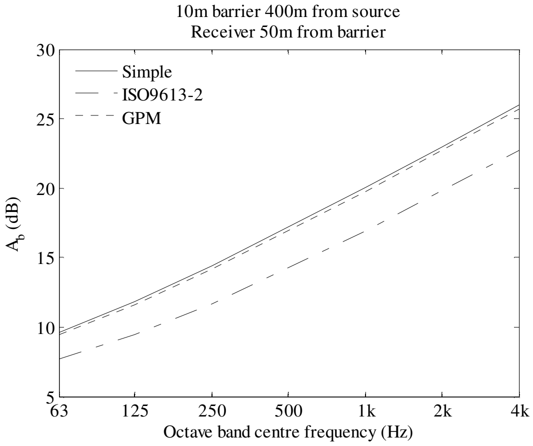

Figure 7. Attenuation 50m from barrier

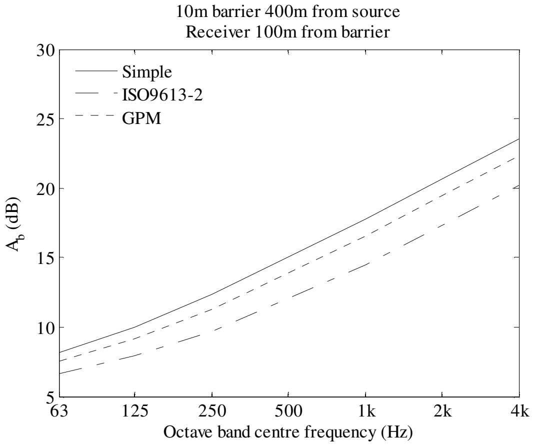

Figure 8. Attenuation 100m from barrier

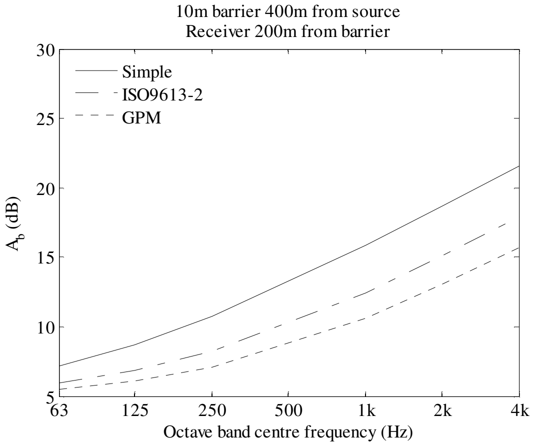

Figure 9. Attenuation 200m from barrier

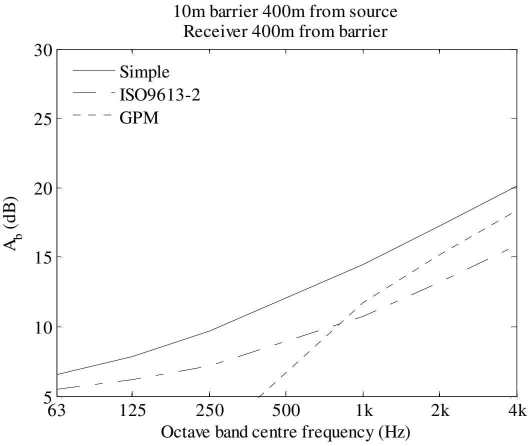

Figure 10. Attenuation 400m from barrier

CONCLUSION

Several algorithms exist for calculating barrier attenuation. This paper discusses the assumptions of each algorithm, and provides comments on their suitability for use under different meteorological conditions.

Table 1 lists the methods reviewed and their suitability for modelling propagation under different conditions.

Table 1. Barrier algorithms for different conditions

Neutral Conditions	Favourable Conditions
Maekawa	ISO 9613-2
Nord2000	General Prediction Method
	Maekawa with Dejong
	Nord2000

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