# NUMERICAL STUDY OF NOISE BARRIER DESIGNS

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## ABSTRACT

Noise barriers are commonly used for reduction of highway traffic noise. Optimising the acoustic performance of a barrier is an important task for those involved with designing cost effective barriers. In this paper numerical models for various barrier designs which have been developed using the finite element method are described. The acoustic performance of noise barriers with vertical, arrow, T-shape, Y-shape, wedge-shape and inclined profiles are compared. The effects of the locations of the source and receiver relative to the various noise barrier designs are examined.

## INTRODUCTION

Noise barriers are commonly used to attenuate road traffic noise. A barrier functions by blocking the line-of-sight between a noise source and a receiver, thus creating a sound shadow zone. When a noise barrier is inserted between a noise source and a receiver, the direct noise is reflected, transmitted and diffracted. Noise barriers generally provide more effective attenuation at high frequencies as short wavelengths are not as easily diffracted into the shadow zone. Figure 1 shows a schematic diagram of the diffraction of sound over the top edge of a barrier.

The performance of a noise barrier depends on several main factors including the position of the barrier with respect to the source and receiver locations, sound reflections from its surroundings, and meteorological conditions such as wind and temperature gradients. An increase in the height and width of a barrier can increase the insertion loss of a barrier, but such increases are not always practical due to aesthetics, maintenance, construction costs, and safety reasons. Profiled noise barrier designs of lower height but equivalent effectiveness to a vertical noise barrier include T-shape, Y-shape, arrow shape, wedge shape and cylindrical configurations along the top of the barrier (Hothersall et al., 1991b; Ho et al., 1997; Venckus et al., 2012).

The two dimensional boundary element method (BEM) has been widely used to predict the insertion loss of noise barriers. Using BEM, the surface of the fluid domain is discretised into small elements and the acoustic pressure is evaluated at each element. Numerical BE models have been developed to calculate barrier efficiency (Seznec, 1980), to assess the acoustic performance of a range of barrier designs (Hothersall et al., 1991a; Ishizuka and Fujiwara, 2004), to model diffusive barriers (Naderzadeh et al., 2011), and for optimisation of the acoustic performance of T-shaped and Y-shaped barriers (Baulac et al., 2008; Greiner et al., 2010).

In this study, the insertion loss of different noise barrier designs developed numerically using the finite element method are calculated. Whilst using FEM requires discretization of the fluid domain and as such can be more time consuming than using BEM, the computational cost is not significant for these 2D numerical models. Results for various barrier shapes are compared against results from boundary element models in literature. The effects of the locations of the source and receiver relative to a vertical barrier are examined.

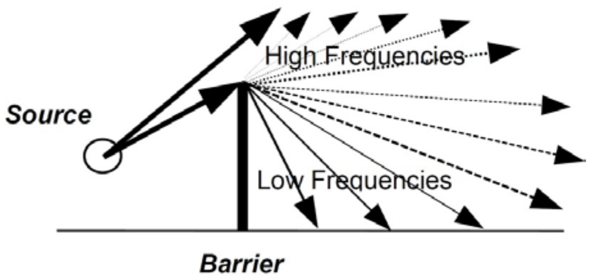


**Figure 1**. Diffraction of sound over the top edge of a barrier (Hendriks, 1998)

## FINITE ELEMENT MODEL

The acoustic model of noise barrier is developed using a cylindrical domain Ω filled with air, as shown in Figure 2. Using the finite element method, the Helmholtz wave equation is solved at each single frequency and is given by (Wu, 2000):

$$\left(\nabla^2 + k^2\right)p = 0 \tag{1}$$

where $p$ is the sound pressure and $k$ is the wave number. The domain is discretised using quadratic triangular elements. The insertion loss (IL) for the barriers is calculated using the acoustic pressure obtained from the FE models using the following expression (Fujiwara et al., 1998):

$$IL = 20\log_{10}\left|\frac{p_g}{p_b}\right| \quad \text{(dB)} \tag{2}$$

where $p_g$ is the acoustic pressure in the presence of flat ground only (in the absence of a barrier) and $p_b$ is the acoustic pressure with the barrier in place. The insertion loss obtained numerically at 1/3 octave band centre frequencies for different noise barrier shapes are compared.

## VALIDATION OF FE MODELS

The finite element models were developed in COMSOL. The FE models were validated by comparing results for existing barrier designs from literature, which were obtained from boundary element models. Noise barrier shapes were divided into three groups corresponding to vertical barriers, wedge-shaped barriers and profiled shaped barriers. The source and receiver geometries are separately shown for each noise barrier model. In the FE model developed using COMSOL, the noise source and receiver positions are considered as point locations. The ground was modelled as an acoustically hard surface with an admittance of zero.

The performance of a 3 m high vertical barrier is compared with the insertion loss from boundary element models presented by Hothersall et al. (1991a) and Monazzam and Lam (2005). The source and receiver are both located on the ground at a distance of 15 m and 50 m, respectively, from the noise barrier. Figure 3 shows good agreement in the results from the FE models developed in this work and BEM results in literature. The performance of the vertical barrier increases with increasing frequency as the wavelengths of sound waves decrease with increasing frequency and hence are not as easily diffracted. The insertion loss for a 3m high wedge-shaped barrier with a wedge angle of 53$^o$, as shown in Figure 4, was then examined. Whilst the occupied surface of the 53$^o$ wedged shaped barrier is greater than that of the vertical barrier, its effectiveness is lower compared to that of the vertical barrier.

## EFFECT OF RECEIVER LOCATION

The receiver is located on the ground for both the vertical and wedge shaped barriers, hence interference effects due to ground reflections do not exist. To examine the effect of the hard ground plane and also to simulate the nominal height of an adult person's hearing, the receiver was located at a height of 1.5 m from the ground. Figure 5 shows the insertion loss for a 3 m high vertical barrier, with the receiver located on the ground and the receiver at a height of 1.5 m from the ground plane. Both receiver locations are at a horizontal distance of 20 m from the barrier. Similar to Figure 3, there is a steady increase in transmission loss with increasing frequency for the receiver located on the ground plane. However, for the elevated receiver position, the insertion loss dramatically increases at some frequencies, which is attributed to constructive interference between direct and reflected waves due to the ground surface (Hothersall et al., 1991b).

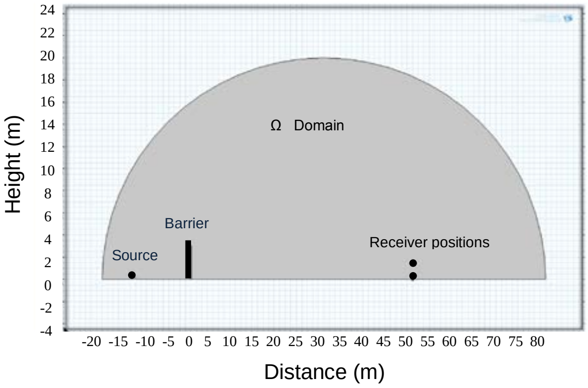


**Figure 2**. Finite element model of a vertical barrier showing the acoustic domain, source location and receiver positions

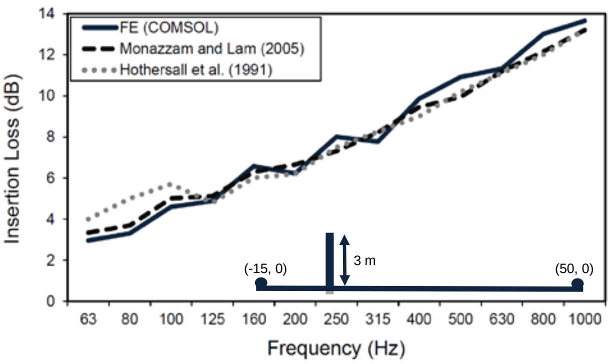


**Figure 3**. Insertion loss of a 3 m vertical barrier for the source and receiver located on the ground

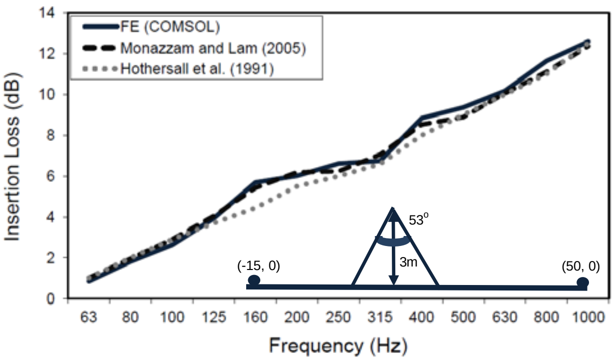


**Figure 4**. Insertion loss of a 3 m high wedge-shaped barrier

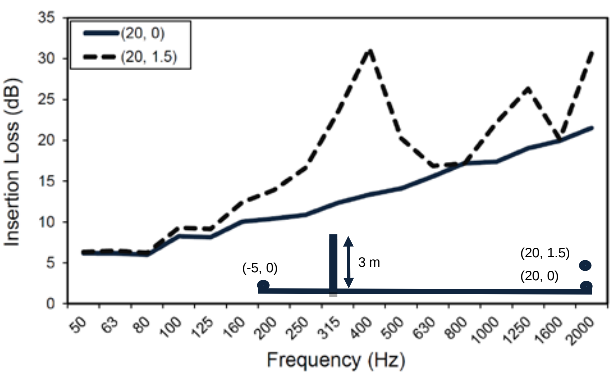


**Figure 5**. Insertion loss of a 3 m vertical barrier for different receiver heights

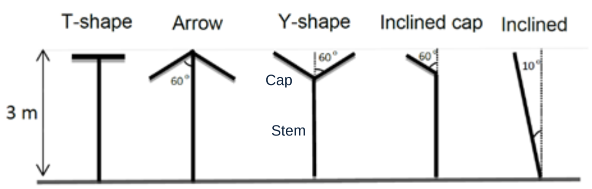


**Figure 6**. Schematic diagram of various noise barrier designs

The insertion loss for different barrier designs for the source located on the ground and the receiver at a height of 1.5 m from the ground is now compared. Figure 6 shows a schematic diagram of the various noise barrier designs, which include T-shaped, arrow, Y-shaped, inclined cap and inclined barriers. For all barrier designs, the height is 3 m, the stem thickness is 0.1 m and the cap thickness is 0.3 m. The angle for the inclined cap shapes associated with the arrow, Y-shaped and inclined cap barriers are 60$^o$, as shown in Figure 6. The inclined barrier is at an angle of 10$^o$.

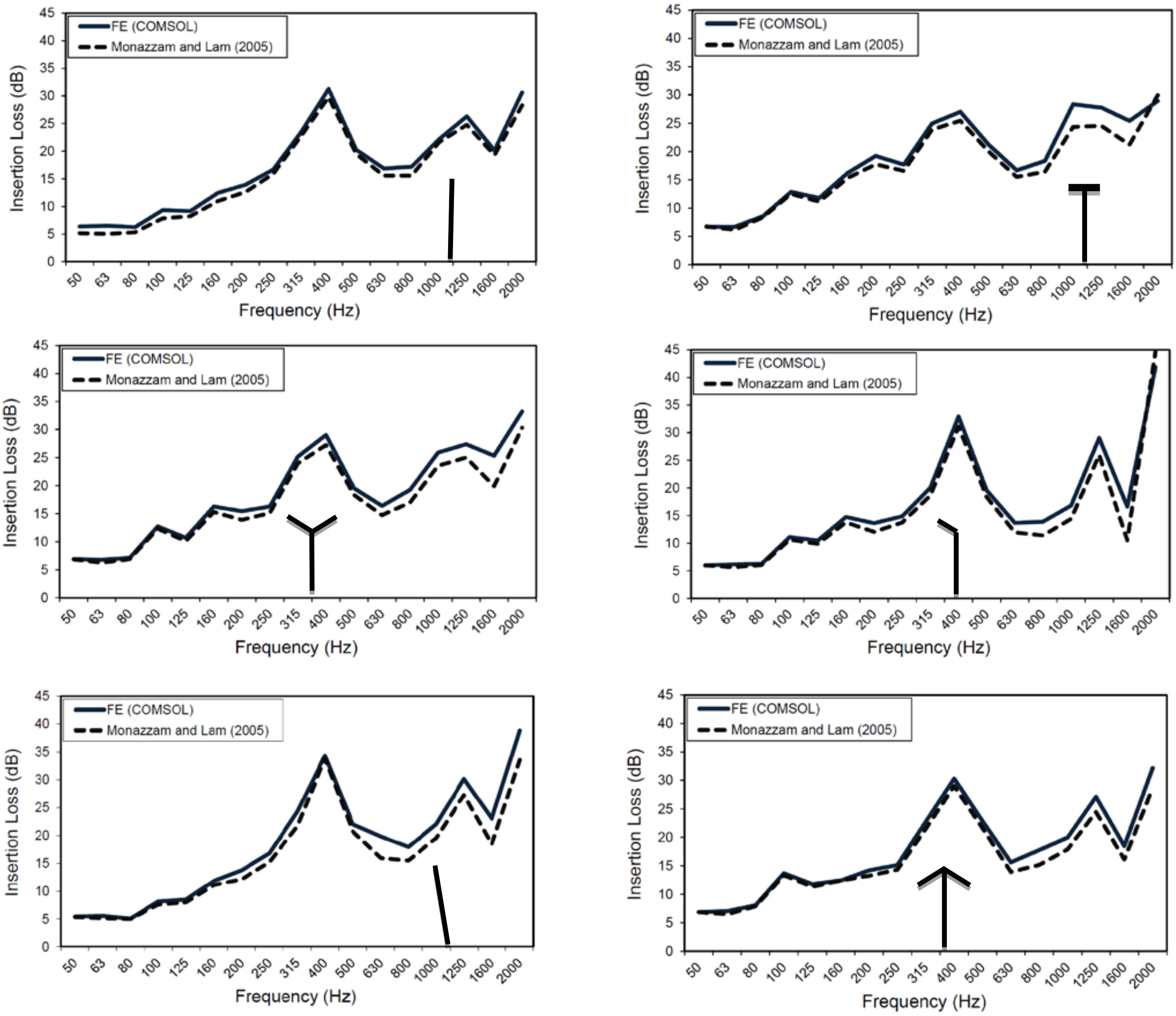


**Figure 7**. Insertion loss for various profiled noise barrier designs

In Figure 7, the insertion loss of the barriers in Figure 6 are presented for the source located on the ground at a distance of 5 m from the barrier, and the receiver located at a distance of 20 m from the barrier at a height of 1.5 m from the ground plane. Good agreement between the results obtained from the FE model in this work and results from a BE model developed by Monazzam and Lam (2005) is observed. The trend in the results for all barrier designs is similar, showing a steady increase in insertion loss with increasing frequency. Sharp increases in insertion loss around 400 Hz, 1250 Hz and 2 kHz are attributed to constructive interference between direct and reflected waves due to the ground surface (Hothersall et al., 1991b).

## EFFECT OF NOISE SOURCE LOCATIONS

A major traffic noise source is attributed to engine and exhaust noise of light and heavy vehicles. The engine and exhaust of light vehicles are approximately at 0.5 m above the ground. However the noise sources of heavy vehicles due to engine noise and engine compression brake noise are generally located at around 1.5 and 3.5 m above the ground, respectively.

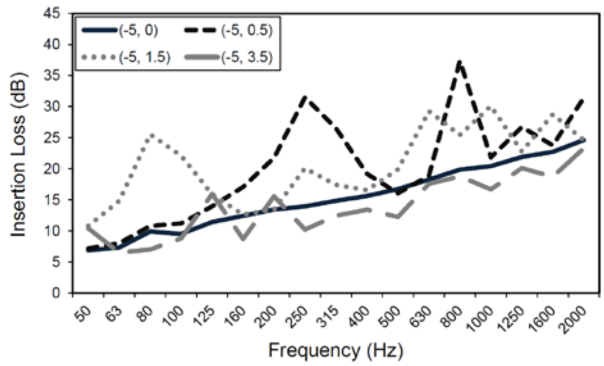


**Figure 8**. Insertion loss of a vertical 4 m noise barrier for various source heights

The acoustic performance of a 4 m high vertical noise barrier for a noise source located on the ground and located at a height of 0.5 m, 1.5 m and 3.5 m from the ground is now examined. The receiver is located on the ground plane. The effect of elevated noise sources on the insertion loss of the vertical barrier is presented in Figure 8. When the source is located on the ground, there is a steady increase in insertion loss with increasing frequency. Sharp increases in insertion loss around 400 Hz, 1250 Hz and 2 kHz when the source is located at heights of 0.5 m and 1.5 m is attributed to constructive interference between the direct and reflected waves from the source and barrier. For a noise source at a height of 3.5 m, the performance of the barrier decreases, due to the proximity of the source to the top of the barrier, allowing the sound waves to be more easily diffracted over the top edge of the barrier.

## SUMMARY

In this study, numerical models to assess the acoustic performance of various noise barrier designs were developed using the finite element software COMSOL. The results for the insertion loss were validated against results from boundary element models in literature. The insertion loss at 1/3 octave band centre frequencies for different barrier designs including a vertical, T-shaped, arrow, Y-shaped, inclined cap and inclined barriers were compared. The trend for the insertion loss for all barrier designs was similar and showed a steady increase with increasing frequency. Significant increases in insertion loss for the source or receiver located at a height of 0.5 m from the hard surface of the ground plane are attributed to constructive interference between direct and reflected waves due to the ground surface.

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