# BEM simulations of diffraction-optimized noise barriers

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## Abstract

Traffic-related noise has been increasing steadily. Noise barriers are one of the main tools used for noise abatement, and there is still potential for optimization and improvement of the acoustic performance by employing non-standard designs. Simulations are a cost-efficient tool for predicting and planning new noise barrier solutions.

The following paper studies some non-standard barrier shapes with particular focus on the formation of a virtual soft-plane for some frequencies. Destructive diffraction from the top edge of the barrier is used in order to optimize the shielding effect of the barrier.

Through the use of 2D-BEM simulations different barrier profiles and their effect of shielding are studied. The focus is to obtain useful shielding in the far-field region with intelligent shapes thus permitting a reduction of the barrier height.
*Keywords: noise barriers, noise abatement, diffraction, 2D-BEM simulations.*

## 1 Introduction

Traffic noise has become an important problem with the increase of traffic volume. To counteract this, noise barriers are the most used traffic noise abatement tool; it is in the public interest to reduce the height of the barriers, that being a natural way to reduce the material, and thus the costs.

Even if good results can be achieved with the use of appropriate absorbing materials on the surfaces or on part of the surfaces (for example on the top of a T-shape barrier (Fig 1)), the porosity of this kind of materials makes them very sensitive to clogging by dirt and changes their absorbance with time.

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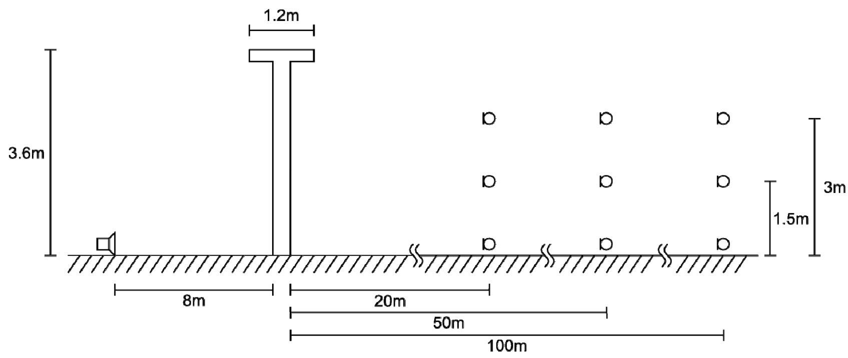


Figure 1: The simplified set-up of the simulations. The source is put on the ground at 8 m from the barrier. On the other side, a grid of 9 microphones is used to explore the far field.

In this paper two non-standard geometrical forms of noise barriers are investigated in order to overcome this problem.

## 2 Investigation

Perfectly reflecting (acoustically hard) materials are not considered the best choice for noise barriers, as they generate many unwanted reflections. Absorbing materials seem much more appropriate, but their impedance changes rapidly with time as mentioned above. One interesting idea is to use geometrical shapes to obtain a specific input impedance, as suggested in [1–3], where different shapes are analysed.

Let us consider the barrier b) depicted in Fig 2, which will be called "fork" barrier below. With rigid surfaces the specific input impedance at the open side can be approximated by

$$Z_{in} = i\cot(kd) \tag{1}$$

where $d$ is the depth of the fork and $k$ the wave vector, as can be seen from (1). According to this equation, at frequencies $f_n$, with $k_n d = (2n+1)\pi/2$, the impedance is zero. This means that the fork element, for the range close to those frequencies, plays the role of a soft plane, with complete absorbance. The condition of soft plane can never be realized 100% with the use of absorbent materials, which makes the geometric solution a useful alternative. As this impedance is only dependent on the geometry, the problem of the time-variance of the absorbent materials is practically solved. On the other hand, this solution is efficient only for some frequencies.

This problem can be coped with using a barrier whose channels have different lengths, as depicted in Fig 2 c), the "fork gradient". This corresponds to using a strip of absorbent material whose impedance changes gradually along the length of the material. The idea is similar to chirped mirrors in optics, made out of different layers that can filter different wavelengths.

For our investigation we performed a 2D BEM analysis, assuming the invariance of the system on the y axis. We used OpenBEM, an open source software developed in Matlab environment by the University of Southern Denmark [4]. OpenBEM solves the Helmholtz equation with a direct collocation approach.

The set-up for the simulation is shown in Fig 1.

In the following, the ground is assumed to be perfectly reflecting. The source is placed on the ground, in order to prevent unwanted reflections, and at 8m distance from the barrier. On the other side of the barrier, 9 microphones are placed in a regular grid structure, at the different heights of 0, 1.5 m and 3 m from the ground, and at the distances 20, 50, 100m from the barrier. Simulations are performed at the middle frequencies of the third octave bands. First simulations are performed without barrier, then with the three different barriers depicted in Fig 2.

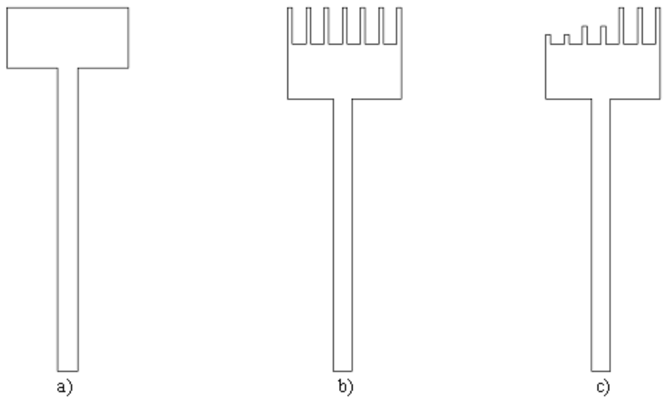


Figure 2: Different barriers that have been used for the simulation. a) will be referred to as T-shape, b) as fork shape, c) as fork gradient.

The insertion loss (IL) is calculated, according to the formula:

$$IL(dB) = -10\log_{10}(R) \tag{2}$$

$$R = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{p_i}{\overline{p_i}}\right)^2$$

where $p_i$ represents the pressure on the i-th microphone and $\overline{p_i}$ the pressure on the i-th microphone position of the configuration without barrier. The results can be seen in Fig 3.

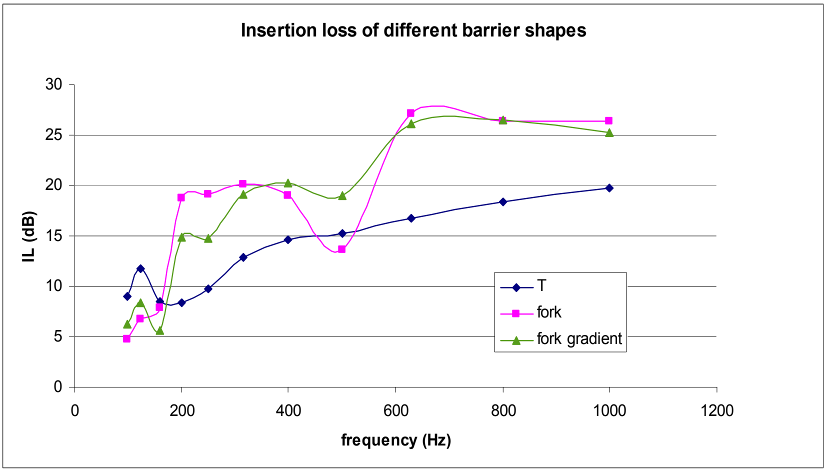


Figure 3: Insertion loss relative to the barriers of shape T, fork and fork gradient.

The expected improvement of the IL can be seen in Fig 3, for some frequencies an improvement of about 10dB for the "fork" shape can be found. On the other hand we also see a dip at around 500 Hz that corresponds to the maximum of the impedance. Following equation (1) the maximum IL is expected when $kd = \pi / 2$, which in our case (d = 400 mm) occurs at the frequency f = 210 Hz.

The graph of the fork barrier also shows a peak between 600 and 800 Hz, which can be seen again in the field lines in Fig.4 as the building of a soft plane.

The use of the "fork gradient", where different channels of different depths are used, presents an input impedance that changes along the length. It represents a considerable improvement in the insertion loss as the attenuation is better distributed along the range of the considered frequencies, as can be seen from the graph. The minimum at 500Hz is now still visible but has an increase of about 5dB compared to the previous shape.

It is interesting to have a closer look at the profile at the frequencies between 400Hz and 600Hz, to see how narrow the dip is. In order to achieve a better accuracy, simulations have been performed at additional frequencies. From Fig 4 it is clear that the profile relative to the fork barrier is smooth and the dip is a broad one. The same applies to a higher degree for the fork gradient barrier.

An average between the 9 microphones positions was calculated in order to represent an arbitrary point in the far field. In Fig 5 two graphs are shown that correspond to the points on the ground, one at 50 m and one at 100 m from the barrier. The behaviour is indeed very similar to that of the chosen average (Fig 3).

 
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For a better quantification of the results it is useful to calculate a single number value and weight it with traffic spectra. The traffic spectrum Lj of [5] has been used to define the quantity

$$D_{1000} = -10 Log \left( \frac{\sum_{j=1}^{fre} 10^{0.1L_j} R_j}{\sum_{j}^{fre} 10^{0.1L_j}} \right)$$

where the index j counts up to the frequency 1000Hz. For the three shapes analysed the single-number values are given in the following table

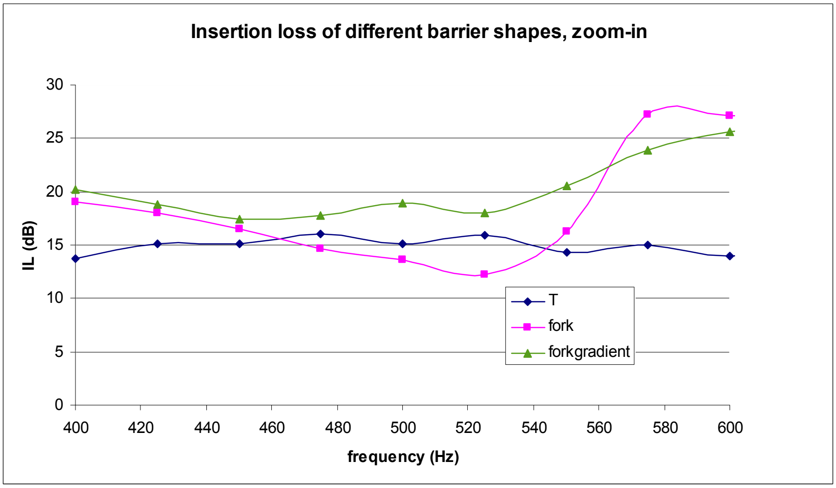


Figure 4: A zoom in of Fig. 3 with higher accuracy for frequencies from 400 to 630 Hz.

| | D1000 |
|---|---|
| T-shape | 14,4 |
| fork | 16,6 |
| fork gradient | 16,8 |

It is interesting to have a look at Fig 5. Here a graphical representation of the "fork" (left) and of the "fork gradient" (right) barrier is given, where field lines at 500 and 630Hz can be seen. On the edge of the barrier, the formation of the soft-plane is clearly visible. According to equation (1) the soft plane is expected at about 630Hz.

 
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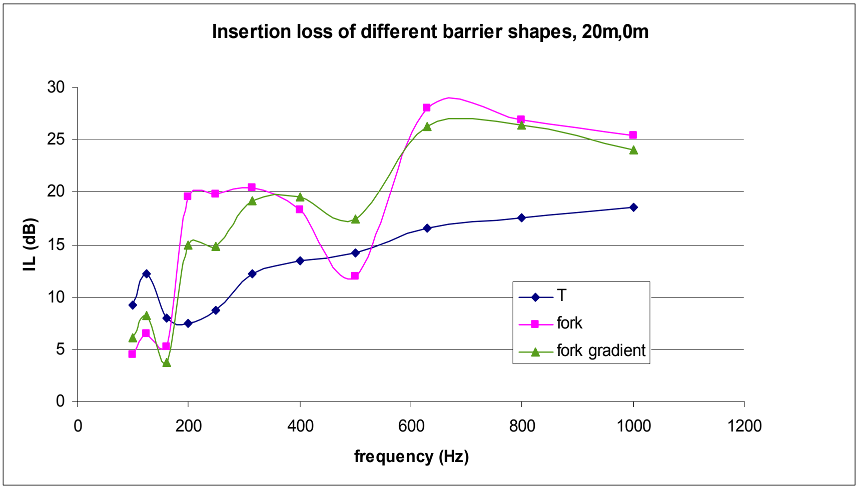


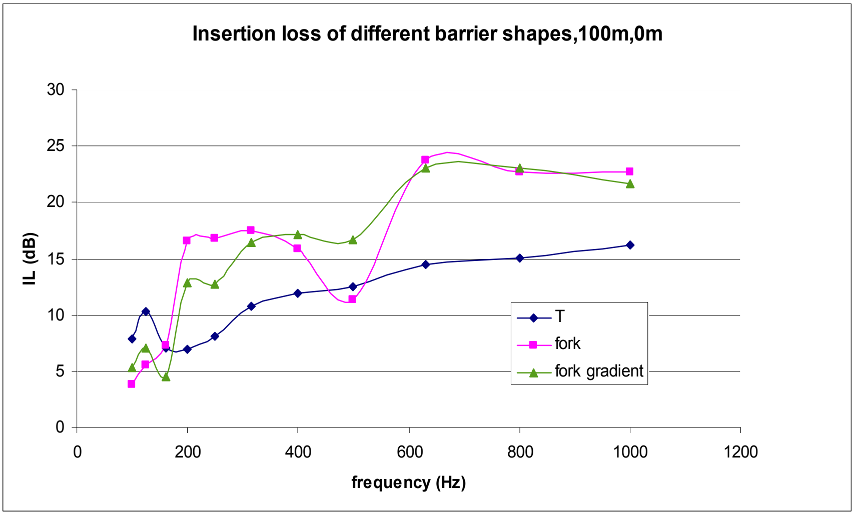


Figure 5: The insertion losses at two different points (20,0; 100,0) have graphs that are very similar to the graph of the average (fig 3).

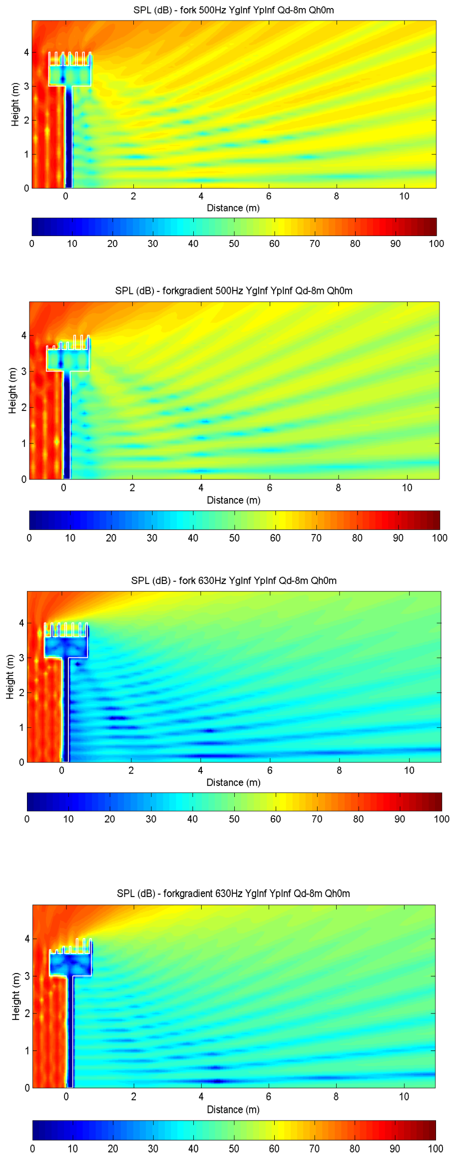


Figure 6: Graphical representation of the simulations for the frequencies of 500 and 630Hz for the fork barrier (left) and the fork gradient (right). The formation of the soft plane at these frequencies is visible.

## 3 Conclusions

Non-standard noise barriers for optimal far-field shielding have been investigated. A purely geometrical solution is not as prone to deterioration as absorbent barriers that tend to change their acoustic properties with time. The results of two-dimensional BEM analysis for the “fork” and “fork gradient” configurations are encouraging, as they present an improved shielding performance.

Moreover, as the performance can be changed with the change of the shape, in particular with the change of the depth of the used channels, these results can be used for a possible tuning of the barrier. If a mechanism is included into the barrier so that the height of the channels can be changed, this gives the possibility to change the spectral profile of the insertion loss. This could be useful in building sustainable barriers, in view of expected but not yet quantifiable shifts of the traffic noise spectrum in the future, as for example due to the increasing number of e-cars on the main transportation routes.

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