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Influence of barrier tops on noise levels: new BEM calculations

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The Danish Road Directorate is currently investigating the possibility to optimise noise barriers by using specially shaped tops. The noise level at different positions behind the noise barrier has been calculated using the boundary element method with the help of the OpenBEM software. The simulated situation is a barrier between a residential area and a motorway. The highway is modelled as a two-lane road and the sound levels are predicted at 10 m, 20 m and 40 m behind the barrier, respectively. Seven different types of barriers were tested including L-, T- and Y-tops as well as more a complex geometry such as a three-panel top. The results show that the T-shaped barrier offers most noise reduction compared to the others. It can indeed bring up to 6.6 dB extra noise reduction at a position 40 m behind the barrier compared to a regular barrier. This study also shows that the noise attenuation achieved with the different tops is dependent on the receiver position. Following this study, in-situ measurements will be carried out in an attempt to validate the predicted noise levels.

1 Introduction

In 2009 the project “Optimised Noise Barriers” was started at the Danish Road Directorate. The first phase of this project aimed at studying the different types of noise barriers. This literature study was concluded by a State-of-the art report [1], which contains a library of examples of noise barriers tested around the world. The second phase of the project aims at simulating different types of barriers to predict their effect on the noise level. Based on the barriers investigated in the literature study and based on how realistic they would be to build, a few examples were chosen to be modelled. This includes a regular thin vertical barrier, which is the most basic form. This type is expected to bring up to 15 dB reduction under good conditions. Another interesting barrier is an L-shaped barrier. Studies have shown that this type of barrier can bring 3 to 5 dB more attenuation than a conventional thin vertical barrier at a certain frequency [2]. An obvious extension of the L-shaped barrier is a T-shape barrier, this type has been extensively studied and results show that an extra attenuation of up to 5 dB compared to a regular barrier can be achieved. These results are highly depending on frequencies and on the materials used. One of the barrier shapes that has given promising results is the three-panel top, sometimes denoted ‘Watts barrier’, measurements show up to 2 dB extra attenuation compared to a regular thin vertical barrier [3]. A barrier type that does not seem to have been studied much is a Y-shaped barrier.

The aim of this study is to investigate the performance of these different types of noise barriers. A real situation is taken as an example to predict the noise level at different positions. The simulated situation is a motorway (Hillerødmotorvejen) in Gladsaxe, near Copenhagen.

The next section presents the location that has been modelled as well as the model used to predict the noise levels. The results are presented for the different noise barrier types. The results are then discussed and a conclusion is drawn.

2 Method

2.1 The modelled situation

At the crossing of Hillerødmotorvejen and Mørkhøjvej in Gladsaxe, a group of dwellings and a youth club are located very close to the highway and are strongly exposed to noise. Their location is shown in Figure 1. The two red lines in the figure represent the location of two planned noise barriers along the highway. The situation that has been modelled in the present study is the longest barrier. Distances between the road and the barrier are shown in Figure 2.

Figure 1: Location of the modelled situation in Gladsaxe, where the highway crosses Mørkhøjvej. The sites where the noise barriers will be built are indicated by red lines. The vertical white line indicates where the cross section of the highway is situated (see figure 2)

The highway has been modelled by two sources located at 13.5 m and 25.5 m from the barrier, respectively. The sound levels have been predicted at 10 m, 20 m and 40 m behind the barrier, respectively. These two source positions were chosen based on data given by Vejman.dk, which is the database of the Danish Road Directorate. The two source positions represent the two north and southbound lanes of the four-lane motorway, respectively. Each driving direction was modelled by two sources located 0.01 m and 0.3 m above the road surface, as suggested by the Harmonoise [4] and the NORD2000 [5] models (see Fig. 2). The lower source is dominated by the rolling noise and the upper source by the propulsion noise. The situation modelled is for one light vehicle per direction, driving at a speed of 110 km/h. This has an influence on the sound level predicted at the receiver positions. In the mathematical modelling, the two sources are weighted according to their contribution to the overall SPL. In this way, the rolling noise is dominant, as expected at a speed of 110 km/h.

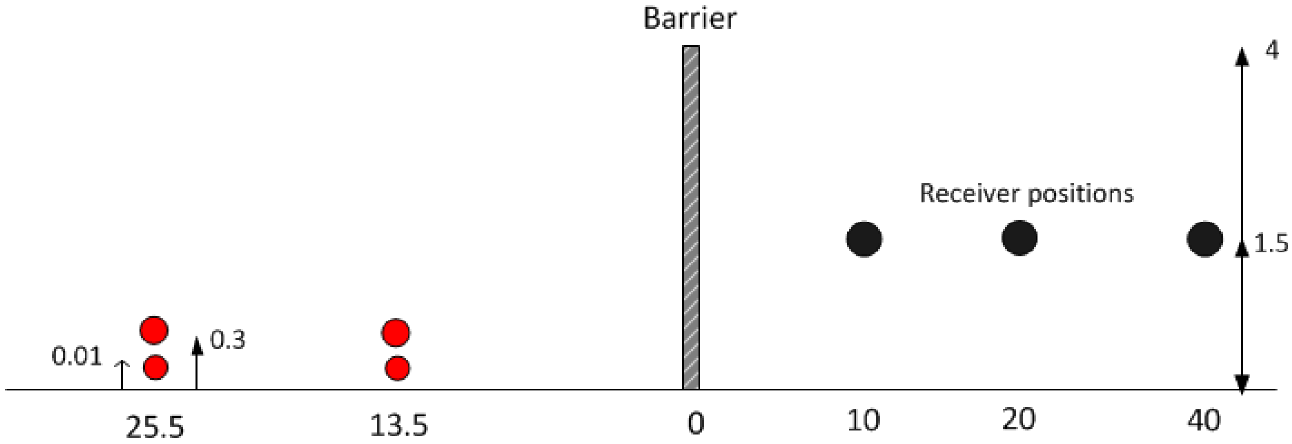


Figure 2: Cross section describing the simulated situation. Each driving direction with two lanes is simulated by two sources (red dots) and the receivers are represented by black dots. Distances and heights are in metres; the figure is not to scale

The sound level was predicted at three positions behind the barrier, 10 m, 20 m and 40 m, respectively, from the barrier and 1.5 m above the ground. This height of 1.5 m is the standard height suggested by the Danish Environmental Protection Agency for assessing the noise exposure of one storey dwellings.

The ground has been modelled as a rigid plane while a flow resistivity of $2 \cdot 10^5$ $N \cdot s \cdot m^{-4}$ was applied for the absorbing elements of the barriers. The present study has investigated both fully reflective and absorbing noise barriers. The next section presents the noise barriers and the elements which were assumed sound absorbing.

2.2 The different types of barriers

The geometry of the different barriers tested is presented in Figure 3. It also shows the name given to the geometry and its dimensions. The dashed green lines indicate which part of the barrier was made sound absorbing.

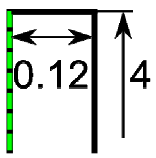
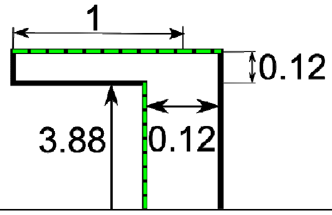
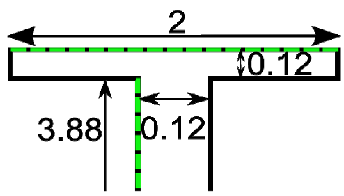
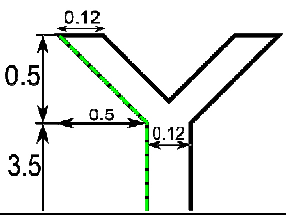
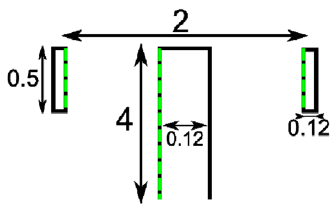
Type	Thin vertical (Ref.)	L top	T top
Dimensions			
	Y top	Three-panel top ('Watts')	
			

Figure 3: Tested barrier geometries. The dashed green lines indicate parts of the barrier which were assumed sound absorbing

The regular thin vertical barrier is the simplest form of a sound screen; it is used as a basis for comparison of the other barriers' effect. The thickness of the regular thin screen as well as of the others is 12 cm. It is the actual width of the element that will be used on site.

The second type of barrier tested is the L top. It is an inverted L with its 'foot' directed towards the road. It can be seen as a half T top. The width of the top is 1 m and its thickness is 12 cm. The T top is similar to the L top and is 2 m wide. The Y top can be seen as a T top with tilted sides. Care was taken that the total height of all barriers is 4 m. The last barrier type tested, is denoted "Watts", named after Dr. Greg Watts who suggested adding a vertical panel on each side at the edge of a flat screen. This was presented in his paper in 1992 [6] and he claimed it could bring about 2.7 dB extra noise reduction.

All screens were first tested with absorbing surfaces and then with reflecting surfaces. The results of both cases are presented in the next section.

2.3 The Boundary Element Method

The effect of each barrier type was modelled using the Boundary Element Method (BEM). This method is used to predict the sound propagation between a source and a receiver and is particularly adapted when an object (e.g. a barrier) is positioned between source and receiver. A great advantage of this method is that the elements of the geometry can be quite complicated and this gives some freedom regarding the shape of the barrier. BEM is based on the Helmotz equations and can be implemented in Matlab. The programme implemented in the present study uses the open source software OpenBEM [7, 8, 9] which is a library of Matlab files that can be used and modified to predict the noise level at a certain position.

The present simulations used a 2D BEM, assuming that the barrier is infinitely long on the y axis. The Matlab programme calculates the insertion loss for each receiver position and for each frequency between 60 Hz and 4 kHz. This broad frequency range was looked at in order to get an idea of the properties of the barrier at frequencies where traffic noise is at its highest (1-2 kHz). The insertion loss is the sound pressure level relative to the no-barrier situation, as expressed in the following formula.

$$IL = 20 \cdot \log_{10}(P/P_{NoBarrier}) \text{ dB} \quad (1)$$

The reader is referred to the authors' publications for further explanations on OpenBEM.

The insertion loss was calculated for each centre frequencies of the 1/12 octave bands between 60 Hz and 4 kHz. 1/12 octave bands have been preferred over 1/3 octave bands in order to get a better estimate of the IL. However, for clarity purposes the curves were then smoothed by averaging three consecutive values. In the next section, only the smoothed curves are presented.

3 Results

3.1 Reflective terrain and absorbing barrier

Figures 4 to 6 show the insertion loss for the different barrier types as a function of frequency, at 10 m, 20 m and 40 m behind the barrier, respectively.

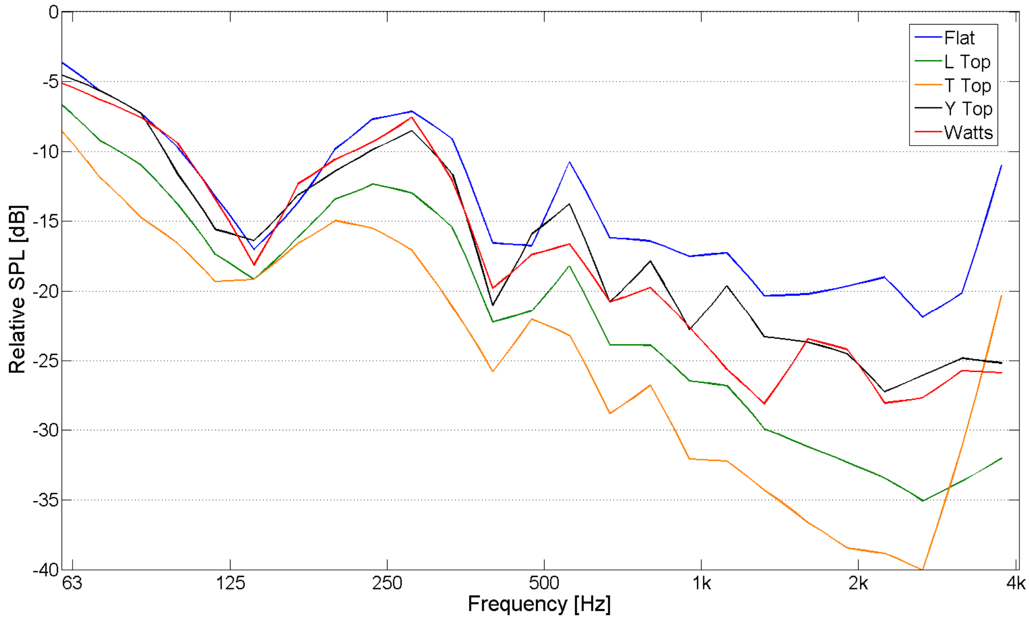


Figure 4: Insertion loss 10 m behind the different types of barrier as a function of frequency. For this case, the barrier is absorbing and the ground is rigid.

What can be observed from Fig. 4, 5 and 6 is that the insertion loss has a decreasing trend for all barrier types. It is around -5dB at 63 Hz and varies between -32 and -12 dB at 4 kHz. This trend is similar for all receiver positions.

The negative values of the relative sound pressure levels reflect the noise reducing property of the barrier tested. For all cases (across receivers and across barrier types), the noise barrier provides noise reduction.

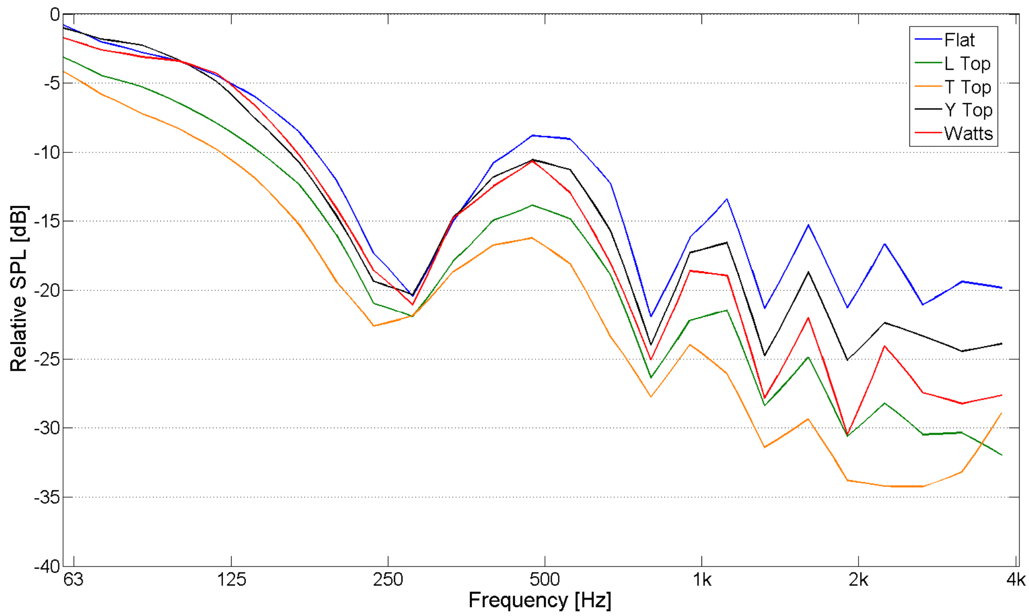


Figure 5: Insertion loss 20 m behind the different types of barrier as a function of frequency.

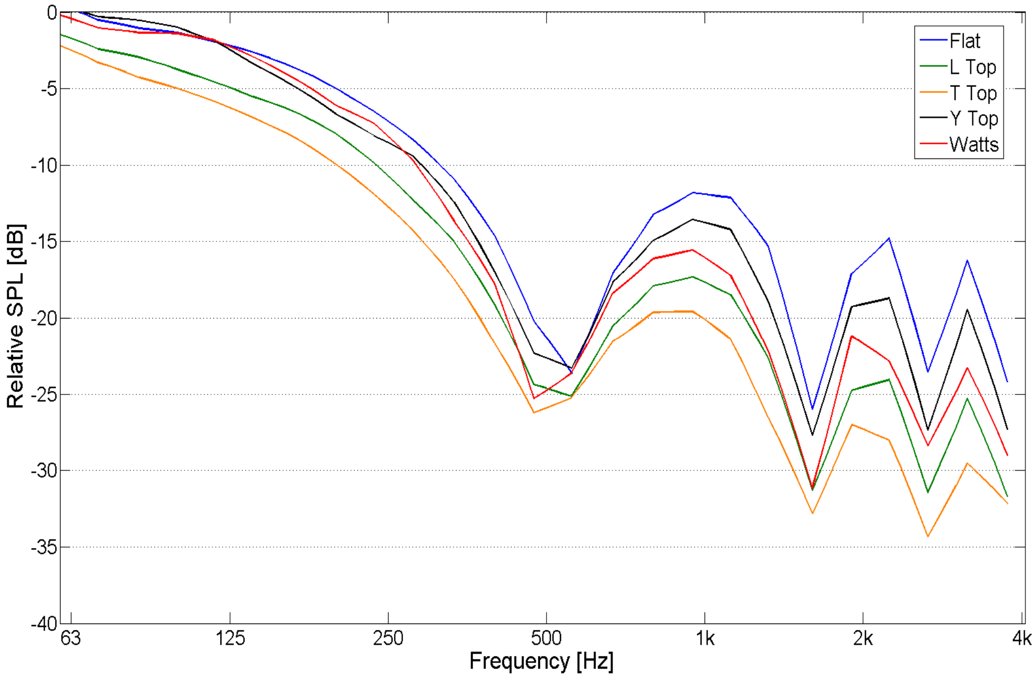


Figure 6: Insertion loss 40 m behind the different types of barrier as a function of frequency.

A common feature for all the results shown here is that the regular thin barrier (blue curve) lies above the other curves. This means that the insertion loss is lowest for this type of barrier, i.e. the noise reduction provided is lowest. At low frequencies (f < 500 Hz) the red and the black curves are close to the blue curve and then show some divergence at higher frequencies. This means that a Y-top and Watts barrier have the similar effect on noise at low frequencies as a regular thin barrier. For higher frequencies the Watts barrier type seems to bring more attenuation than a Y-top barrier, which is itself more attenuating than a regular thin barrier.

The green and orange curves (L- and T-top, respectively) are constantly below the three other curves, with the orange curve being the lowest of all. The direct implication is that the L-top barrier offers more attenuation than a regular thin, Y-top or Watts barrier and the T-top provides even more attenuation.

On all three figures, the curves show peaks and troughs. The frequencies at which they occur depend on the distance source-receiver and the receiver height. For example 40 m behind the barrier dips occur at 500 Hz, 1.5 kHz, 3 kHz and so on. The peaks and troughs correspond to the constructive and destructive interferences respectively. These interferences are due to the reflections from the rigid terrain in the mathematical model. Measurements would show less clear interference effects due to e.g. the averaging effect of fluctuating meteorological conditions.

If we sum the IL across frequencies, the performance of each barrier type can be compared more easily. Table 1 presents the extra attenuation provided by each type of noise barrier compared to a regular thin barrier. For all receiver positions the barrier shape attenuating the noise most efficiently is the T-Top, followed by the L-Top; then follows ‘Watts’ and finally the Y-Top. As expected, the further away the receiver, the lower the attenuation.

Table 1: Extra attenuation provided by the different tops compared to a regular thin barrier.

	Y-Top	Watts	L-Top	T-Top
10 m	-2.8	-3.5	-7.5	-10.4
20 m	-2.0	-3.4	-5.7	-8.1
40 m	-1.5	-2.8	-4.6	-6.6

At a distance of 40 m behind the barrier, the T-Top is expected to bring 6.6 dB more attenuation than a flat barrier. Many of these extra attenuations seem surprisingly large and the computation results need to be verified in full scale measurements.

3.2 Reflective terrain and barrier

In the case where both the ground and the barrier are reflective, the relative sound pressure levels are different from the previous case. The trend of having decreasing sound levels with increasing frequency remains and what differs is that the different curves are closer to one another. At distances of 10 m and 20 m behind the barrier it is not possible to say which barrier type brings most extra attenuation. For a receiver 40 m behind the barrier, the five estimated sound pressure level curves are within 3 dB of each other. In this case the Y and the 'Watts top' provides slightly higher extra attenuation around 1 kHz than the others.

Similarly to the case presented in section 3.1, Table 2 presents the extra attenuation provided by the different types of barrier compared to a regular thin barrier. In the case where all surfaces are reflective, the Y-Top yields the highest attenuation. The other types perform much less efficient than in the previous case. The Watts type hardly provides any extra attenuation.

Table 2: Extra attenuation provided by the different tops compared to a regular thin barrier.

	Y-Top	Watts	L-Top	T-Top
10 m	-3.7	0.3	-1.8	-2.6
20 m	-2.7	-0.5	-1.2	-1.8
40 m	-2.1	-1.1	-0.9	-1.2

At a distance of 40 m behind the barrier, the T-Top now only brings 1.2 dB more attenuation than a regular thin barrier.

4 Discussion

The results obtained in the present study can, to some extent, be compared with results from previous research. May and Osman [10] compared the performances of different barriers with the performance of a 4.9 m high thin barrier. Their experiment used a 1:6 scale model of the barrier, source and receiver being 1.2 m above ground and respectively 12.2 m and up to 37 m from the barrier. They showed that a 2.4 m wide absorbing T-top barrier brings 6 dB extra attenuation compared to the flat barrier, the absorbing top accounting for 2 dB. Although obtained with a slightly different barrier geometry, these results are very close to the value observed in the present study (6.6 dB extra and 5.4 dB due to absortion). May and Osman have also calculated for a reflective Y-Top and find 3.5 dB extra attenuation (2.1 here). Watts et al. [6] made a full scale experiment with different types of barriers providing the average of results at receivers 1.5 m and 4.5 m above ground and 20, 40 and 80 m behind the screen. Their results show that an absorbing T-Top can provide 3.1 dB extra attenuation as an average across the three microphone positions (8.3 dB here). They only placed absorbing elements on the horizontal part of the barrier whereas in the present study the vertical side of the barrier facing the road was made absorbing. This might explain the higher absorption in the present study. Their absorbing 'Watts barrier' was on average across positions 2.7 dB more attenuating than a regular thin screen (2.1 dB here).

In the case where already existing flat barriers have to be improved, adding devices on their top could easily yield better performance. The results show that adding panels on each side of the barrier ('Watts' type) and placing a horizontal extension to create a T shape can provide 4 dB and 7 dB extra reduction, respectively, at 1 kHz. 1 KHz is where the road traffic noise spectrum is highest, and hence maximum attenuation is needed at that frequency.

BEM computation cannot take into account the influence of atmospheric conditions on the sound propagation, and the results of the planned full scale experiment will have to be taken into consideration together with aesthetical and constructional considerations before final conclusions are drawn concerning the applicability of modified screen tops.

5 Conclusion

It can be concluded that the results obtained by means of BEM analysis in this study are in good agreement with results obtained in previous studies.

The purpose of this study has been to compare noise barriers with a special geometry that could lead to significant improvement of their noise reduction ability. The results suggest that building a T-shaped noise barrier would be the best choice, followed by an L-shaped top, a 'Watts' top and finally a Y-shaped barrier, provided the screen components are made sound absorbing. If screen elements are non-absorbing, the Y-shape barrier comes out yielding the highest extra attenuation.

It does indeed seem possible to improve the performance of a regular noise barrier by adding a device on its top. The next step in the Danish Road Directorate experiment will be to implement the most promising and practically feasible solutions in a full scale experiment. The barrier types suited for such an experiment are the regular thin barrier as a reference and the L-, T- and Watts-top. Such a full scale experiment, where the noise level is measured at different positions behind a barrier with various shapes is expected to take place at the end of 2012. The results will allow a comparison of the present BEM predictions with in-situ measurement results.

Since BEM computation cannot take into account the influence of atmospheric conditions on the sound propagation, the results of these full scale experiments, together with aesthetical and constructional considerations will have to be taken into account before final conclusions can be drawn as to the applicability of modified screen edges.

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