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INSERTION LOSS OF NOISE BARRIERS WITH SPECIAL TOP DESIGN USING THE BOUNDARY ELEMENT METHOD

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Abstract: *The calculation of the efficiency of barriers with complex shapes such as T-profiles or arched barriers is problematic in standardized calculation schemes. The project RELSKG aimed to implement calculations for noise barriers with special designs into noise mapping software using simple geometric correction functions based on numerical simulations performed using the 2D boundary element method. In a first step of the study the numerical simulations were tested using models with a scale of 1:4 and in situ measurements. The calculations were found to be in good agreement. Following, the differences between noise barriers of different shapes, dimensions, and absorptive configurations as compared to equally high, straight reflective barriers were calculated as a basis for the correction functions. It was confirmed that the effect of the top becomes important, when highly absorptive material is placed in the sound path around the top of the barrier. Simple correction functions were derived and implemented into the noise mapping software SoundPlan. The corrections function are available for free and support will be given implementing these curves into other noise mapping software tools. The project was supported by the Austrian Research Promotion Agency FFG with financial support from the Austrian Federal Ministry for Transport, Innovation and Technology BMVIT, the Austrian motorway operator ASFINAG and the Austrian railways OEBB.*

Key words: noise barrier, cross-section, design, boundary element method, noise map

1. INTRODUCTION

The boundary element method (BEM) becomes a more and more commonly used tool to simulate noise barriers in 2D, 2.5D and 3D. Due to the high computational effort this method was mostly used for special cases in the past. The approach of the project RELSKG is to do a parametric study with noise barrier shapes that are used in practice today using BEM. This is important as barriers with complex shapes cannot be treated analytically and are thus often approximated, e.g. by a straight noise barrier of different height and position, or by combining multiple diffraction terms [1]. Sometimes additions are used that were measured in situ (e.g. [2]). On the other hand partially numerical evaluations by means of the boundary element method were done (see e.g. [2-11]), however, usually only for a few selected shapes.

In addiditon to the shape of the barrier, the use of absorptive material also has a major contribution to the efficiency of a barrier. For straight barriers absorptive material is mainly used to avoid reflections to the opposite side and to avoid multiple reflections at railways. Experimental investigations and numerical investigations show, however, that absorptive material reduces the energy in the sound path and therefore has a positive effect on the noise level behind the barrier [2-11].

The goal of the project RELSKG is to simulate a large variety of different shapes, sizes, and absorptive configurations for complex noise barriers and to find suitable correction functions that can be used in noise mapping software. These functions will be made publicly available.

The 2D boundary element method is used due to the large number of computations. Partially simulations in 3D were made to check the validity of the 2D simulations. The difficulty of 2D simulations is the assumption of a coherent line source that produces interference effects behind the noise barrier.

The study consisted of three main steps: First, model measurements at a scale of 1:4 were made for a straight barrier, a T-shaped barrier, a barrier with a tilted top, and a barrier with a large overhang similar to an arched barrier. The tilted and the double tilted barrier were tested with a tilt in the direction of the source and in the opposite direction. The measurements were compared with 2D and partially 3D BEM simulations to validate the calculation method. Second, in-situ measurements were performed at the highway A4 near Mannswörth in Austria with two different barrier cross sections and heights. The difference measured between the two barrier types was compared to simulations.

Last, a large set of simulations in 2D was performed accommodating 5 different basic shapes and different configurations of absorbing material.

Based on these simulations, correction factors were derived based on a single parameter: the difference between the direct and the deviated path.

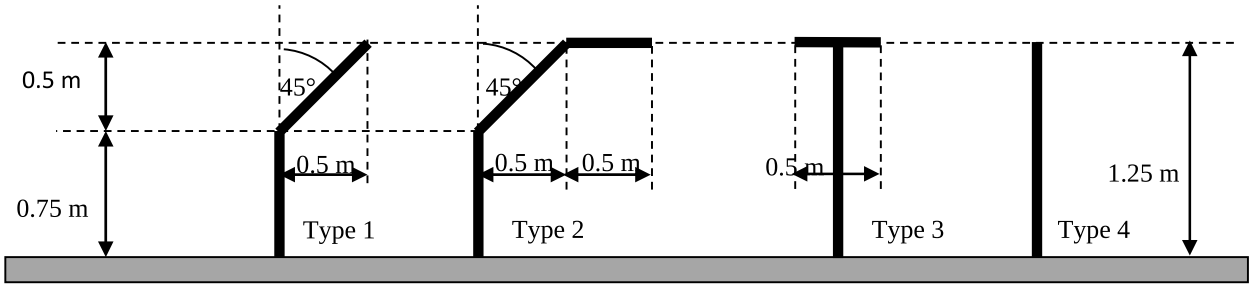

Fig. 1. Dimensions of the noise barriers for the measurements using scaled models

2. VALIDATION OF THE CALCULATION BY MESAUREMENTS

Measurements were done in a model scale 1:4 and in situ at a six-lane motorway A4 near Mannswörth in Austria to check the validity of the numerical method. The 2D-BEM used for the simulations is based on the boundary element method using the collocation and Galerkin approach. The method was used before in the EU-Craft project “Calm Tracks and Routes” for special noise barriers [12]. In this project Measurements were done at a motorway near Strengberg, in the Mur valley in Austria, and at the railway near Brannenburg in Germany. A spatial average behind the noise barrier was used in the former project instead of a spectral average that was used in RELSKG.

2.1. Measurements with scaled models

The measurements took place at a parking ground in Linz with an asphalt layer. A scaling ratio of approximately 1:4 was used due to the limitation in space. The frequency range was adjusted from 400 Hz to 20 kHz corresponding to 100 Hz to 5 kHz in reality.

The loudspeaker was positioned 15 cm above the ground at a distance of 1 m (LP1) and 2 meter (LP2) away from the vertical part of the noise barrier. A position near the ground was chosen as it reduces the interference effects that make comparisons between measurements and simulations difficult. Position LP1 roughly corresponds to the distance given at railways and position LP2 is representative for the distances given at roads. The loudspeaker was positioned at 45° such that the main lobe at LP1 pointed approximately to the diffracting edge of the straight noise barrier. Four types of noise barriers were tested. The cross-sections of the four noise barriers used in the experiment are shown in Fig. 1. Type 1 and 2 were measured with a tilt towards and away from the source, because a former EU-Craft project “Calm Tracks & Routes” [12] came to the result that a tilt away from the source can lead to an increase in the insertion loss, if highly absorptive material is used. Type 4 is the reference barrier.

The noise barriers were made using plywood, which in the simulations was assumed to be fully reflective. Barriers were covered with highly absorptive material. To test the effect of absorption the non-vertical region of type 2 and 3 were measured with and without absorptive material.

2.2. Results of the model measurements

Simulation and measurements were for the most part in good agreement up to 5 kHz and confirmed that absorptive material in the sound path leads to an important increase in the insertion loss behind the barrier. The shape of the top seems to be important in combination with highly absorptive material. A simple explanation is that absorptive material reduces the energy in the sound path above the tip.

Due to the directivity of the loudspeaker, type 1 and 2 with a direction towards the source proved problematic with the near loudspeaker position LP1. The reason for the partly large deviations is the directivity of the loudspeaker, as the diffraction edge is up to 45° out of the axis of the main lobe of the loudspeaker. At LP2 agreement was much better for these two barrier types. Simulations showed, however, large discrepancies above 5 kHz. This deviation was most likely caused by unknown absorption of the asphalt layer and the increasing directivity of the loud speaker at higher frequencies. Further, absorption coefficients of the absorptive material were also known only up to 5 kHz.

2.3. In situ measurements

In-situ Measurements were performed at a six-lane motorway near Mannswörth in Austria for the barriers presented in Fig. 2 and 3. The measurement positions were located 12.5 and 25 m behind the base of the barriers.

Four heights at both positions: 1.5, 3, 4.5, and 6 meters above the traffic lane were measured. A reference measurement was performed on a section without a barrier in 15 m distance 4 meters above the traffic lane.

All six lanes were taken into account in the simulations. The lane-wise scaling of the source level was done using traffic counting data for the six lanes from an automatic counting system. For the difference between the two barriers in dB(A) the source spectrum of the simulations without a barrier was adjusted to match the immission at

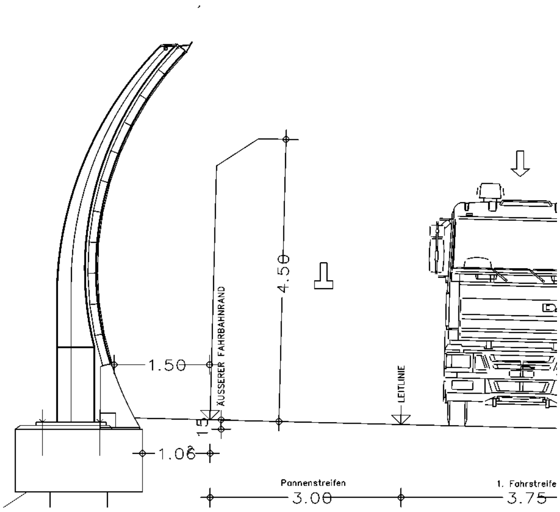

Fig. 2. Low and almost straight noise barrier

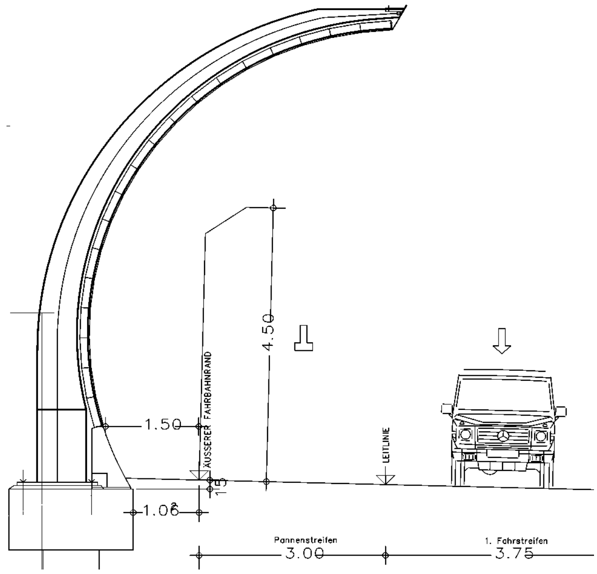

Fig. 3. High and curved noise barrier

the reference location. This source spectrum was used to scale the simulations that included the barriers.

A number of different settings concerning the discretization of the barrier and the terrain behind the barrier were simulated: a drop of one meter behind the barrier versus a straight surface, a grassland model versus reflective ground behind the barrier and middle face elements versa boundary elements.

2.4. Results of the in-situ measurements

The simulation was done using either middle-face elements or boundary elements [13]. Boundary elements are problematic due to the very thin top of the barriers. It was found that middle face elements performed best with less than 1.5dB(A) deviation from measurement (Fig. 5, black line).

Using the classical boundary elements yielded a much larger mitigation of the high barrier because the top region could not be modelled appropriately due to a thin structure on top of the barrier.

Modelling the drop in the terrain of one meter right behind the barrier had a small influence in the frequencies below 500Hz. Higher frequencies were mostly unaffected (less than 1dB in octave bands),

The ground model [14-15] had the largest influence in the low positions (Fig. 4), however, it was always below 1dB(A).

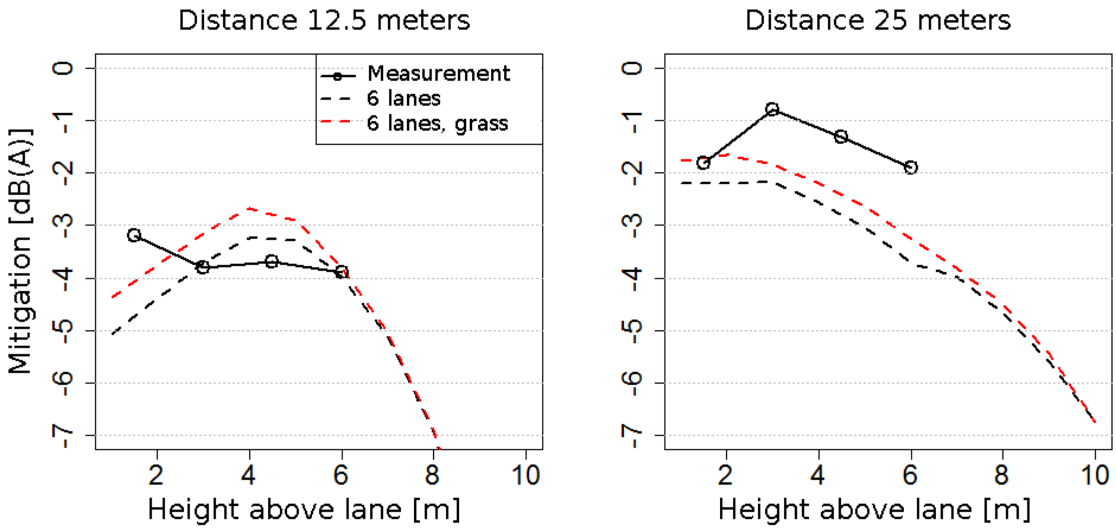

Fig. 4. In-situ validation results with and without a grassland model.

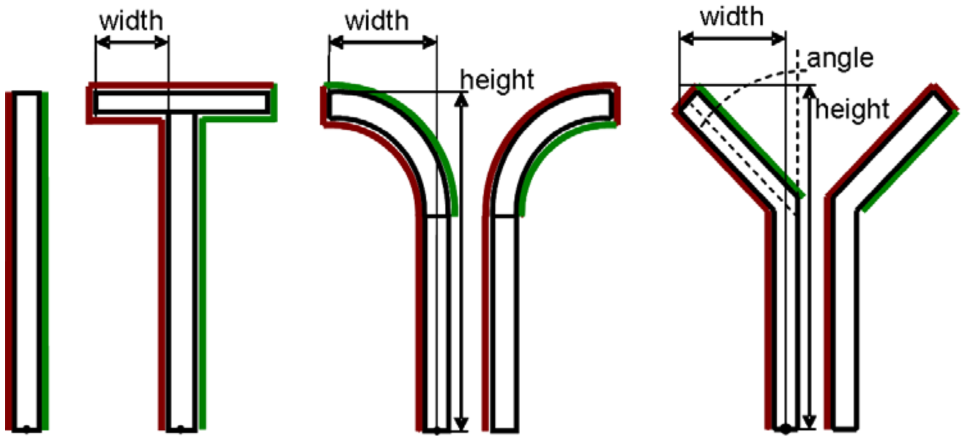

Fig. 5. Noise barrier types used in the simulation

3. SIMULATION OF INSERTION LOSS OF NOISE BARRIERS WITH SPECIAL TOPS

The noise barrier types presented in Fig. 5 were simulated to derive a data base for the derivation of correction functions. The parameters of the barriers are the height, the width, and for the tilted barrier the tilting angle of the top. Additionally the barriers were simulated to be either fully reflective or equipped with highly absorptive material in the direction of the source and additionally in the direction of the shielded region. The reflective straight noise barrier is the reference. The mitigation of the top design against the straight noise barrier was evaluated.
In the BEM an admittance of the surface is needed. Therefore, with reverberant chamber measurements the phase has to be assumed. A phase of zero degree was assumed.
The simulations were done in 2D. The BEM is based on the boundary element method with collocation and Galerkin method. In 2D elements with a variable polynomial degree were used. This gives the possibility to use one mesh for the whole frequency range from 50 Hz to 5 kHz. In 3D the Multi-Level Fast Multipole Method (MLFMM) was used. Simulations in 3D were done using a reflective ground. Due to the limits in the mesh size the length of the barrier was limited to 10 m to each side of the point source using an additional vertical mirror plane. 3D simulations were only possible up to 1.5 kHz due to the limitation of the storage and the computational time although the Multi-Level Fast Multipole Method (MLFMM) was used.
The 3D model showed that the mitigation of a T-profile compared to an equally high straight barrier for a coherent line source was similar to the mitigation of a point source. Further, for this short piece of barrier a coherent line source was similar to a number of coherently or incoherently added point sources placed parallel to the barriers in the 3D simulation.
As in the model measurements the top has a great influence on the mitigation, if highly absorptive material is used.

4. DERIVATION OF SIMPLE MITIGATION FUNCTIONS FOR NOISE MAPPING SOFTWARE

The simulations resulted in a high number of insertion losses of arbitrarily shaped noise barriers compared with straight noise barriers of equal height for varying source and receiver positions and for third octave band frequencies using a spectral average about octave band width. The dependency of the results on geometrical values was investigated. The region behind the barrier was divided into three zones. Zone 1 has a direct path from source to receiver, zone 2 has a single diffracting edge, and zone 3 as long as it exists has two diffracting edges. As long as one variable is used, the best explanatory single variable for a linear regression was found to be the difference of the deviated path related to the direct path (Fig. 6).
The regression curves are shifted with the standard deviation into the direction of less insertion loss to be on the save side. Fig. 7 presents the curve for a T-Profile with 3m height and 2m width of the top using absorptive material at the front and the top of the barrier for a frequency band around 500 Hz.

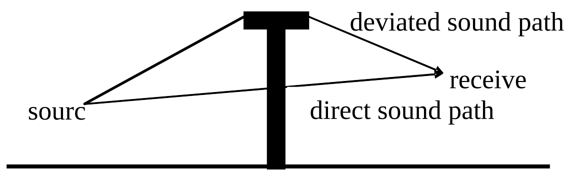

Fig. 6. Direct and deviated sound path with two edges

The correction functions were implemented into the noise mapping software SoundPlan.
If two parameters and non-linear regressions are allowed a better approximation is possible using the angle from the tip of the barrier towards the source position and the angle towards the receiver position.

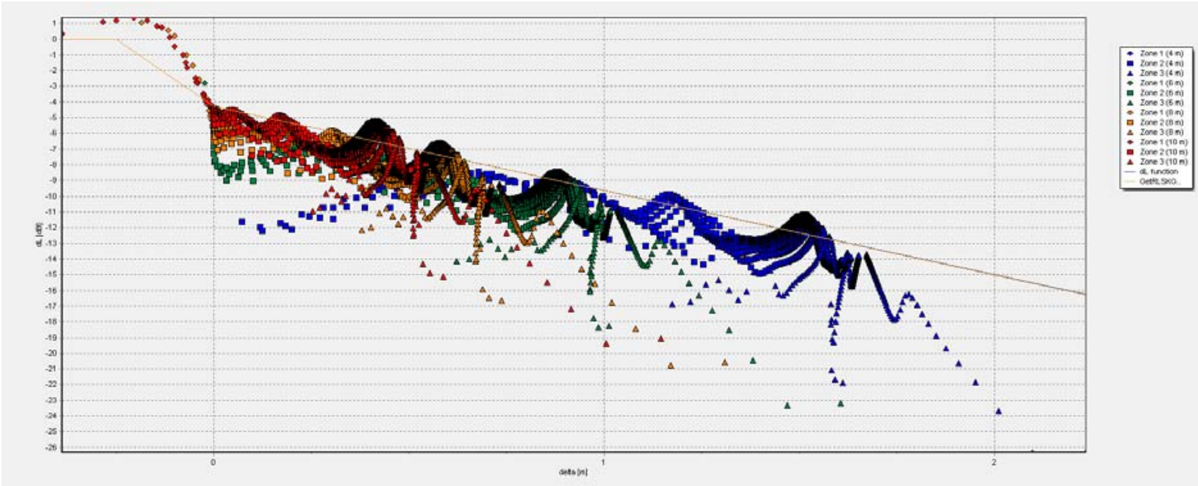

Fig. 7. Mitigation for a 3 m high T-profile with 2 m width at 500 Hz

5. CONCLUSIONS

It was confirmed that absorptive material is important to produce a reduction of the noise using special head types by measurement and calculations. Absorption is not only needed to reduce reflections to the opposite side and multi-reflections at railways but also to increase the insertion loss behind the barrier. Most important is the absorptive material at the tip region of the noise barrier. The absorption coefficient measured in the reverberation room cannot be used directly in the BEM simulations. In this project, the absorption of the standard curve for highly absorptive material from ISO 11654 was converted to an impedance of zero phase. A more realistic way would be to use an impedance model and the random incidence absorption coefficient to fit the model to reverberation room measurements, possibly with a sample size correction [16].

A boundary element method developed at the Acoustics Research Institute was used for the simulations. It was found that a correct representation of the head is important for correct results and that middle face elements are needed for the simulation of very thin structures.

The results of these simulations cannot be included in the noise mapping software directly. Therefore, correction curves were approximated that depend only on one parameter the elongation of the path from the source to the receiver position. These correction functions are implemented and tested in the noise mapping software SoundPlan and are available for free. Anyone who is interested in these curves can contact the authors by Email.

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