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VALIDATION OF RAY ACOUSTICS APPLIED FOR THE MODELLING OF NOISE BARRIERS

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Ray acoustics have been used to investigate the effectiveness of noise barriers in railway applications. Various types and shapes of barriers are modelled using the commercial software RAYNOISE. Absorbing and reflecting configurations as well as barriers at different angles are included. The numerical results are validated by measurement of the insertion loss for four types of barriers. A-weighted sound pressure levels have been calculated at six locations, 25 m from the track and are compared with the experimental values. The source strengths were selected to represent a high-speed train. The measurements were carried out using a microphone array; therefore the tests could be carried out alongside noise barriers of reduced length. The barrier measurements have already been validated against train pass-by measurements and have shown to be accurate within 1–2 dB (A). Insertion losses up to 15 dB (A) have been measured and calculated. Comparison between numerical and experimental values show agreement within 2 dB (A). The sensitivity of the numerical models to some numerical parameters as well as to the barrier-to-track distance was investigated. The results show that there is significant dependence on parameters, such as the number of rays and the order of reflection. Therefore, some guidelines are proposed in order to achieve stable results. In a single case of a reflecting barrier, the barrier-to-track spacing is quite critical, due to a reflection effect. The main conclusion is that ray acoustics can be a powerful tool in investigating the effectiveness of noise barriers, and that the accuracy of the calculated A-weighted sound pressure levels is within acceptable limits.

1. INTRODUCTION

Noise barriers are widely used to reduce noise immission. The noise reduction depends not only on the barrier configuration; the distance to the source and other location parameters also play an important role. Experimental tests and numerical models can be used to optimize the performance of noise barriers. The accuracy of these models plays a major role in their applicability. This paper presents a study on the validation of numerical models.

Numerical models for noise barriers applied along high-speed train tracks have in this case been developed using the commercial program RAYNOISE (revision 3) [1]. This code is an algorithm combining the ray tracing method with the mirror image source method, also known as geometrical acoustics.

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The numerical models were designed to resemble a test location for noise barriers of reduced length. The measurements were carried out using a microphone array which can be used for barriers of reduced length [2]. The numerical models are validated by comparing numerical and experimental results.

This paper describes the validation of four types of noise barriers designed to reduce the noise of high-speed trains. Calculated insertion losses as well as absolute sound pressure values are evaluated. Finally, some calculation parameters are varied to provide some values for accuracy estimation.

2. DESCRIPTION OF THE SIMULATION MODELS

2.1. NOISE BARRIER CONFIGURATIONS

Four different types of noise barriers have been selected to provide sufficient validation of the numerical approach. Figure 1 shows schematic images of the barriers selected for this study. All barriers are 2·5 m high, and are placed at 2·5–3·7 m from the centre of the track. Barrier type 2 has a sound absorbing surface towards the track (black), while type 3 is a reflecting barrier (white). Type 1 and 4 have both reflecting and absorbing sections.

For each type of barrier the surface absorption spectra are specified. The track profile includes ballast and grass, for which spectra are available from literature. The train body is assumed to be fully reflecting, its shape is a cross-section of a TGV-A motor car, which was also included in the experimental set-up.

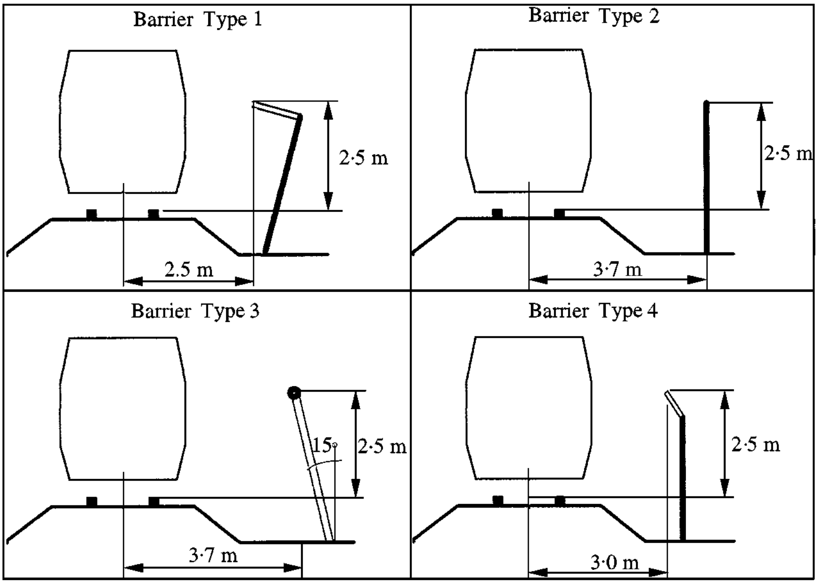

Figure 1. Types of barriers used for simulations.

TABLE 1

Source powers used [dB(A)]

Frequency (Hz)	250	500	1000	2000
0·5 m above track	100	126	130	133
2 m above track	125	123	127	128
3 m above track	100	118	124	100

2.2. SOURCE DESCRIPTION

In the experimental set-up, loudspeakers were located at three positions: 0·5, 2 and 3 m above the track. In the numerical models the sources were simulated by using three monopoles (half-spheres) in one single cross-section. The source spectra are described in four octave bands: 250–2000 Hz, based on a typical spectrum for a high-speed train (Table 1). A noise source at 5 m (the pantograph) was omitted to show the insertion loss for the lower sources.

During the field tests the length of the barriers was limited to about 30 m. In the numerical models the barriers are assumed to be longer, to prevent a diffraction effect at the edges of the barriers. In the experimental set-up this contribution is prevented by the directivity of the microphone array [2]. Diffraction at the top of the barriers is included. The diffraction calculation is a separate post-process step and includes only first order diffraction.

3. NUMERICAL AND EXPERIMENTAL RESULTS

Absolute sound pressure levels and insertion losses were determined at six points, 25 m from the track. These receiver points are 2, 3·5 and 5 m above the track. Three receiver points were 12 m out of this plane but still 25 m from the track. Both sets are used to determine equivalent insertion losses, in a similar way to that used for the experiments. The insertion losses determined for both microphone sets are weighted equally.

3.1. ABSOLUTE SOUND PRESSURE LEVELS

First, a comparison between the calculated and measured absolute sound pressure levels is presented. The transfer path between the source and receiver was calibrated using the sound power level of the source and the measured sound pressure level at the receiver position.

Table 2 shows the measured A-weighted, overall level for the selected barrier configurations. In the table, the dB(A) values for the sound pressure level are shown for each receiver height. The overall level, as shown in the table, is the average sound pressure level for the three receiver positions.

TABLE 2

A-weighted sound pressure levels measured by microphone array (NSTO)

Experimental results	Barrier Type 1	Barrier Type 2	Barrier Type 3	Barrier Type 4
Sound pressure 25 m/2 m (dB)	88·5	84·3	88·6	88·3
Sound pressure 25 m/3·5 m (dB)	89·1	87·2	88·9	88·8
Sound pressure 25 m/5 m (dB)	89·6	88·9	91·0	89·2
Mean sound pressure level	89·1	87·2	89·7	88·8

TABLE 3

A-weighted sound pressure levels calculated with RAYNOISE

Numerical results	Barrier Type 1	Barrier Type 2	Barrier Type 3	Barrier Type 4
Sound pressure 25 m/2 m (dB)	89·6	88·1	89·9	89·0
Sound pressure 25 m/3·5 m (dB)	87·6	88·8	91·8	90·3
Sound pressure 25 m/5 m (dB)	88·0	89·8	89·7	88·9
Mean sound pressure level	88·5	89·0	90·6	89·5

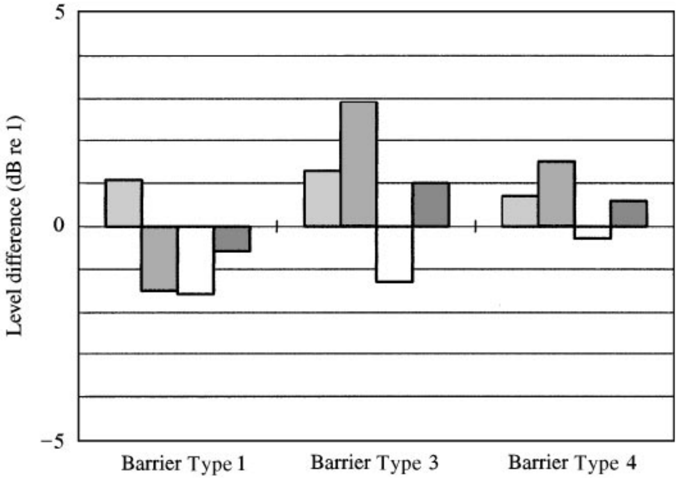

Figure 2. Difference between calculated and measured sound pressure level. ▨ 2 m high; ▩ 3·5 m high; □ 5 m high; ■ overall level.

The calculated sound pressure level for all barrier types is shown in Table 3. Comparison of the calculated and measured results shows a good agreement. This is illustrated in Figure 2, which shows the difference between calculated and measured A-weighted sound pressure level for three barrier types.

It can be seen from the figure that the difference varies between 0·3 and 3 dB(A). Since the deviation depicted is the difference between calculated and measured level, it is concluded that on average the calculated level is over-estimated in most cases, with the exception of barrier Type 1.

3.2. DETERMINATION OF THE INSERTION LOSS VALUES

The insertion loss for each barrier is determined by subtracting the A-weighted sound pressure level with the barrier present from the level without a barrier.

Table 4 presents the numerically calculated insertion losses at three receiver positions. These values vary in the range from 6·4 to 12·2 dB. Due to the differences in barrier designs, the results do not show a similar trend across the different receiver points. The barrier planes under different angles result in different reflection patterns. Hence the radiation patterns show different directivities, which results in varying insertion loss values. Barrier Types 2 and 3 show a trend to be expected: a maximum insertion loss at minimal receiver height. For barrier Types 1 and 4 this is not the case, most probably due to the reflections.

The experimental insertion losses are presented in Table 5. These results confirm the trends found in the numerical results. Differences in field-point values (immission points) are within 3 dB (Table 6). The average values show that the numerical

TABLE 4

Insertion losses calculated for four types of barriers with RAYNOISE

Numerical results	Barrier Type 1	Barrier Type 2	Barrier Type 3	Barrier Type 4
Insertion loss 25 m/2 m (dB)	10·6	12·1	10·0	11·1
Insertion loss 25 m/3·5 m (dB)	12·2	11·0	8·0	9·5
Insertion loss 25 m/5 m (dB)	11·6	9·8	6·4	10·5
Mean insertion loss (dB)	11·5	11·0	8·2	10·3

TABLE 5

Insertion losses measured by microphone array (NSTO)

Experimental results	Barrier Type 1	Barrier Type 2	Barrier Type 3	Barrier Type 4
Insertion loss 25 m/2 m (dB)	11	15	12	12
Insertion loss 25 m/3·5 m (dB)	11	13	11	11
Insertion loss 25 m/5 m (dB)	10	10	8	11
Mean insertion loss (dB)	10·7	12·7	10·3	11·3

TABLE 6

Differences in calculated and measured insertion losses

Differences in results	Barrier Type 1	Barrier Type 2	Barrier Type 3	Barrier Type 4
Delta insertion loss 25 m/2 m (dB)	− 0·4	− 3·0	− 2·0	− 0·9
Delta insertion loss 25 m/3·5 m (dB)	1·2	− 2·0	− 3·0	− 1·5
Delta insertion loss 25 m/5 m (dB)	1·6	− 0·2	− 1·6	− 0·5
Mean difference (dB)	0·8	− 1·7	− 2·2	− 1·0

values underestimate the insertion loss by 1 dB. Only for Type 1 is an overestimation (of 0·8 dB) is found. Barrier Type 3 shows the largest difference (an underestimation of 2·2 dB).

4. ANALYSIS OF RESULTS

In order to provide some measure of error estimation, additional calculations have been carried out, in which some numerical parameters and barrier-track distances have been varied.

Barrier Type 4 shows results which are strongly dependent on the number of rays and the order of reflection. Figure 3 shows the relative error depending on the number of rays. The results gained with 20 000 rays has been set as a reference, since for a higher number of rays the results are stable. Defining fewer rays does not necessarily give larger errors. This depends on whether reflected rays are reflected near a corner and just partly or not reflected at all. The point where the centre point of the beam strikes determines the part to be reflected. For large numbers of rays these errors can be neglected. Sixth order reflections have a role to play for reflecting noise barriers (Figure 4), although this depends strongly on the height of the reflecting part of the barrier. The other barrier types are much less dependent on these parameters, especially absorbent barrier Type 2 which is within 0·2 dB for a similar variation in number of rays and reflection order.

Additionally, some numerical experiments are carried out for barrier Type 4. The reflecting section of this barrier appears to be of major importance for its noise reducing performance. A track distance of 2·5 m instead of 3 m decreases the average insertion loss by 3 dB, while normally an increase is to be expected. Analysis of the ray paths show that this is caused by second order reflections of the source at 0·5 m, which produce a radiation pattern with maximum values in the receiver points at 2 and 3·5 m.

In this paper the numerical values are compared with measurements using a microphone array, which in turn are validated by train pass-by measurements. This latter validation shows that the array and pass-by A-weighted results agree within 1–2 dB. This comparison was performed for insertion losses from 9 to 13 dB.

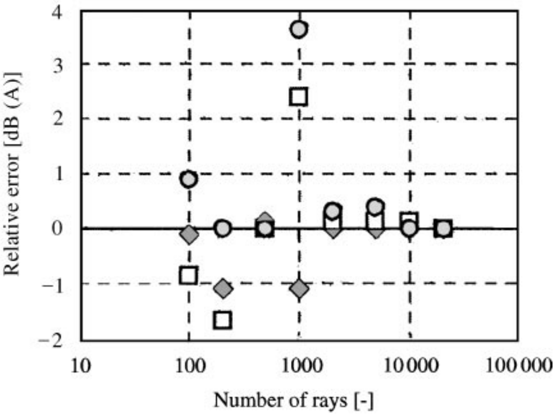

Figure 3. Varying the number of rays (barrier Type 4). ◆ 25 m/2 m high; □ 25 m/3·5 m high; ○ 25 m/5 m high.

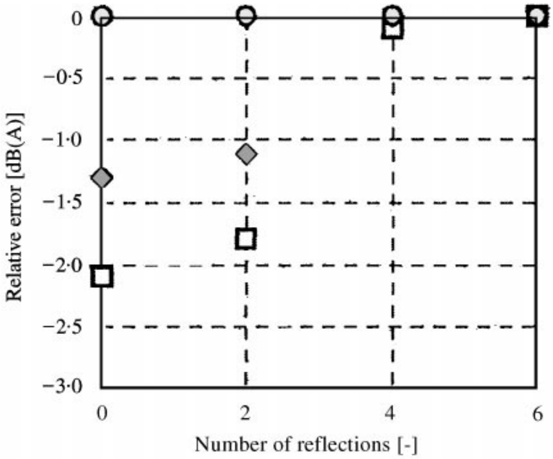

Figure 4. Varying the number of reflections (barrier Type 4). ◆ 25 m/2 m high; □ 25 m/3·5 m high; ○ 25 m/5 m high.

5. CONCLUSIONS

Insertion losses for four types of noise barriers are determined by using the numerical program RAYNOISE. The numerical results are compared with experimental values measured by means of a microphone array on a barrier test site. It is shown that there is good agreement between the calculated and measured A-weighted sound pressure levels. The difference is within 0 and 3 dB (A).

The insertion losses are determined for three different heights at 25 m from of the track. Insertion losses of 8–12 dB have been calculated. The numerical results underestimate the insertion loss by, on average 1 dB. The insertion loss of a reflecting barrier is underestimated by a maximum of 2 dB and L-shaped barrier is overestimated by 1 dB.

On the basis of this validation it can be stated that the numerical models can estimate the insertion loss within 2 dB. However, if more reliable (measured) absorption spectra can be used, it may be expected that the models will estimate the insertion loss even more accurately.

Variation of the number of rays and the reflection order shows that some attention is required to obtain stable numerical results. Reflecting barriers and other surfaces require up to 20 000 rays and sixth order reflections to provide converging sound pressure values.

Small changes in the configuration of reflecting barriers may cause major changes in the insertion loss. The exact track-barrier distance and the barrier angle is required, in order to take account of reflections.

ACKNOWLEDGMENT

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