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NOISE CONTROL FOR A BETTER ENVIRONMENT

Measurement and Acoustic Model Validation of a Train Pass-by Noise Using Ray Tracing Method

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ABSTRACT

The prediction of acoustic radiation, reflections and attenuation of a rail-track and its surroundings is crucial to perform a reliable pass-by noise simulation for trains. This paper describes the measurement of the acoustic propagation of a rail-track and its local environment and the validation of the corresponding simulation model. The experimental campaign has been performed on a ballasted track at a test ring in the Czech Republic. The aim of this work is to consider different surface properties such as ballast and grass and to investigate their influence on the noise propagation and attenuation. Each surface has a different level of diffusion and reflects the noise differently, based on the angle of incidence. Various design studies for different track surroundings and their influence on acoustic propagation have been investigated. The results of this work have been used as a basis for numerical train pass-by noise simulations. The ray tracing method has been shown to be an effective method for fast evaluation of train exterior noise.

Keywords: Noise, Absorption, Ray tracing, Compact Acoustic Sources
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1. INTRODUCTION

In train pass-by noise it is essential to know surrounding surfaces' parameters to be able to create reliable numerical models that correctly account for the reflected noise.

The total sound pressure level is composed of the direct noise and of the various reflections from the different surfaces such as wagons, ballast, sleepers (and their spacing) and the grass.

Real scenarios contain more complicating effects, e.g., not every rail track is perfectly symmetric.

In this paper, the main objective is to identify frequency-dependent absorption coefficients of three different surfaces typical near passing trains: rail track (ballast), concrete and grass.

Several measurements were performed on these surfaces to obtain acoustic transfer functions from which it is possible to extract the desired absorption by means of numerical geometrical method Ray tracing.

As a next objective, derived absorption coefficients were used in a complex Ray tracing model comprised of two container wagons on a rail track, considering diffraction along sharp edges to validate train pass-by noise.

2. EXPERIMENTAL CAMPAIGN FOR ABSORPTION ESTIMATION

An experimental campaign was performed by VÚKV a.s. at Velim railway test circuit (railway rolling stock testing facility at Cerhenice) in the Czech Republic, where certification noise tests according to TSI-NOI [1] are regularly conducted. The aim of the campaign was to measure sound pressure levels at different distances and heights from an omnidirectional source on three different surfaces: ballast, grass and concrete.

2.1 Experimental Setup

An omnidirectional sound source was used as a source for emitting a white noise spectrum. Acoustic responses were recorded at microphones (M2, M3, M4, M5, M6) at certain distances and heights as shown in Figure 1 and 2.
The different distances between microphones were designed to capture the influence of different angles of reflections. The recorded sound pressure level is then composed of direct noise and reflected noise.

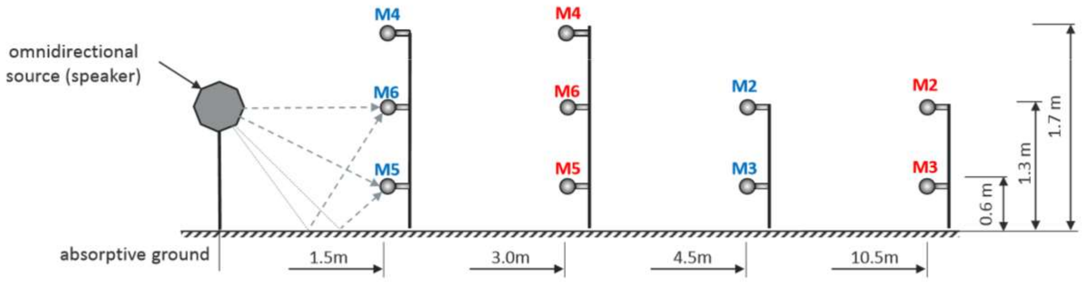


Figure 1 – Experimental setup

Figure 2 – Experimental setup for ballast

For each microphone, two different sets of Acoustic Transfer Functions (ATF) were recorded since each microphone was moved from the original position (blue) to a different one (red) covering the range from 1.5 to 10.5 meters distance from the omnidirectional source. Background noise was recorded as well.

2.1 Test Results

Preliminary test results were not in compliance with expectations and possible reasons could be related to the fact that microphones were placed too close to each other. There was the presence of marginal wind during testing and the measurements were not repeated several times to check consistency. In response, it was decided to change the experimental set up (Figure 3) and measure sound pressure level up to 24 meters distant from the omnidirectional source with a spacing between microphones of 3 meters.

Results were obtained for concrete, grass surfaces and for the ballast in the frequency range from 10Hz to 10kHz. The first measurement was performed on the concrete surface to characterize the source power spectrum. The concrete surface condition was chosen for the source characterization since it can be considered an ideally rigid surface having negligible absorption. Recorded sound pressure levels are presented below in Figures 4 and 5. For the concrete surface, the sound pressure level from the source is higher than background noise but for the ballast below 200Hz, the background noise is comparable to the measured sound pressure level; this means that below 200Hz data cannot be used for the back-calculation of ballast absorption.

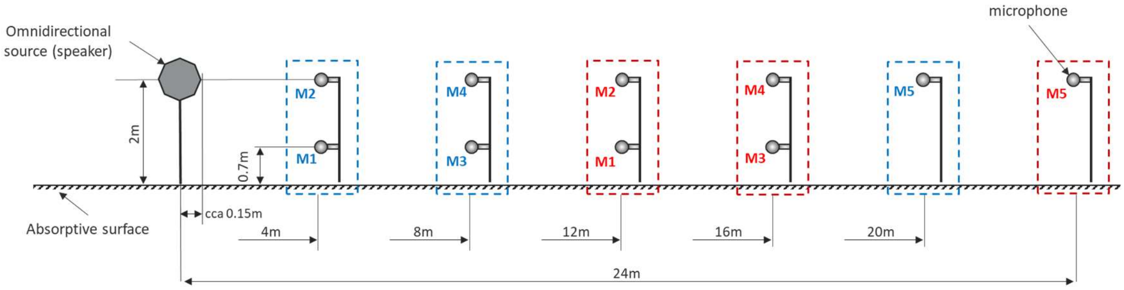


Figure 3 – Experimental setup

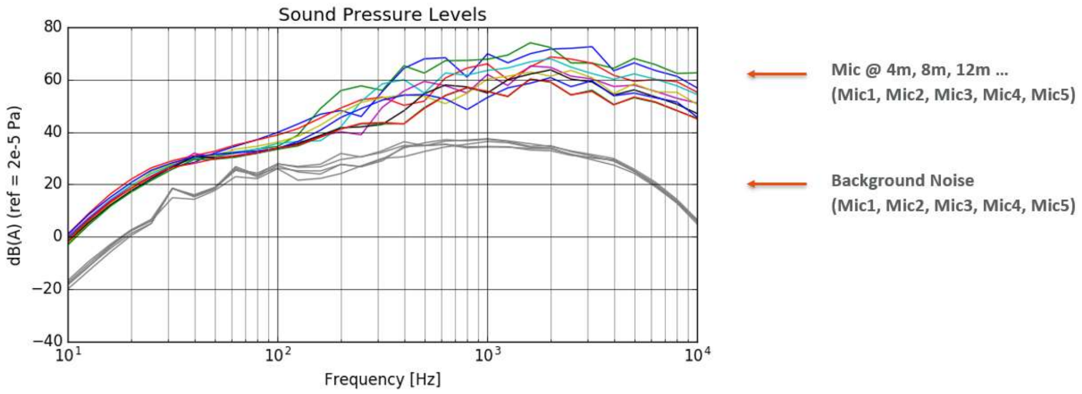
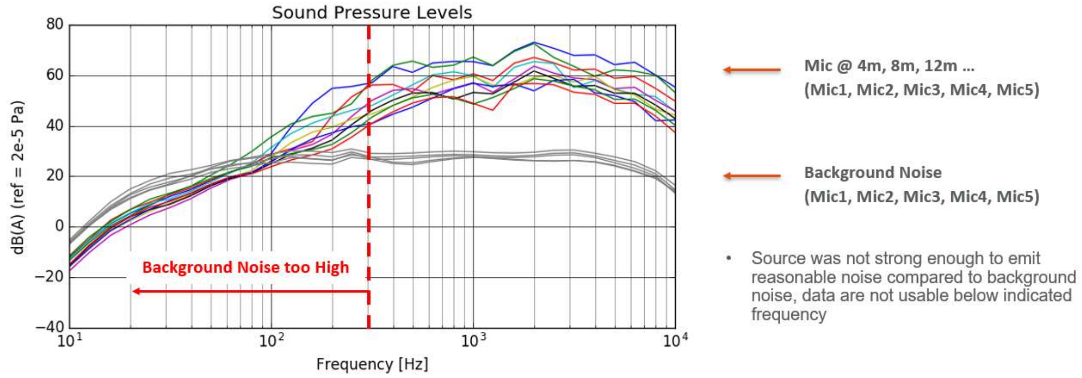


Figure 4 – Sound pressure levels for concrete surface



- Source was not strong enough to emit reasonable noise compared to background noise, data are not usable below indicated frequency

Figure 5 - Sound pressure levels for ballast

3. SOURCE POWER ESTIMATION

Source sound power was not measured in the anechoic chamber so, as mentioned above, it had to be derived from existing concrete surface sound pressure level measurements combined with simulation models. The idea was to back-calculate the source power from the “perfectly” reflective condition for the concrete surface, assuming that the power is not affected by the surface absorption.

Two different simulation models were considered, a Boundary Element model and a Ray tracing model [2], both developed with ESI VA One software [3]. Boundary Element models and Ray tracing models can provide similar results, but Ray tracing was preferred for this application due to a faster calculation speed that does not require more time or effort with increasing frequency and also the ability to support absorption and diffusion effects on any surface.

The Ray tracing model used to replicate the test set up is shown in Figure 6.

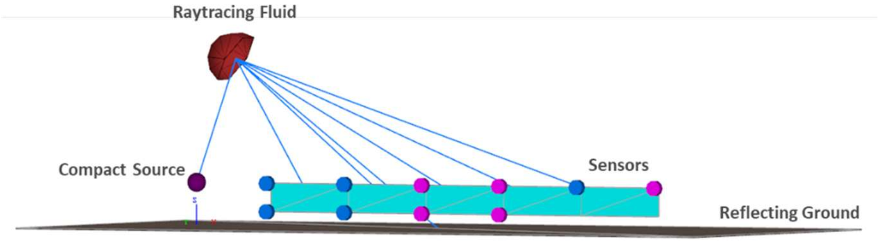


Figure 6 - Ray tracing model for source sound power estimation

A simple Ray tracing model with zero absorption applied to the ground surface and with a source of unit power (1 [W]) was solved to get ATFs at sensors. Then, unit source power was scaled according to the ratio of measured and simulated unit response to get real power spectrum used in measurements. For this purpose, a special filter was developed to eliminate resonances and anti-resonances of both spectra. This, done for every frequency point, gave a good estimate of source power used in measurements.

In Figure 7 the back-calculated source sound power spectrum is shown.

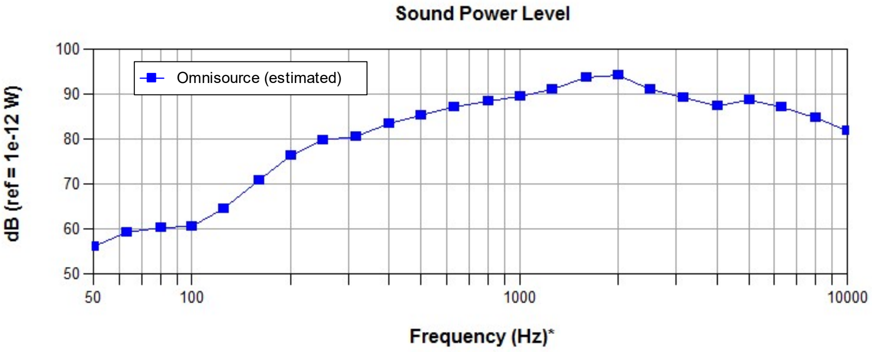


Figure 7- Source sound power spectrum

4. ABSORPTION ESTIMATION PROCESS

Sound pressure levels from the measurements and from the simulation were compared in narrowband and sensitivity analyses with respect to absorption and diffusion were done. Absorption and diffusion strongly influence the interaction of direct and reflected waves. Comparisons were made for every microphone and optimal absorption of concrete, grass and ballast is found by fitting simulation onto measurement by the iterative change of absorption in the third-octave bands and solving the Ray tracing model in narrowband.

Absorption values for certain frequencies were optimized to capture important signatures and characteristics of the measured curve, such as:

- The height of the peaks and the depth of the dips.
- The frequencies of the peaks
- Overall levels
- Comparison in third-octave bands

Figures 8 and 9 show the results of optimized absorption for concrete and ballast at different distances.

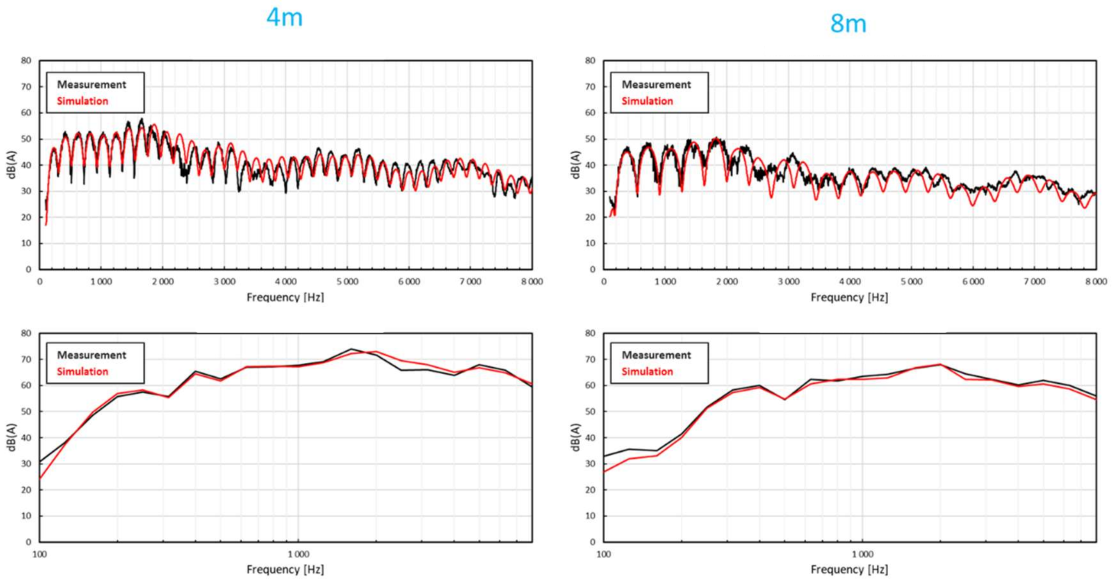


Figure 8 - Test - Simulation comparison for concrete sound pressure levels with optimized absorption in narrowband (top) and third-octave bands (bottom)

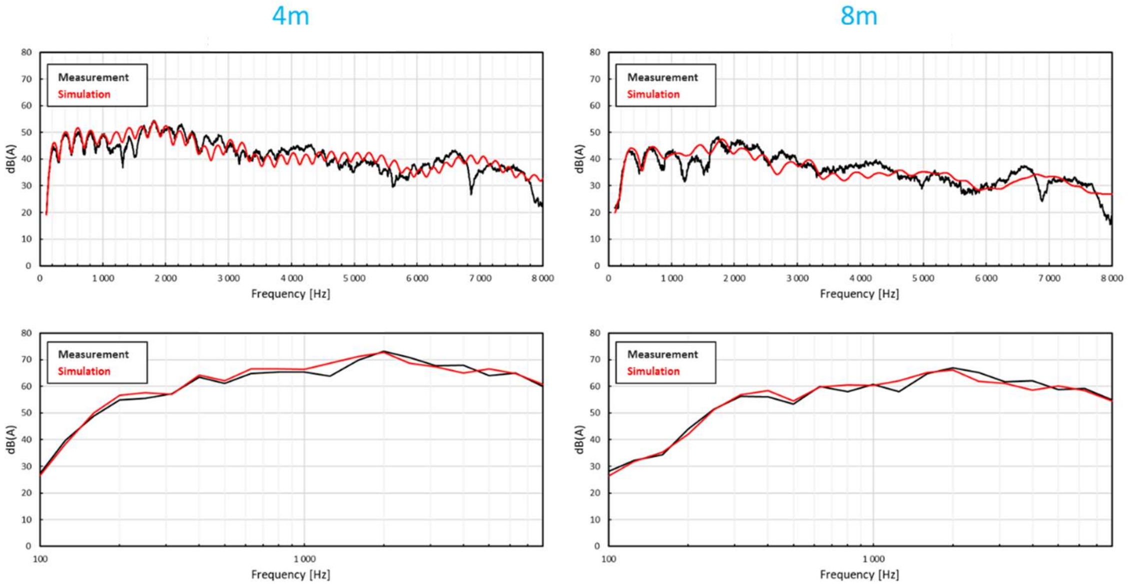


Figure 9 Test - Simulation comparison for ballast sound pressure levels with optimized absorption in narrowband (top) and third-octave bands (bottom)

Ultimately, three absorption curves for grass, concrete and ballast were derived as shown in Figure 10.

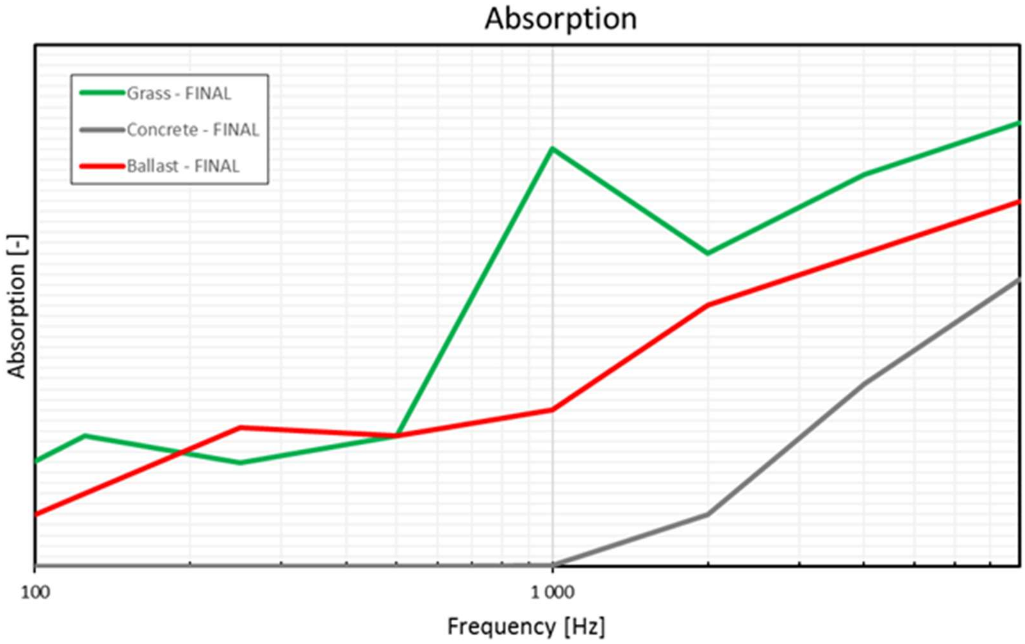


Figure 10- Concrete, grass and ballast absorption

5. PASS BY NOISE SIMULATION

5.1 Ray tracing model

Once absorption coefficients were available a Ray tracing model for pass-by noise evaluation was developed. The model was composed of two wagons geometry, 16 complex acoustic sources representing wheel-rail interaction noise generation, rail-track geometry including different absorptive surfaces, sensors representing pass-by noise microphones and virtual microphones inside the bogie area as shown in Figure 11.

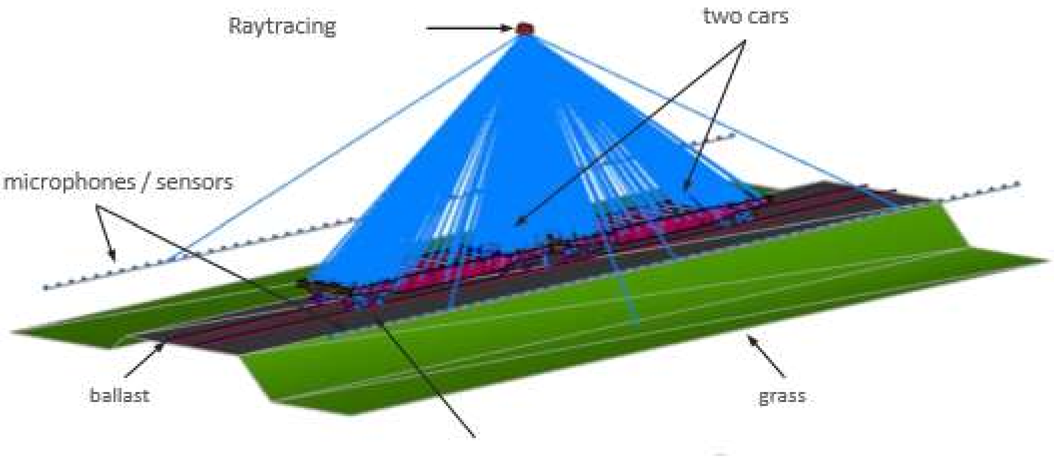


Figure 11 – Ray tracing model for pass by noise evaluation

5.2 Noise sources estimation

An experimental campaign was performed to evaluate pass-by noise levels of the wagons running at a constant speed of 60km/h, 80km/h, 100km/h and 120km/h respectively on the test track.

Sound pressure levels were recorded in the bogie area as shown in Figure 12. Two microphones were placed in front of the wheels and a third was placed in the middle.

Figure 12 – Experimental set up for bogie sound source estimation

Sound pressure levels of the three microphones were averaged and, using the Ray tracing model of the train (Figure 13), sound power levels of corresponding Compact Acoustics Sources (CAS) were back-calculated.

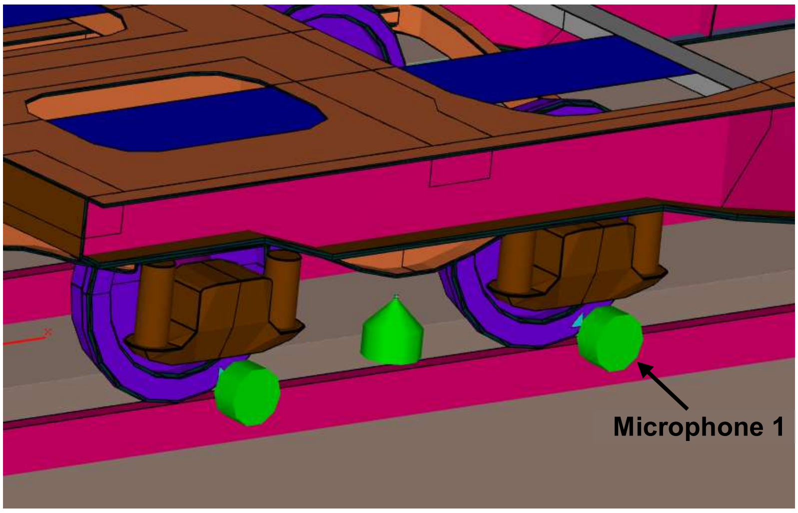


Figure 13 - Ray tracing model of the bogie including Compact Acoustic sources (CAS)

Figure 14 shows good correlation between the measured sound pressure level at microphone 1 and the simulated sound pressure level calculated using the Ray tracing model with the back-calculated Compact Acoustic Sources assuming that the source behaves equivalently to a monopole.

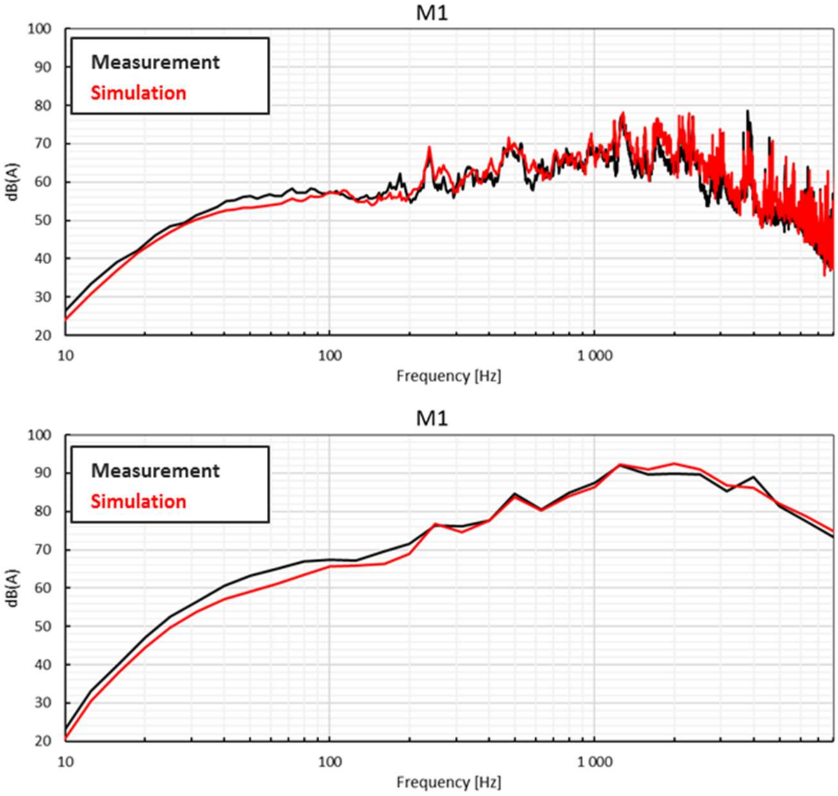


Figure 14 - Test - Simulation correlation of microphone 1 sound pressure level in narrowband (top) and third-octave bands (bottom)

5.3 Pass-by noise correlation

Pass-by noise levels at 80km/h were then calculated using the Ray tracing model and compared to experimental data using a signal with a duration of 0.05s. In Figure 15 the Ray tracing model is shown with the microphones correlated to test data indicated in green.

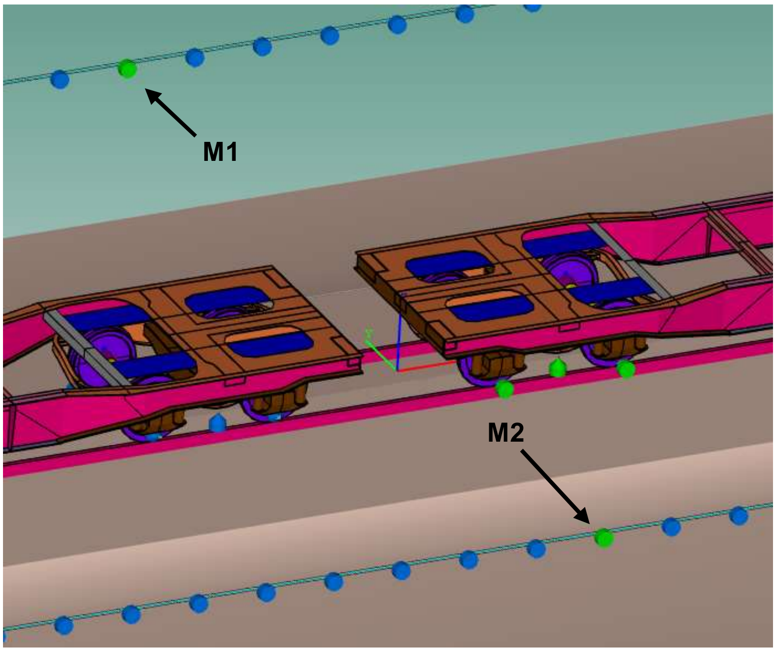
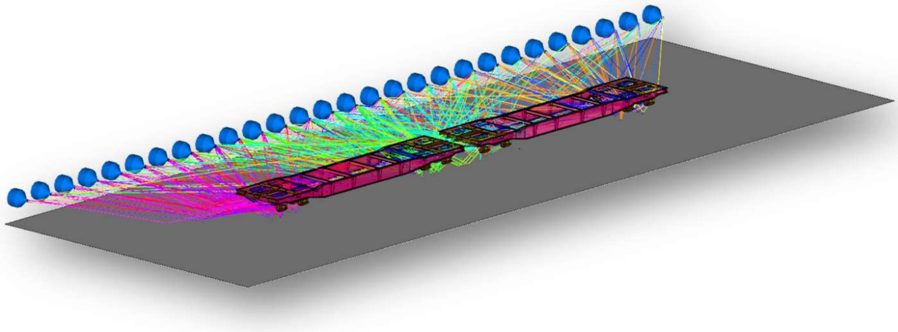


Figure 15 - Ray tracing pass-by noise model

Figure 16 shows the level of correlation between experimental data and simulation in third-octave bands for the selected microphones (at left and right sides of the track).



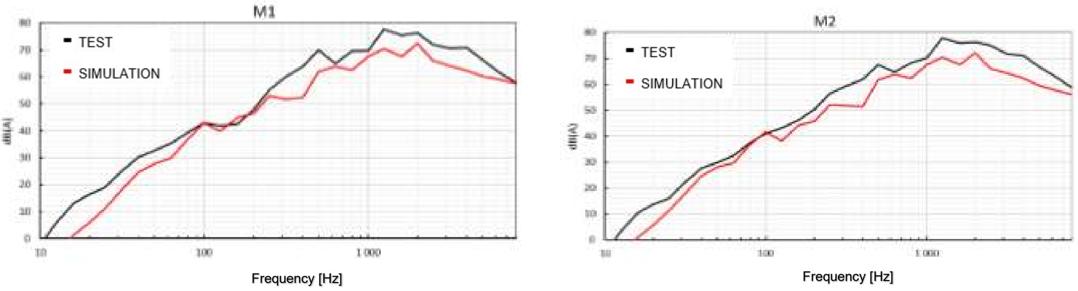


Figure 16 – Pass-by noise sound pressure levels at 80km/h at selected microphones (M1 - left and M2- right)

6. CONCLUSION

In this paper, experimental campaigns to evaluate absorption coefficients of different kinds of surfaces to be used in a Ray tracing model for train pass-by noise prediction were presented. Preliminary test results were not satisfactory so then a second test campaign was performed leading to better results. These were used in combination with a Ray tracing model of the test set up to allow estimation of absorption coefficients of different kind of surfaces. A pass-by noise test campaign was then performed to record sound pressure levels close to the wheel-rail contact area and in the bogie area which was used to back-calculate sound power levels of compact acoustic sources to be used in the pass-by noise Ray tracing model. Sound pressure levels in microphone locations placed according to pass-by noise regulations were recorded to perform a test versus simulation correlation. A pass-by noise Ray tracing simulation was performed and was correlated with experimental data showing good agreement in overall response spectrum shape but with localized differences in the range of 5dB that will be a future investigation objective.

7. ACKNOWLEDGEMENTS

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