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Effects of source type, position, and train structure on BEM calculations

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ABSTRACT

The 2D and 2.5D BEM can be used for calculating the sound field around structures with complex cross-sections. For railways, the calculation of the effects of noise barriers proves particularly challenging for a number of reasons such as the ballasted track, the modeling of the source and the modeling of the structure of the train. In this work, the focus lies on effects of the latter two for diffraction edges positioned close to the track. Such situations occur for example at railway platforms. Different source types, source positions, and train cross-sections are simulated and compared to measurements of train pass-bys near and far away from the track. Furthermore, simulations were performed and compared to measurements on the platform using a defined sound source located on the track. We will show that comparisons to the 2.5D BEM calculations are in good agreement with measurements from the point source. For pass-by measurements we will illustrate the difficulties to reconcile the measurements from positions on the platform and far away from it with the BEM simulations.

Keywords: Boundary element method, railway noise, platform
I-INCE Classification of Subjects Number(s): 76.1.2, 75.5

1. INTRODUCTION

The boundary element method (BEM) has been frequently used for calculating the sound field around structures with complex cross-sections, most commonly using 2D (e.g. (1-6)) but also 2.5D approaches, e.g. (7-9). The majority of this work has focused on relatively simple source models, that is, reducing the sound source to a coherent line source in 2D or a point or incoherent line source for 2.5D, thus ignoring any scattering of the noise source itself.

For road traffic this assumption seems to be well founded, however, for railways the situation is more complex due to large reflecting surfaces of the trains, the acoustic properties of railway ballast, and structures very close to the source. So far only a few BEM-simulations on specific railway noise conditions have been published mostly lacking, however, validation measurements (2,4). In (7) such a comparison was presented for a low noise barrier and showed that good agreement of insertion loss measurements and calculations can be achieved, although different superstructures and source positions were not investigated in detail.

The aim of the current study is to investigate in detail the effects of assumptions about the train superstructure, source position and source type for diffraction edges close to the track. 2.5D BEM calculations are compared to a number of measurements, both, near and far away with and without a

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railway platform. Measurements near the track comprise pass-by measurements as well as measurements using a defined omni-directional sound source. The latter is to illustrate the validity of the BEM approach and assumptions about the ballasted track.

2. METHODS

2.1 Platform Measurements

All measurements took place at a railway station in Austria (see Fig. 1 for the measurement and simulation cross-section). All ballasted tracks are marked by green lines. The track considered for measurements and simulations was the one located centered at the origin of Fig. 1. The cross-section was located 60 m from the end of the platform. In the other direction, on the platform where the measurements were performed a station canopy started about 35 m down the track from the cross-section. In order to investigate the alterations of the sound field due to the railway platform, near-field measurements were performed. Two different approaches were pursued: to describe the sound field under controlled conditions, measurements with a defined sound source were conducted, which enabled an assessment of the absorption properties of the ballasted track. Additionally, pass-by-measurements were performed to investigate the influence of the platform in real-life conditions.

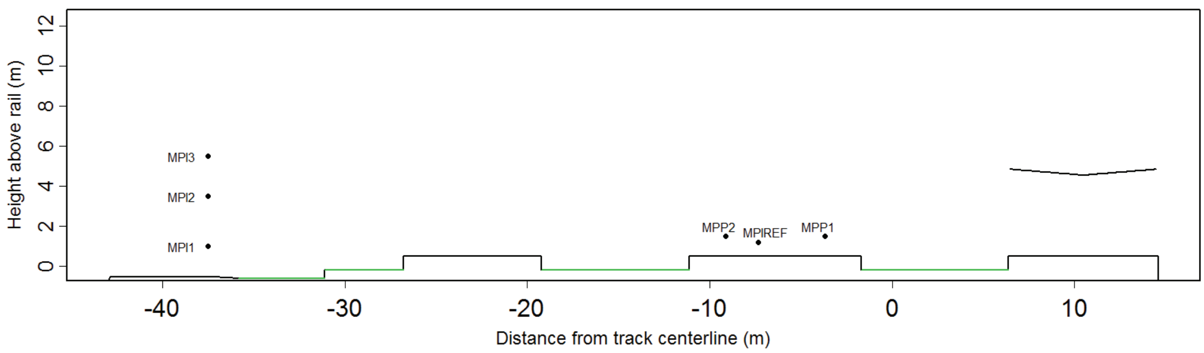

Figure 1 – Railway station cross-section with pass-by measurement positions

2.1.1 Defined source

For the description of the sound field under controlled conditions, transfer function measurements with a defined sound source were performed. To reduce the possible influence of the sound source, a B&K OmniSource was used. The loudspeaker was positioned on the rail track approx. 0.2 m above the ballast in the middle of the rail track as well as on top of the inner track line next to the edge of the platform (Fig. 2). Four microphones were positioned on the platform in a distance of 2 resp. 3 m from the platform edge in a height of 1 and 2 m above the platform. In these configurations, impulse responses were recorded to reduce the disturbance of noise during normal operation at the railway station. To minimize the influence of variations in the transfer path even due to low winds, 60 impulse responses using the MLS technique were measured consecutively and aligned before the customary averaging. For a comparison, analog measurements were performed on a fully reflective surface without platform and ballast. These impulse responses were time-windowed to separate the direct sound field component, and Fourier transformed for further analysis.

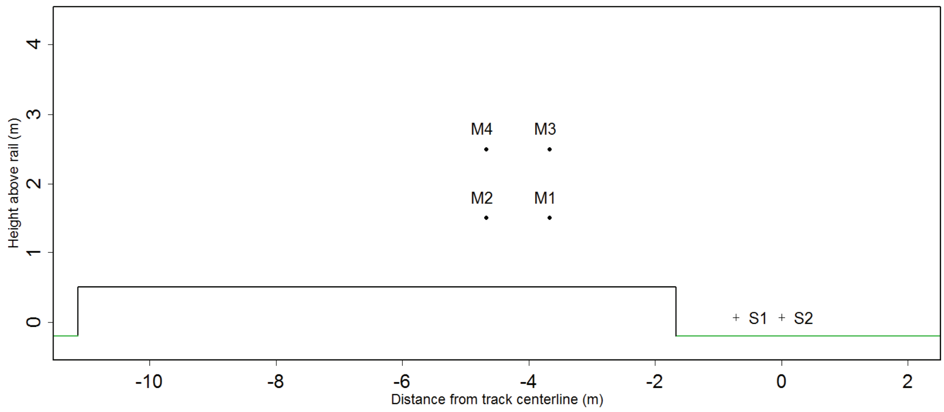

Figure 2 – Measurements with the omni-directional source

2.1.2 Pass-by measurements

Pass-by measurements of trains were performed using two microphones positioned on the platform in a height of 1 m above the platform in distances of 2 m from either platform edge (MPP1 and MPP2). A reference measurement setup was installed before the railway station as to enable the comparison of each train before and in the station. Speed variations of the trains should be negligible, as mostly freight trains were measured passing through the station with constant speeds between 30 and 55 km/h. Third octave-band pass-by levels were measured, whereat analyses were conducted of the whole train-pass-by as well as pass-bys excluding the traction unit.

2.2 Immission Measurements

Three immission measurement positions were located in 37.5 m distance to the railway track and in 1.5 m, 4 m, and 6 m above ground (MPI1 to MPI3). The ground level was almost identical to the level of the railway surface. This distance was a compromise between safety regulations due to the additional railway tracks present and sufficiently high pass-by levels compared to background noise. As can be seen in Fig. 1, the profile included a platform directly adjacent to the analyzed trains, other ballasted tracks and another platform. At the measurement position there was hard ground from an asphalt park and ride-area. A reference point was positioned at 7.35 m distance to the railway axis and 1.2 m above the rail surface (MPIREF). The initially planned distance of 7.5 m according to EN ISO 3095 was not possible due to safety regulations for a neighboring track. At the reference point location, no platform was present. The railway track conditions in terms of roughness and type were constant within the railroad station area and therefore also between the short distance between the track along the platform and at the reference point.

Measurements were performed with the sound analyzer Nor 140 (Norsonic, Norway). The pass-by sound level was recorded in third-octave bands. Only pass-bys on one track (located at 0 m in Fig. 1) were recorded. The background noise was more than 15 dB below the pass-by sound levels. 12 pass-by events of freight trains were recorded. Out of these 12 measurements 11 could be used for further analysis. One pass-by had to be excluded as there was an obvious deceleration observed during the measurement. For all further analysis the difference between the measurement positions at 1.5 m, 4 m, and 6 m and also the difference with respect to the reference position in 7.35 m and 1.2 m height were used. Platform and immission measurements were performed on different days.

2.3 BEM simulations

The cross-section of the railway station (Fig. 1) was the basis for most of the pass-by simulations carried out. The receiver points for the simulations were placed in the same way as the microphones (MPP1 and MPP2 on the platform and MPI1 to MPI3 at the immission distance). For the reference cross-section simulations were carried out with the two wide ballasted tracks (ignoring the two left-most in Fig. 1) and the remainder of the ground assumed fully reflecting 5 cm below the ballasted tracks. MPIREF is the reference point for the immission pass-by measurements.

The ballasted tracks (green lines in Fig. 1) were modeled using a three-layer admittance model (10). Furthermore, the platform edge in the measurements consisted of an absorbing material. Reverberant chamber measurements of a similar material were used to derive a purely real admittance frequency curve. As the omni-directional source was located very close to the rails, in these simulations the track lines were also modeled as fully reflecting structures. The calculation for the reference measurement of the omni-directional source was done analytically.

2.4 2.5D BEM

For the simulations with the omni-directional source a frequency range of 50 to 5000 Hz was covered using 7 frequencies per third-octave band. For pass-by simulations only 4 frequencies per third-octave band were used and spectral averaging was done across three consecutive third octave bands resulting in an octave-band spectrum using all third-octave center frequencies. The range for these simulations was restricted to 64 to 2500 Hz due to the large size of the cross-section.

The 2.5D-BEM (11) requires to perform a number of 2D calculations that were performed using the implementation described in (12). Here, collocation with constant elements was used and the number of elements was adapted to the frequency, resulting in linear systems of equations with up to a few thousands of unknowns.

For the immission measurements the end of the railway platform was taken into account as described in (7). Briefly, a weighted average of the platform simulation and the reference simulation was used. Facing the platform, for points to the left and far away from the cross-section the reference solution was used whereas at the measurement cross-section and extending into the opposite direction the results including the platform were used. The transition zone where both results were combined extended from 60 to 85 m (direct line of sight to source for all receiver locations) to the left from the cross-section. Simulations including, in the same manner, the canopy (which covers only parts of the platform) did not yield large changes. Thus all results are shown without the canopy. As a consequence, for these combined cases incoherent line sources were modeled as a sequence of incoherent point sources extending to ±250 m with a spacing of 0.5 m between the sources.

2.5 Train cross-sections

Different train cross-sections were used for the BEM calculations varying in particular the lower part of the train (Fig. 3). Train 1 and 2 differ only in the height of the lower floor above the railhead (55 and 80 cm, respectively) whereas train 3 (lower floor 45 cm above the railhead) had angled edges that widen the gap between train and platform. For the fourth cross-section (train 4) no train structure was used.

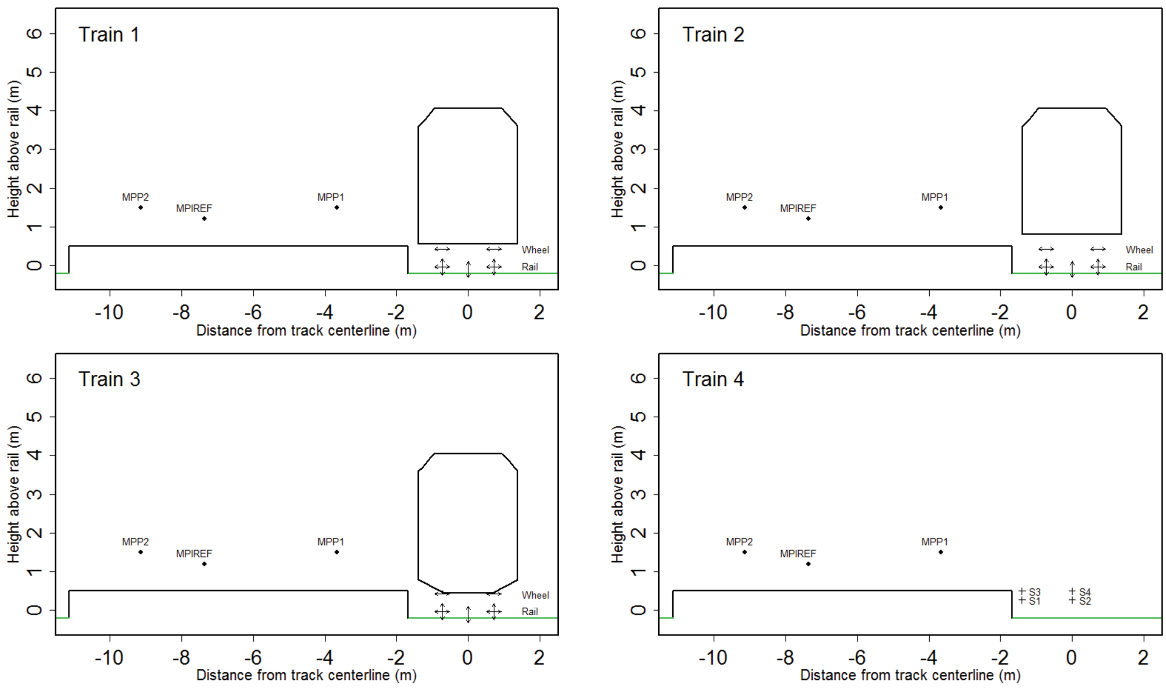

Figure 3 – Train cross-section and source positions used for the BEM simulations

2.6 Source positions

Basically, two different types of sources were used: lines of incoherent point sources as well as lines of incoherent dipole sources oriented in the plane perpendicular to the infinite dimension of the track. Based on (4) a source model consisting of 7 dipole sources modeling the rail, the wheel, and the sleeper (see arrows in Fig. 3 for trains 1 to 3 and also Fig. 1 in (4)) was combined for a source model based on the TWINS model using frequency-dependent source weightings (cf. Fig. 2 in (4)). Dipoles were oriented vertically (ballast), horizontally (wheels) or both (rails). In addition, for the wheel and the rail source position, lines of point sources instead of dipole sources were also tested in two separate models. These three source models were used for train 1 to 3 only.

A second approach was to use two source positions located at the track centerline, around 30 cm above the rail head and at the same height as the platform edge. Two further sources were defined at these same heights but located approximately at the side of the train (1.4 m from the track centerline towards the platform). All these sources were assumed to be incoherent lines of point sources. No superstructure was used here. As the sources models for train 4 are different, results will be displayed separately.

3. Results

3.1 Omni-directional source

Fig. 4 shows the difference in the third-octave band spectra between the cross-sections with and without a platform. The simulations (green lines) are in excellent agreement with the measurements of the defined sound source (black lines with symbols) for all four receiver positions. It can be seen that the interferences that occur due to using a point source are well captured although minor sub-band shifts seem to occur at higher frequencies. The causes for these shifts are unclear, although the most likely reason is that the (reflecting) wooden sleepers cannot be properly accounted for in the 2.5D approach and were thus ignored. Other reasons may include the impedance model used, but also minor deviations between the positioning of the microphones in the measurements and the simulations. Positioning the source above the rail yields a similar agreement of measurement and simulation.

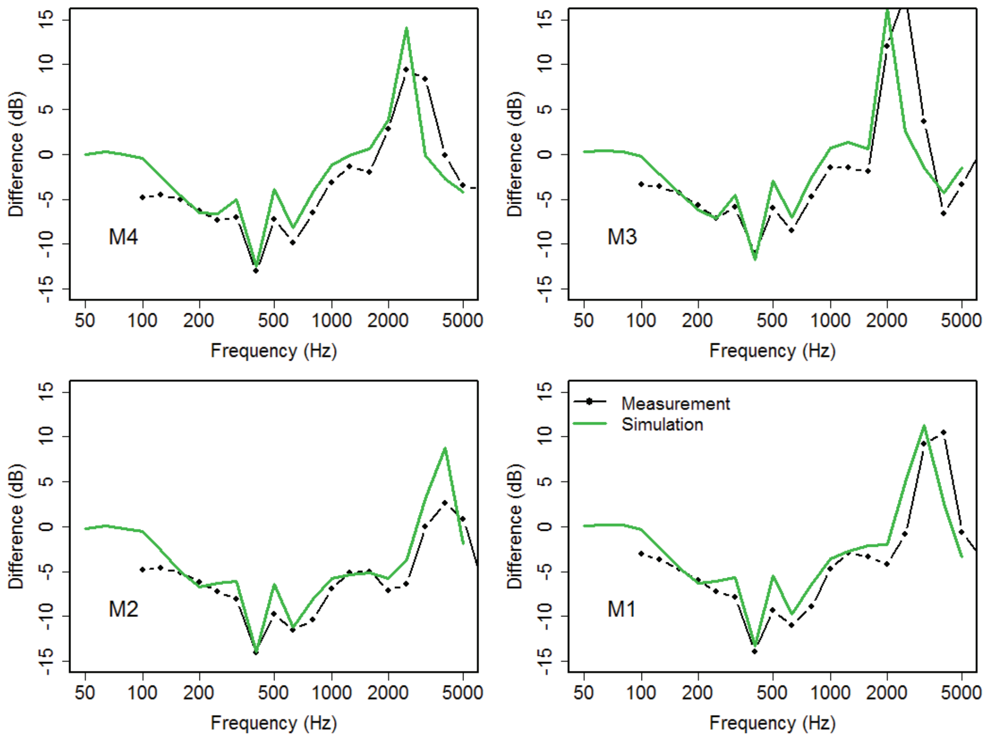

Figure 4 – Comparison of the spectral difference between free-field and platform using an omni-directional sound source located between the rails

3.2 Pass-bys at the platform

The pass-by measurements illustrate a shielding effect that increases when the emission of the traction-unit is neglected, in particular in the near position (cf. dots and crosses in Fig. 5). Comparing the simulation results of the different train structures 1 to 3 it is clear that shifting the superstructure towards the rails increases the shielding effect of the platform edge as the gap between structure and platform becomes smaller. For the lower placed wagon (train1) and the near measurement position (MPP1) this leads to a good agreement with the measurements without the traction unit except for the TWINS model. In contrast, the higher placed wagon (train 2) is in better agreement with the whole-train results. When using train 3, the results are similar to train 2.

For the far position (opposite side of the platform) the simulations indicate a larger shielding effect probably caused by the larger diffraction angle. Interestingly, the measurements do not show this increase. Furthermore, the effect of the traction unit is also significantly lower. The reasons for these results are not entirely clear. Most probably, due to the larger distance between train and measurement position the traction unit cannot be entirely windowed out while simultaneously the lower sources are more strongly shielded. As a consequence, all simulations using a train superstructure overestimate the effect of the edge at the far position on the platform.

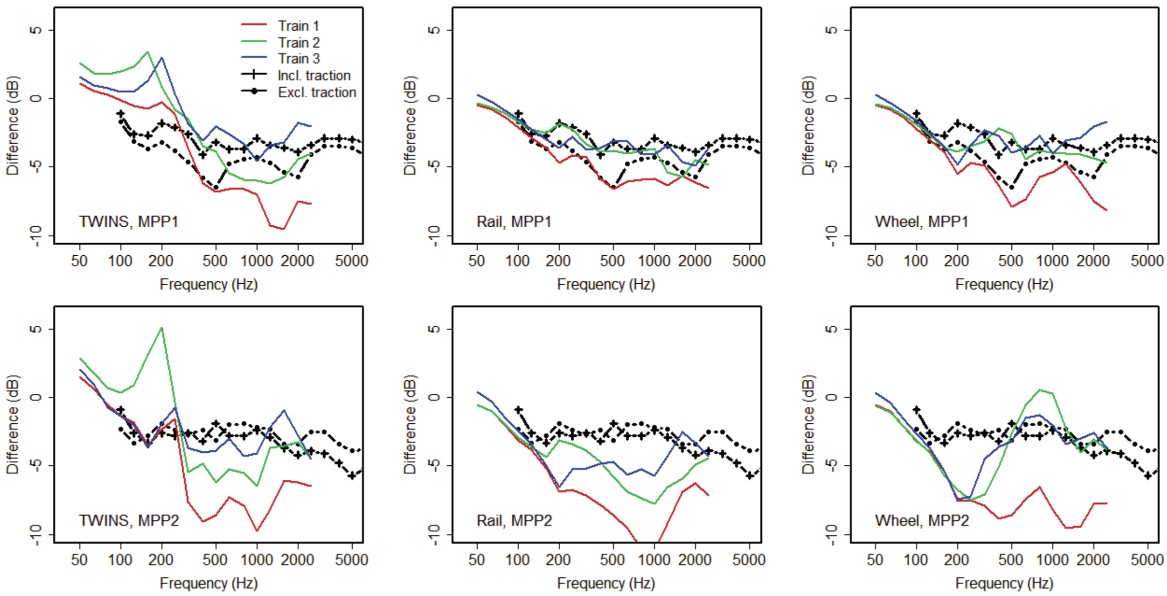

Figure 5 – Comparison of the spectral difference between free-field and platform using pass-by measurements

Using the simple source model without any superstructure (Fig. 6), all but S1 (lower position close to the platform) lead to an underestimation of the shielding effect in the near position (MPP1). In contrast, in the far position MPP2 this particular source position leads to an overestimation of the effect.

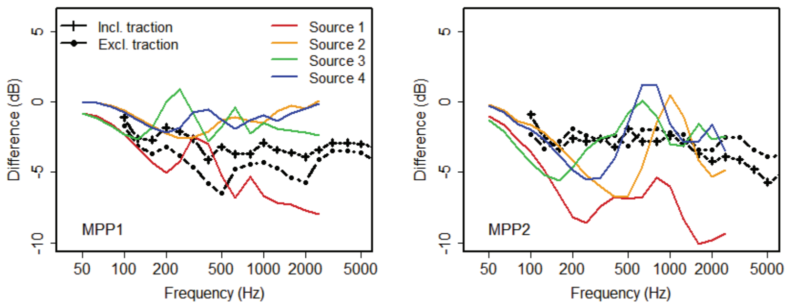

Figure 6 – Comparison of the spectral difference between free-field and platform using pass-by measurements and train 4 for simulations

3.3 Immission points

For the immission points two comparisons were made. First, MPI1 to MPI3 were compared to the reference position MPIREF and, second, the immission points were compared to each other.

From the comparisons to the reference position (Fig. 7) it can be seen that there is a distinct dip between 100 and 500 Hz which is most pronounced for the lowest position (upper row in Fig. 7). In contrast, when comparing only the far-field measurements, the difference between the two higher to the lowest immission point (Fig. 8) is almost flat above 100 Hz with a sharp step towards lower frequencies. The difference between the two high positions is essentially zero (Fig 9., lower right panel). Gray areas show the standard deviation for the measurements.

For the simulation results, the comparison to the reference position and the comparison at the immission distance behave differently. Fig. 7 shows the results for comparisons to the reference position (MPI1 in the upper row and MPI3 in the lower row). There is a strong dependency on the source model for these results. For the TWINS model (left panels in Fig. 7), train 1 and train 3 capture the sharp decrease at 100 Hz well, however, above 200 Hz the effect of the platform is highly overestimated, in particular for the lower placed wagon (train 1). The higher placed wagon (train 2) does not agree well at all for the TWINS-based source model, even at low frequencies. Using simple omni-directional sources at the two rail-wheel contacts shows similar results for all three cross-sections. Placing the source higher (wheel position) shows a much better agreement for train 2 and train 3 although there is still some degree of overestimation at around 200 Hz. The low wagon (train 1) does not show a good agreement for this source model.

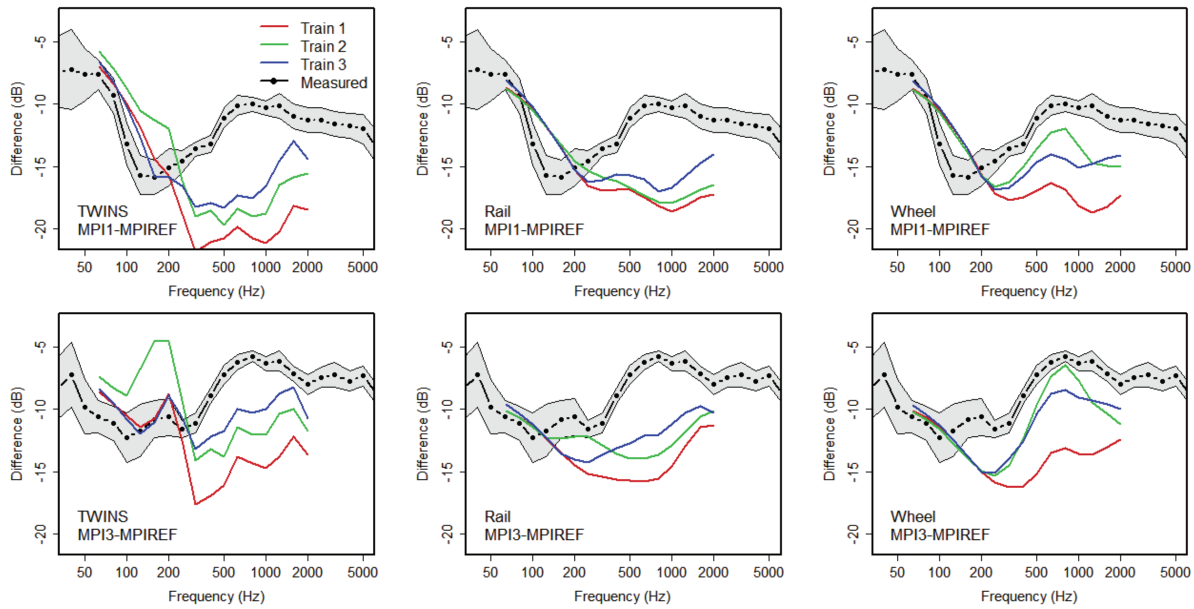

Figure 7 – Comparison between MPIREF and MPI1 (upper row) as well as MPIREF and MPI3 (lower row)

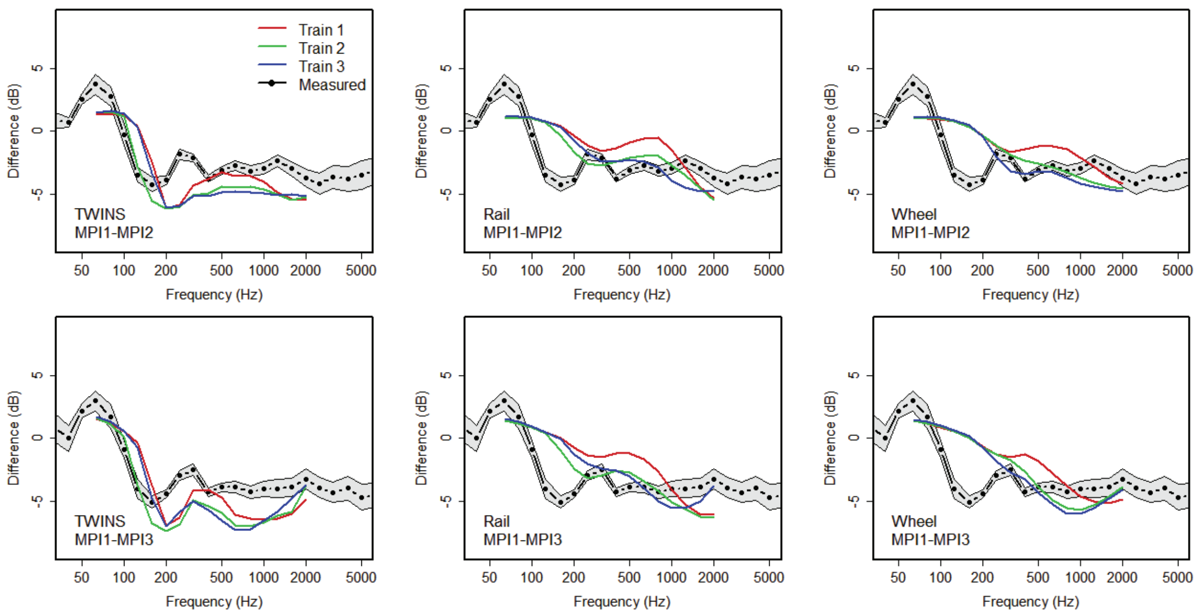

Figure 8 – Comparison between MPI1 and MPI3 (upper row) as well as MPI2 and MPI3 (lower row)

Interestingly, for the comparison of different heights (Fig. 8), the TWINS-based model gives good results for the dip at 100 Hz with a slight bias for the remaining frequency range. Using the omni-directional sources the sharp dip at around 100 Hz seems to be shifted and averaged out although the overall effect of the source model and cross-sections is far less pronounced at the immission points than when compared to the reference position.

Applying the simple source model without a superstructure (lower right panel in Fig. 3) seems to at least partially resolve this contradicting results leading to a good agreement for both comparisons except in MPI1 against MPIREF for frequencies above 1000 Hz (Fig. 9). This result is, however, very sensitive to the exact placement of the microphone. Placing the receiver 0.5 m higher shifts the higher frequencies up by about 2 dB.

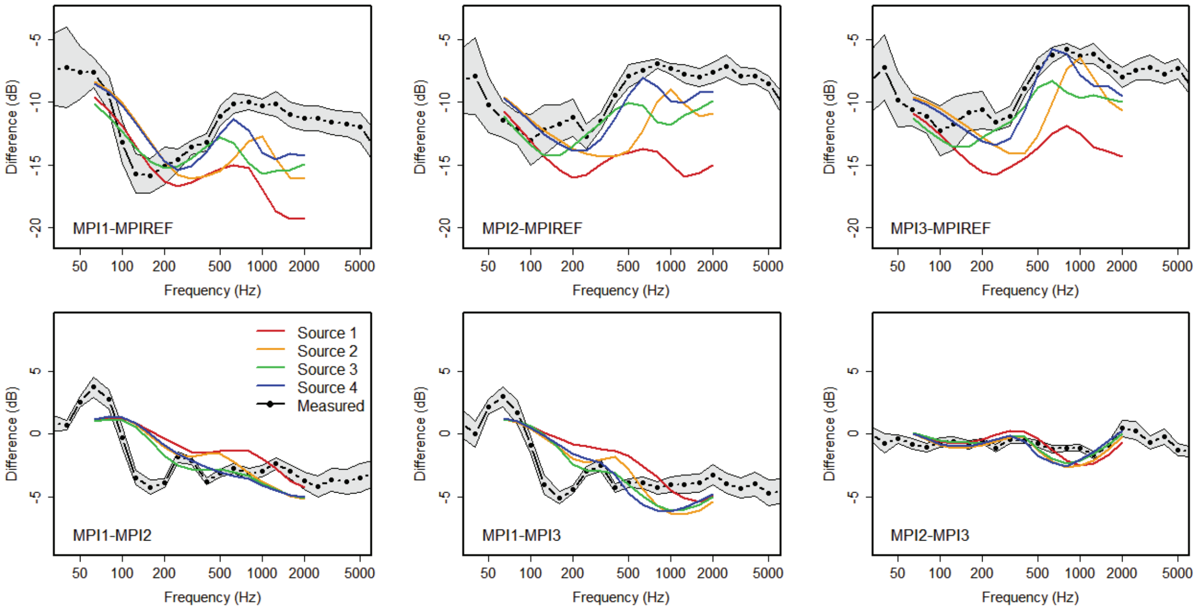

Figure 9 – Comparison between MPIREF and all MPIs (upper row) and between the MPIs (lower row) using train 4

4. SUMMARY

The results shown in this work illustrate the applicability of the 2.5D BEM for railway noise simulation. Using a well-defined source very good agreement can be achieved with only minor frequency shifts. Comparing measurements based on pass-by measurements to simulations it is clear that a suitable definition of the source and the train itself can be quite difficult. While the comparison of the band spectra at large distances seems to be less influenced by the source model, the comparison to the reference position is highly dependent on it. Interestingly, the best agreement so far was achieved by ignoring the train itself and only placing and equivalent source at the track centerline at height of the platform. A reason for this may be higher lying sources (traction unit, noise by the superstructure of cargo trains) that become more dominant when parts of the lower sources are shielded. Such high sources were not modeled in the simulations including a superstructure. Support for this hypothesis comes from the near-field measurements where the effect of the platform edge increases when windowing out the traction unit although the results of the far microphone position (MPP2) on the platform do not show this effect. Using the equivalent source at the track centerline and at the height of the platform edge seems to underestimate the effect of the platform although only in the near position. This holds even when the full pass-by is analyzed (MPP1).

Here, one of the disadvantages of the 2.5D BEM method used in this work is the assumption of the constant cross-section. When considering trains it is clear that the cross-section varies considerably across the length of the train, in particular for cargo trains. For instance, the wheels may increase multiple reflections whereas gaps between wagons (in particular for cargo trains) may reduce them. Furthermore, typically the gap between passenger trains and the platform edge is much closer than for cargo trains.

Summarizing, the best results concerning all measurements were achieved using an equivalent source without any train structure placed at the track centerline and the height of the platform edge. Directly on the platform, however, there are still problems with this approach. As this is ongoing work, it is planned to further place sources in the gap between platform and train. Initial results seem promising, however more work is needed.

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