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Verification of Two Methods of Railway Noise Propagation

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The noise maps of agglomerations comprise those of road traffic-, tram-, aircraft-, industrial- and railway noise. EU recommends the use of a few selected calculation methods for the estimation of noise: for road traffic noise – NMPB-Routes-96, for aircraft noise – ECAC.CEAC Doc 29, for industrial noise – ISO 9613-2 and for railway noise – Reken en Meetvoorschrijft Railverkeerslawaai 1996 (for tram noise – there is no specific computation method). However, the Member States can use their own computations methods provided that these methods have been positively verified. The results of the calculations using their own method and interim method must be compatible. In this paper, two methods of railway noise propagation are compared: the first one recommended by EU and the second one developed at the Adam Mickiewicz University in Poznań. The results obtained by the two methods are similar.

Keywords: railway noise.

1. Introduction

The Directive 2002/49/EC [1] has established common noise indicators and methods for assessment of environmental noise. The common noise indicators are: the day-evening-night indicator (L_{den}) and the night-time noise indicator (L_{night}). In preparations and revision of the strategic noise maps these two indicators must be used. The values of L_{den} and L_{night} can be determined either by computation or by measurement. The EU has recommended the following interim computation methods:

- for road traffic noise: the French national computation method NMPB-Routes-96,

- for aircraft noise – ECAC.CEAC Doc 29 "Report on standard method of computing noise contour around civil airports",
- for industrial noise – ISO 9613-2: Acoustics – Abatement of sound propagation outdoors, Part 2: General method of calculations,
- for railway noise – the Netherlands national computation method published in Reken en Meetvoorschrijft Railverkeerslawaai 1996.

Any national computation method can be used for preparation of noise maps, but it must be positively verified. Unfortunately, Ref. [1] does not specify the method of verification. Such a method is given by the report published by EU in 2008 [2]. This report proposes four protocols for estimation of noise caused by road traffic, railway traffic, industry and aircrafts, which are suggested to be used by the EU Member States to ensure the equivalence of the national assessment methods against the interim methods. Each protocol specifies the type of site at which analyses should be made (type of terrain, source-receiver geometry) for evaluation of the noise level caused by a source of particular type. The set of input data for each configuration is also defined.

The verification is carried out by a comparison of the equivalent A-weighted sound pressure level, L_{Aeq}, calculated using the interim method and the method under test (national method). The question is why the methods cannot be verified by a comparison of the calculations results and the acoustic measurements?

The interim method for railway traffic noise is the Dutch method Reken en Meetvoorschrijft Railverkeerslawaai. This method defines two procedures: a simplified broadband method for a simple geometry, and a very sophisticated method in the octave band for more complex situations. In this paper, the first procedure (the simplified broadband interim method) was analysed and compared to a simple method developed at the Institute of Acoustics at the Adam Mickiewicz University. These two methods were verified by measurements of the sound exposure level of single pass-by noise. The main advantage of these simple methods is a short computation time.

2. Theory

2.1. Method I (interim method)

The basic equation in the simplified broadband interim method for the calculation of noise level from a railway line is [3]:

$$L_{\mathrm{Aeq},T} = E_T - A, \tag{1}$$

where E_T is total noise emission from a railway line for the time period T and A is the noise attenuation. The quantity E_T can be found from

$$E_T = 10\log\left(\sum_c Q_c 10^{0.1E_c}\right), \tag{2}$$

where Q_c is the number of carriages per hour for the train category c, and E_c is the noise emission for one carriage per one hour. The method of E_c determination is presented at the end of this section. Over a flat terrain, without any reflecting obstacles (e.g. buildings), the attenuation of noise A (Eq. (1)) can be expressed as:

$$A = A_d + A_a + A_g + A_m, \tag{3}$$

where A_d denotes the correction for the distance, A_a is the attenuation by the air, A_g stands for the ground effect, and A_m is the correction for meteorological conditions.

The attenuation with distance equals

$$A_d = 10 \log (D), \tag{4}$$

where D is the distance from the track and the air attenuation is defined by

$$A_a = 0.016\, D^{0.9}. \tag{5}$$

The ground attenuation depends on the ground factor B and the heights of the railhead, h_{bs}, and receiver, h_w:

$$A_g = 3B^{0.5}\left(1 - e^{-0.03D}\right)\left(1.25e^{-0.75(0.6h_{bs}+0.5)} + e^{-0.9h_w}\right) + 1.6B - 1.8 - 3(1-B)\left(1 - e^{\frac{-0.01D}{h_w+h_{bs}+0.4}}\right). \tag{6}$$

Acoustically hard ground and acoustically soft ground are characterized by $B = 0$ and $B = 1$, respectively. For a mixed ground, the estimation of the parameter B is sometimes difficult, so the relationships given in Refs. [4, 5] may be helpful. The meteorological correction is given by

$$A_m = 3.5\left(1 - e^{-0.04\frac{D}{h_w+0.6h_{bs}+0.5}-5}\right). \tag{7}$$

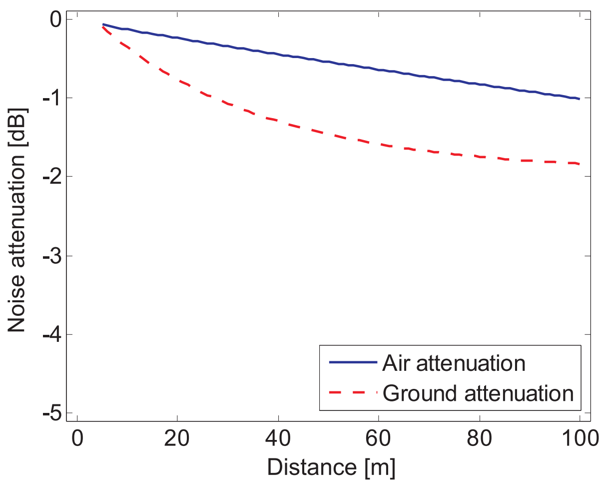

Fig. 1. The noise attenuation due to the air absorption and ground effect (Method I).

If the above equation yields a negative value, then A_m is considered to be zero. The changes in the noise attenuation caused by the air and ground surface (Eqs. (5) and (6)) are presented in Fig. 1. The noise emission for one carriage per one hour E_c (Eq. (2)) can be determined from the sound exposure level measurements of single pass-by at the distance D – relatively close to the track [6]:

$$E_c = L_{AE} - 10\log(3600) + 10\log(D) - 10\log(N_c) + 1, \tag{8}$$

where N_c is the number of carriages. The correction 1 dB in the above equation is for the attenuation of air and the ground effect.

2.2. Method II (Polish method)

The method of railway noise prediction was developed at the Institute of Acoustics, A. Mickiewicz University (Poznań). Its assumptions are as follows:

- the main source of noise is the wheel-rail interaction,
- the train is modelled by a homogeneous line of incoherent point sources.

The above assumptions allow expression of the sound exposure as the product

$$E_A = l \cdot \widetilde{E}_A, \tag{9}$$

where l is the length of the line source and $\widetilde{E}_A$ is the sound exposure of noise from a unit length line source, $l_o = 1$ m. For the train moving from $-\infty$ to $+\infty$, at a constant speed ($V = \text{const.}$), $\widetilde{E}_A$ can be written as [7]:

$$\widetilde{E}_A = \frac{D}{V} \int\limits_{-\pi/2}^{+\pi/2} \frac{\widetilde{p}_A^2(\Phi)}{\cos^2\Phi}\,\mathrm{d}\Phi, \tag{10}$$

where D is the perpendicular distance from the track (Fig. 2) and $\widetilde{p}_A^2$ is the A-weighted squared sound pressure of noise coming from the unit length line source. In an open area, without any reflecting obstacles, $\widetilde{p}_A^2$ is [7]:

$$\widetilde{p}_A^2 = \frac{W_A \Theta(\Phi)\rho c}{4\pi d^2} \cdot G_A(\Phi) \cdot F_A(\Phi), \tag{11}$$

where W_A [Watts] denotes the A-weighted sound power of the unit length line source, $\Theta(\Phi)$ characterizes its directivity, ρc is the characteristic impedance of air, and d expresses the instantaneous source-receiver distance (Fig. 2).

Function G_A describes the ground effect and depends on the distance d and the ground coefficient γ. In this study the simplified form of the ground effect was used [8–10]:

$$G_A = \beta\left[1 + \gamma \cdot \left(\frac{d}{H}\right)^2\right]^{-1}, \tag{12}$$

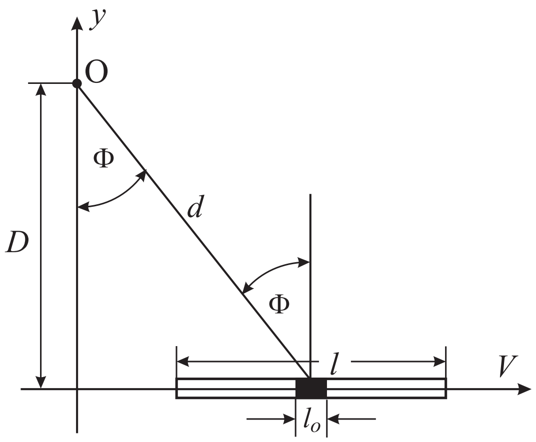

Fig. 2. Train – receiver geometry in the horizontal plane.

where β characterizes reflection from the ground beneath the source. The values of γ for various ground surfaces and the method of their determination can be found in Refs. [5, 7]. The quantity

$$H = \frac{H_s + H_o}{2} \tag{13}$$

is the mean height of propagation (H_s – height of the source, H_o – height of the receiver).

The function F_A (Eq. (11)) represents the air attenuation of noise. The following simplified formula of F_A was used [11]:

$$F_A = (1 + \alpha d)^{-1}, \tag{14}$$

where α [1/m] is the absorption coefficient. The values of α for railway noise, for a wide range of air temperatures and humidities, are given in Ref. [10].

Using Eqs. (9)–(14) and the source-receiver geometry, $d = D/\cos\Phi$ (Fig. 2), one gets,

$$E_A = \frac{\beta W_A l \rho c}{4VD} J_{ga}, \tag{15}$$

where the integral

$$J_{ga} = \frac{1}{\pi} \int\limits_{-\pi/2}^{+\pi/2} \frac{\Theta(\Phi) \cdot \cos^3 \Phi}{(\cos^2 \Phi + \gamma K^2) \cdot (\cos\Phi + \alpha K)} \, \mathrm{d}\Phi, \tag{16}$$

with $K = D/H$, describes the noise attenuation by the ground and air.

Applying the mean value theory of integral calculus with $\Phi = \pi/4$ [12], one obtains the integral (16) in the following form:

$$J_{ga} = \frac{\Theta(\pi/4)}{(1+\sqrt{2}\alpha D)} \frac{2}{\pi} \int\limits_0^{+\pi/2} \frac{\cos^2 \Phi}{[\cos^2 \Phi + \gamma K^2]} \, \mathrm{d}\Phi. \tag{17}$$

Then the above integration can be done to obtain [7]:

$$J_{ga} = \Theta(\pi/4) \frac{1}{(1+\sqrt{2}\alpha D)} \cdot (1 - \frac{K\sqrt{\gamma}}{\sqrt{1+\gamma K^2}}). \tag{18}$$

Using the definition of the sound exposure level

$$L_{AE} = 10 \log \frac{E_A}{p_o^2 t_o}, \tag{19}$$

and Eqs. (15), (16), we obtain the sound exposure level of noise generated by a moving train:

$$L_{AE} = \widetilde{L}_{WA} + 10 \log \frac{l l_o}{4VDt_o} + B_{ga}, \tag{20}$$

where

$$\widetilde{L}_{WA} = 10 \log \frac{\beta W_A \Theta(\Phi/4)}{W_o} \tag{21}$$

is the sound power level of the unit length line source, affected by reflection beneath the source and source directivity, and

$$B_{ga} = 10 \log(J_{ga}) = 10 \log \left\{ \frac{1}{(1+\sqrt{2}\alpha D)} \cdot \left(1 - \frac{K\sqrt{\gamma}}{\sqrt{1+\gamma K^2}} \right) \right\}, \tag{22}$$

is the noise attenuation due to the air absorption and ground effect.

Close to the source, with $\alpha D \ll 1$, air absorption can be neglected:

$$B_{ga} \to B_g = 10 \log \cdot \left(1 - \frac{K\sqrt{\gamma}}{\sqrt{1+\gamma K^2}} \right). \tag{23}$$

The function B_g denotes the noise attenuation caused by the ground surface.

High above the ground with $K\sqrt{\gamma} = \frac{D}{H}\sqrt{\gamma} \ll 1$:

$$B_{ga} \to B_a = 10 \log \left(\frac{1}{1+\sqrt{2}\alpha K} \right). \tag{24}$$

The function B_a describes the noise attenuation due to the air absorption.

In this study, the noise attenuation due to the ground effect and air absorption was determined by Method I and Method II. The ground effect as a function of the distance from the source is presented in Fig. 3 and as a function of the air absorption – in Fig. 4. As follows from Fig. 3, the difference in noise attenuation caused by the ground surface reaches 1.5 dB (at the distance $D = 100$ m).

The effect of noise attenuation by the air is definitely weaker than the ground effect and the differences between the results provided by the two methods are smaller (Fig. 4).

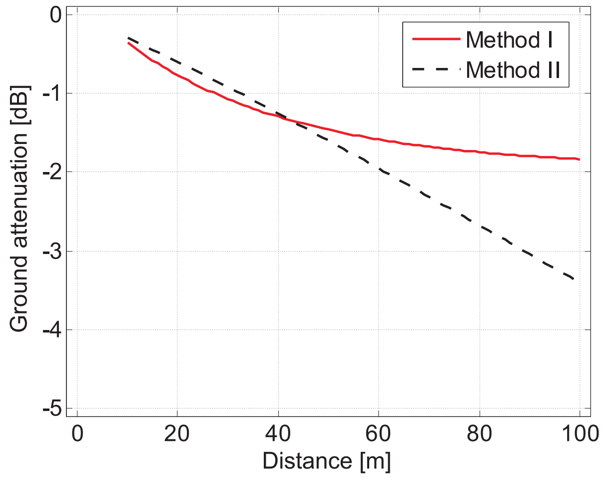

Fig. 3. The noise attenuation due to the ground effect: Method I (Eq. (6)) and Method II (Eq. (21)), $H_o = 4.0$ m.

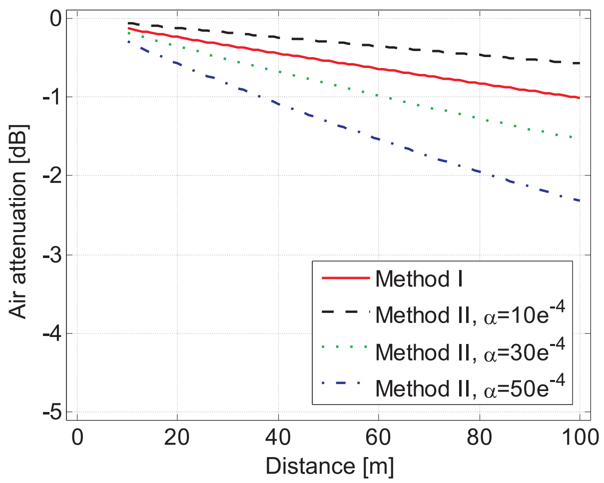

Fig. 4. The noise attenuation due to the air absorption: Method I (Eq. (5)) and Method II (Eq. (22)).

3. The measurements

The verification of the two methods presented in the previous sections was made using the measurements of the railway noise performed at three different

Table 1. Characterisation of the measurement sites.

Measurement site	The track's characteristics		The receiver points		Noise source	Number of events	Atmospheric conditions		
	Rail	Sleepers	Distance [m]	Height [m]			Wind v [m/s]	Temperature T [°C]	Humidity h [%]
Site A Line Poznań–Szczecin	Without joints	Concrete	$D_1 = 25.0$	$H_o^1 = 1.2$	Intercity trains, goods trains, passenger trains	40	≤ 3	$5 < T < 15$	$40 < h < 70$
			$D_2 = 100.0$	$H_o^2 = 1.3$					
			$D_3 = 104.5$	$H_o^3 = 1.5$					
Site B Line Poznań–Warszawa	Without joints	Concrete	$D_1 = 25.0$	$H_o^1 = 1.2$	Intercity trains, goods trains, passenger trains	67	≤ 5	$7 < T < 26$	$30 < h < 80$
			$D_2 = 200.0$	$H_o^2 = 1.2$					
			$D_3 = 200.0$	$H_o^3 = 1.8$					
Site C Line Poznań–Wągrowiec	Without joints	Wooden	$D_1 = 7.5$	$H_o^1 = 1.4$	Railbuses	53	≤ 3	$15 < T < 27$	$30 < h < 60$
			$D_2 = 25.0$	$H_o^2 = 1.4$					
			$D_3 = 75.0$	$H_o^3 = 4.0$					

sites. In all cases the terrain was flat, without trees and any reflecting obstacles. The tracks were straight and level on an embankment of a height of about 0.5–1.0 m. The measurement sites are characterised in Table 1.

At each measurement site the sound exposure level of a single pass-by noise L_{AE} was measured at three distances. During the measurements the speed V, the length of train l and the number of carriages were measured. The atmospheric conditions during the acoustic measurements are reported in Table 1.

4. The calculations

The measurements of the L_{AE}, performed close to the track at the distance $D_1 = 25.0$ m (site A, B) and $D_1 = 7.5$ m (site C), were used to obtain the noise emission for one carriage per one hour (Method I, Eq. (8)) and sound power level of the unit length line source (Method II, Eq. (18)),

$$\widetilde{L}_{WA} = L_{AE} - 10 \log \frac{l l_o}{4 V D t_o}. \tag{25}$$

Then, using the values of E_c and $\widetilde{L}_{WA}$, the sound exposure level L_{AE} was calculated at the distances D_2 and D_3.

A comparison of the calculated and measured sound exposure levels is presented in Figs. 5–8. The diagonal line in each figure indicates the ideal relationship between the two levels, i.e. the situation when the calculation corresponds exactly to the measurement. The mean values of the measured and cal-

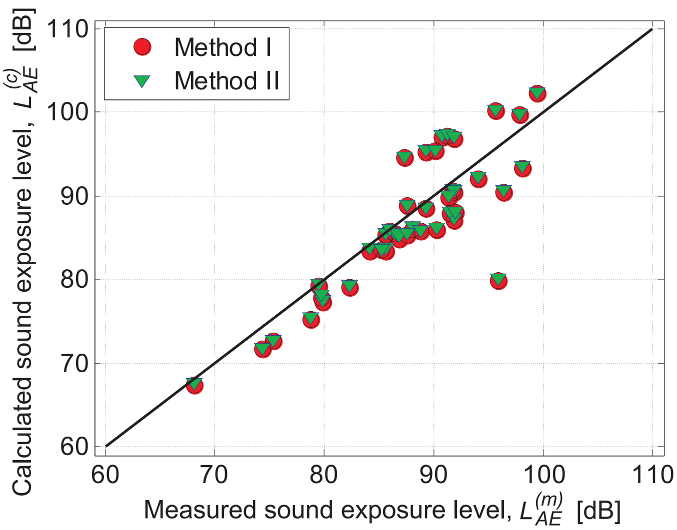

Fig. 5. Calculated and measured values of the sound exposure level, $L_{AE}^{(c)}$ and $L_{AE}^{(m)}$ (site A, $D = 100.0$ m, $H_o = 1.3$ m).

culated sound exposure level are presented in Table 2. At distances 25, 75 and 100 m, both methods give very similar results (at all sites). At $D = 200$ m the error between the measurements and calculations is greater for the interim method.

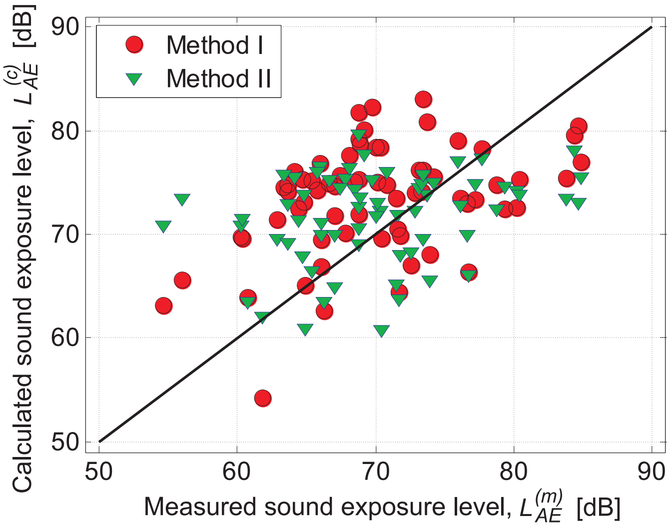

Fig. 6. Calculated and measured values of the sound exposure level, $L_{AE}^{(c)}$ and $L_{AE}^{(m)}$ (site B, $D = 200.0$ m, $H_o = 1.8$ m).

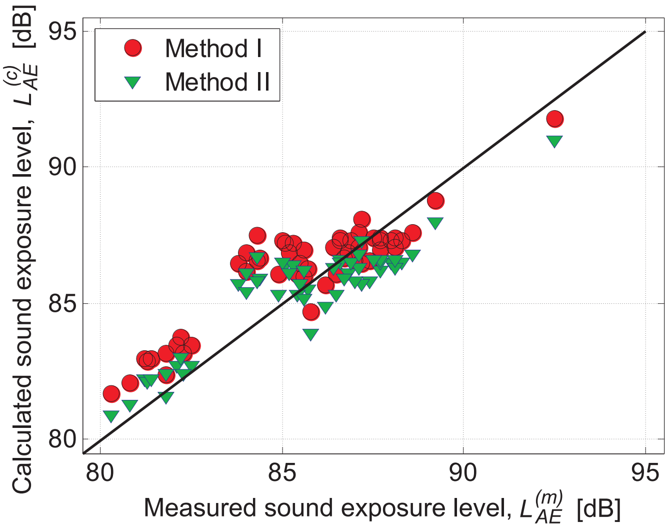

Fig. 7. Calculated and measured values of the sound exposure level, $L_{AE}^{(c)}$ and $L_{AE}^{(m)}$ (site C, $D = 25.0$ m, $H_o = 1.4$ m).

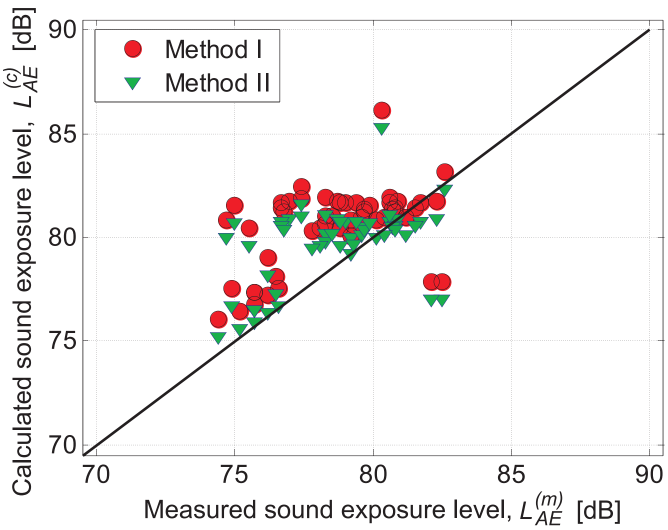

Fig. 8. Calculated and measured values of the sound exposure level, $L_{AE}^{(c)}$ and $L_{AE}^{(m)}$ (site C, $D = 75.0$ m, $H_o = 4.0$ m).

Table 2. The mean values of the measured $L_{AE}^{(m)}$ and calculated $L_{AE}^{(c)}$ sound exposure level.

Receiver point	$L_{AE}^{(m)}$	Method I		Method II	
		$L_{AE}^{(c)}$	ΔL_{AE}	$L_{AE}^{(c)}$	ΔL_{AE}
Site A					
$D = 100.0$ m, $H_o = 1.3$ m	87.9	87.0	**0.9**	87.3	**0.6**
$D = 104.5$ m, $H_o = 1.5$ m	87.9	86.9	**1.0**	87.3	**0.6**
Site B					
$D = 200$ m, $H_o = 1.2$ m	70.5	73.2	**−2.8**	68.7	**1.8**
$D = 200$ m, $H_o = 1.8$ m	70.1	73.4	**−3.3**	71.8	**−1.7**
Site C					
$D = 25.0$ m, $H_o = 1.4$ m	85.5	86.2	**−0.7**	85.4	**0.1**
$D = 75.0$ m, $H_o = 4.0$ m	78.6	80.5	**−2.0**	79.7	**−1.1**

5. Conclusion

In the present study, two methods of the railway noise prediction have been presented and examined by comparison with the acoustic measurements. Method I is recommended by EU as the interim method and Method II is the Polish method of railway noise propagation. Both methods take into account the ground effect and air absorption. Using these methods, the sound exposure level L_{AE} has been calculated and compared to the results of measurements. Both methods give results being in good agreement with the measured values up to 100 m. At the distance 200 m from the track, the Polish method seems to be a little better than the interim method. The ΔL_{AE} for the proposed method is smaller than that for the interim method (about 1 dB).

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