Field measurements of sound power spectrum for predicting road traffic noise

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1. Introduction

The noise emitted by road vehicles varies with the vehicle type and running speed as well as the pavement type. The sound power level of vehicles is one of the essential physical quantities used in the prediction and evaluation of traffic noise in urban areas. In the road traffic noise prediction model “ASJ RTN-Model 2013” [1], which has been developed by the Research Committee in the Acoustical Society of Japan (ASJ), the calculation formula for the A-weighted sound power level, L_{WA} , of each road vehicle type is given as a function of the running speed, and the influence of the pavement type on L_{WA} can be considered. Furthermore, the sound power spectrum of road vehicles is necessary for the calculation of frequency-dependent propagation or wave-based numerical analyses. For example, in ASJ RTN-Model 2013, the calculation method for diffraction due to acoustical barriers is derived by considering the representative sound spectrum of road traffic noise on each pavement type. This traffic noise prediction model is widely used in environmental impact assessment in Japan.

On the other hand, the Research Committee in ASJ has accumulated new data about noise emission to improve the accuracy of the model [2,3] and changed some parts of the calculation formulas for L_{WA} and the representative sound power spectra of traffic noise on pavement types. In addition, the calculation formulas for diffraction were modified on the basis of the updated sound spectra. The revised model “ASJ RTN-Model 2018” was published in April 2019 [4].

In this paper, field measurement data on dense asphalt pavement used in the development of ASJ RTN-Model 2018, and the process of deriving the representative sound power spectrum of road traffic noise are introduced. In addition, the results of comparisons of sound power spectra for different vehicle and pavement types are described.

2. Methods based on measurement data

Field measurements were performed on conventional dense asphalt pavement at 40 sites (R1–R40) in Japan from 2010 to 2018 [2]. Among them, the measured data at 32 sites (R9–R40) were used in the examination of the sound power spectra of road vehicles. The measuring points of noise

emission were located at heights (h) 1.2–1.5 m above the road surface, except at two sites with guard pipes (microphone heights: 1.9 and 2.1 m), and the horizontal distances (l_h) from the microphone to the center of the driving lane were 3.0–9.4 m (35 sites: 6.0–7.5 m), as shown in Fig. 1. The road vehicles were divided into four categories: passenger cars, and small-, medium-, and large-sized vehicles [1].

The A-weighted band power level, $L_{WA}(f_c)$, of a vehicle running at a steady speed is obtained from the sound exposure level, $L_{EA}(f_c)$ [5], as follows:

$$L_{WA}(f_c) = L_{EA}(f_c) + 3 + 10 \lg vl - 10 \lg \frac{\theta}{\pi}, \quad (1)$$

$$\theta = \tan^{-1} \frac{vt_1}{l} + \tan^{-1} \frac{vt_2}{l}, \quad (2)$$

where f_c is the center frequency for the 1/3-octave bands from 50 Hz to 5 kHz, v is the running speed [m/s], and l [m] is the slant distance from the microphone to the center of the driving lane. $L_{EA}(f_c)$ at the receiving point is derived from the A-weighted sound pressure levels, $L_{A,F}$, during a time interval ($t_1 - t_2$), which are lower than the maximum level, $L_{A,Fmax}$, by 10 dB. The symbol θ is the angle of the integration range ($vt_1 - vt_2$) in which a single vehicle passes in front of the receiver (see Fig. 1).

Moreover, the A-weighted relative band power level, $\Delta L_{WA}(f_c)$, at each center frequency is calculated by

$$\Delta L_{WA}(f_c) = L_{WA}(f_c) - L_{WA}, \quad (3)$$

$$L_{WA} = 10 \lg \sum 10^{L_{WA}(f_c)/10}, \quad (4)$$

where L_{WA} is the A-weighted sound power level obtained as an overall value (i.e., the sum of all frequency components) of $L_{WA}(f_c)$. Also, $\Delta L_{WA}(f_c)$ for each road vehicle type is set to a constant value regardless of the running speed in consideration of practicality and convenience, and the energy synthesis value of $\Delta L_{WA}(f_c)$ is adjusted to 0 dB.

3. Measurement results of power spectrum

To examine the representative sound power spectrum for each vehicle type under steady running conditions, $\Delta L_{WA}(f_c)$ was calculated by Eqs. (1)–(4) using the measurement data at running speeds of 50 km/h or more, and the arithmetic mean of the obtained values was determined. The total number of newly accumulated data was 904 for passenger

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Fig. 1 Schematic of time history of road traffic noise level.

cars, 44 for small-, 101 for medium-, and 114 for large-sized vehicles.

Figure 2 shows examples of measured $\Delta L_{WA}(f_c)$ in 1/3-octave bands for passenger cars at nine measurement sites. The thin lines and circles ($\circ$) indicate the measured $\Delta L_{WA}(f_c)$ for individual vehicles and the calculated arithmetic mean levels at each site. On the whole, the A-weighted sound power spectra for passenger cars are dominated by frequency bands of 1 to 1.6 kHz, whereas narrow band components are seen in the sound levels at frequencies less than 500 Hz. These narrow band components included in traffic noise are considered to be due to power-unit noise (e.g., engine, exhaust, transmission, and air intake) [6].

The calculated mean $\Delta L_{WA}(f_c)$ for each vehicle type is shown in Fig. 3 and Table 1. It can be seen that the frequency characteristics of $\Delta L_{WA}(f_c)$ for road vehicles are divided into two categories: light vehicles (passenger cars and small-sized vehicles) and heavy vehicles (medium- and large-sized

Fig. 3 Mean $\Delta L_{WA}(f_c)$ for different types of road vehicles.

vehicles). The power spectra for heavy vehicles tend to shift to slightly lower frequencies than those for light vehicles.

Note that similar tendencies were confirmed in the previous survey [7].

4. Representative power spectrum of road traffic noise

In the model, the relative power spectrum of representative road traffic noise is specified, because actual traffic flows consist of any type of road vehicle included in not only one category but in different categories.

Specifically, for each type of road vehicle, the A-weighted band power levels $L_{WA}(f_c)$ in 1/3-octave bands are calculated

Fig. 2 Examples of A-weighted relative band power level $\Delta L_{WA}(f_c)$ for passenger cars at nine measurement sites (n : number of data, $\circ$: arithmetically averaged levels in 1/3-octave bands).

Table 1 Mean $\Delta L_{WA}(f_c)$ for each road vehicle type.

Frequency [Hz]	Relative sound power level [dB]			
	Passenger	Small	Medium	Large
50	-39.9	-38.7	-36.7	-39.1
63	-37.4	-33.6	-33.9	-35.3
80	-34.6	-32.2	-31.5	-32.2
100	-32.9	-31.1	-28.7	-28.5
125	-30.9	-28.4	-26.0	-25.8
160	-28.0	-25.2	-23.2	-24.3
200	-24.4	-22.9	-21.7	-19.1
250	-20.9	-20.3	-18.6	-17.5
315	-19.3	-18.4	-16.3	-16.2
400	-17.8	-16.3	-14.8	-14.1
500	-14.8	-14.4	-13.1	-12.3
630	-12.5	-12.4	-10.9	-9.1
800	-9.4	-9.9	-8.2	-7.2
1,000	-6.9	-8.0	-7.3	-7.2
1,250	-7.1	-7.7	-8.0	-9.1
1,600	-8.1	-8.1	-9.7	-10.7
2,000	-9.8	-9.4	-11.3	-12.3
2,500	-12.8	-11.5	-12.9	-14.4
3,150	-15.8	-13.9	-15.2	-16.9
4,000	-19.1	-16.8	-17.9	-19.6
5,000	-22.7	-19.3	-20.2	-22.6

Table 2 Calculation conditions for determination of representative power spectrum of road traffic noise.

Vehicle types		a^* [dB]	Ratio [%]	
Two-category	Four-category			
Light vehicles	Passenger cars	45.3	70	80
	Small-sized vehicles	48.1	10	
Heavy vehicles	Medium-sized vehicles	51.4	10	20
	Large-sized vehicles	54.4	10	

* a is a coefficient of calculation formula for L_{WA} ($= a + 30 \lg V$, V : running speed [km/h]) [2,4].

from L_{WA} and $\Delta L_{WA}(f_c)$ (see Eq. (3) and Table 1). L_{WA} can be determined using the coefficient a ($L_{WA} = a + 30 \lg V$, see Table 2), which represents the differences in L_{WA} between vehicle types. L_{WA} depends on the vehicle type as well as the running speed (V), whereas the speed dependence of L_{WA} in the model is assumed to be the same regardless of vehicle type.

Next, using the energy sum of $L_{WA}(f_c)$ considering the composition ratio of each vehicle type, the representative $\Delta L_{WA}(f_c)$ is rederived from Eqs. (3) and (4). In the case of light vehicles, the composition ratio of passenger cars to small-sized vehicles was assumed to be 7:1, and the ratio of heavy vehicles was 1:1 (medium-sized:large-sized vehicles), as in the previous model [2].

The estimated $\Delta L_{WA}(f_c)$ for the representative traffic noise consisting of light and heavy vehicles is presented in

Table 3 Estimated $\Delta L_{WA}(f_c)$ for road traffic noise consisting of light and heavy vehicles on dense asphalt pavement (ASJ RTN-Model 2018).

Frequency [Hz]	Relative sound power level [dB]			
	All types	Light	Heavy	
50	-38.7	-39.6	-38.2	
63	-30.2	-36.3	-34.8	
80	-32.7	-34.0	-31.9	
100	-29.8	-32.5	-28.6	
125	-22.1	-30.2	-25.8	
160	-25.0	-27.2	-23.9	
200	-21.2	-24.1	-19.8	
250	-14.0	-20.7	-17.8	
315	-17.2	-19.1	-16.2	
400	-15.4	-17.5	-14.4	
500	-7.9	-14.7	-12.6	
630	-10.6	-12.5	-9.6	
800	-8.3	-9.5	-7.5	
1,000	-3.0	-7.1	-7.3	
1,250	-8.0	-7.3	-8.7	
1,600	-9.3	-8.1	-10.4	
2,000	-6.0	-9.7	-11.9	
2,500	-13.2	-12.5	-13.9	
3,150	-15.8	-15.3	-16.2	
4,000	-13.4	-18.5	-19.0	
5,000	-21.7	-21.7	-21.6

Fig. 4 $\Delta L_{WA}(f_c)$ obtained using new measurement data and that in the previous model ASJ RTN-Model 2013 (dense asphalt pavement).

Table 3. Figure 4 shows the obtained $\Delta L_{WA}(f_c)$ and that in the previous model, ASJ RTN-Model 2013. The frequency characteristics of $\Delta L_{WA}(f_c)$ calculated using the newly accumulated data were similar to those in ASJ RTN-Model 2013. However, differences in the sound power level at frequencies lower than 500 Hz were seen.

As a reference, $\Delta L_{WA}(f_c)$ on dense asphalt pavement was compared with those on two other types of pavement defined below (Fig. 5).

Fig. 5 Schematic of porous asphalt and gap-graded asphalt mixture (GGAM) pavement.

Fig. 6 $\Delta L_{WA}(f_c)$ for different types of road pavement (ASJ RTN-Model 2018).

- (1) Porous asphalt pavement: porous asphalt with a maximum chipping size of 13 mm and a designed void content of 20%.
- (2) Gap-graded asphalt mixture (GGAM) pavement: porous asphalt, which is referred to as “KOUKINOU II,” formed in two layers with the top layer having a maximum chipping size of 13 mm and the bottom layer of stone mastic asphalt (SMA).

In a previous study [3], these power spectra of traffic noise were collected on nine expressways paved with porous asphalt and six expressways paved with GGAM. Figure 6 presents $\Delta L_{WA}(f_c)$ in 1/3-octave bands on different types of road pavement. For porous asphalt pavement, the peaks of $\Delta L_{WA}(f_c)$ are at frequencies of 630 and 800 Hz, and the components at frequencies above 1 kHz are lower than those for dense asphalt pavement. Moreover, the power spectrum of traffic noise on GGAM is similar to that on dense asphalt pavement except in the frequency range of 2 kHz or more.

5. Conclusions

The A-weighted relative band power level $\Delta L_{WA}(f_c)$ for each vehicle type was examined using measured data of about 1,160 vehicles at 32 actual roads in Japan. Additionally, the representative $\Delta L_{WA}(f_c)$ for road traffic noise was derived from the energy sum of $\Delta L_{WA}(f_c)$ for each vehicle type. As a result, some differences between the derived $\Delta L_{WA}(f_c)$ and that in ASJ RTN-Model 2013 were revealed. In the revised model, ASJ RTN-Model 2018, $\Delta L_{WA}(f_c)$ in Table 3 was adopted as the representative power spectrum of traffic noise on dense asphalt pavement.

In this study, a practical power spectrum model of traffic noise was obtained using a large amount of measurement data; however, there are still several problems to be solved. A major problem is the ignoring of the running speed dependence of $\Delta L_{WA}(f_c)$ for the sake of practicality and convenience. As future work, to validate the effectiveness of $\Delta L_{WA}(f_c)$ adopted in the model, we intend to investigate the difference from other power spectrum models considering the dependence on speed (e.g., Harmonoise source model in EU, and Nord 2000 in Denmark [6]). In addition, the influence of these differences on the prediction results must also be examined.

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