PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Road Traffic Noise Prediction Model "ASJ RTN-Model 2018" Proposed by The Acoustical Society of Japan –Part 2: Calculation model of sound emission of road vehicles

Yasuaki OKADA[1]; Akinori FUKUSHIMA[2]; Katsuya YAMAUCHI[3]; Shinichi SAKAMOTO[4]

[1] Faculty of Science and Technology, Meijo University, Japan

[2] NEWS Environmental Design Inc., Japan

[3] Faculty of Design, Kyushu University, Japan

[4] Institute of Industrial Science, The University of Tokyo, Japan

ABSTRACT

The Acoustical Society of Japan (ASJ) has published a new revised version of road traffic noise prediction model "ASJ RTN-Model 2018", in which the calculation formula for the A-weighted sound power level of each type of road vehicles is specified. The sound power level is given basically as a function of the running speed in consideration of practicality and convenience. The Research Committee in ASJ has been accumulating new data about noise emission of vehicles running on expressways and general roads over the last decade. As results, the sound power level of light vehicles, which include passenger cars, hybrid vehicles and small-sized vehicles, for the dense asphalt pavement was changed to a lower value than those in the previous model. In addition, the calculation formula for sound emission on the porous asphalt pavement was revised, and that on the road paved with the gap-graded asphalt mixture (GGAM, referred to as "KOUKINOU II") was introduced into the model. In this paper, the revised model of the sound power level and power spectrum for road vehicles based on the newly acquired data are described.

Keywords: Sound Power Level, Power Spectrum, Hybrid Vehicles

1. INTRODUCTION

The calculation formulas for the A-weighted sound power level L_{WA} of road vehicles have been developed based on a large amount of pass-by noise measurements performed at roadsides of expressways and general roads (1, 2). The sound power level depends not only on the vehicle type but also on the running condition, pavement type and so on. The basic calculation formula for L_{WA} is given as a function of the running speed, and the influences of other factors are considered in the correction terms. The most measurement data used for determining the formulas have been acquired in 1991–1998 for the dense asphalt pavement, and in 1996–2008 for the porous asphalt pavement (3-5), respectively. On the other hand, in order to improve those models more accurately, the Research Committee has been accumulating new data about noise emission of road vehicles after the previous model was published. In this paper, the revised model of sound power level and power spectrum for road vehicles using the newly acquired data are described. In addition, the differences between L_{WA} on the dense asphalt pavement and on the road paved with the gap-graded asphalt mixture (GGAM) introduced into the new model are presented.

2. CLASSIFICATION OF ROAD VEHICLES

In ASJ RTN-Model 2018, road vehicles are basically classified into two or three categories, as shown in Table 1. The three-category classification (light vehicles, medium- and large-sized vehicles) places importance on noise radiation characteristics, while the two-category classification (light and

[1] okada@meijo-u.ac.jp
[2] fuku-new@wonder.ocn.ne.jp
[3] yamauchi@design.kyushu-u.ac.jp
[4] sakamo@iis.u-tokyo.ac.jp

heavy vehicles) takes practicality into account. In the prediction of road traffic noise, not only the sound power level of each road vehicle but also the percentage of each type of vehicle comprising the traffic volume is an important factor. Thus, the percentage of heavy vehicles (medium- and large-sized vehicles) in the two-category classification is widely used in the environmental impact assessment of roads. Additionally, the noise generated from motorcycles can be also considered separately.

Table 1 – Vehicle categories defined in ASJ RTN-Model 2018.

Two-category	Three-category	Characteristics
Light vehicles		Passenger cars used exclusively for carrying passengers with capacity of 10 or fewer
		*Small-sized vehicles with engine displacement exceeding 0.050 liter and with overall length of 4.7m or less
Heavy vehicles	Medium-sized vehicles	Vehicles with overall length exceeding 4.7m excluding large-sized vehicles (most vehicles in this category have 2 axles)
		Medium-sized buses with capacity from 11 to 29 passengers
	Large-sized vehicles	Vehicles with gross vehicle weight of over 8 t or maximum authorized payload of over 5 t (most vehicles in this category have 3 or more axles).
		Large-sized buses with capacity of 30 or more passengers
		Large-sized special motor vehicles
Motorcycle		Motorcycles and mopeds

Note: * In the previous model (ASJ RTM-Model 2013), light vehicles were classified into two types: passenger cars and small-sized vehicles. However, these vehicle types are specified in the same category, because the ratio of number of the registered small-sized vehicles to passenger cars decrease to about 14% in recent years.

3. SOUND POWER LEVEL OF ROAD VEHICLES

The sound power level of road vehicles generally varies not only with the road vehicle type, but also with the running condition of vehicle and pavement type. In this model, the sound power level is set separately for pavement types and sections taking into account vehicle running conditions, which are defined as follows.

Types of pavement (see Fig.1):

(a) Dense asphalt pavement: road surface with a dense asphalt concrete pavement

(b) Porous asphalt pavement: porous asphalt with a maximum chipping size of 13 mm and a designed void content of 20%

(c) Gap-graded asphalt mixture (GGAM): porous asphalt, which is referred as to "KOUKINOU II", formed in layers with the top layer having a maximum chipping size of 13 mm and the bottom layer of stone mastic asphalt (SMA).

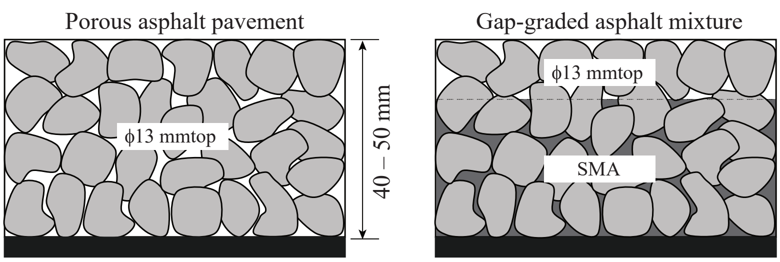


Figure 1 – Schematic of porous asphalt pavement and gap-graded asphalt mixture (GGAM).

Types of section taking into account vehicle running conditions:

(a) Steady traffic flow section: This is a section of expressway or general road sufficiently distant from signalized intersections, where vehicles can be driven in top-gear position or equivalent. The vehicle running speed V is in the range from 40 to 140 km/h (see Fig.2).

(b) Non-steady traffic flow section: This is a general road including signalized intersections, where vehicles frequently accelerate and decelerate. The speed V is in the range from 10 to 60 km/h (see Fig.2).

(c) Acceleration section: The running condition in this section is defined as a transitional state from the stopping condition at an expressway tollgate to the steady running condition in the main lane. The speed V is in the range from 1 to 80 km/h. Acceleration at speeds exceeding 80 km/h is treated as the steady running condition. Also, a constant power level is applied at speeds of less than 1 km/h (see Fig.5).

(d) Deceleration section: The running condition in this section is defined as the transitional state from the steady running condition in the main lane to the stopping condition at the tollgate. The speed V is in the range from 10 to 140 km/h. A constant power level is applied at speeds of less than 10 km/h (see Fig.5).

3.1 Sound Power level of Road Vehicles on Dense Asphalt

In this model, the sound power level for each type of road vehicles is given basically as a function of the running speed, similarly to that in the previous model for practicality and convenience. The A-weighted sound power level L_{WA} of a road vehicle running on the dense asphalt pavement is given by

$$L_{WA} = a + b \lg V + C, \tag{1}$$

$$C = \Delta L_{grad} + \Delta L_{dir} + \Delta L_{etc}, \tag{2}$$

where V is the vehicle running speed [km/h], a and b are regression coefficients, and C is the correction term for the change in the sound power level due to the road gradient ΔL_{grad} [dB], sound radiation directivity ΔL_{dir} [dB] and other factors ΔL_{etc} [dB]. The calculation methods for these corrections were assumed to be the same as the previous model.

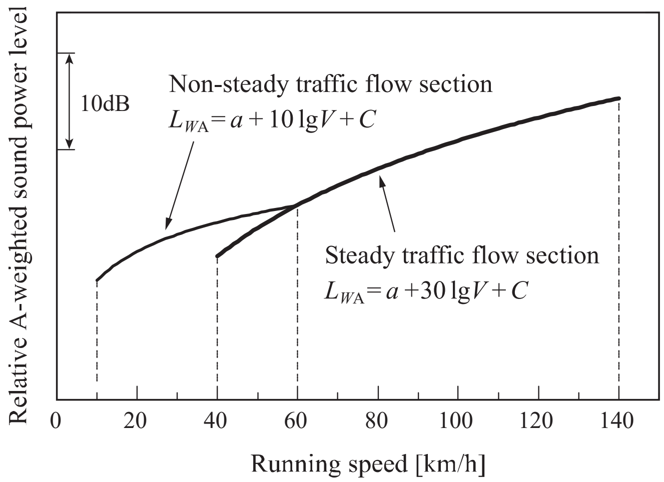


Figure 2 – Illustration of L_{WA} in steady and non-steady traffic flow sections (dense asphalt pavement).

Figure 2 shows an illustration of L_{WA} on the dense asphalt pavement in the steady and non-steady traffic flow sections. The coefficients a, b for each vehicle type in the both sections are given in Table 2. For the determination of the coefficient b which represents the running speed dependence of the generated noise, the pass-by noise measurements have been performed on test tracks and several general roads using each type of vehicle. As results of those studies (4, 5), it was revealed that the value of coefficient b can be given by 30 for steady traffic flow section, and 10 for non-steady traffic flow section, respectively.

The coefficient a depending on vehicle types was determined using the pass-by measurement data conducted at actual roads. The newly acquired data for L_{WA} of each vehicle type was 4,529 for light vehicles, 688 for medium-, and 606 for large-sized vehicles. From the measurement results, L_{WA} for light vehicles on the dense asphalt pavement was changed to 0.9 dB lower than that in the previous model (0.9=46.7–45.8, Table 1). The principal reason of this change in L_{WA} is that the number of the low-emission vehicle such as hybrid and electric vehicles (HVs/EVs) and mini-sized vehicles (also referred to as K-cars) are increasing year by year. The discussion on L_{WA} of those road vehicles is described in subsequent section. On the other hand, for heavy vehicles including medium- and large-sized vehicles, the collected L_{WA} were the same as that adopted in the previous model. The other calculation formulas for L_{WA} in acceleration and deceleration sections on the dense asphalt pavement were assumed to be the same as the previous model, and please refer to the model (1).

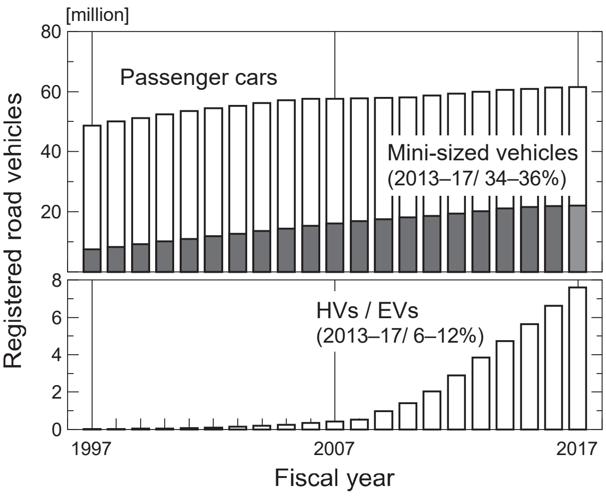
Table 2 – Coefficients a and b for L_{WA} on urban roads (dense asphalt pavement).

Classification	Steady traffic flow section (40 km/h $\leq V \leq 140$ km/h)		Non-steady traffic flow section (10 km/h $\leq V \leq 60$ km/h)	
	a	b	a	b
Light vehicles	45.8	30	82.3	10
Heavy vehicles	53.2		88.8	
Medium-sized vehicles	51.4	30	87.1	10
Large-sized vehicles	54.4		90.0	
Motorcycles	46.9	30	85.2	10

3.1.1 Low Emission Vehicles

The number of the registered mini-sized vehicles and HVs/EVs in Japan are shown in Fig.3. At end of March 2017, the number of the registered mini-sized vehicles and HVs/EVs contained in the category of passenger cars are about 2,200 million and 70 million, respectively. The percentage of these vehicle types are about 35% and 10% of overall passenger cars during the last five years. In particular, the market share of HVs/EVs is expected to grow in the future.

As mentioned the previous section, L_{WA} for light vehicles obtained from the newly acquired data were revealed to be lower than that adopted in the previous model. Therefore, the measurement data of passenger cars were divided into conventional gasoline engine vehicles (GEVs), HVs/EVs, and mini-sized vehicles, and L_{WA} for those types of road vehicles were compared with each other.



Examples of mini-sized vehicles (also referred to as K-cars, displacement: 0.66 lit., overall length: 3.4m)

Figure 3 – Number of registered mini-sized vehicles and HVs/EVs in the category of passenger cars.

Table 3 – Coefficient a for vehicle types in the category of light vehicles.

Classification	a	Meas. number
Passenger cars	45.3	4,221
Conventional GEVs	45.8	2,527
HVs	45.2	451
Mini-sized vehicles	44.3	1,243
Small-sized vehicles	48.1	308

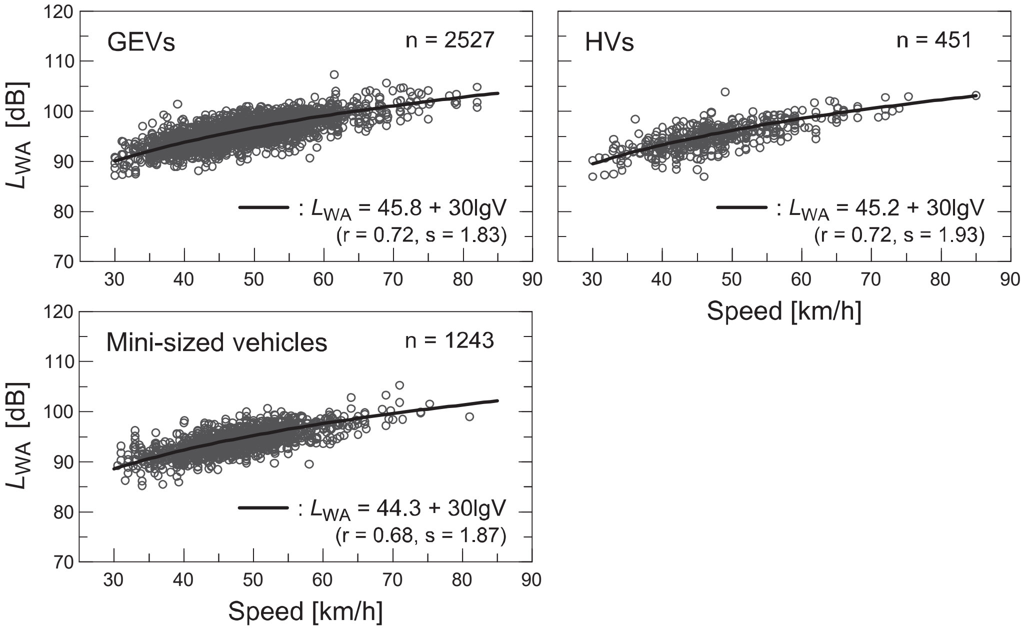


Figure 4 – Speed dependence of L_{WA} for conventional GEVs, HVs and mini-sized vehicles (Passenger cars, *n*: number of data, *r*: correlation coefficient, *s*: standard error).

Table 3 and Figure 4 show the coefficients a in the formulas for L_{WA} of each vehicle type contained in the category of light vehicles. The number of the acquired data were 2,527 for GEVs, 451 for HVs (including two EVs), and 1,243 for mini-sized vehicles. The L_{WA} for HVs and mini-sized vehicles were 0.6 dB and 1.5 dB lower than that for conventional GEVs, respectively. The reasons for the decrease in L_{WA} of light vehicles could include the increase in the number of these low-emission vehicles.

Furthermore, the noise reduction effect of the low-emission vehicles can be expected in the vicinity of signalized intersections or expressway tollgates, where are dominated by the power-unit noise of vehicles (6-8). The accumulating measurement data of L_{WA} for HVs/EVs and examination of the noise reduction effect by the low-emission vehicles are necessary for assessing road traffic noise in the future environment.

3.2 Sound Power level of Road Vehicles on Porous Asphalt

Regarding the porous asphalt pavement and GGAM, the sound power level L_{WA} for each type of road vehicles is given as functions of the running speed and the number of years since the pavement was constructed, as follows:

$$L_{WA} = a + b\lg V + c\lg(1 + y) + C \quad (3)$$

$$C = \Delta L_{\mathrm{grad}} + \Delta L_{\mathrm{dir}} + \Delta L_{\mathrm{traf}} + \Delta L_{\mathrm{etc}} \quad (4)$$

where a, b and c are regression coefficients, and y indicates the number of years since the pavement was constructed. Among the correction terms C, ΔL_{traf} is a term taking into account the changes in noise reduction effect depending not only on the elapsed years y, but also on the daily traffic volume. However, the relationships between the traffic volume and noise reduction effect of the porous pavement have not yet been analyzed quantitatively. Therefore, the correction value ΔL_{traf} is assumed to be 0 dB. Figure 5 shows an illustration of L_{WA} on the porous asphalt pavement in the acceleration and deceleration sections near an expressway tollgate. The examples of coefficients a, b and c for porous asphalt pavement are given in Table 4, and those for GGAM are presented in Table 5, respectively.

To determine the coefficient a, b and c in the steady traffic flow section, the pass-by noise measurements have been conducted on 17 expressways paving with porous asphalt, and 7 expressways paving with GGAM (9). Also, the annual changes in L_{WA} was examined using the measurement data performed up to 11 years for the porous asphalt pavement, and up to 7 years for GGAM. The traffic volume of the target road was almost 15,000 or less vehicles per day for measuring noise generated from a single running vehicle. In ASJ RTN-Model 2018, from these examination results, the coefficients b which represents the running speed dependence of L_{WA} is fixed at 25 for the porous asphalt pavement, and at 30 for GGAM, respectively. In the case of motorcycles, the noise reduction value by these low-noise road surfaces is 0 dB. Besides, the formulas for L_{WA} in the acceleration section was assumed to be the same as the previous model (Table 4).

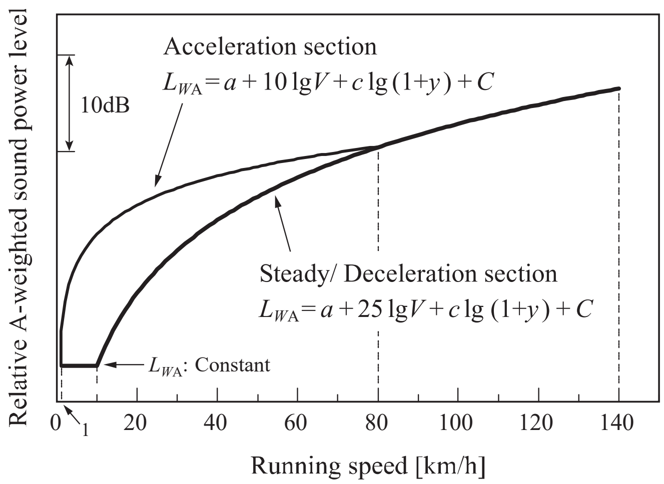


Figure 5 – Illustration of L_{WA} near an expressway tollgate (porous asphalt pavement).

Table 4 – Coefficients a, b and c for L_{WA} near an expressway tollgate (porous asphalt pavement).

Classification	Steady/ Deceleration section (60 km/h ≤ V / 10 km/h ≤V)			Acceleration section (1 ≤ V ≤ 60 km/h)			Acceleration section (60 ≤ V ≤ 80 km/h)		
	a	b	c	a	b	c	a	b	c
Light vehicles	50.6	25	1.5	79.1	10	6.4	88.0	5	6.4
Heavy vehicles	57.7		0.6	87.4		3.6	96.3		3.6
Medium-sized vehicles	56.5	25	0.7	85.7	10	3.6	94.6	5	3.6
Large-sized vehicles*	58.7		0.5	88.6		3.6	97.5		3.6
Motorcycles	49.6	30	–	87.7	10	–	87.7	10	–

*Except for large-sized buses (a = 56.1, b = 25, c = 0.5) in the case of steady/ deceleration section

Table 5 – Coefficients a, b and c for L_{WA} near an expressway tollgate (GGAM).

Classification	Steady traffic flow section (60 ≤ V ≤ 140 km/h)		
	a	b	c
Light vehicles	45.2	30	0.1
Heavy vehicles	50.3		0.4
Medium-sized vehicles	49.5	30	0.5
Large-sized vehicles*	50.9		0.4
Motorcycles	49.6	30	–

*Except for large-sized buses (a = 47.9, b = 30, c = 0.4)

Figure 6 shows a comparison of the calculated A-weighted sound pressure levels L_A between different pavement types under the steady running conditions. In this calculation, the coefficients for L_{WA} of light and heavy vehicles (two-category classification) in steady/ deceleration section are used, and the elapsed years y and the percentage of heavy vehicles comprising the traffic volume is assumed to be zero and 20%. At a running speed of 80 km/h, it can be seen that the noise reduction compared with conventional dense asphalt pavement is 4.9 dB for porous asphalt pavement, and 1.8 dB for GGAM, respectively.

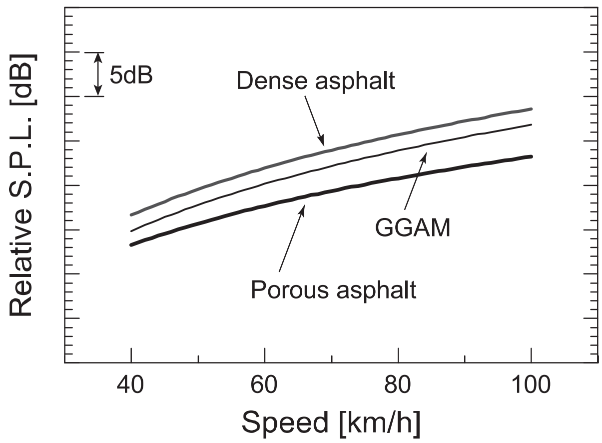
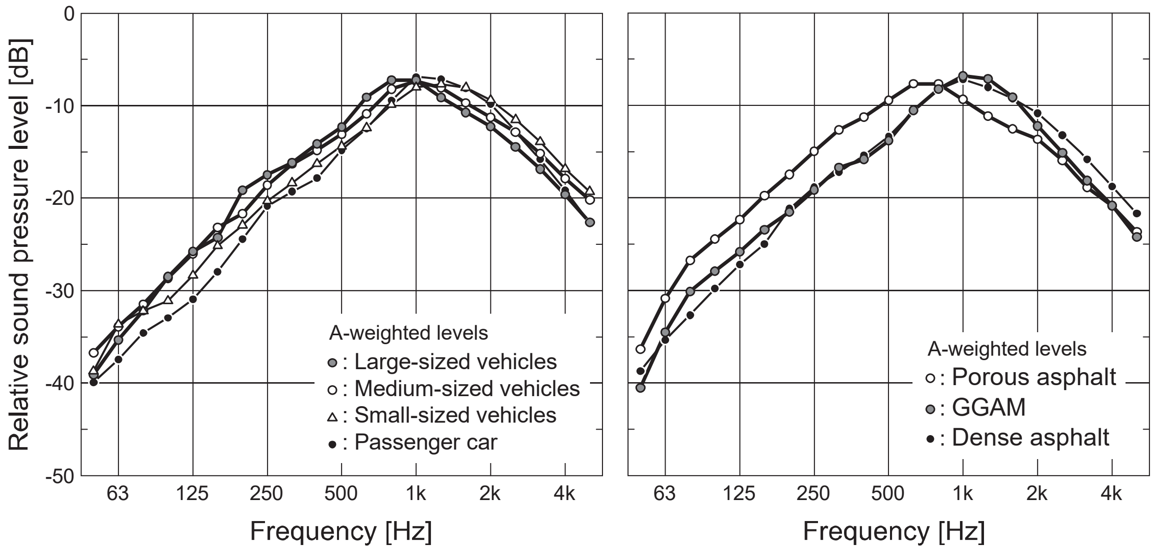


Figure 6 – Comparison of calculated L_A of road traffic noise between different pavement types (steady/ decreasing running conditions).



(a) Dense asphalt pavement (b) Porous asphalt pavement and GGAM

Figure 7 – A-weighted relative sound power levels in 1/3-octave bands on different types of road pavements.

4. SOUND POWER SPECTRUM OF ROAD VEHICLES

The A-weighted sound power level for each frequency band (1/n-octave band) is given by the following method. For the frequency bands, the center frequencies for the 1/1-octave bands are from 63 Hz to 4 kHz, and those for 1/3-octave bands are from 50 Hz to 5 kHz. The A-weighted band power level $L_{WA}(f_{c,i})$ for the i-th center frequency is calculated as

$$L_{WA}(f_{c,i}) = L_{WA} + \Delta L_{WA}(f_{c,i}) \tag{5}$$

where L_{WA} is the A-weighted sound power level of road traffic [dB] and $\Delta L_{WA}(f_{c,i})$ is the A-weighted relative power level for the frequency band of $f_{c,i}$ [dB]. The energy synthesis value of $\Delta L_{WA}(f_{c,i})$ is adjusted to 0 dB.

Figure 7(a) shows the A-weighted relative sound power levels $\Delta L_{WA}(f_{c,i})$ in 1/3-octave bands for four types of road vehicles on dense asphalt pavement. It can be seen that the A-weighted sound power levels for heavy vehicles (medium- and large-sized vehicles) are dominated by the low-frequency components, and the maximum of the sound spectrum shifts to lower frequency than that for light vehicles (passenger cars and small-sized vehicles).

The comparison of the typical $\Delta L_{WA}(f_{c,i})$ for road traffic noise, which is calculated from L_{WA} of heavy and light vehicles, between different pavement types is presented in Fig.7(b). Regarding the porous asphalt pavement, the peaks of the relative 1/3-octave band levels are at frequencies of 630 and 800 Hz, and the components at frequencies above 1 kHz are lower than those for the dense asphalt pavement. On the other hand, the sound spectrum of traffic noise on GGAM is quite similar to that on the dense asphalt pavement except for a frequency range of 2 kHz or more.

5. CONCLUSIONS

The calculation formula for the A-weighted sound power level L_{WA} and the sound power spectrum model of each road vehicle type have been revised in ASJ RTN-Model 2018. The main results are as follows:

(1) The category of the road vehicle types was changed from four-category classification to three-category classification (light-, medium-, and large-sized vehicles).

(2) The calculation formula for L_{WA} of road vehicles under steady running conditions was modified based on newly accumulating data of pass-by noise measurements. The noise reduction relative to the conventional dense asphalt pavement is almost 5 dB for porous asphalt pavement, and 2 dB for GGAM, respectively.

(3) The typical sound power spectrum of road traffic noise on each type of pavement was revised. The sound spectra for GGAM and dense asphalt pavement are similar except for high-frequency components of road traffic noise.

(4) The sound power levels of HVs/EVs on the dense asphalt pavement are almost 1 dB lower than those of conventional passenger cars (GEVs) at steady running speeds over 40 km/h. The further measurement under acceleration running conditions will be necessary to assess the noise reduction effect by these low-emission vehicles near the intersections in urban areas.

REFERENCES

1. S. Sakamoto. Road traffic noise prediction model “ASJ RTN-Model 2013”: Report of the Research Committee on Road Traffic Noise. Acoustic Science and Technology 2015; **36**(2): 49-108.
2. K. Yamamoto. Road traffic noise prediction model “ASJ RTN-Model 2008”: Report of the Research Committee on Road Traffic Noise. Acoustic Science and Technology 2010; **31**(1): 2-55.
3. S. Kono, et al. Road traffic noise prediction model “ASJ RTN-Model 2003” proposed by the Acoustical Society of Japan –Part 2: Calculation model of sound emission of road vehicles. Proc ICA 2004; Kyoto, Japan 2004.
4. Y. Oshino, et al. Road traffic noise prediction model “ASJ Model 1998” proposed by the Acoustical Society of Japan –Part 2: Calculation model of sound power levels of road vehicles. Proc INTER-NOISE 2000; Nice, France 2000.
5. Y. Oshino, et al. Prediction of road traffic noise taking account of transient running conditions of vehicles. Proc INTER-NOISE 93; Leuven, Belgium 1993.
6. M. Pallas, et al. Towards a model for electric vehicle noise emission in the European prediction method CNOSSOS-EU. Applied Acoustics 2016; **113**:89-101.
7. H. C. Vicente, et al. The effect of electric vehicles on urban noise maps, Applied Acoustics 2017; **116**: 59-64.
8. Y. Okada, et al. Road traffic noise prediction model “ASJ RTN-Model 2013” proposed by the Acoustical Society of Japan –Part 2: Study on sound emission of road vehicles. Proc INTER-NOISE 2014; Melbourne, Australia 2014.
9. A. Fukushima, et al. Sound power level and power spectrum of road vehicles running on expressways, Tech. Rep, Noise and Vib. Acoust. Soc. Jpn, N-2019-14 (in Japanese).
10. S. Sakamoto. Road traffic noise prediction model “ASJ RTN-Model 2018”: Report of the Research Committee on Road Traffic Noise. Acoustic Science and Technology 2020; **41**(3) (issue for next year).