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Sound power level and frequency characteristics of running vehicles on general roads measured at 20 sites in Japan

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ABSTRACT

Road traffic noise prediction model, the ASJ RTN-Model, is widely used for environmental noise assessment and monitoring in Japan. In the model, sound power levels and its spectral characteristics were determined based on measurement results obtained from real road traffic. Recently, next-generation vehicles like hybrid and electric vehicles (HV/EV) is becoming widespread and road traffic noise may change with the lapse of time. To keep the Japanese road traffic noise model as accurate as possible, the change of the sound power levels of vehicles should be continuously monitored. The authors have investigated the sound power levels and frequency characteristics of running vehicles on Japanese general roads for recent three years between 2015 and 2018 in order to contribute to revision of ASJ RTN-Model. As a result, it is found that the sound power level of passenger cars including HV/EV is about 1 dB less than before, and as for frequency characteristics of vehicle running noise, components at lower frequencies than 630 Hz and at higher frequencies than 1.6 kHz become less than before, especially for passenger cars.

Keywords: Road traffic noise, ASJ RTN-Model, Sound power level of running vehicles
I-INCE Classification of Subject Number: 13

1. INTRODUCTION

In order to predict and estimate road traffic noise in Japan, the ASJ RTN-Model[1], which is proposed by the Acoustical Society of Japan has been widely used. In the model, representative values of the sound power level of vehicles in Japan are shown. They were set based on measurement data acquired at actual roads. In recent years, in order to reduce CO_2 emissions which lead to global warming, the introduction of next-generation vehicles such as electric vehicles (EV), hybrid vehicles (HV) and plug-in hybrid vehicles (PHV) instead of gasoline engine vehicles (GEV) is being

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strengthened. By such changes in power mechanism of automobiles, as an issue on environmental noise, representative values of vehicle sound power levels which are used for the aim of environmental assessment may have to be changed. In order to maintain the accuracy of the road traffic noise prediction model continuously, it is necessary to confirm the change of the power levels of the vehicles. Under such a circumstance, the authors have investigated sound power levels of running vehicles in Japan in the period from 2015 to 2018. The number of the measurement sites ranged 20. In this paper, the measurement results of sound power levels and frequency characteristics of the vehicle running noise in Japan are reported.

2. MEASUREMENT AND ANALYSIS

Measurements of vehicle running noise were carried out at 20 sites nationwide as shown in Fig. 1. The measurements were made on straight flat roads with 1 to 3 lanes on one side for steady-state running condition. Measurement set-up is shown in Fig.2. An omnidirectional microphone was set at a receiving point 3.0 to 11.5 m from the centre of the driving lane. The height of the microphone was basically 1.2 m, and in the case where there are obstacles such as a guard pipe, the height of the microphone was set as appropriate within the range of 1.2 to 2.1 m so as to avoid the influence thereof. A video camera was used for recording of the running vehicles in order to confirm traffic condition after the measurement. Running speed of target vehicles was measured with a speed gun, and the category of the running vehicle was confirmed visually.

Figure 1 Location of 20 measurement sites in Japan.

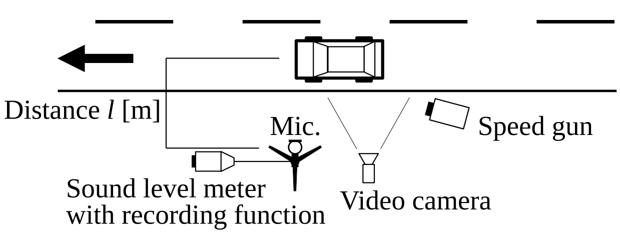

Figure 2 Measurement set-up for determination of sound power level of running vehicles.

A-weighted sound power level was determined from maximum level of A-weighted sound pressure level with time weighting F, $L_{A,Fmax}$, using the following equation.

$$L_{WA} = L_{A,Fmax} + 8 + 20\log_{10} l \qquad (1)$$

where, l is the shortest distance [m] from the measurement point to the driving lane. Independent running vehicle data of which signal-to-noise (S/N) ratio at least 10 dB could be secured and which did not be contaminated by running sounds from any other vehicles was analysed for determination of the sound power levels. In addition, frequency characteristics of the passing sounds of the independent running vehicles were analysed by A-weighting and 1/3 cotave band filterling with the rfequency range of 50 Hz to 5 kHz. The obtained frequency component values were corrected to obtain relative level to the A-weighted sound power level calculated by Eq. (1). Table 1 shows number of measured vehicles of every classification at all measurement sites. In this study, the vehicles were clasified to a large-sized vehicles, medium-sized vehicles, small cargo, gasoline engine passenger cars (GEV), Kei-cars, which are distinguished Japanese vehicle category of light vehicles, hybrid or electric vehicles (HV/EV). In the table, the numbers in parentheses are cases where the number was less than 4, and the cases were excluded from the subsequent analysis because the number of samples were considered to be statistically insufficient.

Table 1 Number of vehicles analysed for sound power level determination.

No.	Large-sized vehicles	Medium-sized vehicles	Small cargo	GEV	Kei-cars	HV/EV
1	23	32	(0)	45	20	27
2	5	20	11	125	55	17
3	26	6	(1)	7	(1)	(1)
4	31	10	(1)	14	(2)	(2)
5	44	20	(1)	28	(2)	7
6	(2)	4	(0)	36	27	5
7	26	12	(1)	40	17	9
8	32	10	(0)	34	25	8
9	20	31	(3)	35	21	14
10	(2)	11	(1)	36	23	14
11	(0)	4	13	11	8	13
12	15	10	(0)	25	31	11
13	(0)	4	(1)	53	31	11
14	(3)	23	(0)	63	30	12
15	(0)	(2)	(1)	26	28	16
16	5	21	9	52	39	17
17	(0)	8	(3)	39	23	14
18	19	7	5	23	21	12
19	5	(1)	(0)	30	27	5
20	7	5	(0)	48	12	16

3. A-WEIGHTED SOUND POWER LEVELS

Figure 3 shows the relationship between the sound power level and the running speed of the GEV at the 20 measurement sites. In the figure, solid lines idicate the A-weighted sound power level of the passenger cars in accordance with the running speed, V, specified in the ASJ RTN-Model 2013[1], which is calculated as,

$$L_{WA} = 46.4 + 30\log_{10} V \qquad (2)$$

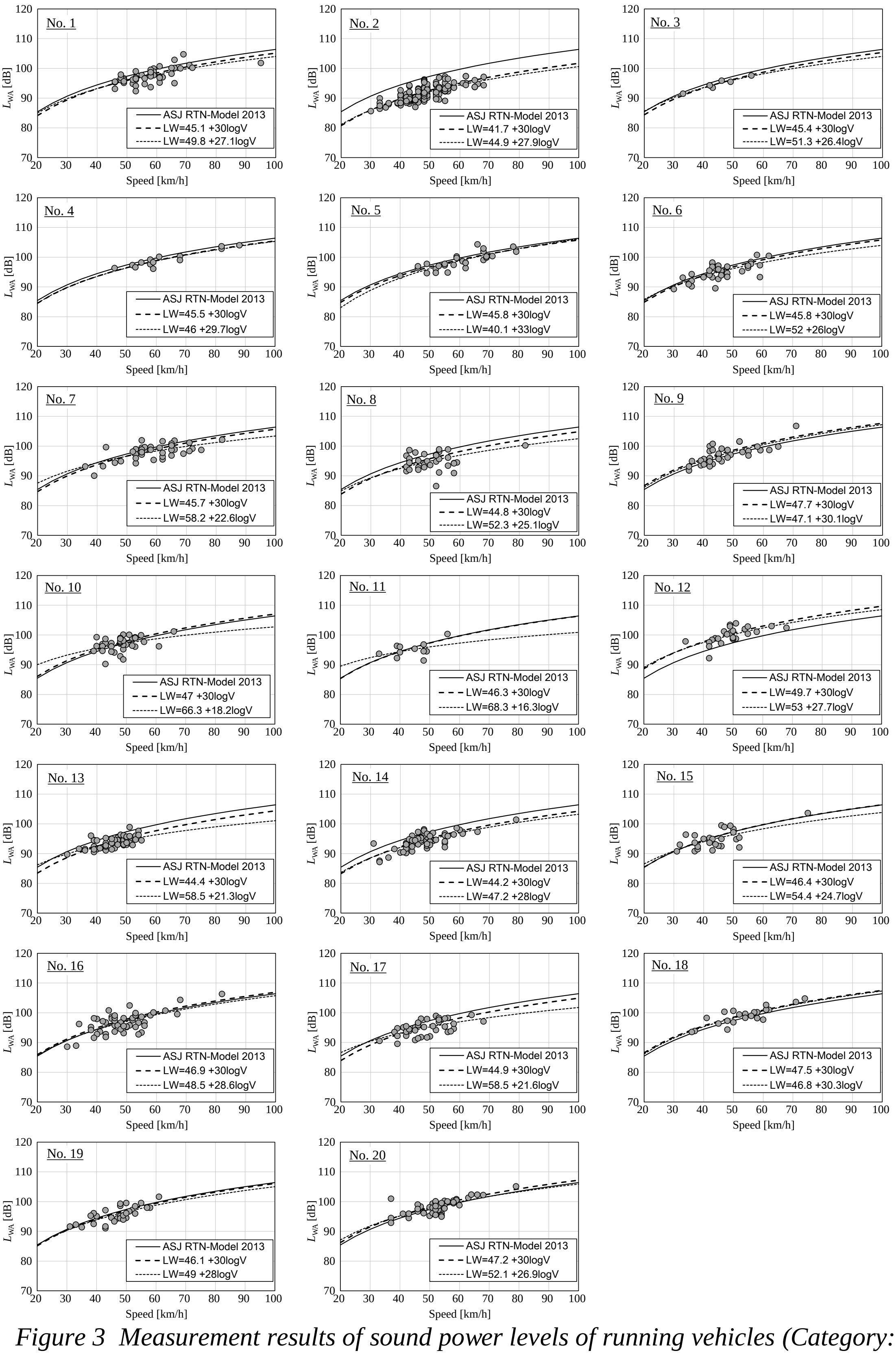

Figure 3 Measurement results of sound power levels of running vehicles (Category: GEV) at 20 sites.

In the ASJ RTN-Model, sound power level of running vehicle is expressed as a function of *V*, such as,

$$L_{\mathrm{WA}} = a + b\log_{10} V \qquad (3)$$

where, *a* and *b* are modeled parameters determined for every vehicle category and running condition. The broken line and the dotted line in the figure are regression curves based on the measurement data, the broken line shows the case where the coefficient *b* of the running speed dependent term is fixed to 30, and the dotted line shows the case where both the parameters *a* and *b* are identified as variables. Obviously it is observed from the measurement results that there is considerable differences of the sound power level depending on the measurement site. The maximum difference was 8 dB (between No. 12 and No. 2) for the constant *a* when $b = 30$.

Based on the measured data, A-weighted sound power level for each vehicle category was analyzed. According to the ASJ RTN-Model, the parameter *b* in Eq. (3) was set to be 30 because vehicle running condition for the measurement was steady state, and the parameter *a* in Eq. (3) was determined as power averaged value of the measurement data at each measurement site. The results are shown in Table 2. In the table, the arithmetic average value ("(21) average" column) and standard deviation ("(22) standard deviation" column) of the parameter *a* for each category, and 95 % confidence interval ("(23) 95 % CI" column) calculated from the the average and standard deviation by assuming normal distribution are also shown. Values of parameter *a* indicated in the ASJ RTN-Model 2013 was referred in the bottom row. It is noted that the values for GEV, Kei-cars and HV/EV are the same as the parameter value for passenger cars in the ASJ RTN-Model 2013. Numbers of data (measurement sites) used for this analysis were 13 for large-sized vehicles, 18 for medium-sized vehicles, 4 for small cargo, 20 for GEV, 17 for Kei-cars and 18 for HV/EV. Number of sites for analysis of small cargo was extremely small, so they were excluded from the discussion below. The average values of the parameter *a* of the large-sized vehicles and the medium-sized vehicles are + 0.3, -0.2 compared with the value indicated in the ASJ RTN-Model 2013, respectively, but the values of the ASJ RTN-Model 2013 are within the range of 95% confidence interval, and therefore both values can be considered to be almost the same as the parameter values indicated in the ASJ RTN-model 2013. The values of the parameter *a* for GEV, Kei-cars and HV / EV are -0.5, -1.5, -1.1 compared with the value in the ASJ RTN-Model 2013, which is systematically low. For GEV, the value of parameter *a* of the passenger car in the ASJ RTN-Model 2013 is within the 95% confidence interval, but for Kei-cars and HV/EV, they are outside the 95% confidence interval. When GEV, Kei-cars and HV/EV are summarized together as the category of passenger cars, the average value of parameter *a* was 45.4, which was 1 dB lower than the ASJ RTN-Model 2013.

3. FREQUENCY CHARACTERISTICS OF VEHICLE RUNNING NOISE

Frequency characteristics of vehicle running noise were analyzed by the method described in chapter 2. Obtained frequency characteristics of the measured running noises were averaged every measurement site and for each vehicle category. As an example of the analysis, frequency characteristics of GEV at measurement site No. 1 are shown in Fig. 4. The gray thin solid line is the frequency characteristic of individual vehicle running noise and the thick solid line is the averaged frequency characteristics of the GEV by power averaging at the measurement site. For each vehicle category, data of all measurement sites was arithmetically averaged. The obtained average characteristic was corrected again so that the overall level would be 0 dB, thereby obtaining the representative frequency characteristics for the vehicle category. Figure 5 shows the analysis results for large-sized vehicles, medium-sized vehicles, GEV, Kei-cars, HV/EV. In the figures, the gray thin lines are the frequency characteristics for all measurement sites and the thick solid lines are representative frequency characteristics for each vehicle category.

Table 2 Measured A-weighted sound power level for each vehicle category.

No.		Large-sized		Medium-sized		Small cargo		GEV		Kei-cars		HV/EV	
		a	*n*	*a*	*n*	*a*	*n*	*a*	*n*	*a*	*n*	*a*	*n*
(1)	1	54.36	23	50.74	32		(0)	45.14	45	43.75	20	43.13	27
(2)	2	51.99	5	49.28	20	46.11	11	41.71	125	40.07	55	40.61	17
(3)	3	55.16	26	50.77	6		(1)	45.39	7		(1)		(1)
(4)	4	55.43	31	51.77	10		(1)	45.50	14		(2)		(2)
(5)	5	55.46	44	52.11	20		(1)	45.79	28		(2)	45.09	7
(6)	6		(2)	52.47	4		(0)	45.82	36	44.95	27	44.22	5
(7)	7	55.47	26	51.33	12		(1)	45.70	40	45.51	17	45.14	9
(8)	8	55.18	32	50.40	10		(0)	44.84	34	44.55	25	44.68	8
(9)	9	56.74	20	51.98	31		(3)	47.70	35	47.17	21	47.28	14
(10)	10		(2)	52.39	11		(1)	47.02	36	45.61	23	47.29	14
(11)	11		(0)	52.79	4	48.28	13	46.33	11	45.51	8	47.46	13
(12)	12	54.81	15	52.36	10		(0)	49.65	25	49.04	31	49.06	11
(13)	13		(0)	50.72	4		(1)	44.40	53	43.94	31	44.08	11
(14)	14		(3)	50.41	23		(0)	44.24	63	42.89	30	44.01	12
(15)	15		(0)		(2)		(1)	46.43	26	45.41	28	45.19	16
(16)	16	54.57	5	52.81	21	51.64	9	46.90	52	45.87	39	47.97	17
(17)	17		(0)	50.63	8		(3)	44.90	39	41.80	23	41.31	14
(18)	18	54.10	19	51.49	7	51.83	5	47.54	23	45.66	21	46.44	12
(19)	19	53.60	5		(1)		(0)	46.09	30	44.82	27	46.20	5
(20)	20	53.73	7	49.39	5		(0)	47.21	48	46.55	12	46.54	16
(21)	Average	54.7		51.3		49.5		45.9		44.9		45.3	
(22)	Standard deviation	1.2		1.1		2.8		1.6		2.1		2.2	
(23)	95% CI	55.4-54.0		51.8-50.8		52.2-46.8		46.6-45.2		45.9-43.9		46.3-44.3	
(24)	ASJ RTN-Model 2013	54.4		51.5		47.6		46.4		46.4		46.4	

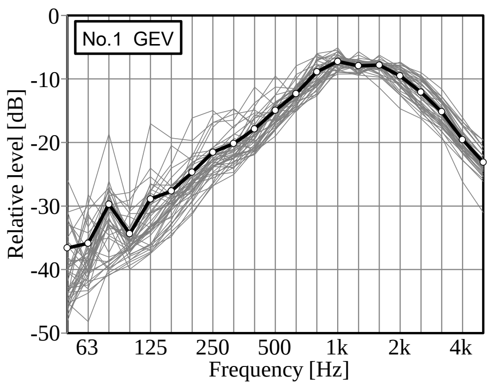

Figure 4 An example of frequency characteristics of vehicle running noise. Site No. 1, vehicle category GEV. Gray thin lines are individual data and black thick line is the representative characteristics for the measurement site No. 1 obtained by power averaging the individual characteristics.

Figure 6 summarizes the frequency characteristics of each vehicle category. The figure also shows A-weighted relative band power level shown in the ASJ RTN-Model 2013[1]. For all vehicle categories, the band levels of the measurement results are higher than the ASJ RTN-Model 2013 at 800 Hz, 1 kHz and 1.25 kHz, and lower at frequency ranges below 630 Hz and over 1.6 kHz. The tendency is remarkable for passenger cars (including GEV, Kei-cars and HV/EV).

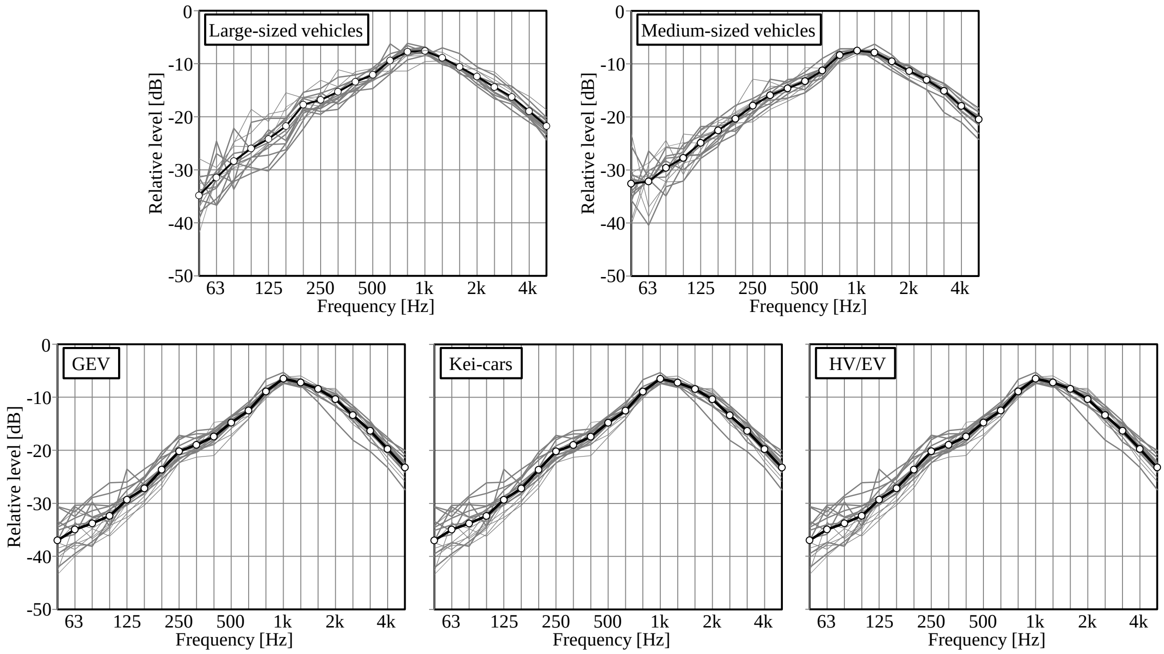

Figure 5 Frequency characteristics of running noise of every vehicle category.

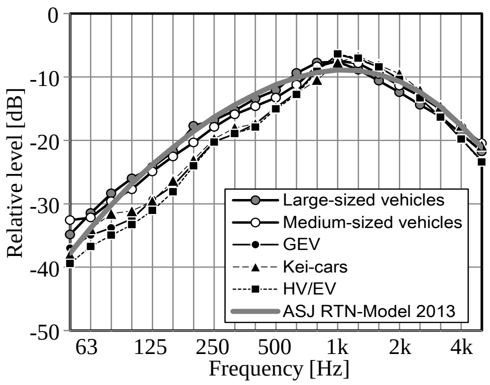

Figure 6 Comparison of frequency characteristics of vehicle running noise among vehicle categories.

4. CONCLUSIONS

Field measurements of vehicle running noise were conducted on 20 general roads in Japan during the period from 2015 to 2018, and the results of analyzing the sound power level and frequency characteristics were reported. As a result of comparison with the ASJ RTN-Model 2013, the sound power level was the same for large-sized and medium-sized vehicles, whereas the sound power levels of Kei-cars and HV/EV are about 1 dB lower than the power level of passenger cars of the ASJ rtN-Model 2013. Frequency characteristics of vehicle running noise are lower at the low frequency range of 630 Hz or less and at the high frequency range of 1.6 kHz or more than the frequency characteristics shown in the ASJ RTN-Model 2013, and this tendency is remarkable for passenger cars. The collected data in this study contributes to revision of the ASJ RTN-Model 2013.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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