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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

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ABSTRACT
The calculation formulas for the sound power levels of road vehicles adopted in the ASJ Model 1998 have been introduced. The relationship between running speed and sound power level on urban roads is much different from that on freeways. On freeways and urban roads under steady running condition in the speed rang higher than 40km/h, the expression of $30\log_{10} V$ is adopted as the speed dependence. On the other hand, for the case of urban roads where vehicles accelerate and decelerate in the speed range lower than 60 km/h, the expression of $10\log_{10} V$ is adopted.

1 - INTRODUCTION
The Acoustical Society of Japan published a new prediction model of road traffic noise, ASJ Model 1998, in which the calculation model of sound power level of each type of road vehicle is specified. The model consists of two kinds of calculation formulas. One is for the calculation of sound power level under steady running condition in the speed range higher than 40km/h. The other is for that under transient running condition in the speed range lower than 60 km/h. In this paper (Part 2), the constructions of these formulas are introduced.

2 - SOUND POWER LEVELS OF ROAD VEHICLES
The sound power levels of road vehicles much vary with the difference of vehicle type and running speed. In this section, classification of road vehicles and speed dependence of sound power level are described.

2.1 - Classification of road vehicles
In ASJ Model 1998, road vehicles are classified into four types as shown in Table 1; large-sized vehicle, medium-sized vehicle, small-sized vehicle and passenger car. This classification almost corresponds to that of the motor vehicle noise regulations in Japan which is based on vehicle weight and engine output. In the two-type classification which is for simplicity, vehicles are classified into two categories; heavy vehicle and light vehicle.

Vehicle weight and engine output	Four-type classification	Two-type classification
Motor vehicles with GVW (gross vehicle weight) of over 3.5 t, and maximum engine output of over 150 kW	Large-sized vehicles	Heavy vehicles
Motor vehicles with GVW of over 3.5 t, and maximum engine output of 150 kW or less	Medium-sized vehicles	
Motor vehicles with GVW of 3.5 t or less	Small-sized vehicles	Light vehicles
Motor vehicles used exclusively for carrying passengers, with capacity of 10 or fewer passengers	Passenger cars	

Table 1: Motor vehicle classification.

2.2 - Sound power level under steady running condition

For the determination of the formulas expressing the sound power level under steady running condition, pass-by noise measurements were performed at roadsides of freeways and urban roads with steady traffic flow. Table 2 shows the number of vehicles in the regression analysis. In the calculation, road vehicles were assumed as omni-directional point sources on a reflecting plane and the sound power level of each vehicle was calculated from the pass-by noise data. The relationships between running speed and sound power level for each type of vehicle are shown in Fig. 1, respectively. In this figure, the formulas indicate the regression expression. The coefficients for the term of $\log_{10} V$ (V: running speed in km/h) are close to 30.

	Lage-sized vehicles	Medium-sized vehicles	Small-sized vehicles	Passenger cars	Total
Urban roads	1 694	1 520	450	997	4 661
Freeways	1 311	1 034	285	2 152	4 782
Total	3 005	2 554	735	3 149	9 443

Table 2: Number of vehicles.

2.3 - Sound power level under transient running condition

For general urban roads, transient running condition including acceleration and deceleration has to be considered. In order to obtain the formulas expressing the sound power levels of vehicles running under such a condition, field experiments were performed using each type of vehicle and the sound power levels were calculated from the measured vehicle speed, engine revolution speed and throttle opening [1], [2]. The running path on the urban road under test was divided into finite sections of a constant length and the average running speed and average sound power level in each section were obtained. Figure 2 shows the relationship between average speed and average sound power level within 1 km. The relationship is expressed by two kinds of regression formulas for each type of vehicle, respectively. One of these indicates the relationship in the speed range lower than 60 km/h. The other indicates that in the speed range higher than 60 km/h. The former corresponds to the sound power level under the transient running condition and is expressed by 9-15 $\log_{10} V$, whereas the latter corresponds to the sound power level under the steady running condition and is expressed by 31-36$\log_{10} V$.

3 - CALCULATION FORMULAS FOR SOUND POWER LEVEL AND POWER SPECTRUM

3.1 - Sound power level

Based on the results mentioned above, the calculation formulas for sound power levels of road vehicles were determined as shown in Fig. 3. On freeways and urban roads under steady running condition, vehicles run at the top gear position in the speed rang higher than 40km/h. For this condition, the expression of 30$\log_{10} V$ is adopted as the speed dependence. On the other hand, for the case of urban roads where vehicles accelerate and decelerate in the speed range lower than 60 km/h, the expression of 10$\log_{10} V$ is adopted. The calculation formulas of each running condition are as follows.
For transient running condition on urban roads (10 km/h$<V<$60 km/h)

$$L_{WA} = A + 10\log_{10} V \quad (1)$$

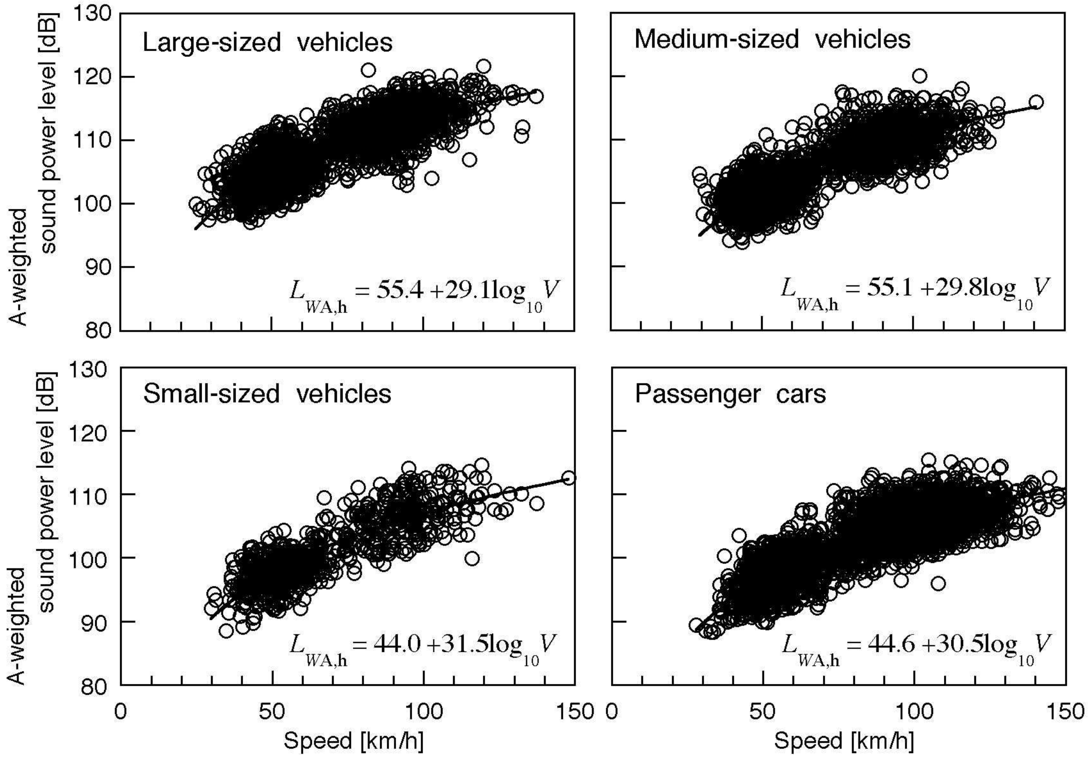

Figure 1: Relationships between running speed and sound power level under steady running condition.

L_{WA}: A-weighted sound power level [dB], V: running speed [km/h], A: regression coefficient.
For steady running condition on freeways and urban roads (40 km/h< V <140 km/h)

$$L_{WA} = B + 30\log_{10}V \tag{2}$$

B: regression coefficient.
The regression coefficients are shown in Table 3 and Table 4 for four-type classification and two-type classification of road vehicles, respectively. Besides, according to the latest regulation of motor vehicle noise in Japan, it can be expected that the sound power level would reduce in future. In case of the environmental impact assessment for road traffic noise, the values in parenthesis in the table are used as the coefficients A and B. These values are only applicable to the steady running condition [3].

Classification	A	B
	$L_{WA} = A + 10\log_{10}V$	$L_{WA} = B + 30\log_{10}V$
	(10km/h< V <60km/h)	(40km/h< V <140km/h)
Large-sized	90,0	54.4 (53.8)
Medium-sized	87,1	51.5 (50.3)
Small-sized	83,2	47.6 (46.5)
Passenger	82,0	46.4 (44.9)

Table 3: Regression coefficients of four-type classification.

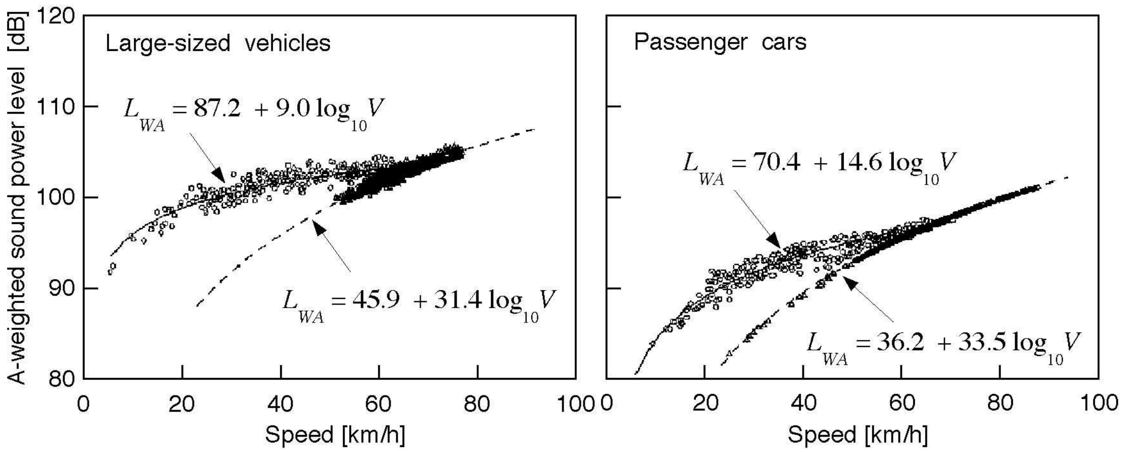

Figure 2: Relationships between average speed and average sound power level under transient running condition.

Classification	A	B
	$L_{WA} = A + 10\log_{10}V$	$L_{WA} = B + 30\log_{10}V$
	(10km/h< V <60km/h)	(40km/h< V <140km/h)
Heavy vehicles (Large-sized + Medium-sized)	88,8	53.2 (52.3)
Light vehicles (Small-sized + Passenger)	82,3	46.7 (45.3)

Table 4: Regression coefficients of two-type classification.

3.2 - Power spectrum

For both of steady and transient running conditions, the same sound power spectrum characteristic expressed by Eq. (3) is assumed. The frequency range for the calculation is 63Hz to 4 kHz in octave bands or 50Hz to 5 kHz in 1/3 octave bands.

$$\Delta L(f) = -10\log_{10}\left[1 + \left(\frac{f}{2000}\right)^2\right] \tag{3}$$

$\Delta L(f)$: relative sound power level for the frequency band centered at f (Hz).
The A-weighted sound power spectra in octave bands and in 1/3 octave bands are obtained by using $\Delta L(f)$ and A-weighting values for each frequency band. Figure 4 shows the relative A-weighted sound power spectra, where overall level assumed 0 dB.

3.3 - Consideration of the noise reduction effect by drainage asphalt pavement

In order to examine the noise reduction effect by drainage asphalt pavement, pass-by noise measurements were performed on several urban roads and test tracks paved with drainage asphalt pavements. The measurement results were compared with those measured on the normal asphalt pavements as shown in Fig. 5. Although the effect of noise reduction by drainage asphalt pavement is much scattered according to the difference of measurement site, the tendency can be seen that the noise reduction effect increases with increase of running speed. From these data, the regression analysis between the noise reduction and the running speed was performed and the following result was found.

$$\Delta L_{WA,dr} = -3.5\log_{10}V + 3.2 \tag{4}$$

$\Delta L_{WA,dr}$: noise reduction by drainage asphalt pavement [dB].
As a result, the sound power levels of vehicles running on drainage asphalt pavement are estimated by considering the following correction term $\Delta L_{WA,dr}$.

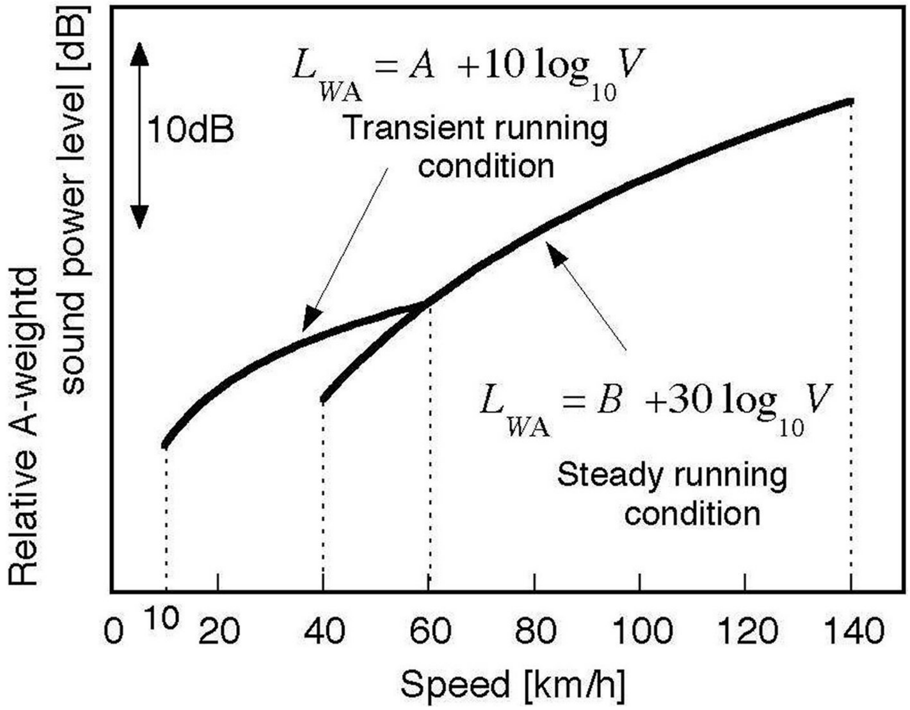

Figure 3: Illustration of calculation formulas for sound power level.

$$L_{WA,dr} = L_{WA} + \Delta L_{WA,dr} \tag{5}$$

$L_{WA,dr}$: sound power level on drainage asphalt pavement [dB], L_{WA}: sound power level on normal asphalt pavement [dB].
This formula is applicable in the speed range of 40 to 140 km/h for light vehicles and 40 to 120 km/h for heavy vehicles in the two-type classification.

4 - CONCLUSION

The calculation formulas for the sound power levels of road vehicles adopted in the ASJ Model 1998 have been introduced. The relationship between running speed and sound power level on urban roads is much different from that on freeways. Therefore, two kinds of calculation formulas for sound power level are determined. The first formula expressed by $30\log_{10} V$ is for the calculation of sound power levels under steady running condition in the speed range of 40 to 140 km/h. The second one expressed by $10 \log_{10} V$ is for the calculation under transient running condition in the speed range of 10 to 60 km/h.

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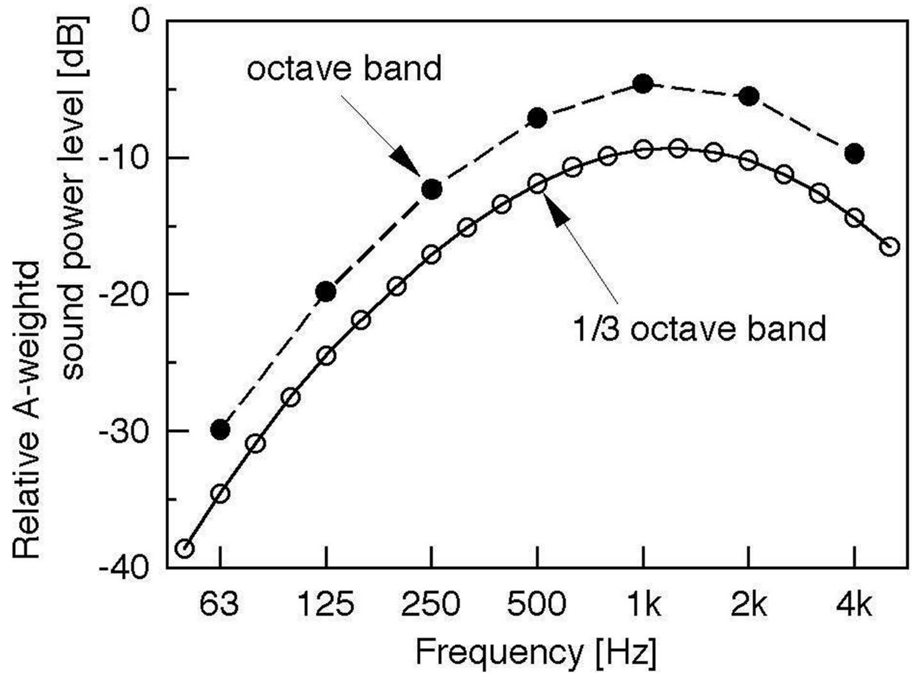

Figure 4: A-weighted power spectrum.

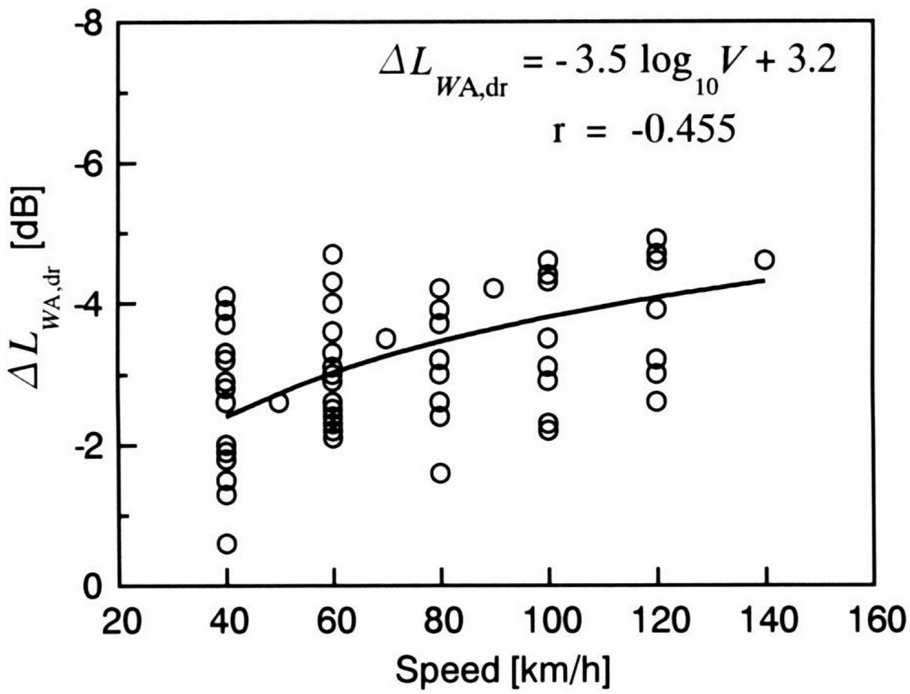

Figure 5: Noise reduction by drainage asphalt pavement.