Estimation of equivalent sound pressure levels of community noise and road traffic noise

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This study was aimed at making sure usefulness of assumption of Weibull distribution or Rayleigh distribution for estimating L_{eq} of community noise and road traffic noise from noise levels in L_5 , L_{50} and L_{95} . The results showed that Weibull distribution was very useful to estimate L_{eq} except few cases like the exponential distribution of noise levels and that Rayleigh distribution was also useful with permitting errors of about 1.5 dB (A) except such cases as distributions of noise levels were largely skewed to lower levels or higher levels.

Keywords: Community Noise, Road traffic noise, L_{eq} , Weibull distribution, Rayleigh distribution

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1. INTRODUCTION

As for evaluation of community noise and road traffic noise, many noise indices have been used and L_{eq} (equivalent sound pressure level) and L_a (percentile noise level, *e.g.* L_5 , L_{50} , L_{95}) have often been used in Japan. So relations among these indices, especially between L_{eq} and L_a , are very important to evaluate road traffic noise and community noise.¹⁾ Hence, Yamaguchi *et al.* have reported that two types of approach are there to investigate into relations among noise indices for road traffic noise.¹⁾ One of them is based on probability theory²⁻⁴⁾ and the other is only based on measured data.^{5,6)} As for road traffic noise, for example, Takagi *et al.*³⁾ investigated into noise on assumption of exponential distributions of headway for road traffic flows and Ohta *et al.*²⁾ studied into noise in a general distribution of headway for road traffic flows. Ishii and Tachibana⁶⁾ reported a simple relation between L_{eq} and L_{50} in relation to a variable of l/d , where l was a minimum distance from a road to a receive point of its noise and d was a mean headway. A simple

relationship between L_{eq} and L_{50} in relation to the variable of l/d has been proposed by the Acoustical Society of Japan for estimation of road traffic noise of freely flowing traffic.⁷⁾ As for community noise, for example, Nishinomiya⁸⁾ reported that Weibull distribution was useful to estimate community noise. Mori *et al.*⁹⁾ also studied into relations between the parameters of Weibull distribution and physical and social parameters of environments for estimating L_{eq} , and reported that the shape parameter of Weibull distribution was near 2.0 in average for community noise.

This suggests that levels of community noise fluctuate around Rayleigh distribution, because Rayleigh distribution corresponds to Weibull distribution with the shape parameter of 2.0.¹⁰⁾

This study was aimed at estimating L_{eq} of community noise and road traffic noise on assumption of Weibull distribution or Rayleigh distribution by only using data of noise levels in L_5 , L_{50} and L_{95} , and at making sure usefulness or limitation of these assumptions of distributions of noise levels.

2. WEIBULL DISTRIBUTION AND RAYLEIGH DISTRIBUTION

The density function and distribution function of Weibull distribution are given by

$$f(x) = \frac{k \cdot x^{k-1}}{b^k} \exp\left(-\frac{x^k}{b^k}\right) \quad (1)$$

$$F(x) = 1 - \exp\left(-\frac{x^k}{b^k}\right) \quad (2)$$

where b is a scale parameter, k is a shape parameter and $x = L$ (noise levels) - Min. (a minimum noise level). Then, L_α is represented as follows.⁸⁾

$$L_\alpha = b(-\ln \alpha')^{(1/k)} + \text{Min.} \quad (3)$$

where $\alpha' = 1 - F(x)$ ($\alpha' = \alpha/100$, $0 < \alpha' < 1$). If L_{95} , L_{50} and L_5 are known, the parameters of Weibull distribution can be estimated by plotting each of L_{95} , L_{50} and L_5 in a Weibull probability paper.⁸⁾ But this is a roughly approximate method with trial and error because of lack of the minimum level⁹⁾ and it cannot often be known if fitting L_{95} , L_{50} and L_5 to a probability paper of Weibull distribution is a exact fit. So, the following procedure of calculation was used in this study for estimating the parameters of Weibull distribution.

Now, the following equations are obtained from the Eq. (3).

$$\text{Min.} = L_5 - b(-\ln(.05))^{(1/k)} \quad (4-1)$$

$$\text{Min.} = L_{50} - b(-\ln(.50))^{(1/k)} \quad (4-2)$$

$$\text{Min.} = L_{95} - b(-\ln(.95))^{(1/k)} \quad (4-3)$$

From the Eqs. of (4-1)~(4-3), the following equations are also obtained.

$$b = (L_5 - L_{50}) / \{(-\ln(.05))^{(1/k)} - (-\ln(.50))^{(1/k)}\} \quad (5-1)$$

$$b = (L_{50} - L_{95}) / \{(-\ln(.50))^{(1/k)} - (-\ln(.95))^{(1/k)}\} \quad (5-2)$$

From the Eqs. of (5-1) and (5-2), the following Equation is obtained.

$$d_2 e^{KM_1} - d_3 e^{KM_2} + d_1 e^{KM_3} = 0 \quad (6)$$

where $K = 1/k$, $M_1 = \ln(-\ln(.05))$, $M_2 = \ln(-\ln(.50))$, $M_3 = \ln(-\ln(.95))$, $d_1 = L_5 - L_{50}$, $d_2 = L_{50} - L_{95}$ and $d_3 = L_5 - L_{95}$.

At first, the parameter of K can be calculated by using Newton's method for the Eq. (6). Next, the parameter of b can be obtained by using the Eq. of (5-1) and (5-2). Then, Min. can be obtained by using the Eq. (4-1)~(4-3). At last, L_{eq} can be estimated by the following equation.⁸⁾

$$L_{eq} = (10/\ln(10)) \cdot \ln \left\{ \int_0^\infty \exp(-x) \cdot \exp((\ln(10)/10)b \cdot x^{(1/k)}) dx \right\} + \text{Min.} \quad (7)$$

The Eq. (7) can be calculated by, for example, Gauss-Laguerre method,⁸⁾ but it is very complicated.

By the way, the function (1) represents Rayleigh distribution if the shape parameter k is equal to 2. If $b/\sqrt{2}$ is denoted by s , the percentile levels (L_α) are represented by

$$L_\alpha = s\sqrt{2\{-\ln(\alpha')\}} + \text{Min.} \quad (8)$$

Then, L_5 , L_{50} , L_{95} are directly proportional to the scale parameter of s and these noise indices are represented as follows.

$$L_5 \doteq 2.45s + \text{Min.} \quad (9-1)$$

$$L_{50} \doteq 1.18s + \text{Min.} \quad (9-2)$$

$$L_{95} \doteq 0.32s + \text{Min.} \quad (9-3)$$

Furthermore, L_{eq} is represented by the following equation.⁸⁾

$$L_{eq} = \frac{s^2}{2} \left(\frac{\ln 10}{10} \right) + \left(\frac{10}{\ln 10} \right) \cdot \ln \left(1 + s \frac{\ln 10}{10} \sqrt{\pi/2} \right) + \text{Min.} \quad (10)$$

Hence, if some errors can be permitted within about 1.5 dB (A), the following equations are obtained in approximation.

$$L_{eq} \doteq 1.60s + \text{Min.} \quad (0 < s < 10) \quad (11-1)$$

$$L_{eq} \doteq s^{1.27} + \text{Min.} \quad (0 < s < 15) \quad (11-2)$$

These relationships were obtained by regression

Fig. 1 Differences among the equations of (10), (11-1) and (11-2).

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methods. Figure 1 shows differences among the Eqs. (10), (11-1) and (11-2). Difference between Eq. (10) and Eq. (11-2) becomes larger at $s > 15$ and difference between Eq. (10) and Eq. (11-1) becomes larger at $s > 10$. If L_{95} , L_{50} and L_5 are known, the parameter of s and Min. can be estimated by using the following equations which are obtained from the Eqs. of (9-1), (9-2) and (9-3).

$$s = (1/2) \left\{ \frac{L_5 - L_{50}}{1.27} + \frac{L_{50} - L_{95}}{0.86} \right\} \quad (12)$$

$$\text{Min.} = L_5 - 2.45s \quad (13)$$

Hence, the minimum noise levels estimated by (9-1), (9-2) and (9-3) are often different from one another, because Rayleigh distribution is assumed instead of Weibull distribution. So accuracy of estimating L_{eq} on assumption of Rayleigh distribution depends on the Eq. of (9-1), (9-2) or (9-3). It was found in preliminary calculations that the Eq. (9-1) led to the best estimation of the minimum levels for estimating L_{eq} , as far as the data in this study. So the Eq. (13) was used in this study for estimat-

ing minimum noise levels, and L_{eq} was calculated by using the Eq. of (10), (11-1) or (11-2).

3. ESTIMATION OF L_{eq} FROM L_α

Noise 1 involved road traffic noises measured at main roads far from traffic signals or crossings. Noise 2 also involved road traffic noises measured at main roads near traffic signals or crossings. Noise 3 involved road traffic noises of highways. Noise 4 involved environmental noises. Some of them contained aircraft noise, construction noise or railway noise. Each case of the noises measured contained 250~1,000 data which were measured in height of 1.2 meters above the ground and were read at intervals of 5/3 seconds. Noise 5 was calculated by some simulations for freely flowing traffic. Noise 6 was calculated by some simulations for traffic flows with signal stops. In these simulations, such parameters were assumed in each case as mean headway between cars, mean speeds of cars, rates of large cars, a minimum distance from a road to a receive point and lane numbers of the road. Each position of

Table 1 Noises using for estimation of L_{eq} .

Noises	Sources	Numbers of cases*	Ranges of $L_5 - L_{95}$	Measured or calculated
Noise 1	Roads far from signals	20	6~23 dB (A)	Measured
Noise 2	Roads near signals	20	10~31	
Noise 3	Highways	12	7~13	
Noise 4	Environments	24	5~34	
Noise 5	Freely flowing road traffics	80	4~19	Calculated
Noise 6	Road traffics near a signal	48	8~34	
Noise 7	(Normal distribution)	30	9~31	

* Each case of noises measured contained 250~1,000 data at intervals of 5/3 s and each case of noises calculated contained 3,000 data calculated at intervals of 1 s.

Table 2 Estimation of L_{eq} on the assumption of Weibull distribution.

Noise	Corr. coef.	Differences of L_{eq} (measured) - (estimated)			Parameters of Weibull distribution	
		Mean	Ranges	s.e.	k	b
Noise 1	0.996	0.6	0.0~1.3	0.3	1.52~5.09	3.02~22.26
Noise 2	0.999	0.3	-0.1~1.2	0.3	1.54~7.24	4.77~38.52
Noise 3	0.972	0.5	0.0~1.5	0.5	1.25~5.05	2.87~10.79
Noise 4	0.979	0.3	-4.3~3.7	1.3	0.71~1.93	2.20~10.96
Noise 5	0.998	0.2	-0.3~1.0	0.2	1.34~5.28	1.96~10.44
Noise 6	0.998	0.8	-0.1~2.5	0.4	1.95~9.34	5.40~39.82
Noise 7	0.988	0.5	-0.2~1.6	0.4	1.70~3.72	6.39~15.59

Corr. coef.: correlation coefficients for regressions between L_{eq} measured and L_{eq} estimated.

Table 3 Estimation of L_{eq} on the assumption of Rayleigh distribution.

Equations	Noises	Corr. coef.	Differences of L_{eq} (measured)–(estimated)			Scale parameter
			Mean	Ranges	s.e.	
Eq. (11-1)	Noise 1	0.982	2.1	0.2~ 4.1	0.6	2.9~11.0
	Noise 2	0.979	2.1	–0.4~ 9.3	0.8	4.6~16.6
	Noise 3	0.972	0.7	0.1~ 1.9	0.7	3.0~ 6.0
	Noise 4	0.979	0.4	–1.6~ 5.3	0.9	2.5~14.6
	Noise 5	0.976	0.5	–0.8~ 3.0	0.6	1.9~ 9.4
	Noise 6	0.951	5.8	1.1~10.2	1.6	3.8~17.8
	Noise 7	0.983	3.9	0.3~ 6.7	0.8	4.4~15.4
Eq. (11-2)	Noise 1	0.993	1.0	0.1~ 2.1	0.5	
	Noise 2	0.996	0.5	–0.9~ 1.5	0.5	
	Noise 3	0.970	1.1	0.3~ 2.1	0.5	
	Noise 4	0.984	0.4	–2.6~ 3.0	1.1	
	Noise 5	0.982	0.9	–0.4~ 2.6	0.6	
	Noise 6	0.969	1.0	–1.1~ 3.2	0.8	
	Noise 7	0.996	–0.2	–1.7~ 1.7	0.6	
Eq. (10)	Noise 1	0.990	2.2	1.5~ 3.4	0.5	
	Noise 2	0.989	1.2	–3.5~ 2.4	1.1	
	Noise 3	0.973	1.8	1.3~ 3.1	0.5	
	Noise 4	0.981	1.0	–3.1~ 3.7	1.2	
	Noise 5	0.982	1.6	0.4~ 3.0	0.5	
	Noise 6	0.968	0.4	–6.8~ 4.6	2.2	
	Noise 7	0.987	–0.3	–4.1~ 2.9	1.3	

Corr. coef.: correlation coefficients for regressions between L_{eq} measured and L_{eq} estimated.

cars on the road was calculated one by one for 300 meters along the road and each of noise levels was calculated at intervals of one second. Noise 7 was calculated on assumption of the normal distribution of noise levels. Table 1 shows characteristics of these noises used for estimating L_{eq} in this study.

Table 2 shows the results of L_{eq} estimated on the assumption of Weibull distribution. Table 2 demonstrates that Weibull distribution is very effective to estimate L_{eq} , because the correlations are very high (statistically significant at $p < 0.01$), the standard errors are smaller than 1.5 dB(A), and the mean differences are very small between L_{eq} measured and L_{eq} estimated. But some cases of Noise 4 and Noise 6 showed rather large differences between L_{eq} measured and L_{eq} estimated.

Table 3 shows the results of L_{eq} estimated on the assumption of Rayleigh distribution. Table 3 illustrates that the Eq. (11-2) is better than the Eq. (10) or the Eq. (11-1) for estimation of L_{eq} . Errors of estimating L_{eq} on the assumption of Rayleigh distribution with Eq. (11-2) were larger a little than those assumed on Weibull distribution

(see Table 2 and Table 3).

4. DISCUSSION

As for community noise, Nishinomiya⁸⁾ and Mori *et al.*⁹⁾ have reported the usefulness of Weibull distribution for estimating L_{eq} of community noise. In this study, the usefulness of Weibull distribution or Rayleigh distribution was also found in Table 3 to estimate L_{eq} from L_5 , L_{50} and L_{95} , not only for community noise but also for traffic noise. But the limitation of both assumptions has not been clear in the previous researches.^{8,9)}

By the way, Table 4 shows the typical examples with the larger errors of estimating L_{eq} than 1.5 dB (A). It was suggested in Table 4 that the assumption of Rayleigh distribution for estimating L_{eq} was not adequate especially in such cases as distributions of noise levels were largely skewed to lower levels or higher levels of noises and that the assumption of Weibull distribution for estimating L_{eq} was also inadequate to estimation of L_{eq} in such cases of the noise levels as yielding to the exponential distribution. Nevertheless, the assumption of Weibull

Table 4 Examples with larger errors than 1.5 dB(A).

Noise	Differences		Parameters			Noise levels			
	(R_2)	(W)	k	b	s	L_{95}	L_{50}	L_5	L_{eq}
Noise 4	-2.6	-4.3	0.71	4.89	9.70	43	46	66	57.3
Noise 7	-1.7	0.3	1.85	15.73	15.36	45	60	76	68.4
Noise 7	-1.6	0.4	1.70	15.09	14.37	46	60	76	68.9
Noise 4	-1.5	-3.7	0.96	10.96	14.59	45	52	78	70.6
Noise 7	-1.5	0.4	1.94	15.21	15.29	46	63	77	69.4
Noise 4	2.2	3.7	0.91	3.62	5.16	47	49	59	56.2
Noise 4	3.0	2.5	1.54	4.14	3.97	52	55	61	58.8
Noise 3	2.1	0.2	4.75	10.79	5.03	57	63	67	63.9
Noise 1	2.1	0.4	4.06	12.11	5.96	70	77	82	77.8
Noise 6	3.2	0.2	6.98	13.69	5.92	51	59	63	59.8
Noise 6	3.2	0.2	7.77	18.54	8.01	44	55	58	55.2
Noise 6	2.7	-0.1	8.32	19.40	8.43	43	55	58	54.7
Noise 6	2.8	0.2	6.77	17.23	7.46	44	54	58	54.6

Differences are shown as (L_{eq} measured) - (L_{eq} estimated).

(R_2): Estimation by Eq. (11-2). (W): Estimation by Eq. (10).

distribution was very useful to estimate L_{eq} of community noise or road traffic noise in almost cases except some special cases, although those calculations were very complicated and difficult for estimating L_{eq} . The assumption of Rayleigh distribution was also useful with permitting about 1.5 dB (A) except some special cases, and those calculations were easy for estimating L_{eq} .

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