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TECHNICAL REPORT

Methods for predicting noise in the vicinity of signalized intersections

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Abstract: To accurately estimate the noise at a signalized intersection, it is necessary to precisely reproduce the traffic volume, signal cycle and traffic noise for each vehicle behavior and driving state. Precise reproduction requires considerable effort, such as continuous calculations of vehicles and the setting of parameters such as engine speed, engine load and velocity. A simple method that involves using A-weighted sound power levels (L_{WA}) under nonsteady running conditions has already been proposed for estimating noise at signalized intersections in a previous paper. In this study, the authors developed two simple methods for predicting noise in which the effects of acceleration and deceleration by signals is reflected. One method is based on a microsimulation traffic model, in which equivalent continuous A-weighted sound pressure levels (L_{Aeq}) is calculated by adding the noise of vehicles passing a green signal and the noise of vehicles decelerating and stopping at a red signal then accelerating when the signal turns green. The other method is even simpler and involves the assumption that an intersection zone is an unsteady running section and that L_{WA} for a nonsteady running section is larger than that for a steady running section. Noise predicting by the three simple methods is compared with actual measurements at 10 sites. The two new methods had slightly improved accuracy relative to the measured results.

Keywords: Intersection, Equivalent continuous A-weighted sound pressure level, A-weighted sound power level, Noise, ASJ RTN-Model

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1. INTRODUCTION

In order to accurately estimate the noise at a signalized intersection, it is necessary to reproduce the traffic volume, signal cycle and traffic noise for each type of vehicle behavior and driving state (using the method of Suzuki *et al.* [1] or another method). Precise reproduction requires considerable effort, such as continuous vehicle calculations and the setting of parameters such as engine speed, engine load and velocity. We investigated two simple methods for calculating L_{Aeq} at signalized intersections.

A simple method that involves using L_{WA} under nonsteady running conditions has already been proposed for estimating noise at signalized intersections (Method 1) [2]. Nonsteady running means not driving at a constant speed but accelerating and decelerating, in which case the speed V is the average speed of the vehicle during acceleration, deceleration and stopping. In this paper, we propose two practical noise estimation methods that reflect the effects of acceleration and deceleration depending on the state of traffic signals. One method is based on a microsimulation traffic model, in which L_{Aeq} is calculated

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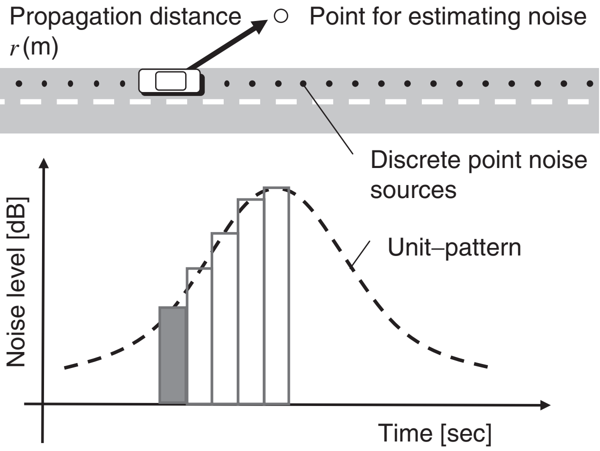

Fig. 1 Noise prediction using ASJ RTN-Model.

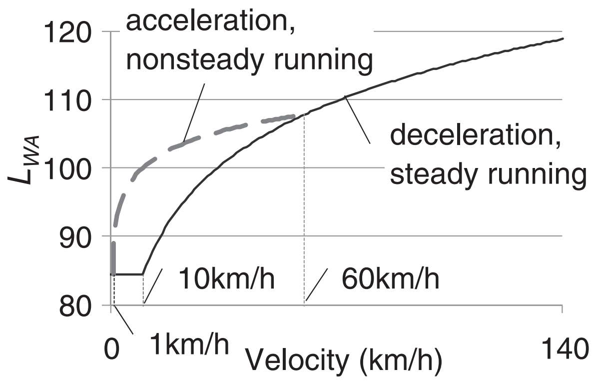

Fig. 2 Schematic view of L_{WA} used for estimations.

by adding the noise of vehicles passing a green signal and the noise of vehicles decelerating and stopping at a red signal then accelerating when the signal turns green (Method 2). The other method is even simpler and involves assuming the vicinity of a signalized intersection to be a nonsteady running section with L_{Aeq} larger than that at a steady running section (Method 3). The proposed methods were assessed by comparing the calculated results with actual measurements of L_{Aeq}.

2. PRACTICAL NOISE ESTIMATION METHODS

2.1. Summary of Estimation Methods

Noise prediction using ASJ RTN-Models [3] involves assuming separate noise sources with sound power corresponding to the vehicle type and driving state and calculating the propagation of noise from each source to the receiving point (Fig. 1). It was decided that the practical methods for predicting noise at signalized intersections would also involve setting separate noise sources. Three methods were comparatively investigated.

- Method 1: The calculation method proposed by Yoshihisa *et al.* [2]. L_{WA} under nonsteady running conditions is used for two intersecting roads.
- Method 2: The values of L_{WA} for steady running, accelerating vehicles, decelerating vehicles and vehicles standing with the engine idling are used to produce the driving conditions at an intersection.
- Method 3: A simplification of Method 2. The value of L_{WA} for steady running and accelerating vehicles are used.

In most cities, signals are mutually connected, and traffic flows in groups of vehicles. In the proposed calculation methods, the percentage of vehicles that stop at a signal was simplified to that of the duration of a red signal relative to the total duration of the signal cycle. It must be noted that traffic noise estimated by these methods contains the effects of this assumption. Acceleration near a signal was assumed to be constant irrespective of the distance from the signal and the speed limit.

2.2. L_{WA} for Each Vehicle Type and Driving Condition

It was decided to estimate L_{WA} during acceleration using the equation for calculating L_{WA} during nonsteady running proposed in the ASJ RTN-Model [3] and to estimate L_{WA} during deceleration using the equation for calculating L_{WA} during steady running proposed in the ASJ RTN-Model. A schematic view of $L_{WA} = a + b \lg V$, where a and b are parameters and V is the velocity [km/h], which is used for estimations, is shown in Fig. 2, and the parameters used are listed in Table 1.

2.3. Method 1 [2]

As there are many signalized intersections on ordinary roads in urban districts, vehicles repeatedly start, accelerate, run at steady speed, decelerate and stop. Thus, the traffic flow is transient.

In Method 1 L_{Aeq} is calculated by applying the equation for L_{WA} under nonsteady running conditions for two intersecting roads (Fig. 3) and composing the energy using the following equation:

$$L_{\mathrm{Aeq}} = 10 \cdot \lg(10^{L_{\mathrm{Aeq,A}}/10} + 10^{L_{\mathrm{Aeq,B}}/10}) \qquad (1)$$

where $L_{\mathrm{Aeq,A}}$ is the noise contribution [dB] from the vehicles on Road A, and $L_{\mathrm{Aeq,B}}$ is that from the vehicles on Road B.

2.4. Method 2

2.4.1. Basic equations

We propose a method that involves the use of a simplified microsimulation traffic model for the prediction of L_{Aeq}. The calculation method is as follows.

$$L_{\mathrm{Aeq}} = 10 \cdot \lg \frac{E_{\mathrm{A},T}}{T \cdot E_0} \qquad (2)$$

Table 1 Parameters of L_{WA} used for predicting noise levels at signalized intersections at velocity V.

Vehicle categories		steady running 40 km/h $\leqq V \leqq$ 140 km/h deceleration 10 km/h $\leqq V \leqq$ 140 km/h			nonsteady running 10 km/h $\leqq V \leqq$ 60 km/h acceleration 1 km/h $\leqq V \leqq$ 60 km/h			deceleration and idling $V \leqq$ 10 km/h	
		a		b	a		b	L_{WA}	
passenger cars (light vehicles)	Light vehicles	46.4	46.7	30	82	82.3	10	76.4	76.7
small-sized vehicles (light trucks and heavy vans)		47.6			83.2			77.6	
medium-sized vehicles (medium Heavy vehicles)	Heavy vehicles	51.5	53.2		87.1	88.8		81.5	83.2
large-sized vehicles (Heavy vehicles)		54.4			90			84.4	
motorcycles (two-wheelers)		49.6			85.2			79.6	

$L_{WA} = a + b \lg V$ where a and b are parameters.
L_{WA} for vehicles at rest and during deceleration ($V \leqq 10$ km/h) is assumed to be the value during deceleration at 10 km/h.

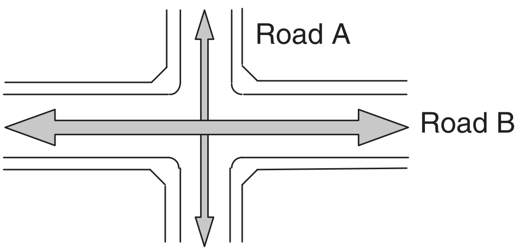

Fig. 3 Roads at a signalized intersection.

$$E_{A,T} = \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{m}\sum_{l=1}^{3} N_{i,j,k,l}\, e_{i,j,k,l} \quad (3)$$

$$e_{i,j,k,l} = E_0 \sum_{D=1}^{9} \int_{t_{1,D}}^{t_{2,D}} \frac{1}{2\pi r^2} 10^{\frac{L_{WA,D,Avg}-C}{10}} dt \quad (4)$$

$$L_{WA,D,Avg} = 10 \cdot \lg \sum_{p} q_{rate,p} \cdot 10^{\frac{L_{WA,D,p}}{10}} \quad (5)$$

L_{Aeq}: equivalent continuous A-weighted sound pressure level at the point of estimation [dB]. The '$\fallingdotseq$' in Eqs. (2) and (4) assumes that the air density and the speed of sound are the standard values. L_{Aeq} at the point of estimation is the time-averaged sound exposure due to vehicles running near the intersection for each lane and each traveling direction.
$E_{A,T}$: A-weighted sound pressure exposure at the point of estimation in a signal cycle [Pa^{2}s]. For one signal cycle, $E_{A,T}$ is calculated for vehicles passing a green signal and those that decelerate and stop at a red signal and then accelerate when the signal turns green, separately for each lane.
E_0: reference sound exposure of 4×10^{-10} [Pa^{2}s]
T: length of signal cycle [s]
i: indication of major or minor road, $i = 1$: major road, $i = 2$: minor road
j: green or red signal, $j = 1$: green signal, $j = 2$: red signal
k: lane, m: number of lanes
l: traveling direction, $l = 1$: turning left, $l = 2$: straight, $l = 3$: turning right
$N_{i,j,k,l}$: traffic volume in a signal cycle for each lane and traveling direction [vehicles]
$e_{i,j,k,j}$: single-event A-weighted sound exposure for each lane and traveling direction [Pa^{2}s]. Sound exposure is defined as the integral of the unit pattern integration shown in Fig. 1. It is calculated by dividing the zone near the intersection into sections because the driving states differ among the driving sections.
D: driving state while passing an intersection, $D = 1$: steady running before the intersection, $D = 2$: deceleration before stopping at the signal, $D = 3$: stopping at the signal, $D = 4$: accelerating from rest from signal, $D = 5$: steady running to the intersection after stopping at the signal, $D = 6$: deceleration to turn left or right, $D = 7$: steady running while turning left or right, $D = 8$: accelerating after making a left or right turn, $D = 9$: steady running after passing the intersection. Example: $D = 1, 9$ for passing a green signal, $D = 1, 2, 3, 4, 9$ for stopping at the signal and then going straight, $D = 1, 2, 3, 4, 5, 6, 7, 8, 9$ for stopping at the signal and then turning left or right.
$t_{1,D}$: time [s] at which integration is started for each driving state D, $t_{2,D}$: time [s] at which integration is finished for each driving state D. $t_{1,D}$ and $t_{2,D}$ are set on the basis of traffic conditions.
$L_{WA,D,Avg}$: mean value of L_{WA} for all vehicle types and each driving state D [dB], i.e., the mean L_{WA} which is determined from the composition according to vehicle type.
r: distance [m] from the sound source to the point of estimation
C: correction due to directivity, propagation, etc. [dB]
p: vehicle type
$q_{rate,p}$: proportion of vehicle type p
$L_{WA,D,p}$: L_{WA} [dB] for each vehicle type p. Values vary

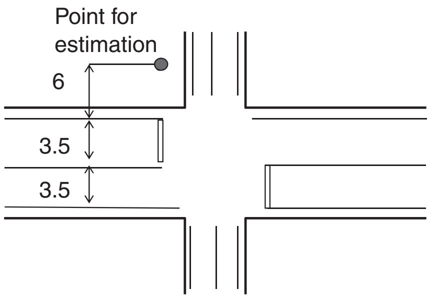

Fig. 4 Road conditions used in noise estimation [unit: m].

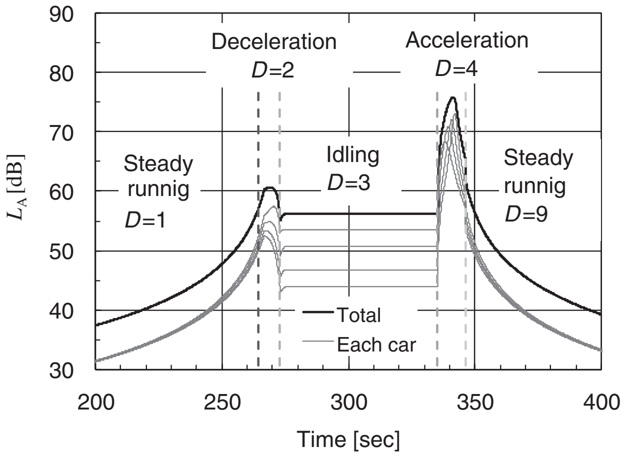

Fig. 5 Concept of L_A at a red signal.

even among the same type of vehicle depending on driving speed and state.

2.4.2. Examples of unit patterns

An example of estimation is shown in Figs. 4 and 5. The unit patterns of four vehicles at the point of estimation in Fig. 4 are shown in Fig. 5. The total L_{Aeq} is estimated by adding the total values for vehicles running at a green signal and stopping at a red signal.

2.4.3. Examples of parameters

For the comparison of measurements, which is described in Chap. 3, the calculation was based on the following.

(1) Range of calculation

In the calculation of single-event sound exposure levels, the range of the intersection was assumed to be 3000 m before and after the intersection.

(2) Setting the traffic volume

The traffic volume $N_{i,2,k,l}$ [vehicles/cycle] that stops at a red signal is set as

$$N_{i,2,k.l} = \sum_j N_{i,j,k,l} \cdot \frac{T_{RY}}{T_C}, \tag{6}$$

where T_{RY} is the total duration of red and yellow signals [s], and T_C is the time of one signal cycle [s].

(3) Mean running speed while turning left or right

Table 2 Acceleration of vehicles [m s^{-2}].

deceleration	−1.3
acceleration	1.0

Vehicles are assumed to run at a mean speed of 20 km/h while turning left or right. The speed of the vehicle until it reaches 20 km/h is set using the value of acceleration given in Table 2.

(4) Acceleration of vehicles

The values of acceleration for decelerating and accelerating vehicles at signalized intersections are those for heavy vehicles shown in Table 2.

(5) Mean headway and source position of vehicles that stop at red signal

The mean space headway d [m] of vehicles that stop at a red signal is calculated using

$$d = d_L + (d_H - d_L) \cdot q, \tag{7}$$

where d_L is the spacing between light vehicles that stop at a red signal (= 6 m) [m], d_H is the spacing between heavy vehicles that stop at a red signal (= 12 m) [m] and q is the proportion of heavy vehicles. The source position x_{pn} (distance from the stop line) [m] of the n_Pth vehicle that stops at a red signal is calculated using

$$x_{pn} = (n_p - 0.5)d. \tag{8}$$

(6) Values of L_{WA} used for the calculation

The values of L_{WA} used for the calculation are those given in the 2-type classification shown in Table 1. The speed of a vehicle during steady running is not the speed limit but the actually measured speed.

(7) Correction C accompanying directivity and propagation

C was assumed to be $C = 0$ [dB].

2.5. Method 3

2.5.1. Basic equations

This method is a simplified version of Method 2. In Method 2 the single-event sound exposure is calculated by considering the changes in speed caused by stopping at signals and turning left or right for each vehicle. In Method 3 the calculations were simplified by representing all vehicles in a section under certain running conditions by one vehicle, which is assumed to run at a constant speed (steady running condition). Each road at an intersection is divided into two types of section. In one section all vehicles are assumed to run steadily, and in the other section some vehicles stop and accelerate at a red signal (a compound section with accelerating and steady running vehicles). The equations of Method 3, obtained by simplifying those of Method 2, are given as Eqs. (9)–(14). Equation (12) is a discrete expression of Eq. (11). The 'dt' in Eq. (4) has been converted to '$\mathrm{d}t = \mathrm{d}l/v$' in Eq. (11) because '$v$' was assumed to be constant in Method 3.

$$L_{\mathrm{Aeq}} = 10 \cdot \lg \frac{E_{\mathrm{A},T}}{T \cdot E_0} \quad (9)$$

$$E_{\mathrm{A},T} = \sum_{i=1}^{2} \sum_{k=1}^{m} N_{i,k} e_{i,k} \quad (10)$$

$$e_{i,k} = E_0 \sum_{D=1}^{3} \int_{l_1}^{l_2} \frac{1}{2\pi r^2 v} 10^{\frac{L_{W\mathrm{A,Rd},D,\mathrm{Avg}} - C}{10}} \mathrm{d}l \quad (11)$$

$$e_{i,k} = E_0 \sum_{D=1}^{3} \sum_{s} \frac{\Delta l}{2\pi r_s^2 v} 10^{\frac{L_{W\mathrm{A,Rd},D,\mathrm{Avg}} - C}{10}} \quad (12)$$

$$L_{W\mathrm{A,Rd},D,\mathrm{Avg}} = 10 \cdot \lg \sum_{p} q_{\mathrm{rate},p} \cdot 10^{\frac{L_{W\mathrm{A,Rd},D,p}}{10}} \quad (13)$$

$$L_{W\mathrm{A,Rd,2},p} = 10 \cdot \lg \left(\frac{N_c - N_R}{N_c} 10^{\frac{L_{W\mathrm{A,Rd,G},p}}{10}} + \frac{N_R}{N_c} 10^{\frac{L_{W\mathrm{A,Rd,R},p}}{10}} \right) \quad (14)$$

$E_{\mathrm{A},T}$: A-weighted sound pressure exposure [$\mathrm{Pa}^2\mathrm{s}$] at the point of estimation at assessment time T

T: assessment time [s], $N_{j,k}$: traffic volume in each lane at assessment time T [vehicles]

$e_{i,k}$: single-event A-weighted sound exposure for each lane [$\mathrm{Pa}^2\mathrm{s}$] The '=' in Eqs. (9), (11) and (12) assumes that the air density and the speed of sound are the standard values.

D: driving state while passing the intersection. $D = 1$: steady running before the intersection, $D = 2$: mixture of accelerating and steady running, $D = 3$: steady running after the intersection

l: position of sound source in integration [m], l_1: position of the starting point of the sound source [m], l_2: position of the end point of the sound source [m]. l_1 and l_2 are set on the basis of traffic conditions.

v: velocity [$\mathrm{m\,s^{-1}}$]

$L_{W\mathrm{A,Rd},D,\mathrm{Avg}}$: mean value of $L_{W\mathrm{A}}$ [dB] per length (1 m) for all vehicle types and each driving state D

r, r_s: distance [m] from the sound source to the point of estimation,

$L_{W\mathrm{A,Rd},D,p}$: $L_{W\mathrm{A}}$ [dB] per length (1 m) for each vehicle type p and each driving state D.

N_c: traffic volume in one signal cycle [vehicles]

N_R: number of vehicles stopping at a red signal then starting in one signal cycle [vehicles]

$L_{W\mathrm{A,Rd,G},p}$: $L_{W\mathrm{A}}$ per length (1 m) during steady running at a green signal for each vehicle type [dB]

$L_{W\mathrm{A,Rd,R},p}$: $L_{W\mathrm{A}}$ per length (1 m) of vehicles accelerating after stopping at a red signal for each vehicle type [dB]

2.5.2. Comparison of the three methods

The equations used in Method 3 can be simplified further to Eqs. (15)–(18) by changing the order of calculation without affecting the result. Equation (16) is a discrete expression of Eq. (15). The values of $L_{W\mathrm{A}}$ used for calculation are set in Eqs. (19) and (20). Here, the difference between Method 1 and Method 3 is explained. The use of $D = 2$ at all road sections and $N_\mathrm{C} = N_\mathrm{R}$ in Eqs. (15)–(20) corresponds to Method 1.

$$L_{\mathrm{Aeq}} = 10 \cdot \lg \sum_{i=1}^{2} \sum_{k=1}^{m} \sum_{D=1}^{3} \int_{l_1}^{l_2} \frac{1}{2\pi r^2} 10^{\frac{L_{W\mathrm{A,Rd},D} - C}{10}} \mathrm{d}l \quad (15)$$

$$L_{\mathrm{Aeq}} = 10 \cdot \lg \sum_{i=1}^{2} \sum_{k=1}^{m} \sum_{D=1}^{3} \sum_{s=1}^{n_{tc}} \frac{\Delta l}{2\pi r_s^2} 10^{\frac{L_{W\mathrm{A,Rd},D} - C}{10}} \quad (16)$$

$$L_{W\mathrm{A,Rd},D} = 10 \cdot \lg \frac{N_{i,k}}{3600 v} 10^{L_{W\mathrm{A,VcAvg},D}/10} \quad (17)$$

$$L_{W\mathrm{A,VcAvg,2}} = 10 \cdot \lg \left(\frac{N_c - N_R}{N_c} 10^{\frac{L_{W\mathrm{A,VcAvg,G}}}{10}} + \frac{N_R}{N_c} 10^{\frac{L_{W\mathrm{A,VcAvg,R}}}{10}} \right) \quad (18)$$

$$L_{W\mathrm{A,VcAvg,G}} = 10 \cdot \lg \sum_{p} q_{\mathrm{rate},p} \cdot 10^{\frac{L_{W\mathrm{A,Std},p}}{10}} \quad (19)$$

$$L_{W\mathrm{A,VcAvg,R}} = 10 \cdot \lg \sum_{p} q_{\mathrm{rate},p} \cdot 10^{\frac{L_{W\mathrm{A,Acc},p}}{10}} \quad (20)$$

$L_{W\mathrm{A,Rd},D}$: $L_{W\mathrm{A}}$ per length (1 m) of each lane for each driving state D [dB]

$N_{i,k}$: hourly traffic volume for each lane [vehicles/h]

$L_{W\mathrm{A,VcAvg},D}$: mean $L_{W\mathrm{A}}$ for all types of vehicles and each driving state D [dB]. For the section with accelerating and steady running vehicles, $L_{W\mathrm{A,VcAvg,2}}$ is the equivalent mean of $L_{W\mathrm{A,VcAvg,G}}$ [dB] during steady running (when the signal is green) and $L_{W\mathrm{A,VcAvg,R}}$ [dB] during accelerating (when the signal turns from red to green) with the ratio of traffic volume that passes through the intersection at each signal phase.

N_C: traffic volume in one signal cycle [vehicles]

N_R: number of vehicles stopping at a red signal then starting when the signal turns green in one signal cycle [vehicles]

$L_{W\mathrm{A,VcAvg,G}}$: mean $L_{W\mathrm{A}}$ for all vehicle types passing at a green signal [dB]

$L_{W\mathrm{A,VcAvg,R}}$: mean $L_{W\mathrm{A}}$ for all vehicle types stopping then starting at a signal [dB]

$L_{W\mathrm{A,Std},p}$: $L_{W\mathrm{A}}$ for steady running of each vehicle type [dB]

$L_{W\mathrm{A,Acc},p}$: $L_{W\mathrm{A}}$ for acceleration of each vehicle type [dB]. $L_{W\mathrm{A,Acc},p}$ during acceleration is determined by substituting the speed in the steady running sections into the equation for calculating $L_{W\mathrm{A}}$ during acceleration.

2.5.3. Example of a unit pattern

Figure 6 depicts steady running sections and a section with accelerating and steady running vehicles. A diagram of a unit pattern is shown in Fig. 7. The figure shows that the sound level of the unit pattern increased in the section with accelerating and steady running vehicles.

2.5.4. Example of parameters

For the comparison of measurements, which is describ-

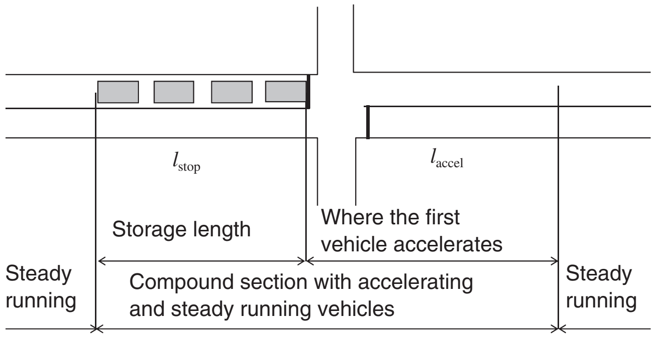

Fig. 6 Concept of a section with accelerating and steady running vehicles.

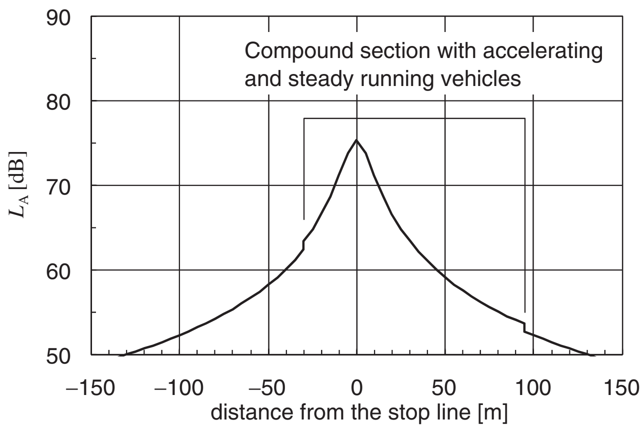

Fig. 7 Concept of a unit pattern.

ed in Chap. 3, the detail of calculation was based on the following.

(1) Setting of compound section and steady running sections

The length of a compound section with accelerating and steady running vehicles is determined by the sum of the section lengths l_{stop} [m] and l_{accel} [m]. l_{stop} is the distance from the front of the first vehicle to the rear of the final vehicle when vehicles stop at a red signal. The length l_{accel} is the distance required for the first vehicle to accelerate to a constant speed after the signal turns green. The lengths of these sections are calculated as

$$l_{stop} = d \cdot N_R \qquad (21)$$

and

$$l_{accel} = \frac{v^2}{2a_{accel}}, \qquad (22)$$

where a_{accel} is the acceleration [m s^{-2}] given in Table 2 and v is the speed in the steady running section [m s^{-1}]. Equation (22) is the distance for the first vehicle that stopped at a red signal to reach velocity v. A steady running section is specified at both ends of the compound section.

(2) Other details

The range of the intersection, the traffic volume that stops at a red signal, the mean stopping interval, the values of L_{WA}, and the correction C were set in the same way as Method 2.

3. COMPARISON BETWEEN ACTUAL MEASUREMENTS AND VALUES CALCULATED USING METHODS 1, 2 AND 3

(1) Site and results of measurement

The estimation methods were evaluated using measurements from the 10 sites listed in Table 3. Traffic volume, L_{Aeq}, and other variables were measured. At all sites, the signals were pretimed signals, which direct traffic to stop and permit it to proceed in accordance with predetermined time schedules. The points of measurement were 1.2 m above the ground surface at the edge of the road 200 m before to 250 m after the stop line of the outside lane along the running direction. Figure 8 shows an example of the arrangement of measurement points.

(2) Results of comparison

The measured and estimated values of L_{Aeq} using the three methods are shown in Fig. 9. Six measurements have been excluded from the 624 measurements, because they were affected by sources near the microphones. The values estimated using Method 1 were on average 0.9 dB larger than the measured values with a standard deviation of 1.9 dB and they reproduced the measurements well. The values estimated using Methods 2 and 3 were on average 0.1 dB smaller and 0.4 dB larger than the measured values with standard deviations of 1.7 and 1.7 dB, respectively, reproducing the measurements even better than Method 1.

4. CONCLUSIONS

With the goal of constructing a simple method for predicting equivalent continuous A-weighted sound pressure levels (L_{Aeq}) in the vicinity of a signalized intersection, two simple, practical calculation methods were proposed. The results of this study are summarized below:

- It was decided that the proposed methods would involve assuming separate noise sources on roads. Three methods for estimating L_{Aeq} were compared.
- Method 1, which was proposed prior to this study, involves the application of L_{WA} under nonsteady running conditions to signalized intersections. In Method 2, which is a new method, L_{Aeq} is calculated by adding the noise from vehicles passing at a steady speed at green signals and the noise from vehicles that decelerate and stop at red signals and then accelerate when the light turns green. In Method 3, which is a simplified version of Method 2, steady running sections and sections with accelerating and steady running vehicles are set near intersections.

Table 3 Overview of the measurement sites.

No.	Traffic volume on the major road, vehicles/h*1,*2	Percentage of heavy vehicles etc. on the major road*1,*2	Percentage of traffic volume on the minor road*1,*3	speed limit (km/h) major road	speed limit (km/h) minor road	pavement phase*4 major road	pavement phase*4 minor road	Length of cycle time for the signal [s]*2,*5	Split time for green phase [s]*2	Number of measurements*6	Number of lanes*1 major road	Number of lanes*1 minor road	L_{Aeq}*1 [dB] MAX	L_{Aeq}*1 [dB] MIN
1	1173	12%	63%	50	50	DAC	DAC	113	41	6	5	3	71.2	68.2
2	913	37%	85%	50	50	DAC	DAC	127	52	24	5	3	76.7	69.5
3	1243	15%	21%	50	50	DAC	DAC	116	65	6	5	3	73.6	69.4
4	1035	19%	20%	60	50	DAC	DAC	125	77	6	5	3	72.4	68.1
5	917	12%	19%	50	40	DAC	DAC	97	47	6	5	3	69.7	59.2
6	1911	18%	113%	60	50	DAC	PAC	125	40	6	6	7	74.7	71.9
7	1340	30%	31%	50	50	DAC	DAC	110	49	6	5	3	75.2	72.9
8	1321	28%	23%	60	50	DAC	DAC	113	70	6	2	3	73.2	71.3
9	1153	11%	33%	50	50	DAC	DAC	108	62	6	5	2	71.9	67.4
10	361	9%	77%	60	50	DAC	DAC	133	54	6	5	3	68.6	63

*1 Point near the lane measured
*2 Mean of measurements
*3 Traffic volume on the minor road/traffic volume on the major road (%)
*4 DAC: Dense asphalt concrete; PAC: Porous asphalt concrete (drainage asphalt pavement)
DAC is a conventional, ordinary pavement. PAC is a drainage pavement providing improved driving safety during rainy weather and a noisereducing effect.
*5 Length of time for the signal to complete a cycle of green, yellow, right-turn green, yellow, and red
*6 The length of each measurement is 20 min.
The measurement was performed at 1 h intervals; thus, '24' means 24 h measurement.

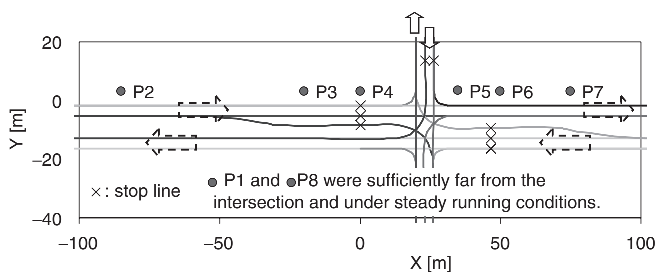

Fig. 8 Arrangement of measurement points.

- The calculation is simplest for Method 1, followed by Method 3 then Method 2. When the calculated values were compared with the measured values, Method 2 reproduced the measured values most accurately, followed by Method 3 then Method 1. However, the differences between the three methods were smaller than we expected when we started this study.
- Method 1 was recommended in ASJ RTN-Model 2008 [3] on the basis of a comprehensive judgment of simplicity and precision of calculation.

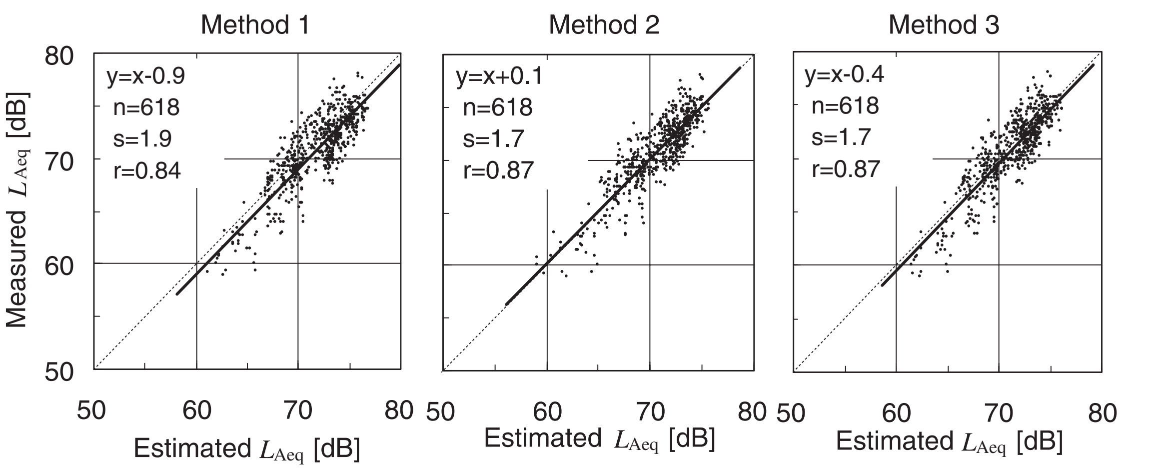

Fig. 9 Comparison between estimated and measured values of L_{Aeq}.

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