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# PROPAGATION OF NOISE GENERATED BY SINGLE MOVING SOURCES IN OPEN AREA

J. JARZĘCKI, R. MAKAREWICZ

Institute of Acoustics, Mickiewicz University
(60-769 Poznań, ul. Matejki 48/49)

The sound level ($L$) of noise generated by a single moving source (e.g. vehicle) is a starting point for the determination of the resultant level of noise emitted by sets of moving sources (e.g. streams of vehicles). The aim of the investigations was to find the relations among $L$, the motion velocity and the distance of the observation point from the source for different weather conditions. The investigations were performed in a flat area covered with concrete and grass, taking into consideration two basic vehicle types: light and heavy. Logarithmic-and-linear relations between these quantities have been obtained.

## 1. Introduction

The major sources of urban noise are moving sources, i.e. means of transport, and, in particular, vehicles. Noise (assessed by means of so-called noise indexes) affects the quality of the environment of man from the acoustic viewpoint. The shaping of the environment so that the indexes of noise do not exceed some predetermined values is the object of environmental acoustics. This aim can be achieved when the acoustic field generated by single sources is known (since it is then possible to predict the values of the indexes of noise emitted by sets of these sources, i.e. streams of vehicles etc.).

The aim of the investigations was to find the dependence of the sound level $L$ of noise on the distance and on the velocity of a single noise source. Two kinds of noise sources were considered: light vehicles (passenger cars) and heavy vehicles (lorries and buses). The measurements were made in a flat area covered with grass and concrete, typical for modern urban area. The present problem

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has been the object of investigations of many authors [1 - 4, 6 - 9]. The source of urban noise, traffic, is, however, different in each country. This fact was the reason why this problem was raised anew, the more so that the effect of weather conditions has not always been considered in other authors' papers.

This paper is a contribution to the development of methodology for predicting the acoustic climate in the vicinity of highways.

## 2. The dependence of the sound level on the distance

In a flat area of homogeneous cover and for the distance of the source from the observation point of the order of a dozen or so metres the pressure of noise generated by a single source is a monotonously decreasing function of the distance $d$ (Figs. 1 and 2). In the literature the following two functions approximating this relation can be met most frequently,

$$p^2 = \frac{W\exp(-ad)}{d^2}, \tag{1}$$

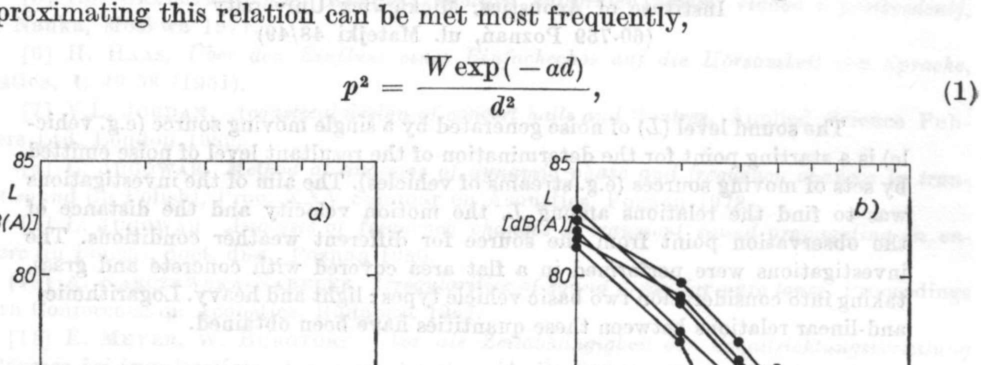

Fig. 1. The dependence of the sound level of noise generated by a single light (a) and heavy (b) vehicle on the distance $d$

**the surface was covered with concrete, the number of measurement series corresponding to the weather conditions described in Fig. 5 is given in brackets**

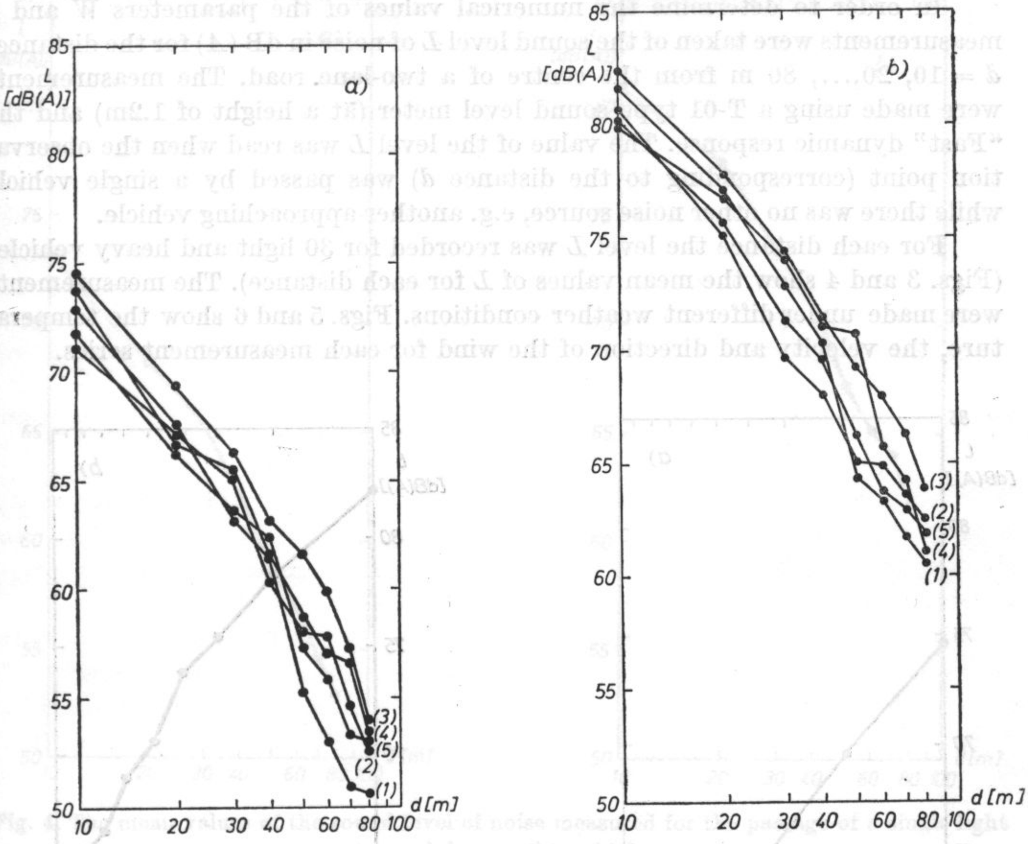

**Fig. 2. The dependence of the sound level of noise generated by a single light (a) and heavy (b) vehicle on the distance *d***

**the surface was covered with grass, the number of measurement series corresponding to the weather conditions described in Fig. 6 is given in brackets**

where $a$ is the coefficient of attenuation in air, and

$$p^2 = \frac{W}{d^{\varrho}}, \qquad (2)$$

where $W$ and $\varrho$ are parameters describing the source and processes accompanying propagation. Function (1) involves the attenuation quantity expressed in dB per unit length, e.g. dB/m. According to relation (2), the attenuation is expressed as "level decrease per double distance". Paper [5] showed that if attenuation (for double distance) exceeds 8 dB, both functions approximate equally well the curves in Figs. 1 and 2. In the case of less attenuation (e.g. when noise propagates over a concrete-covered surface) much better approximation can be achieved using function (2). The further part of the present paper uses this relation.

In order to determine the numerical values of the parameters $W$ and $\varrho$ measurements were taken of the sound level $L$ of noise in dB ($A$) for the distances $d = 10, 20, \ldots, 80$ m from the centre of a two-lane road. The measurements were made using a T-01 type sound level meter (at a height of 1.2m) and the "Fast" dynamic response. The value of the level $L$ was read when the observation point (corresponding to the distance $d$) was passed by a single vehicle while there was no other noise source, e.g. another approaching vehicle.

For each distance the level $L$ was recorded for 30 light and heavy vehicles (Figs. 3 and 4 show the mean values of $L$ for each distance). The measurements were made under different weather conditions. Figs. 5 and 6 show the temperature, the velocity and direction of the wind for each measurement series.

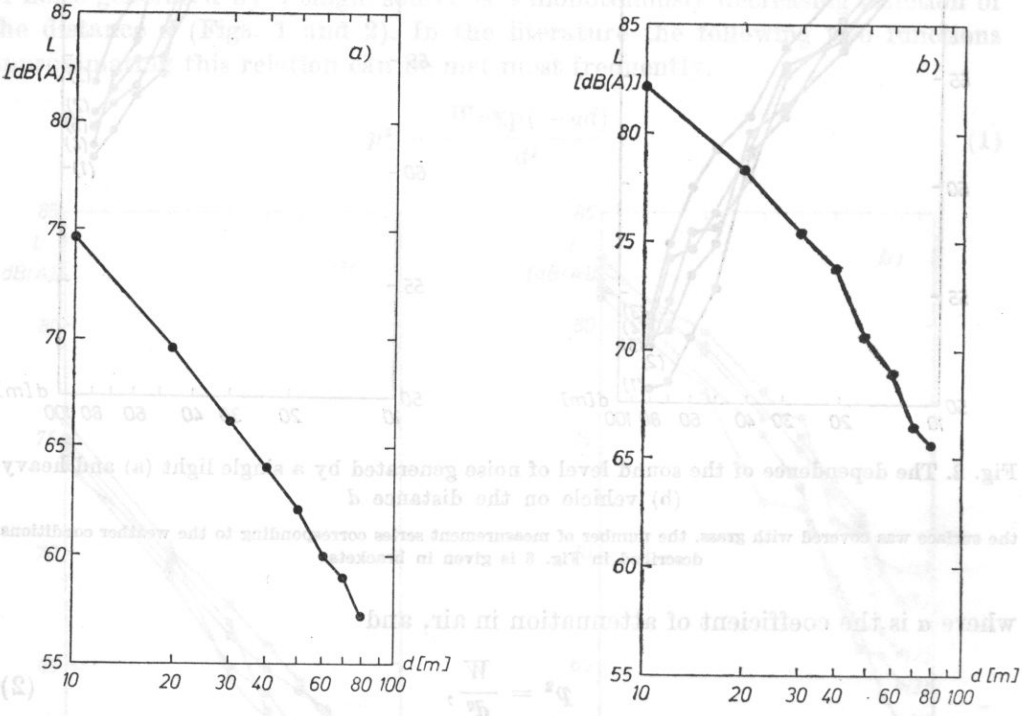

Fig. 3. The mean values of the sound level of noise measured for the passage of a single light (a) and heavy (b) vehicle

the surface was covered with concrete

It follows from the measurement results shown here that weather conditions do not clearly affect the values of the sound level. It is, for example, difficult to say whether a decrease on the sound level with increasing distance is slower or faster as the temperature decreases. This probably results from a too small number of measurements or from neglecting other parameters, essential in acoustic wave propagation, describing the weather conditions (e.g. the tempera-

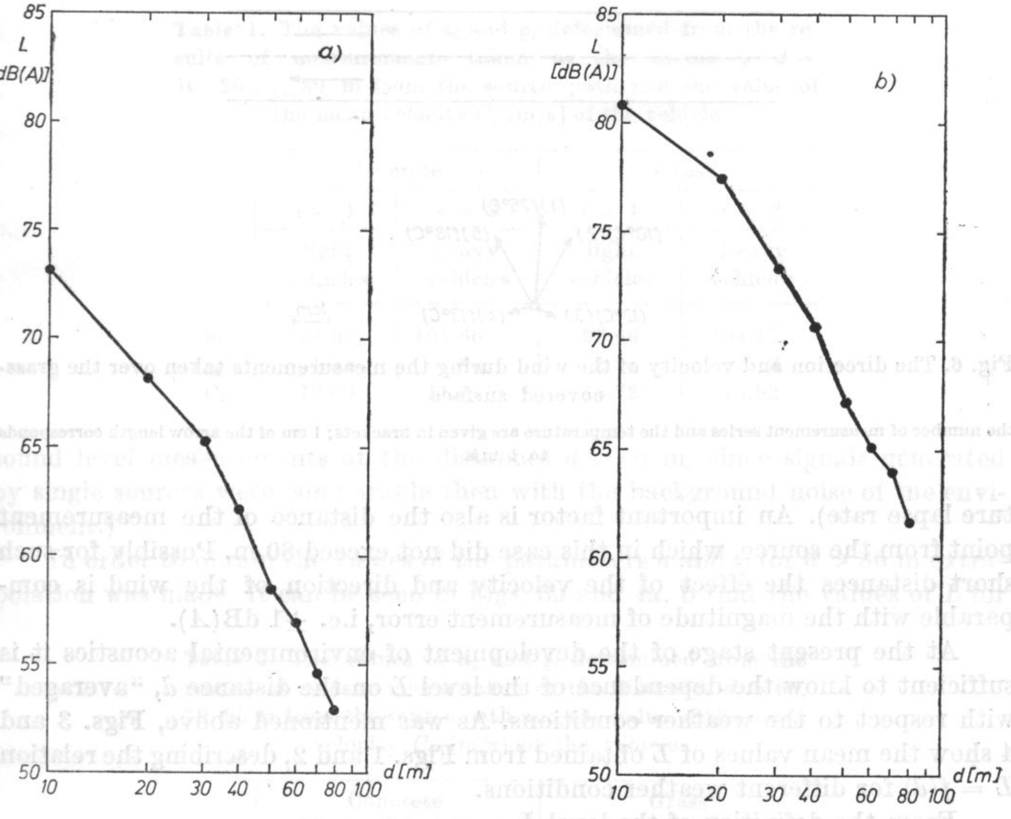

Fig. 4. The mean values of the sound level of noise measured for the passage of a single light (a) and heavy (b) vehicle

the surface was covered with grass

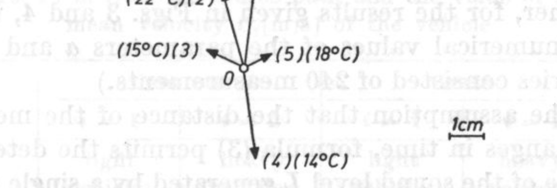

Fig. 5. The direction and velocity of the wind during the measurements taken over the concrete-covered surface

the number of measurement series and the temperature are given in brackets; 1 cm of the arrow length corresponds to 1 m/s

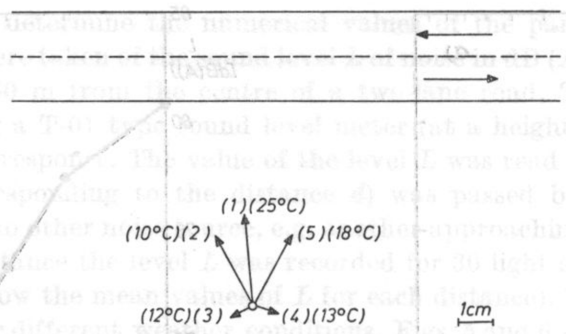

**Fig. 6.** The direction and velocity of the wind during the measurements taken over the grass-covered surface

the number of measurement series and the temperature are given in brackets; 1 cm of the arrow length corresponds to 1 m/s

ture lapse rate). An important factor is also the distance of the measurement point from the source, which in this case did not exceed 80 m. Possibly for such short distances the effect of the velocity and direction of the wind is comparable with the magnitude of measurement error, i.e. ±1 dB($A$).

At the present stage of the development of environmental acoustics it is sufficient to know the dependence of the level $L$ on the distance $d$, "averaged" with respect to the weather conditions. As was mentioned above, Figs. 3 and 4 show the mean values of $L$ obtained from Figs. 1 and 2, describing the relation $L = f(d)$ for different weather conditions.

From the definition of the level $L$

$$L = 10\log(p^2/p_0^2)$$

($p_0$ being the reference pressure) and from formula (2) the following linear equation can be derived,

$$L = a - bx, \tag{3}$$

where

$$a = 10\log(W/p_0^2), \quad b = 10\varrho, \quad x = \log d. \tag{4}$$

Applying further, for the results given in Figs. 3 and 4, the linear regression analysis, the numerical values of the parameters $a$ and $\varrho$ were obtained (Table 1). (Each series consisted of 240 measurements.)

Thus, under the assumption that the distance of the measurement point from the source changes in time, formula (3) permits the determination of the instantaneous value of the sound level $L$ generated by a single source, under the condition, however, that the source is at the distance $d < 80$ m from the observation point. Problems related to town planning require knowledge of $L$ for longer distances. (It is necessary to explain that it was impossible to take

**Table 1.** The values of $a_i$ and $\varrho_i$ determined from the results of measurements taken at the distances $d$ = 10. 20,..., 80 m from the source path and the value of the mean velocity $C_i$ [m/s] of the vehicle

| | Concrete | | Grass | |
|---|---|---|---|---|
| | $i = 1$ | $i = 2$ | $i = 1$ | $i = 2$ |
| | light vehicles | heavy vehicles | light vehicles | heavy vehicles |
| $a_i$ | 94.02 | 101.66 | 96.49 | 104.17 |
| $\varrho_i$ | 1.89 | 1.83 | 2.24 | 2.18 |
| $C_i$ | 13.69 | 11.11 | 15.72 | 13.92 |

sound level measurements at the distances $d > 80$ m, since signals generated by single sources were comparable then with the background noise of the environment.)

In order to obtain the values of the parameters $a$ and $\varrho$ for $d > 80$ m extrapolation was made. It can be seen in Figs. 3a and 4a, b that the values of $L$ for

**Table 2.** The values of $a_i$ and $\varrho_i$ determined from the results of measurements taken at the distances $d$ = 60, 70, 80 m from the source path and the value of the mean velocity $C_i$ [m/s] of the vehicle

| | Concrete | | Grass | |
|---|---|---|---|---|
| | $i = 1$ | $i = 2$ | $i = 1$ | $i = 2$ |
| | light vehicles | heavy vehicles | light vehicles | heavy vehicles |
| $a_i$ | 92.08 | 116.72 | 115.24 | 110.60 |
| $\varrho_i$ | 1.78 | 2.68 | 3.28 | 2.56 |
| $C_i$ | 13.69 | 11.11 | 15.72 | 13.92 |

**Table 3.** The values of $a_i$ and $\varrho_i$ determined from the results of measurements taken at the distances $d$ = = 10. 20 m from the source path and the value of the mean velocity $C_i$[m/s] of the vehicle

| | Concrete | | Grass | |
|---|---|---|---|---|
| | $i = 1$ | $i = 2$ | $i = 1$ | $i = 2$ |
| | light vehicles | heavy vehicles | light vehicles | heavy vehicles |
| $a_i$ | 91.22 | 93.77 | 91.69 | 94.18 |
| $\varrho_i$ | 1.64 | 1.17 | 1.86 | 1.32 |
| $C_i$ | 13.69 | 11.11 | 15.72 | 13.92 |

$d = 60$, 70 and 80 m decrease faster than those for shorter distances. The results of other authors, e.g. COOK and VAN HAVERBECKE [1] show that this tendency should also sustain for $d > 80$ m. The linear regression analysis performed for the last three points leads to other values of $a$ and $\varrho$ (Table 2). Table 3 gives the parameters $a$ and $\varrho$ for the distances $d = 10$, 20 m. (These are useful, for example, in determining the level of noise near the edge of the road.)

In the course of measurements in an area covered with concrete (Fig. 3) and grass (Fig. 4) the mean velocities of light and heavy vehicles were, respectively, $C_1 = 13.69$ m/s, $C_2 = 11.11$ m/s and $C_1 = 15.72$ m/s, $C_2 = 13.92$ m/s.

### 3. The dependence of the sound level on the traffic velocity

Each highway is characterized among other things, by the traffic velocity $V$. In order to obtain quantitative information on the dependence of the sound level $L$ dB $(A)$ on the velocity of the source $V$, measurements were made at the distance $d_0 = 7.5$ m from the centre of the lane. As in the case of investigations aimed at determining $L$ as a function of $d$ (section 2), also in this case the sound level $L$ was registered when a single source was "passing" the observation point. Each time its velocity $V$ [m/s] was registered. The results are given in Figs. 7 and 8.

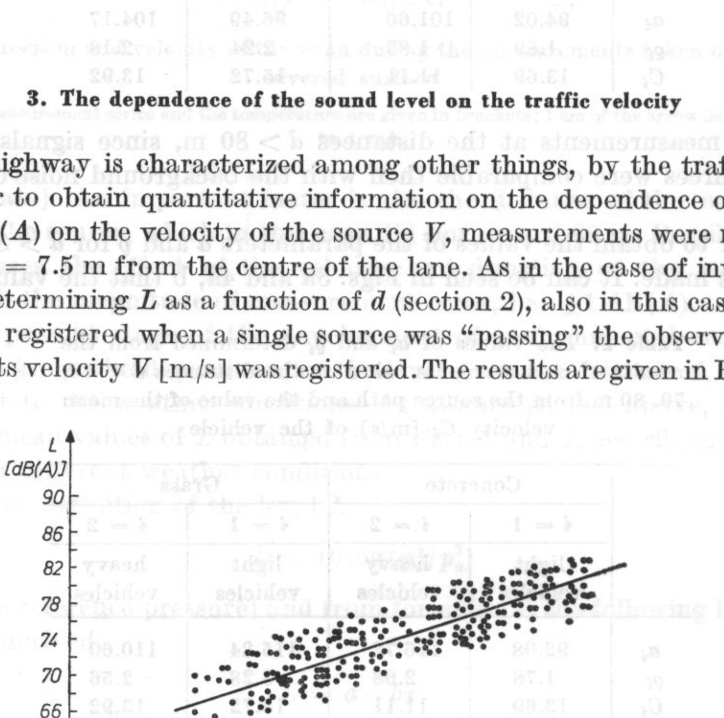

Fig. 7. The dependence of the sound level $L$, in dB$(A)$, on the velocity $V$ for light vehicles; $L = 34.0 \log V + 32.0$; $r = 0.93$ is the correlation coefficient

It was assumed for analytical description of the dependence of the level $L$ on $V$ that the parameter $W$ (2) is the following function of the velocity

$$W = W_0 V^m. \tag{5}$$

Since the measurements were made at the distance $d_0 = 7.5$ m from the centre of the traffic lane, at the moment of "passing", the microphone was in the near field of the noise source (vehicle). In this case the simple dependence of the pressure on the distance, which is valid for the far field, $p^2 \sim d^{-\varrho}$ (formula

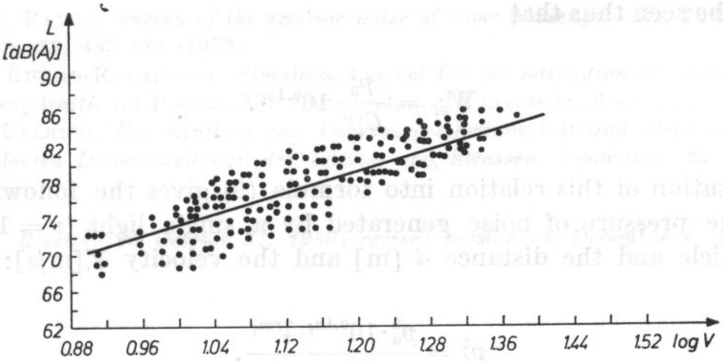

Fig. 8. The dependence of the sound level $L$, in dB$(A)$, on the velocity $V$ for heavy vehicles; $L = 29.0 \log V + 44.4$; $r = 0.84$ is the correlation coefficient

(2)) should be replaced with a more general one, $f(d)$. Finally, for $d = d_0$ this formula can be rewritten in the form

$$p^2 = W_0 V^m f(d_0). \tag{6}$$

(The explicit form of the function $f(d)$ is not important now.)

Using the definition of the level $L = 10\log(p^2/p_0^2)$,

$$L = A + Bx', \tag{7}$$

where

$$A = 10\log W_0 f(d_0)/p_0^2, \qquad B = 10\,m, \qquad x = \log V. \tag{8}$$

From the regression analysis for the results in Figs. 7 and 8, $m_1 = 3.4$ was obtained for light vehicles and $m_2 = 2.9$ for heavy ones. There is disagreement among the results obtained by other authors. This is caused by the differences in the set of vehicles (noise sources).

## 4. Conclusions

It follows from formulae (2) and (5) that if the observation point is at a distance of at least a dozen or so metres from the centre of the traffic lane,

$$p^2 = \frac{W_0 V^m}{d^\varrho}. \tag{9}$$

As was mentioned in section 2, the values of $\varrho_i$ and $a_i = 10 \log (W_i/p_0^2)$ were obtained for the mean velocity $C_i$ (Tables 1 and 2). It can be derived further from formula (5) that

$$a_i = 10 \log (W_{0i} C_i^m i/p_0^2).$$

It can be seen thus that

$$W_{0i} = \frac{p_0^2}{C_i^{mi}} 10^{0.1a_i}. \tag{10}$$

Substitution of this relation into formula (9) gives the following relation between the pressure of noise generated by a single light ($i = 1$) or heavy ($i = 2$) vehicle and the distance $d$ [m] and the velocity $V$ [m/s]:

$$p_i^2 = \frac{p_0^2 \cdot 10^{0.1a_i}}{C_i^{m_i}} \frac{V^{m_i}}{d^{\varrho_i}}. \tag{11}$$

The numerical values of the parameters $a_i$, $\varrho_i$, $C_i$ are given in Tables 1-3, while $m_1 = 3.4$, $m_2 = 2.9$. From the definition $L = 10\log(p^2/p_0^2)$,

$$L_i(t) = a_i - 10\varrho_i \log d(t) + 10\, m_i \log(V/C_i), \quad i = 1, 2. \tag{12}$$

This formula makes it possible to determine the value of the sound level in dB ($A$) of noise generated by a single source (vehicle) moving at the velocity $V$ constant in time, when its distance from the observation point is $d$ at the time $t$. In view of the dependence of $a_i$ and $\varrho_i$ on wind velocity, its direction, air temperature, etc., equation (12) gives the relation $L_i(t) = f\{d(t), V\}$ for different weather conditions. The set of the values of $a_i$ and $\varrho_i$ given in this paper is at present complemented with the measurements of noise generated by single vehicles for the different weather conditions.

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