DOI: 10.24427/978-83-66391-87-1_14

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14. DETERMINATION OF THE NOISE SOURCE HEIGHT BASED ON THE VEHICLE TYPES

In this work, we present a developed mathematical model for determining the height of a dominant noise source in a transportation flow of vehicles. The theoretical approach proposed in [1, 2] which uses road noise forecasting methods to improve the accuracy of methods for determining the noise barriers effectiveness was experimentally substantiated.

14.1. INTRODUCTION

Today, designers of noise barriers that have to protect from the linear noise sources apply methods that do not take into account specifics of a modern traffic. It is apparent that in the '80s and even '90s, the percentage of trucks in the vehicle flow was much larger and scientists who developed these methods and regulations believed that the percentage of trucks was no more than 60%. Besides this, different methods use different sources of noise height position above the road. For example, the VDI-2720 method [3] recommends a height of 0.5 m for noise sources, and *Guide to the design and calculation of building protection from transport noise* [4] recommends 1 m.

The task of investigating at which height the major noise sources in vehicles are located and constructing a mathematical model for determining the height of the dominant noise source in the vehicle flow as a function of speed, to improve the accuracy of methods for determining the effectiveness of noise barriers is urgent.

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14.2. DETERMINATION OF THE NOISE SOURCE HEIGHT

The results obtained in the frame of the Harmonoise and Imagine [5] projects were intended for use by the EU Member States during the creation of noise maps and other purposes related to the evaluation of noise pollution and city noise protection. In the framework of these projects, experimental studies of sound power levels from individual sources of noise in cars and trucks were conducted. The main sources of noise are the tires and road surface interaction, as well as the car exhaust system. The results of the experiments are presented in Fig. 14.1 and Fig. 14.2.

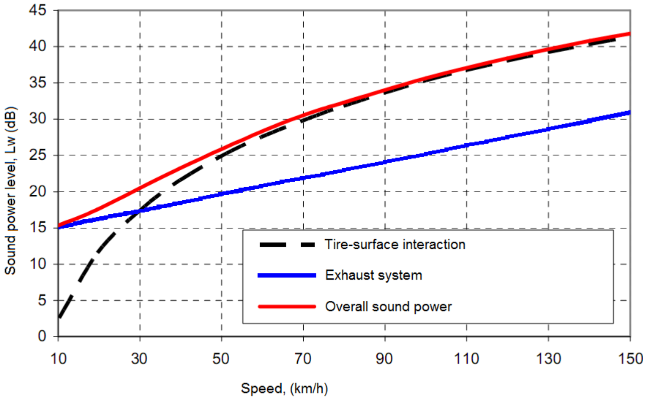

Fig. 14.1. Dependence of sound power level of speed for cars [6]

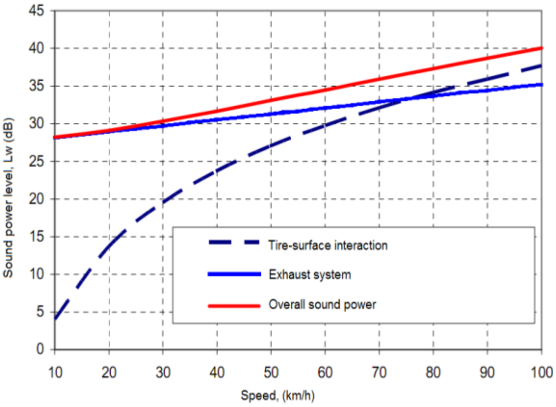

Fig. 14.2. Dependence of sound power level of speed for trucks [6]

The three curves of the graph (Fig. 14.1) represent the dependence of the sound power level rate for cases where the interaction is assessed separately for automobile tire and coated roads, exhaust system and the overall level of sound power for automobiles. A similar graph for trucks is shown in Fig. 14.2. As seen on the graph in Fig. 14.1 for the car sound power level of interaction between car tires and the coated road starts to dominate above the sound of the power exhaust system at speed 30 km/h. Therefore, we propose to take this fact into account when determining the shielding effectiveness of sound energy. A mathematical model allows an accurate determination of the height of the dominant source of noise above the road and improve the accuracy of methods to define the efficiency of sound barriers.

In the work [6] based on experimental data, the height of the main noise sources in cars and trucks were found. For automobiles, the height noise source position is 0.3 m for the exhaust system and 0.01 m for the noise source from the interaction of car tires with the road surface (Fig. 14.3). For trucks, the noise source from the interaction of tires with the road surface is 0.01 m and the noise source height from the exhaust system is larger and amounts to 0.7 m (Fig. 14.3).

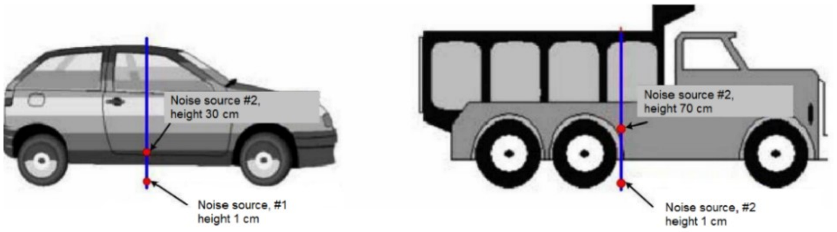

Fig. 14.3. Placing the main sources of noise in cars and trucks [6]

We used a designed subsystem to determine the effectiveness of noise barriers to calculate the influence of height on the screening efficiency for different values of the distances between the screen and the noise. It was found that at small distances between the point of observation of the noise barriers and the source noise, the change of the height of the dominant sources of noise from 1 cm to 70 cm, which is typical of trucks, makes the difference in 1 dB, and typical height for the dominant sources of noise in cars from 1 cm to 30 cm gives the difference of 0.5 dB. Therefore, for trucks and cars, the height of noise sources positions will be 0.7 m and 0.3 m respectively, while the sound power level of interaction between car tires with the road surface will be greater than the level of sound power of exhaust system at 1 dB for trucks and 0.5 dB for cars. From the graph presented in Fig. 14.2, it follows that the height of the dominant noise source for trucks at the speed of 85 km/h is 0.7 m. At higher speeds, the difference between sound power level of interaction between car tires with the road surface and the exhaust system is not increased significantly. Considering the previous fact and that the source of noise from the exhaust system is higher, it follows that this noise source will make a significant contribution to the emission of sound energy. Based on the above, for trucks, we propose to take the height of the dominant sources of noise at 0.7 m above the road surface regardless of the speed.

Analyzing the graph for cars in Fig. 14.1, the height of the noise source position for speeds up to 32 km/h will be constant and equal to 0.3 m. If the difference between the level of the sound from the exhaust system and tire interaction with the surface is over 10 dB [7], there is no need to take into consideration the noise from the exhaust system. Therefore, for speeds above 100 km/h, the noise from the exhaust system can be neglected. That means, the height of the noise source is 0.01 m (corresponding to the height of the noise source of the interaction of the tire with the road surface). For speeds in the range of 32 to 100 km/h, the height of the noise source will vary in proportion to speed. Based on the above, the following mathematical expression was constructed

$$h_{h,car} = \begin{cases} 0.3 & \text{at } V < 32[\text{km/h}], \\ -0.0043 \cdot v + 0.4365 & \text{at } 32 \leq V < 100[\text{km/h}], \\ 0.01 & \text{at } V > 100[\text{km/h}], \end{cases} \tag{14.1}$$

where $h_{S,car}$ is a height of the dominant noise sources for cars [m], V is an average speed of cars [km/h]

$$v = \frac{V \cdot [h]}{1000}.$$

Applying the Heaviside function [8] to the expression (14.1)

$$H(x) = \begin{cases} 0, & x < 0, \\ 1, & x \geq 0, \end{cases}$$

a model of the height of the dominant sources of noise in the traffic flow is the following

$$h_{S,car} = \frac{3H(32 - V_H)}{10} + H(V_H - 32)H(99 - V_H)\left(\frac{873}{2000} - \frac{43 \cdot V_H}{10000}\right) + \frac{H(V_H - 99)}{100}, \tag{14.2}$$

where $V_H = \frac{V \cdot [h]}{[km]}$, $x \in \mathbb{R}$.

Expression (14.2) allows us to determine the height of the dominant noise sources in the traffic flow depending on the speed.

Table 14.1. Dependence of equivalent sound level of traffic for a distance of 10 m from noise sources

Trafic intensity, vehicles/hour	Trucks	Cars	Difference between cars and trucks [dB]	Total
	Leq [dB]	Leq [dB]		Leq [dB]
200	61.1	57.3	3.7	62.5
400	64.1	60.4	3.7	65.5
600	65.8	62.1	3.7	67.2
800	67.1	63.4	3.7	68.5
1000	68.0	64.3	3.7	69.5
1200	68.8	65.1	3.7	70.2
1400	69.5	65.8	3.7	70.9
1600	70.1	66.4	3.7	71.5
1800	70.6	66.9	3.7	72.0
2000	71.1	67.3	3.7	72.5

Some methods of predicting road noise do not allow us to determine separately the noise level from different categories of vehicles, so the task is to investigate the change in the equivalent noise level in 10% of trucks, depending on the intensity of traffic. For different vehicle intensities, 10% of trucks and a distance of 10 m from the noise source, equivalent noise levels were calculated. Based on the calculations, it was discovered that the difference between the equivalent noise level from cars and trucks remains constant and does not change with the change of intensity. The results obtained are presented in Table 14.1.

Graphical dependence is shown in Fig. 14.4. was built based on data from Table 14.1.

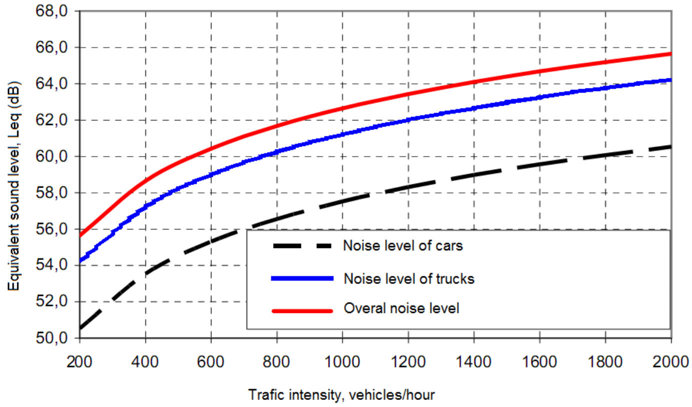

Fig. 14.4. Dependence of equivalent sound level of car traffic

Analyzing the above-listed graph, one can say that the difference between the equivalent noise level from cars and trucks is constant and does not change when the intensity is changed.

Table 14.2. Dependence of equivalent sound level of traffic for a distance of 25 m from the noise sources

Trafic intensity, vehicles/h	Trucks	Cars	Difference between trucks and cars [dB]	Total
	Leq [dB]	Leq [dB]		Leq [dB]
200	50.5	55.6	3.7	54.2
400	53.5	58.7	3.7	57.2
600	55.3	60.4	3.7	59.0
800	56.5	61.7	3.7	60.3
1000	57.5	62.6	3.7	61.2
1200	58.3	63.4	3.7	62.0
1400	59.0	64.1	3.7	62.7
1600	59.6	64.7	3.7	63.3
1800	60.1	65.2	3.7	63.8
2000	60.5	65.6	3.7	64.2

It was investigated whether this difference remains constant when the distance is changed from the noise source. For this purpose, an equivalent noise level with different traffic intensity was calculated for a distance of 25 m from the noise source whose values are given in Table 14.2. As seen from the gained results (Table 14.2), the difference between the equivalent noise level from cars and trucks by changing the distance to the source of noise is also constant. In this regard, determining what percentage of trucks in the vehicle stream will have an equivalent noise level will prevail, this value will be true for any distance and intensity. The next step will be to define the equivalent sound level depending on the percentage of trucks in the traffic flow. The calculated data are given in Table 14.3 and Fig. 14.5.

Table 14.3. Dependence of equivalent sound level of the percentage of trucks in the flow of vehicles

Percentage of trucks	Total	Trucks	Cars	Difference between trucks and cars, [dB]
	Leq [dB]	Leq [dB]	Leq [dB]	
0.1	50.6	34.2	50.5	-16.3
10	55.6	54.2	50.1	4.2
20	57.9	57.2	49.6	7.7
30	59.4	59	49	10
40	60.5	60.3	48.3	11.9
50	61.4	61.2	47.5	13.7
60	62.1	62	46.5	15.5
70	62.8	62.7	45.3	17.4
80	63.3	63.3	43.5	19.7
90	63.8	63.8	40.5	23.2

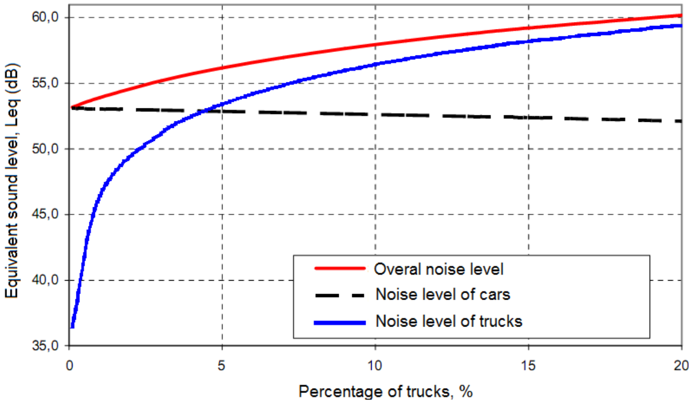

Fig. 14.5. Dependence of equivalent sound level of the percentage of trucks

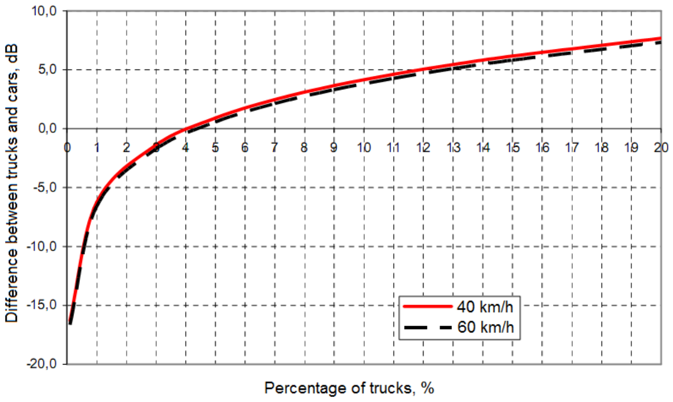

Fig. 14.6. The difference of equivalent sound levels between trucks and cars

Studies showed (Fig. 14.5 and Fig. 14.6) that when the number of trucks in the traffic flow is more than 4%, the height of the noise source will be the same as that of trucks and will be independent of the speed of 0.7 m. When the number of trucks is less than 0.5%, the height of the source noise will be determined from (14.1). The height of the dominant noise source for traffic flows consisting of 0.5% to 4% of trucks will be determined by the following relationship

$$h_S = 0.198 \cdot p - 0.089, \tag{14.3}$$

where p is the percentage of trucks in the traffic flow [%].

Therefore, to determine the height of the dominant noise source in the flow of vehicles, depending on the speed and percentage of trucks, we constructed the following relation

$$h_S = \begin{cases} 0.3 & \text{at}\, V < 32[\text{km/h}] & \text{at}\, p \leq 0.5, \\ -0.0043v + 0.4365 & \text{at}\, 32 \leq V < 100[\text{km/h}] & \text{at}\, p \leq 0.5, \\ 0.01 & \text{at}\, V \geq 100[\text{km/h}] & \text{at}\, p \leq 0.5, \\ 0.198p - 0.089 & & \text{at}\, 0.5 < p \leq 4, \\ 0.7 & & \text{at}\, p > 4. \end{cases} \tag{14.4}$$

Applying the Heaviside function to the expression (14.4) we wrote it as follows

$$\begin{aligned} h_S = H(0.6 - p) \times h_{S,car} + H(p - 0.6)H(4.1 - p)\left(\frac{99 \times p}{500} - \frac{89}{1000}\right) \\ + \frac{H(p - 4.1) \times 7}{10}. \end{aligned} \tag{14.5}$$

Expression (14.5) can be used to determine the height of the dominant sources of noise in the traffic flow depending on the speed and percentage of trucks. By determining the exact height of the noise source position, we can more accurately determine the effectiveness of noise barriers.

In summary, the resulting model can be used to determine the dominant noise source for passenger cars and trucks separately. Accordingly, it can be used to improve the accuracy of road noise forecasting methods that allow the determination of noise levels separately for trucks and cars.

14.3. CONCLUSIONS

Mathematical models to determine the dominant noise sources for cars and trucks, as well as in the flow of vehicles were created that allowed the increase in the accuracy of forecasting methods of road noise and methods for determining the efficiency soundproofed screens.

The project is financed by the Polish National Agency for Academic Exchange, No. PPI/APM/2018/1/00049/U/001.

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