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INFLUENCE OF SOUND-ABSORPING PROPERTIES OF NOISE PROTECTION BARRIERS ON ROAD TRAFFIC PARTICIPANTS

The object of research is the sound field from linear sound sources between two parallel impedance noise barriers. The presence of barriers changes the structure of the sound field, as a result of which the sound pressure level in the area between the barriers increases. An increase in sound levels leads to both a decrease in the effectiveness of noise barriers and an increase in the negative impact on road users. One of the ways out of this situation is the construction of barriers with sound-absorbing properties. In this paper, the influence of the impedance properties of the barriers at the level of sound pressure in the area between the barriers is considered.

The finite element method was chosen to calculate the sound field around the barrier. A computer model of a linear sound source with vertical sound-absorbing barriers on both sides of the source was built in the Comsol Multiphysics software environment. The sound absorption properties of the barrier were determined by the acoustic impedance of the face of the barrier. The sound fields were calculated in octave bands with geometric mean frequencies from 31 to 500 Hz. In addition, the parameters that were also analyzed were the distance between the barriers and their height.

The solution of the problem made it possible to obtain a field of sound pressure levels around the barrier. Changeable simulation parameters made it possible to analyze a large number of situations of relative position of barriers and their heights encountered in engineering. Studies have shown that only at low frequencies and relatively small distances between barriers, the sound pressure level can increase significantly. However, it has also been shown that the use of sound-absorbing lining of noise barriers can reduce the sound pressure levels in the area between the barriers and improve the acoustic conditions for road users.

Keywords: *noise barrier, sound pressure level, impedance properties, sound-absorbing barrier, sound reflection, parallel barriers.*

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1. Introduction

The main means of reducing the noise of traffic flows is the device of artificial building structures – noise protection barriers. This practice is widespread throughout the world. The effectiveness of noise protection barriers depends on many factors, in particular on the geometric dimensions of the barrier, its location relative to the sound source and noise protection objects, the acoustic properties of the materials from which it is made, etc.

Very often there is a situation when the barrier must be located on both sides of the traffic flows. This can lead to a decrease in their efficiency [1] and an increase in the sound level in the area between the barriers [2]. Several works [3, 4] were devoted to the question of the influence of the second barrier on the efficiency of the first one, but the assessment of the increase in sound levels in the region between the barriers was carried out quite a long time ago and only by approximate methods [5].

That is why the question of the influence of the parameters of double-sided barriers on the acoustic field between them is an urgent task, the solution of which will allow the barriers to be built in such a way as to reduce the negative impact on road users.

2. The object of research and its technological audit

The object of research is the sound field from linear sound sources between two parallel impedance noise barriers.

One of the most problematic areas is that noise barriers installed on both sides of highways can have different acoustic characteristics. And the effect of sound-absorbing lining of barriers on the acoustic field between two barriers is not fully understood.

3. The aim and objectives of research

The aim of research is to assess the influence of the sound-absorbing properties of double-sided noise-protective barriers on the sound field between them.

To achieve the set aim, it is necessary to complete the following objectives:

1. Determine the relationship between the sound-absorbing properties of the barrier and the sound field between them for different geometric dimensions of the barriers and the distances between them.
2. Determine the minimum requirements for the sound absorption coefficient of barriers when they are installed on both sides of the road.

4. Research of existing solutions to the problem

The study of sound fields around noise barriers has been carried out since the middle of the last century. Initially, experimental studies were carried out only on single barriers [6] without taking into account other reflective surfaces, such as the surface of the earth and roads. Later, studies of the sound field around the barrier were carried out taking into account the influence of the reflective surfaces of the road and the ground [7]. However, these studies were based on the geometric theory of sound propagation, and therefore had a rather narrow field of application.

The impact of sound-absorbing properties of barriers was studied in works [8, 9]. However, in these studies, the main goal was to analyze the sound field behind the barrier, not in front of it.

In [10], re-reflections arising between two parallel barriers were investigated, but this also occurred within the framework of the geometric theory of sound propagation, which led to limited application of the research results. In addition, experimental studies were carried out with the use of double-sided noise protection barriers [11]. These studies also focused on the analysis of the sound field behind barriers.

With the development of computer technology, numerical methods for finding sound fields are widely used. In [12, 13], the application of the partial element method (FEM) and the boundary element method (BEM) for finding the field around barriers with a specially shaped edge is presented.

Work [14] is devoted to the use of the Comsol Multiphysics software for the analysis of sound fields. In [15], studies of the optimization of noise protection barriers using this software are presented.

Other scientists have proposed to determine the sound field around two-sided barriers using the analytical method [16] based on the wave theory of sound propagation. However, the solution to the problem concerned only acoustically rigid barriers. In addition, for the analysis of the sound field, such physical quantities have been used that make them impossible to apply in practice.

In [17], an analytical solution to the problem was proposed using acoustically rigid rounded baffles on both sides of the road. This approach made it possible to estimate the maximum increase in sound pressure in the space between the barriers. However, the unanswered dependence of the sound pressure in the space above the road on the sound-absorbing properties of the barrier. In addition, it is also desirable that the absorption of sound in the atmosphere itself be taken into account.

5. Methods of research

This problem can be solved by computer simulation and sound field calculation using the partial element method. This method is implemented in the Comsol Multiphysics software, which allows to limit the calculation area by applying the perfectly matched layer (PML) condition. The functionality of the software allows to build noise protection barriers of different geometries, as well as set different impedance and sound-absorbing properties in an explicit form.

6. Research results

6.1. Initial data of the computer model. A two-dimensional model was built with vertical barriers, the acoustic impedance Z of which was changed. This made it possible to simulate noise protection barriers with sound absorption coefficients from 0.1 to 1.0. Variable parameters were also the height of the barriers H_{ekr} – 3, 5 and 7 m; as well as the distance between the barriers l – 10, 20 and 30 m (Fig. 1). The sound source was chosen in the middle between the barriers at a height of 0.5 m. The barriers had a rectangular cross-section with a thickness of 0.1 m.

The calculation was carried out for octave frequency bands with geometric mean frequencies f – 31.5, 125 and 500 Hz.

The source productivity parameter is $Q=0.01$ m^2/s, which did not affect the research results within the framework of the linear model.

The sound field was built with a step of 0.1 m from −15 to 15 m horizontally and from 0 to 10 m vertically.

To build the dependencies and analyze them, a height of 1.5 m above ground level was chosen, which is due to the average height of the head of the driver and passengers of vehicles. The acoustically rigid noise-absorbing baffle had a rectangular section with a height of H_{ekr} m and a width of 0.1 m. This width corresponds to the majority of noise-barriers built in Ukraine.

The sound-absorbing properties of the barrier were set through the acoustic impedance of the barrier material. All other barrier surfaces were modeled acoustically rigid.

The sound absorption coefficient in terms of intensity is determined by the known relationship:

$$\alpha = \frac{4 \cdot Z_1 \cdot Z_2}{\left(Z_1 + Z_2\right)^2}, \qquad (1)$$

where Z_1 – impedance of the medium with which the acoustic wave propagates; Z_2 – input impedance of the barrier.

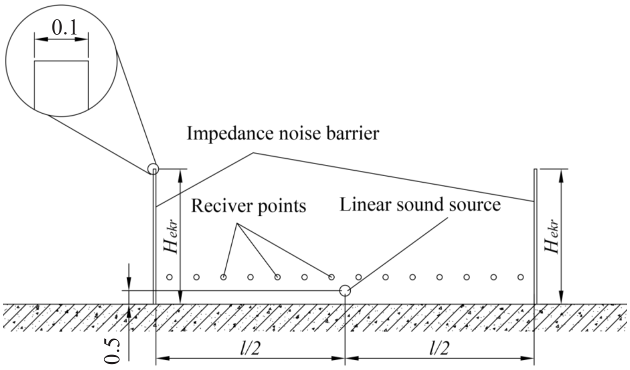


Fig. 1. Mutual arrangement of the noise source, barrier and calculated points

Let's choose 4 sound absorption coefficients α, for which the calculations are performed (Table 1) [9].

Table 1

Sound absorption coefficients and input acoustic impedance of the barrier

Z_1, kg/(m^2·s)	411.6			
Z_2, kg/(m^2·s)	411.6	792.3	2399.0	15630.0
α	1	0.9	0.5	0.1

For each value of the acoustic impedance, a barrier model was constructed and the distribution of acoustic pressures in octave bands with geometric mean frequencies of 31.5, 125 and 500 Hz was calculated.

To simulate the sound pressure of a noise signal, sound pressures were calculated at 11 frequencies evenly distributed over the octave band. The calculation results at each frequency were summed up energetically. More details about this are given in [18].

6.2. Effect of distance between barriers. Fig. 2 shows the distribution of sound pressure levels in the octave band of 31.5 Hz.

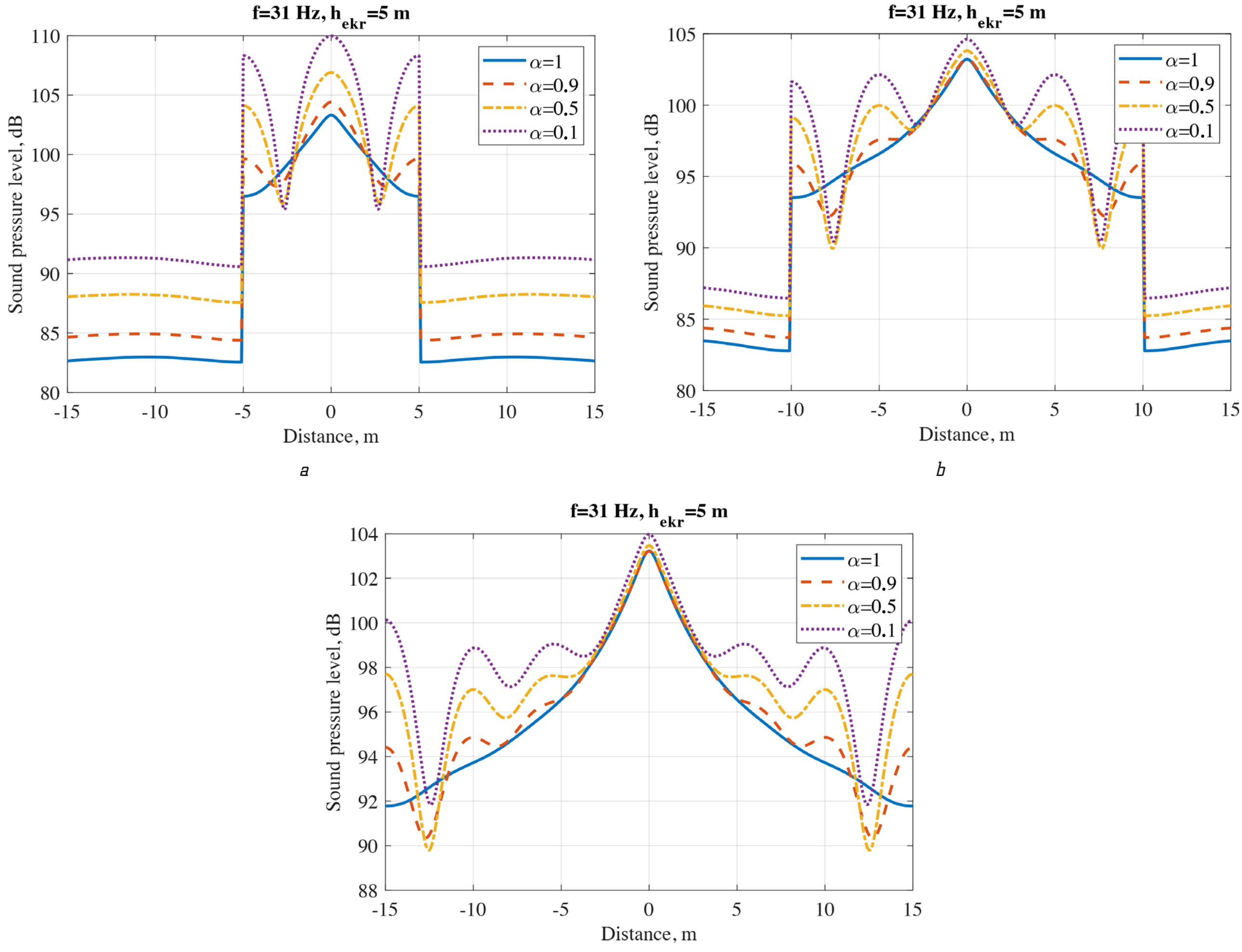
As it is possible to see, with a small distance between the barriers (Fig. 2, *a*), the effect of sound absorption of the barriers is quite significant. So, for a sound-reflecting barrier with α=0.1, the sound pressure levels will increase by up to 7 dB inside the barrier and by up to 11 dB at the barrier.

However, with an increase in the distance between the barriers, the effect of sound-reflecting barriers decreases, and at a distance of 30 m between barriers (Fig. 2, *c*), the increase in sound levels inside is only 1 dB, and at the barrier 8 dB.

With an increase in the height of the barrier to 7 m, the effect of sound-reflecting barriers increases by about 2 dB (Fig. 3, *a*); when the height decreases to 3 m, it decreases by 2 dB at a distance between barriers of 10 m. If the distance between barriers increases to 30 m dB, then the sound levels at the barrier increase by 8 dB, and inside between the barriers the increase is from 0.5 dB (for H_{ekr}=3 m) to 3 dB for (H_{ekr}=7 m).

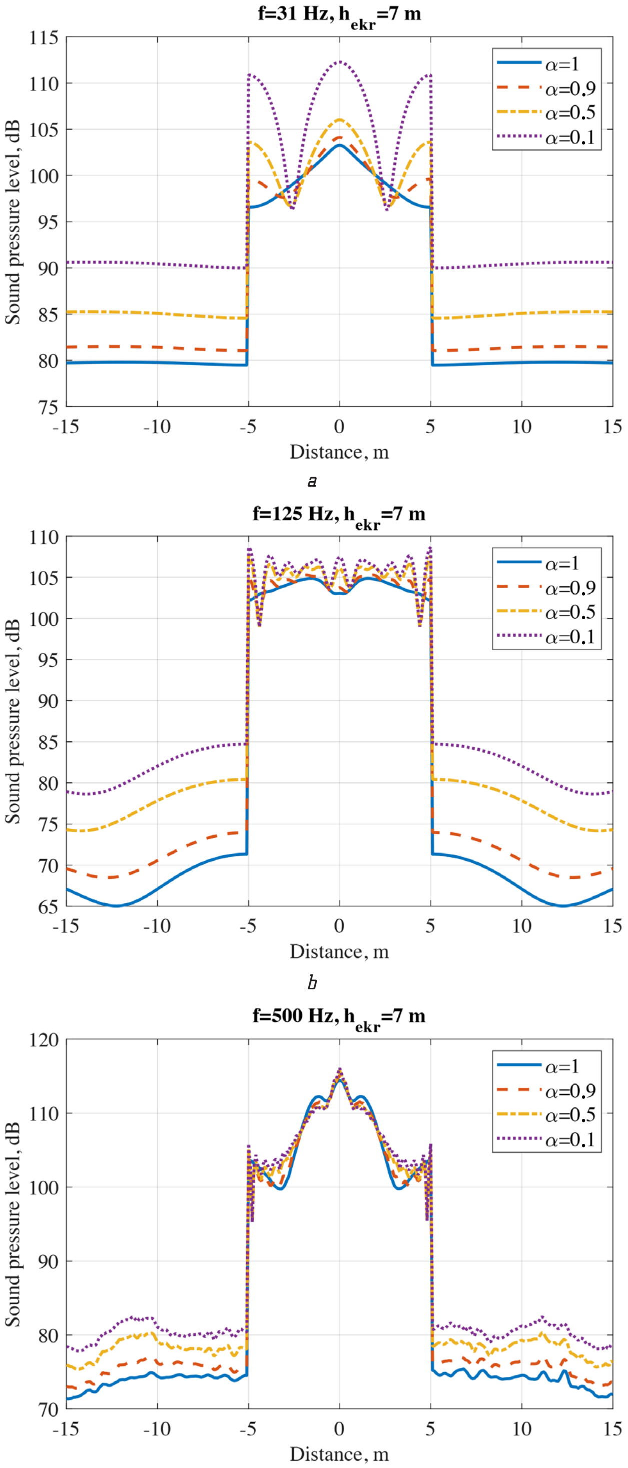
6.3. Effect of sound frequency. Fig. 3 shows the sound pressure levels between impedance barriers at different frequencies.

As it is possible to see in Fig. 3, with an increase in frequency, the effect of sound-reflecting barriers decreases. For a frequency of 31.5 Hz, the presence of sound-reflecting barriers led to an increase in sound pressure by 9 dB in the middle and 13 dB at the barrier. With an increase in frequency to 500 Hz, this effect decreases to 1 dB and 5 dB, respectively.



a *b* *c*

Fig. 2. Distribution of sound pressure levels between barriers in an octave band with a frequency of 31.5 Hz and a barrier height of 5 m: *a* – *l*=10 m; *b* – *l*=20 m; *c* – *l*=30 m



a

b

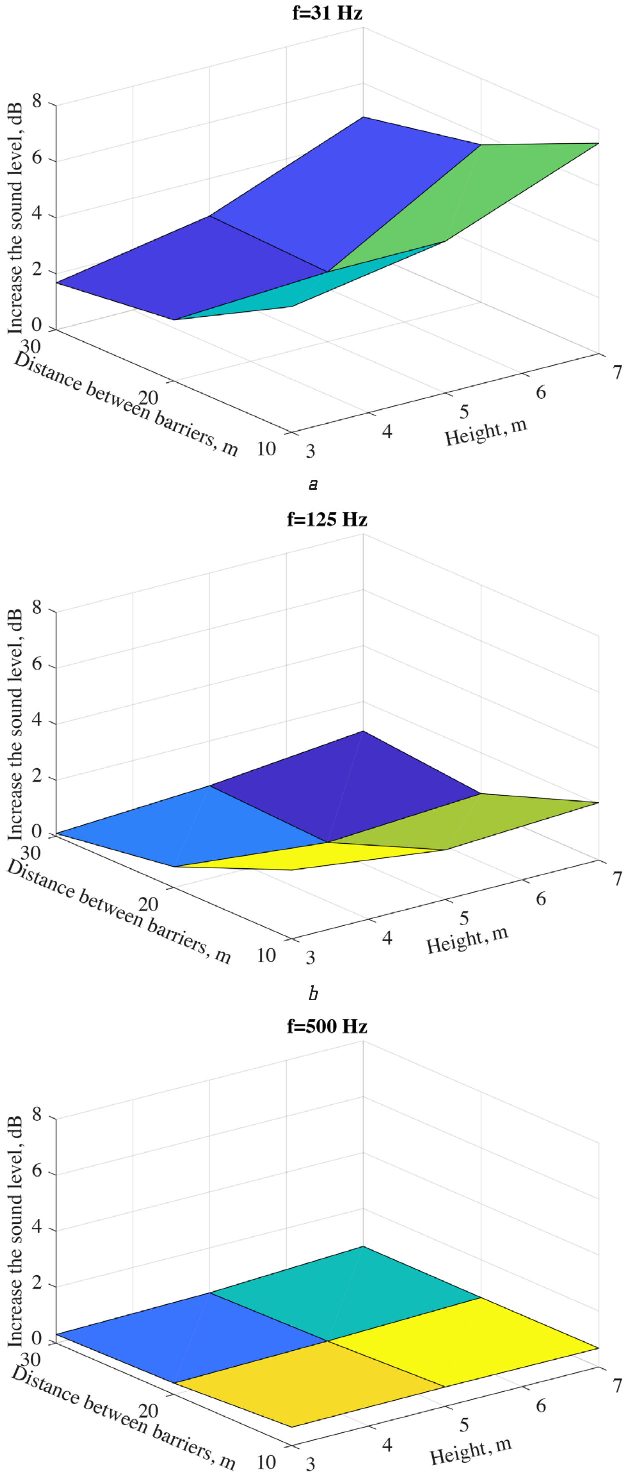
c

Fig. 3. Distribution of sound pressure levels between barriers. The height of the barriers is 7 m, the distance between the barriers is 10 m: *a* – *f*=31.5 Hz; *b* – *f*=125 Hz; *c* – *f*=500 Hz

As the distance between the barriers increases, this tendency persists, however, the absolute values of the exposure decrease.

6.4. The discussion of the results. From Fig. 2, 3, it can be seen that the values of the sound pressure levels, depending on the distance, vary over a wide range (more than 10 dB); therefore, an integral estimate of the sound pressure levels was proposed.

For the integral analysis, the average values of the change in sound pressure at a height of 1.0 m were found with sound-reflecting (α=0.1) and sound-absorbing (α=1.0) barriers (Fig. 4).



a

b

c

Fig. 4. Increase in the average sound pressure levels with sound-reflecting barriers (α=0.1) and sound-absorbing barriers (α=1.0) depending on the height of the barriers and the distance between the barriers: *a* – *f*=31.5 Hz; *b* – *f*=125 Hz; c – *f*=500 Hz

As it is possible to see from Fig. 4, with an increase in frequency, the effect of sound-reflecting barriers at the sound pressure level decreases and at a frequency of 500 Hz does not exceed 1 dB. At the same time, at low frequencies, the increase in average sound levels can reach 8 dB at a frequency of 31.5 Hz and more than 2 dB at a frequency of 125 Hz.

It can also be argued that with a decrease in the height of the barriers or with an increase in the distance between the barriers, the effect of sound-reflecting barriers decreases.

7. SWOT analysis of research results

Strengths. In the course of the study, it was shown that when sound-reflecting barriers are used on both sides of the transport highway, sound pressure levels can increase. It was revealed that the greatest increase in sound levels is characteristic of low frequencies. The influence of the height of the barriers and the distance between them is also shown.

Weaknesses. The studies presented are only a computer simulation of the sound field around a linear sound source with impedance barriers. As is known, this approach does not allow evaluating the accuracy of calculations.

Opportunities. In the future, it is necessary to conduct laboratory studies on the model of the impact of impedance barriers on the sound field between them. It would also be advisable to carry out field measurements, but this can be a rather complicated process. In such studies, it is necessary to closely monitor conditions such as wind, temperature, etc.

Threats. It is the strength and direction of the wind, as well as the temperature gradient, that can be quite influential factors that do not allow to finally come to unambiguous conclusions about the effect of barriers on the acoustic field between them.

8. Conclusions

1. As a result of the study, it was found that the sound field from a linear sound source with parallel noise barriers depends on:
- barrier heights;
- distance between barriers;
- sound frequency;
- sound absorption coefficient of the barrier material.

It was revealed that a significant increase (more than 5 dB) of the sound field between sound-reflecting barriers is observed only at low frequencies (up to 125 Hz) at small distances between barriers (up to 20 m).

2. It was found that at medium and high frequencies the change in the sound field levels does not occur at any real heights (up to 7 m) and distances between barriers (from 10 to 30 m).

Therefore, the requirement to install sound-absorbing noise-protective barriers should first of all be substantiated from the point of view of increasing the efficiency of the barrier, as shown in [19].

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