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Article

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INFLUENCE ESTIMATION OF THE INCLINATION ANGLE OF THE TOP OF THE NOISE PROTECTION BARRIER ON ITS EFFICIENCY

The object of research is the sound field from linear sound sources around a rounded noise barrier of the same height and different angles of inclination of the top part of the barrier. It is known that the effectiveness of noise protection barriers depends primarily on the geometric dimensions of the barrier and the relative position of the sound source, barrier and area of noise protection. A large number of publications have been devoted to the study of the influence of these factors and some others, such as the influence of the earth's surface, sound absorption, sound insulation of the barrier. However, these works did not study the effect of the angle of the top part of the barrier on the change in the barrier efficiency.

In this paper, the reduction of sound levels from linear sound sources around noise barriers with different inclination angle of the top part of the barrier is investigated. Rounded barriers of the same height with different radii are considered, which made it possible to simulate barriers in which the top part of the barrier has a different inclination angle. An effectiveness of such barriers for various locations of the sound source, which could also affect the establishment of a pattern of changes in the effectiveness of barriers, is also considered. In addition, the results were analyzed over a wide frequency range. The calculation of the field around such a barrier was carried out using computer simulation using the finite element method. This method allows to easily change the geometric parameters of the barrier and the position of the sound source. The barriers were considered acoustically hard.

Thus, an influence of the inclination angle of the top part of the barrier on the sound field around the barrier from various locations of sound sources in a wide frequency range is analysed. The results must be taken into account when designing noise barriers to reduce noise levels from traffic flows.

Keywords: *noise barrier, inclination angle, wide frequency range, noise reduction, traffic flow noise.*

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1. Introduction

Numerous studies show that transport is the most common source of excessive noise in the world. Reducing traffic noise is one of the biggest problems in acoustic ecology. One of the most effective ways to reduce noise is to install noise barriers.

A large number of publications have been devoted to the question of determining the effectiveness of noise protection barriers, but over time the number of studies is growing. The reason for this is that the effectiveness of noise protection barriers depends on a large number of parameters, and this influence is interrelated. So, in works [1, 2] it is shown that the efficiency of noise barriers depends on the type of sound source, frequency and relative position of the barrier source and the design point. Works [3, 4] show a significant effect of the earth's surface on the efficiency of barriers. Studies [5] show the influence of the shape of the barrier on its efficiency, and this influence significantly depends on the frequency and on the relative position of the sound source and the calculated point. Recently, it has become relevant to study the influence of various parameters of the top part of the barrier on its effectiveness. Therefore, this study is devoted to determining the effect of the inclination angle of the top of the barrier on its effectiveness.

2. The object of research and its technological audit

The object of research is the sound field from linear sound sources around a rounded noise barrier of the same height and different inclination angles of the top part of the barrier.

Noise barriers installed along highways can be both vertical and of a more complex shape, in particular, in the form of a circular arc.

It is known that the effectiveness of noise protection barriers depends primarily on the geometric dimensions of the barrier and the relative position of the sound source, barrier and area of noise protection. A large number of publications have been devoted to the study of the influence of these factors and some others, such as the influence of the earth's surface, sound absorption, sound insulation of the barrier. However, these works did not study the effect of the angle of the top part of the barrier on the change in the barrier efficiency.

3. The aim and objectives of research

The aim of research is to evaluate the effect of the inclination angle of the top of the barrier on the ability to reduce the noise level behind the barrier.

To achieve this aim, it is necessary to complete the following tasks:

1. Build a computer model of the sound field around a rounded noise barrier.
2. Determine the effectiveness of barriers in a wide frequency range with different locations of the sound source and inclination angle of the top of the barrier.

4. Research of existing solution of the problem

One of the ways to increase the efficiency of barriers is to decorate the top edge of the barrier with a specially shaped diffuser [6, 7]. A large number of noise barriers with a modified top edge have been proposed and investigated [8, 9]. These studies were based on numerous methods of calculation by the finite element method (FEM) [10] or the boundary element method (BEM) [11]. However, in some studies [12, 13] it has been shown that the effectiveness of the application of the top edges of the barrier is highly dependent on the sound frequency in a wide frequency range and it is not possible to achieve significant barrier efficiency.

In addition, studies have been carried out [14, 15] to increase the efficiency of the barrier by changing the acoustic impedance of the top of the barrier. These studies have shown that the design of barriers with high sound absorption properties of the tops leads to an increase in barrier efficiency by up to 2.5 dB.

In [16, 17], an analytical method is proposed for finding the efficiency of noise barriers with an impedance top part, based on the method of integral equations. This method allows to reduce the amount of required RAM and reduce the calculation time. The method of partial regions has also found application [18, 19]. This method makes it possible to find the efficiency of noise protection barriers of a more complex shape [20], as well as to take into account their own sound insulation of barriers [21].

However, the use of analytical research methods is possible only for fairly simple barrier configurations. When using barriers with complex geometry, the derivation of analytical relationships becomes much more complicated and the advantage of numerical calculation methods becomes indisputable. Therefore, to find out the influence of the inclination angle of the top part of the rounded barriers, it was proposed to use the method of partial elements.

5. Methods of research

To solve the set objectives, a computer model of noise protection barriers was created in the Comsol Multiphysics software environment. The acoustic field from a linear sound source operating at zero mode was calculated by the finite element method.

A two-dimensional geometric model of the noise barrier is shown in Fig. 1.

The horizontal surface of the road and ground behind the barrier was modeled on an acoustically rigid plane.

The surface of the barrier was also acoustically rigid and did not transmit sound.

The use of Perfectly Matched Layer made it possible to simulate the free field in the computational domain, as shown in [14].

The thickness of the barrier was 0.1 m. For frequencies in the range up to octave bands with a geometric mean frequency of 500 Hz, it can be assumed that the barrier was thin.

6. Research results

6.1. Building a computer model. To analyze the results, effective protection means were insured for seven angular slopes of the top parts of the selected and five positive sound sources (Fig. 2) in three octave frequency bands. All initial data for the calculation are summarized in Table 1.

In the computer model, for one geometric barrier size and the location of the sound source, the calculation was carried out at 11 frequencies, evenly located in the octave frequency band. The result of the calculation was the energy sum of the sound fields at each frequency. More details about this are given in [21].

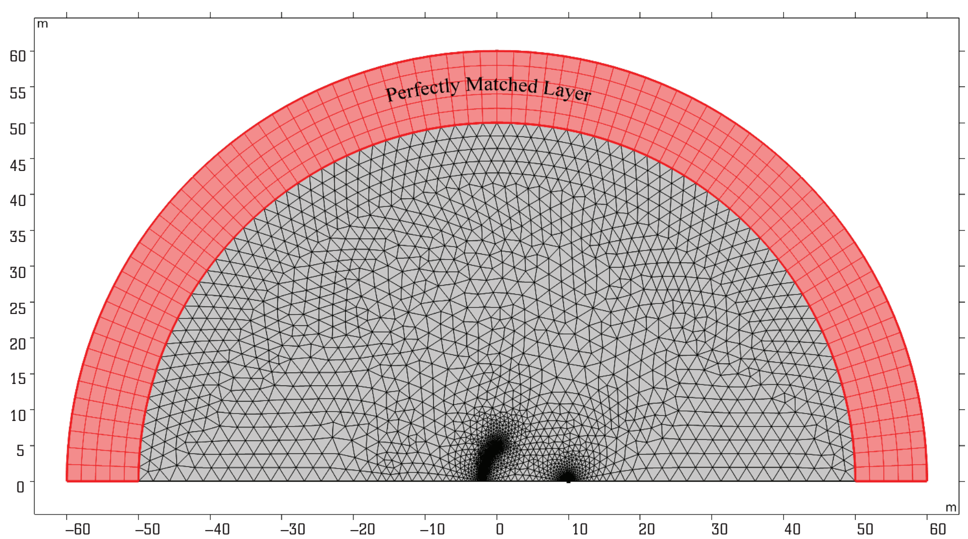

Fig. 1. Mesh for calculation by the finite element method using the Perfectly Matched Layer

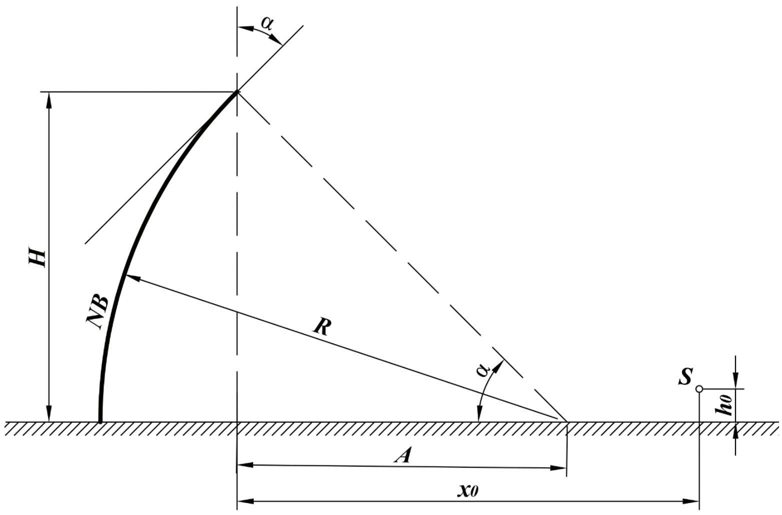

Fig. 2. Mutual arrangement of the noise barrier (NS) and the sound source (S)

Table 1

Initial data for computer modeling

Sequence number	Parameter	Value						
1	Inclination angle, α°	0	15	30	45	60	75	90
2	Radius of curvature of the barrier, R, m	∞	19.52	10.00	7.07	5.77	5.18	5.00
3	Offset of the center of the circle, A, m	∞	18.66	8.66	5.00	2.87	1.34	0
4	Sound source offset, x_0, m	1; 5; 15						
5	Average geometric frequencies of the octave band, f, Hz	31; 125; 500						
6	Number of frequencies in the octave band	11						
7	Height of sound sources, h_0, m	0.01						
8	Barrier height, H, m	5.0						

The location of 3 linear sound sources is typical for traffic flows with a different number of lanes. The height of the sound sources – 0.01 m corresponds to the noise generated when the tire rolls on the road surface.

The study of the change in sound levels with the barrier was carried out at points at a distance of 20 m behind the barrier with a height of 0 to 20 m (with a step of 0.1 m).

6.2. Calculation results. Fig. 3–5 shows the effectiveness of noise barriers at different inclination angles of the top edge, at different positions of the sound source and at different frequencies.

Fig. 3, *a–c* shows the barrier efficiency, provided that the distance to the sound source is $A=1$ m. Fig. 3, *a* shows that the highest efficiency at a frequency of 31 Hz is achieved with the inclination angles of the top part of the barrier 60° and 75°.

For octave bands with an average geometric frequency of 125 Hz (Fig. 3, *b*), the highest barrier efficiency is also observed for angles of 60° and 75°. With an increase in frequency to 500 Hz (Fig. 3, *c*), the efficiency of the barrier reaches its maximum values at different heights along the angles of 45–75°.

An increase in the distance between the sound source and the barrier up to 5 m (Fig. 4, *a–c*) leads to the fact that the maximum efficiency is observed at angles of 30–60° in the octave band of 31 Hz. At frequencies of 125 Hz and 500 Hz, the efficiency is already weakly dependent on the inclination angle of the top edge of the barrier.

At a distance of 15 m between the barrier and the sound source (Fig. 5, *a–c*), the influence of the inclination angle becomes less pronounced even for the octave band with geometric mean frequencies of 31 Hz. However, the maximum efficiency values are observed at angles of 0–30°. At high frequencies (Fig. 5, *b–c*), the barrier efficiency does not depend on the inclination angle of the top part of the barrier.

6.3. Discussion of results. Studies have shown that as the distance between the sound source and the barrier increases, the effect of the inclination angle of the top part of the barrier on its effectiveness decreases. It can be argued that for $kA>10$, where $k=2\pi f/c$, the effectiveness of the noise barrier does not depend on the inclination angle of the top part of the barrier.

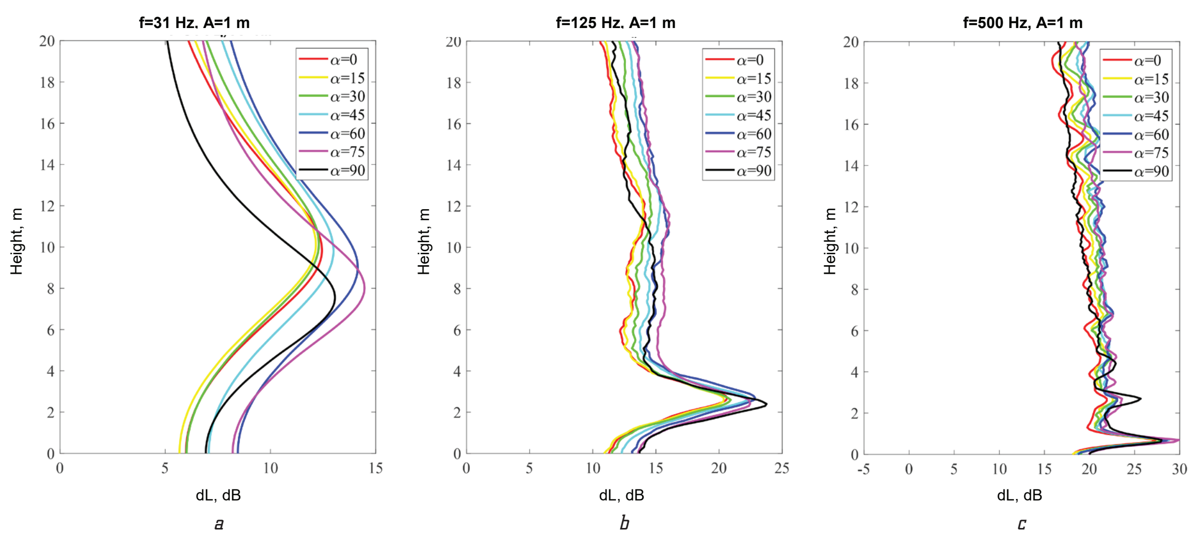

Fig. 3. Barrier efficiency depending on the inclination angle of the top part of the barrier at $A=1$ m: *a* – $f=31$ Hz; *b* – $f=125$ Hz; *c* – $f=500$ Hz

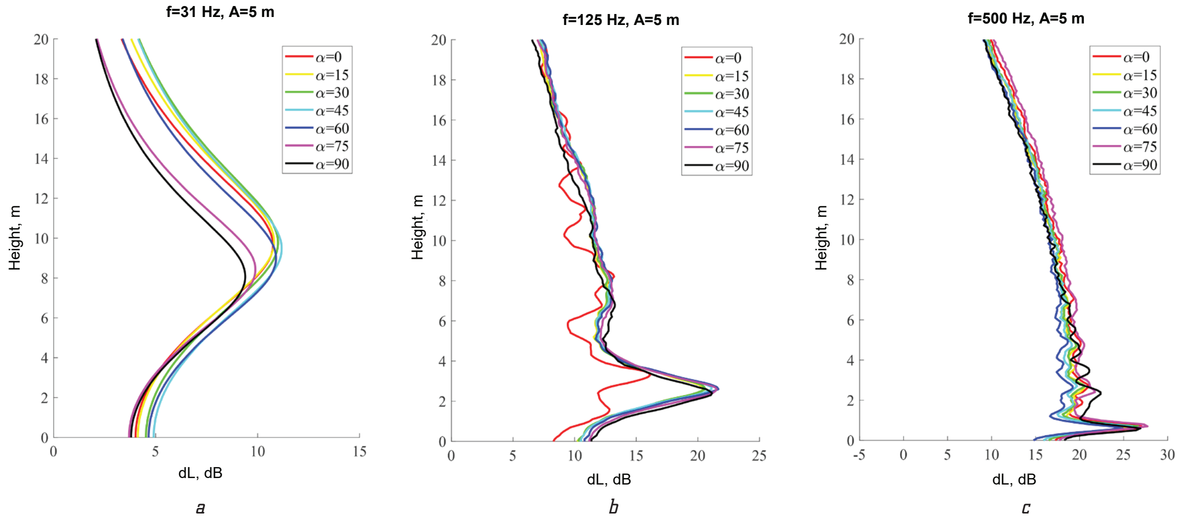

Fig. 4. Barrier efficiency depending on the inclination angle of the top part of the barrier at $A=5$ m: *a* – $f=31$ Hz; *b* – $f=125$ Hz; *c* – $f=500$ Hz

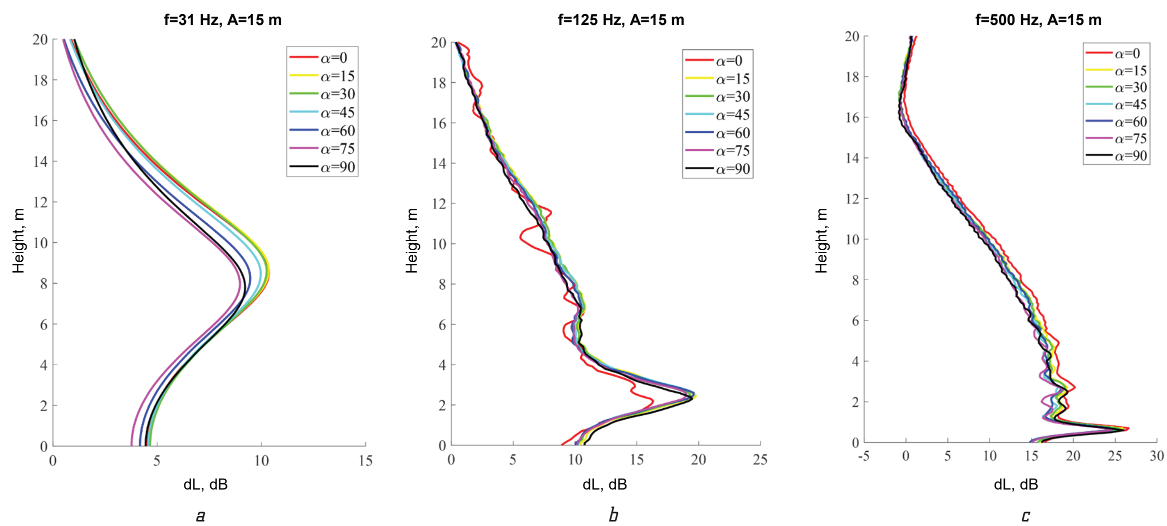

Fig. 5. Barrier efficiency depending on the inclination angle of the top part of the barrier at $A=15$ m: *a* – $f=31$ Hz; *b* – $f=125$ Hz; *c* – $f=500$ Hz

At low frequencies, when the sound source and the barrier are located close ($kA\leq 10$), the highest efficiency of noise barriers is achieved at inclination angles corresponding to the normal incidence of a sound wave on the top of the barrier. That is, it is desirable that the sound source and the center of the circle, of which the barrier is a part, coincide. The size of the increase in efficiency of a slant-top barrier compared to a vertical barrier can be 2–4 dB.

7. SWOT analysis of research results

Strengths. Studies have shown that the influence of the inclination angle of the top part of the barrier on its efficiency is possible only at low frequencies for a relatively short distance between the sound source and the barrier. At $kA>10$, the influence of the inclination angle of the top part of the barrier on its efficiency is insignificant.

Weaknesses. The weaknesses of the research include the fact that at this stage only computer modeling of the sound field around a rounded barrier with a different inclination angle of the top part was carried out.

Opportunities. In the future, it is necessary to conduct experimental studies to determine the sound field around rounded barriers with different radii in natural conditions or on physical models.

The results of such studies will make it possible in practice to assess the need for the use of barriers with inclined top parts.

Threats. The use of barriers with an inclined top part leads to a shift in the center of mass of the barrier, which necessitates the use of more powerful struts and an increase in the requirements for the bearing capacity of foundations. Such material costs can lead to the leveling of those advantages, which are due to the presence of an inclined top of the barrier.

8. Conclusions

1. A computer model of rounded noise protection barriers with different radii was built, which made it possible to analyze the sound field around the barriers with different inclination angle of the top part. With the help of the created model, it was possible to estimate the effect of the barrier inclination angle in the range from 0° to 90° of different positions of the sound source (from 1 m to 15 m) and in the frequency range from 31 Hz to 500 Hz.

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2. As a result of the research, it was found that in the near field of the sound source (kA≤10), the inclination angle of the top part of the barrier significantly affects the decrease in sound levels behind the barrier. The size of the increase in the efficiency of the barrier, compared with the vertical barrier, can reach 4 dB. Moreover, it is advisable to choose the inclination angle of the top part of the barrier so that the direction of the sound wave is perpendicular to the surface of the top part of the barrier. In the far field at kA>10, the inclination angle of the top part of the barrier has almost no effect on its efficiency.

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