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SOME OBSERVATIONS ON THE DESIGN OF NOISE BARRIERS

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Abstract:
The issue connected with effectiveness of noise barriers has been the subject of numerous considerations among acousticians. On the one hand, noise barriers are still the most popular and the most frequently used protection against traffic noise, on the other hand, however, the excessive number of noise barriers and the results of research focusing on effectiveness of the existing barriers make us reflect whether it is reasonable to use them. Very often low effectiveness of noise barriers is related to a badly conducted designing process. This article presents the basic mistakes made by noise barriers' designers and the consequences thereof. Next, the paper describes the appropriate approach to the process of the noise barriers' design which consists in the use of computer methods and conducting of a detailed analysis of the acoustic field's distribution both behind the barrier and on the facades of the acoustically protected buildings.

Key words: *acoustic screens, screen design, the effectiveness of screens*

INTRODUCTION

At present acoustic barriers are one of the most often used means of passive noise reduction. The barriers are constructed almost everywhere, along roads, railways, tram lines, factories, etc. There are more and more noise barriers around us. Nevertheless, do they meet the established requirements? Do they protect us against noise well enough? In order to give a clear answer to this question it is necessary to analyse a number of factors affecting the barriers' performance; and the design process comes to the fore. It has turned out that too low noise barriers' effectiveness is mainly due to mistakes made in the barriers' planning and designing, generally resulting from the lack of sufficient knowledge of acoustics and environment protection against noise, as well as from the intention to minimize the costs of acoustic protection implementation.

Although the principles of selection and design of noise barriers have already been described in a great number of Polish and foreign publications [2, 3, 4, 5, 6], numerous mistakes and omissions are still made. That is why the purpose of this article is not to describe in detail the principles of noise barriers' design, but to present the most common mistakes made in the designing process and to show an example of the correct approach to sound barriers' design.

METHODS OF CALCULATING NOISE BARRIERS' EFFECTIVENESS

Design of noise barriers consists in such a selection of a location as well as geometric and material features of the barrier so as to secure the protected structures against excessive and inconvenient noise. The designed noise barrier should be characterized by appropriately high effectiveness (efficiency). According to [11], noise barrier's effectiveness is described by the following formula:

$$D_{IL} = L_A - L_B \tag{1}$$

where:
L_A – sound level in a particular point before the barrier's installation in dB,
L_B – sound level in a particular point after the barrier's installation in dB.

It is important to make sure that the effectiveness is always checked in the same point before and after the barrier's installation and with invariable characteristics of the noise source. In case of road noise the measurements ought to be made at similar flow and structure of traffic. Should it be impossible to ensure sufficient similarity of the source, an additional reference point specifying the source ought to be used. So, effectiveness of a noise barrier depends on the observation point location. It decreases with increase of the distance from the barrier and with increase of the observation point 's height. The best effectiveness is obtained in points located at low heights directly behind the barrier. Consequently, one may state that the effectiveness of the barrier depends mainly on geometry of the following scheme: *source – barrier – observer*, which has been presented in Fig. 1. Material properties of the screen are of secondary importance here, as in practice in case of insulation greater than 20 dB, acoustic wave energy that permeates through the material of a noise barrier is much smaller than the energy of the acoustic wave diffracted at the top edge or side edges of the barrier; it is also much smaller than the direct wave coming from places which are not protected with such barriers. For that reason, its impact is rightly ignored in the calculations.

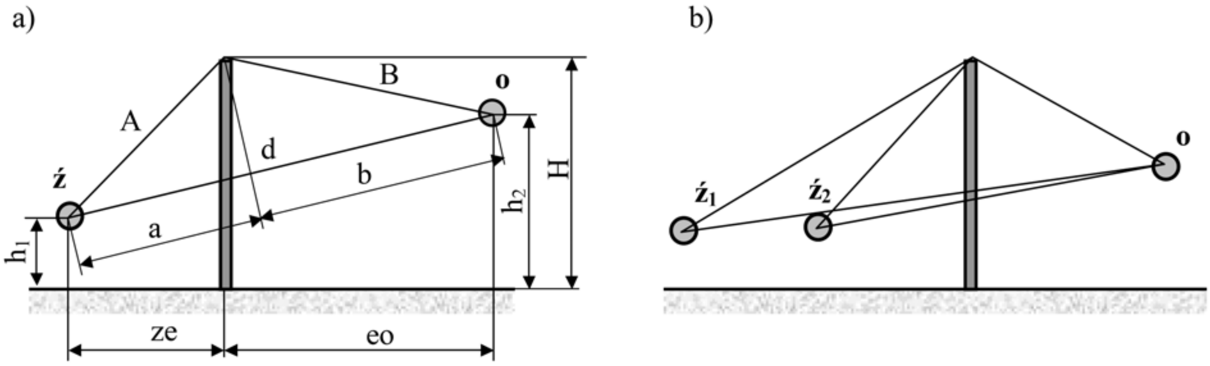

Fig. 1 Geometry of the source – barrier – observer scheme [2]:
a) model with one source, b) model with two sources, e.g. two roads

Noise barriers' effectiveness can be calculated at the stage of their design with the use of one of the following methods: Delany's, Maekawa'a, Rettinger's, Redfearn's or VDI-2720. It is assumed that a noise barrier constitutes an impermeable acoustic barrier and the sound level behind the barrier is a function of the distance and diffraction of the acoustic wave at the barrier's top edge. The so-called acoustic shadow is created behind a noise barrier and the shadow's layout depends on the wavelength and geometric parameters of the scheme.

When using Redfearn's, Delany's and Meakawa's methods, the indicator of a barrier's effectiveness is the difference of paths of the radius of the wave diffracted at the barrier's edge and of the direct wave δ, or the Fresnel number N = 2δ/λ defined as the quotient of the δ value and half of the acoustic wave length. When determining a noise barrier's effectiveness ΔL_E, in accordance with A corrective specification, one ought to assume the wavelength equal λ = 0.68 metre, which corresponds to frequency *f* = 500 Hz. The Rettinger method is based on determination of a w indicator dependent on the scheme geometry, determination of *x, y* values for relevant Fresnel integrals and then calculation of the noise barrier's effectiveness. Whereas determination of a noise barrier's effectiveness with the use of VDI-2720 method requires making a number of calculations taking into consideration: geometry of the area, reflection of sound waves from the road surface, correction factor for weather conditions, etc. Detailed description of all the aforementioned methods is presented in [5] and their comparison in [2].

The calculation methods described above assume that the barrier is infinitely long and the acoustic wave diffraction takes place only at the barrier's top edge. Therefore, effectiveness of a noise barrier is calculated in a selected section. In fact, noise barriers are of a finite length and that is why we also have to deal with acoustic wave diffraction at the side edges. Figure 2a shows the acoustic wave propagation path from the source point to the reception point. The wave diffracted at side edges is marked in red and the wave diffracted at the barrier's top edge is marked in blue, whereas the wave penetrating the noise barrier due to the barrier's finite insulation is marked in green. Figure 2b presents an example of acoustic wave diffraction at side edges of a noise barrier depending on location of the point source (e.g. a car going along the road). In some extreme locations of the noise source, effectiveness of the noise barrier equals zero.

The failure to consider, in the calculations at the designing stage, the influence of acoustic wave diffraction at the barrier's side edges is a very common and serious mistake which results in obtaining of a significantly less effective noise barrier constructed than assumed.

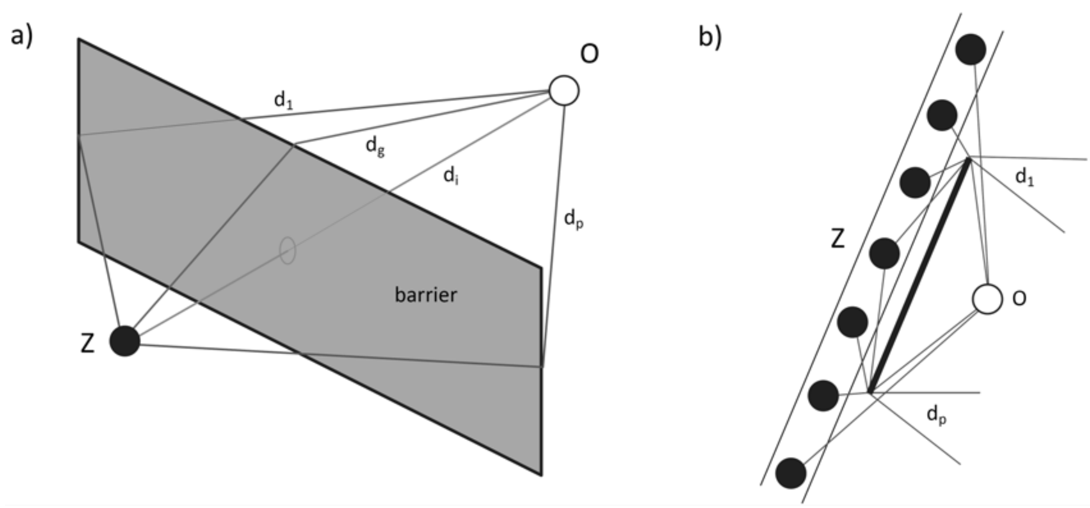

Fig. 2 Acoustic wave propagation from the source (Z) to the observation point (O)
a) for a point source, b) for a line source
d_l, d_p – diffraction at the left/right side edge of the barrier, d_g – diffraction at the barrier's top edge,
d_i – acoustic wave penetrating the noise barrier

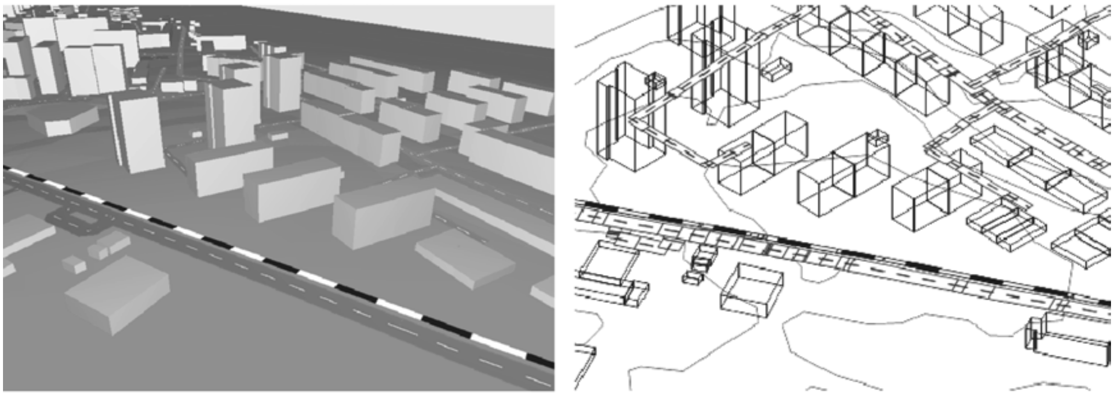

Fig. 3 Geometric model (3D) of the research site

DESIGN OF NOISE BARRIERS WITH THE USE OF COMPUTER METHODS

It is possible to take into account most of the phenomena having a significant influence on acoustic wave propagation thanks to the use of specialist software assisting in the process of acoustic protections design. There are numerous calculation programs such as CadnaA, SoundPlan, LimaA, Immi, etc. Their common feature is the possibility to make a three-dimensional geometric model of the calculated area taking into account characteristics such as natural lay of the land, buildings and shielding structures, green areas, land absorption, the influence of weather conditions and other objects relevant to the acoustic wave propagation (e.g. embankments, slopes, overpasses, bridges, reservoirs, etc.). Acoustic calculations are carried out in accordance with PN-ISO 9613-2 standard recommended by Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise, and in line with the ITB 338/96 instructions. Skilful application of the above software makes the designer able to conduct a full analysis of the sound field distribution behind a noise barrier in horizontal sections (noise maps) and vertical sections (acoustic shadow analysis), as well as the analysis of distribution of sound level on buildings' facades.

EXAMPLE OF THE PROCESS OF A NOISE BARRIER DESIGN

The process of a noise barrier design is always associated with the necessity to conduct an optional computational analysis as a result of which one ought to make an optimal selection of the barrier's (or complex of barriers) location, its length, height and type (absorbing or reflecting barrier).

For this purpose a geometric and acoustic model of the area subject to acoustic tests ought to be created first.

This model should take into account the actual topography of the land as well as all the shielding elements affecting the acoustic wave propagation such as buildings, embankments slopes, etc. An example of such a geometric model used to calculate the effectiveness of a designed noise barrier has been presented in Figure 3.

Initial location of a noise barrier is assumed depending on the actual possibilities of the barrier's foundation, taking into consideration the ecological effect which can be obtained, utilities, changes that must be made in the organization of pedestrians' and cyclists' movement as a result of the barrier's construction, traffic safety, shadowing, etc. Having selected one or several possible locations, initial calculations of the noise barrier's effectiveness are made by analyzing the obtained acoustic maps made in horizontal sections at appropriate heights. An example of such analyses has been presented in Figure 4.

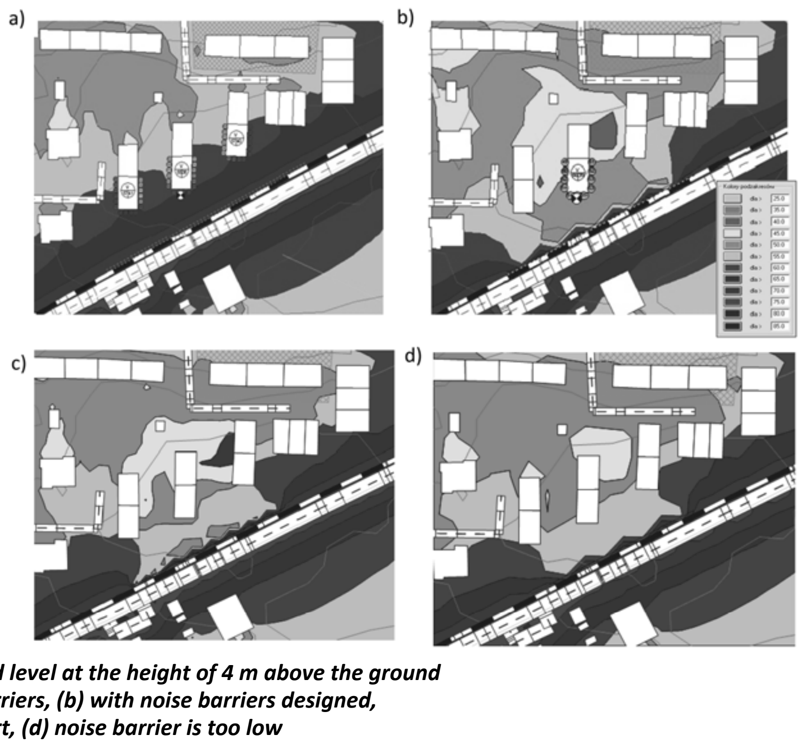

Fig. 4 Distribution of sound level at the height of 4 m above the ground (a) state without noise barriers, (b) with noise barriers designed, (c) noise barrier is too short, (d) noise barrier is too low

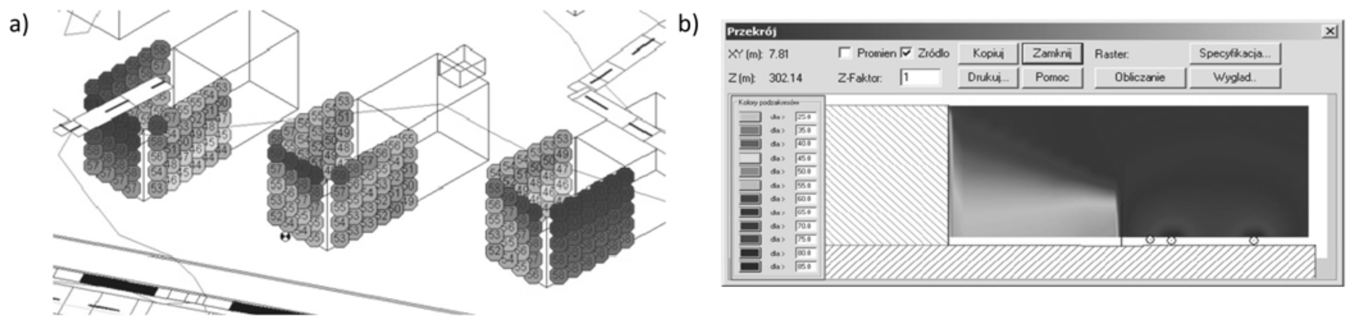

Fig. 5 Analysis of acoustic field distribution
a) within a grid of points on buildings' facades, b) analysis of acoustic shadow in a cross section

At this point it is still possible to modify the length, height and shape of the barrier in order to obtain the right effectiveness. The sound level is usually calculated within a grid of observation points of dimensions 5´5m or 10´10m spread at the height corresponding to the lowest and the highest floor of the protected building. Thickness of the calculation grid may be changed depending on the dimensions of the calculated area.

It is usually assumed that the number of the analyzed reflections equals 2, absorption coefficient of "acoustically soft" land (e.g. lawns, meadows, fields, unpaved roads, etc.) is agreed to be 0.6, whereas the loss of reflections at the buildings' façade is assumed to be 1 dB (α = 0.21).

Having selected the best option, one ought to check and, possibly correct, parameters of the noise barrier in such a way so as to make sure that both the lowest and the highest floors of the building are protected. Additionally, it is also important to verify distribution of the sound level on respective facades of the buildings. In case when a noise barrier is too short, it can happen that not all the facades are protected well enough in respect of acoustics. Example of an analysis of the sound level distribution on respective facades has been presented in Figure 5, whereas a barrier which protects residential buildings and which has been optimized for acoustic performance has been presented in Figure 6.

MAIN MISTAKES MADE IN NOISE BARRIERS' DESIGN

In practice, engineers very often encounter designs of noise barriers made by persons who do not have adequate knowledge of the environmental acoustics, made without the use of specialized computer tools, and even worse (which happens in the case of large linear investments) without even inspecting the site where the barriers are to be constructed. Such design of noise barriers "from behind the desk" results in errors which we can see later while driving on our roads. The most common mistakes made in the design of noise barriers are:

- too low and too short noise barriers, which is connected with the pressure to limit the construction expenses or with incompetent designing,
- construction of noise barriers along highways in undeveloped areas, e.g. erected in fields, woods, etc.,
- designing noise barriers with numerous gaps, e.g. entries to properties; such barriers should not be constructed as their effectiveness is practically none,
- barrier's location is too far away from the noise source, which usually takes place in case of erecting noise barriers for industrial plants, a noise barrier is treated as fencing,
- using noise barriers which reflect acoustic wave in places where the wave should be absorbed; such a mistake often results in worsening of the acoustic conditions after the barrier's construction,
- designing barriers with the foundation level lower than the level of the road; such a noise barrier is ineffective up to the height of the source, and the cost of the barrier's construction is very high,
- too rare use of natural barriers which are very effective, e.g. keeping roads in ditches or using embankments.

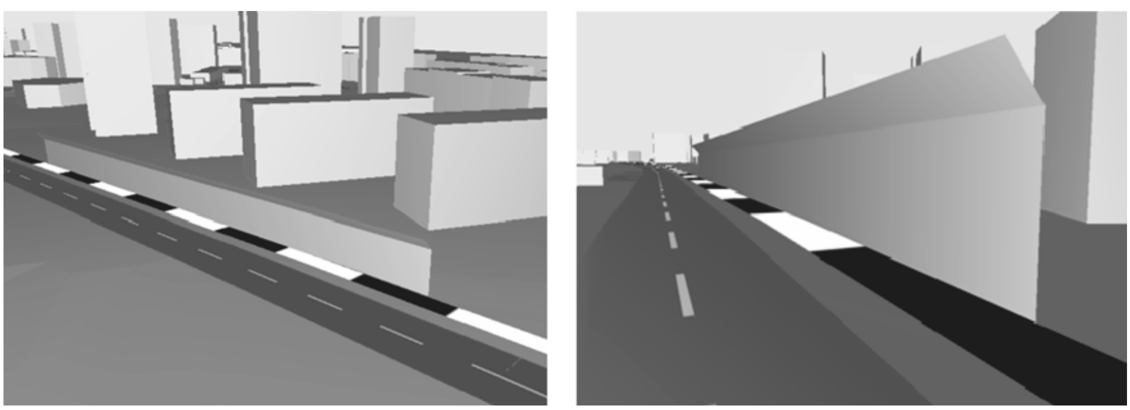

Fig. 6 Form of a designed noise barrier

CONCLUSIONS

The process of noise barriers' design is connected with the necessity to consider a number of factors influencing the barriers' effectiveness. The most important ones are: natural topography of the land, noise shielding by means of other buildings and volume objects, diffraction of the acoustic wave at top and side edges of the noise barrier, absorption properties of the barrier's surface, the barrier's shape, land absorption, etc. Taking all the aforementioned factors into consideration during the process of the barrier's design makes it possible to properly estimate the acoustic effects which can be obtained, and thus it allows to make a conscious decision regarding construction of a noise barrier. Unfortunately, very often even the best designed barriers cannot guarantee compliance with the standards in areas to be protected from noise and one should know about this fact before making any decisions to build a noise barrier. Such information will enable to consciously manage the acoustic climate and shape the sound environment, which has already been noted in [8, 9, 10]. The calculation methods presented in this article are also used in for designing noise protection systems in industrial environments, which has been described in [1, 7].

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