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The use of sound-absorbing properties of acoustic panels with different degree of perforation on the outer lining layer in modeling and calculations of traffic noise

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Abstract The article presents research studies on the impact of perforation of the outer lining layer of an acoustic panel used for the construction of road noise reduction devices on its absorbing properties. The research included measurements of the reverberation time in the laboratory conditions of diffusion field, on the basis of which the values of sound absorption coefficient as a function of frequency were determined. In addition, for various solutions of acoustic panels based on a corrugated fiber cement board on the top surface and on two types of mineral wool inside the panel, the α_w and α_p indices as well as sound absorption rating index $DL_{\alpha NRD}$ were calculated. Then, computer simulations were carried out to show the influence of laboratory-determined acoustic parameters of the panels on the acoustic climate in the vicinity of a selected transport system. The key aspects of the modeling process are presented, the characteristics of the noise source and the analysis of the results are described. An important goal of traffic noise modeling is to strive to develop more friendly and sustainable material solutions that will reduce the negative effects of noise on people and the environment.

Keywords: Reverberation time, sound absorption coefficient, acoustic screen, SoundPLAN.

1. Introduction

Road noise during the development of transport networks is a problem affecting around 113 million EU citizens [1, 2]. Permissible road noise levels in Poland depend on land use and range from 64 to 70 dB for the noise level of the day and night and from 55 to 65 dB for noise at night in urban areas. The most commonly used means of protection in Poland are acoustic screens [3]. The sound absorption of noise barriers is one of the main factors that determine their effectiveness [4, 5]. In terms of acoustic effectiveness, an appropriate design process of acoustic protection facilities requires designers to have information about their sound-absorbing and sound-insulation properties. Such parameters are obtained based on laboratory tests for properly prepared test samples [6–10]. Knowledge of the acoustic parameters of acoustic panels and a suitable design of their geometry allow proper shaping of protection facilities against environmental noise.

The presented sound absorption parameters are directly the result achieved in laboratory tests by a given method and size of perforation, but obviously in real calculations such an approach should be followed. Knowing the screen parameters, as well as other important data, such as road parameters or the shape of the terrain with buildings, you can proceed to modeling and simulation, which are described in detail in the French guidelines [11].

2. Description of tested samples

Absorption tests were carried out for five test samples (Fig. 1) consisting of acoustic panels containing two types of sound-absorbing materials secured with slats (PANEL FR and PANEL RI) and external lining with two degrees of perforation: 5% (PANEL FR5) and 23% (PANEL FR23 and PANEL RI23) across the entire surface. The sample containing the structural diagram is shown in (Fig. 1), was placed on the floor of the reverberation chamber in accordance with the recommendations for the assembly method A (Fig. 2) defined in the standard [6]. The sample was mounted in the reverberation chamber for 24 hours prior to taking measurements to equalize and stabilize the temperature and humidity. The tested samples had the following dimensions: 380 × 293.5 × 11 cm with an area of 11.15 m^2. The elements subjected to tests comprised in their structure a pole HEB 160 with a length of 2.935 m, according to the recommendations [6] presented in (Fig. 4). The edge of the tested sample was shielded with a wooden frame and sealed with tape. The noise absorption coefficient α_{si} were carried out using the intermittent noise method in accordance with the guidelines contained in the standard [9].

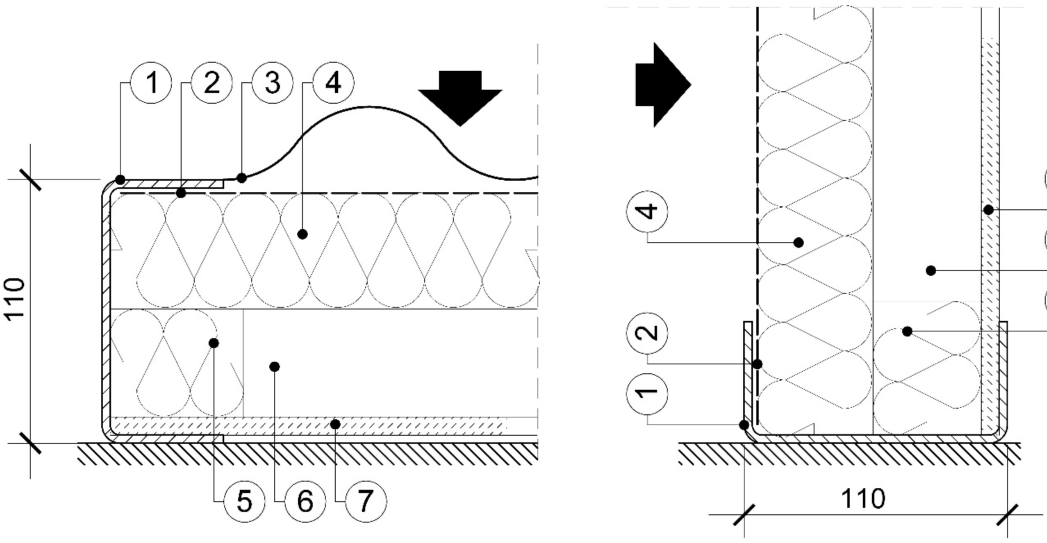

Figure 1. Schematic representation of the structure of the panels tested. The arrow indicates the top side of the screen (subject to a sound absorption test). Other markings in the drawing:
1 – steel channel bar; 2 – protective fabric; 3 – corrugated perforated fiber-cement board, 6 mm thick; 4 – mineral rock wool, 50mm thick and a density of 80 kg/m^3 for the FR sample and a density of 31 kg/m^3 for the RI sample; 5 – mineral wool used as a spacer, 50mm thick and a density of 80 kg/m^3 for the FR sample and a density of 31 kg/m^3 for the RI sample; 6 – air gap, 50 mm thick; 7 –fiber cement board, 10 mm thick.

a) b)

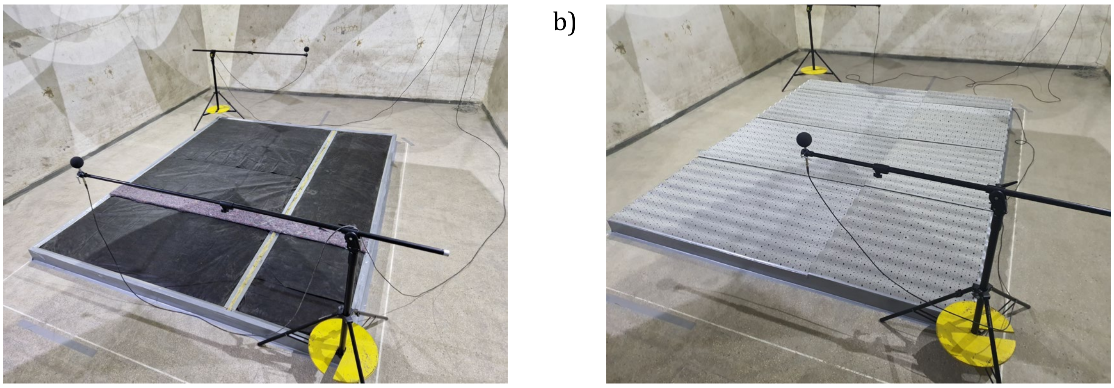

Figure 2. View of the test samples mounted in the reverberation chamber: a) sample without outer lining, b) sample with perforated outer lining.

3. Laboratory tests

To determine the appropriate reverberation time in an auditorium, office, or production hall, and to reduce noise with the use of sound-absorbing means and systems, it is essential to know the acoustic absorption characteristics of individual surfaces. The standard [9] presents a uniform method and conditions for the measurement of sound absorption in reverberation chambers and the calculation of the sound absorption coefficient α_S, while the conversion of frequency-dependent values of the sound absorption coefficient α_S into one number is carried out using the procedures described in the standard [10]. The measured values of the sound absorption coefficient for individual 1/3 octave bands are converted into the calculated (practical) sound absorption coefficient α_p for the octave bands and into the single-number sound absorption coefficient α_w.

The tests of absorbing properties of materials or construction elements are carried out in a reverberation chamber on a specially prepared test sample. The diagram of the laboratory structure is presented in (Fig. 3) and the preparation method of the sample for testing is presented in (Fig. 2). The test consists in determining the reverberation time for an empty chamber and for a chamber with the mounted test sample. The results obtained on the basis of the measurements are processed and, in the final stage, the single-number sound absorption index $DL_{\alpha NRD}$.

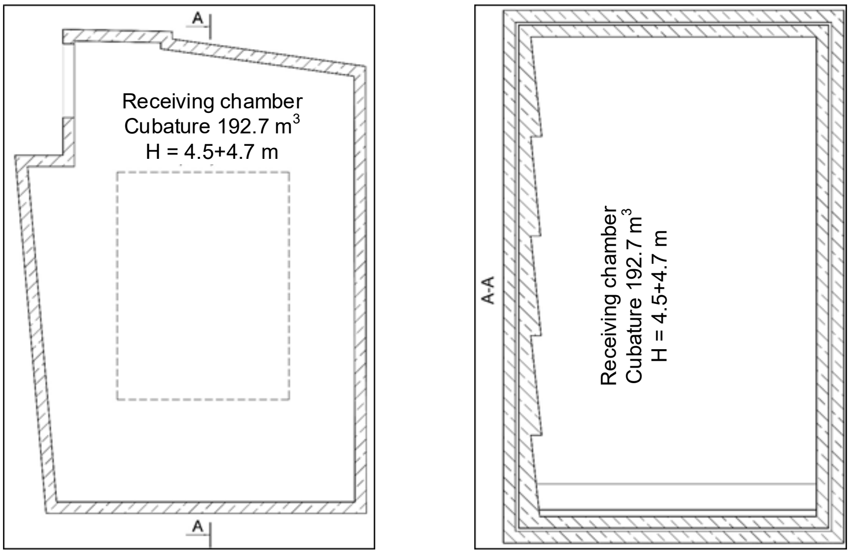

Figure 3. Schematic of the reverberation chamber.

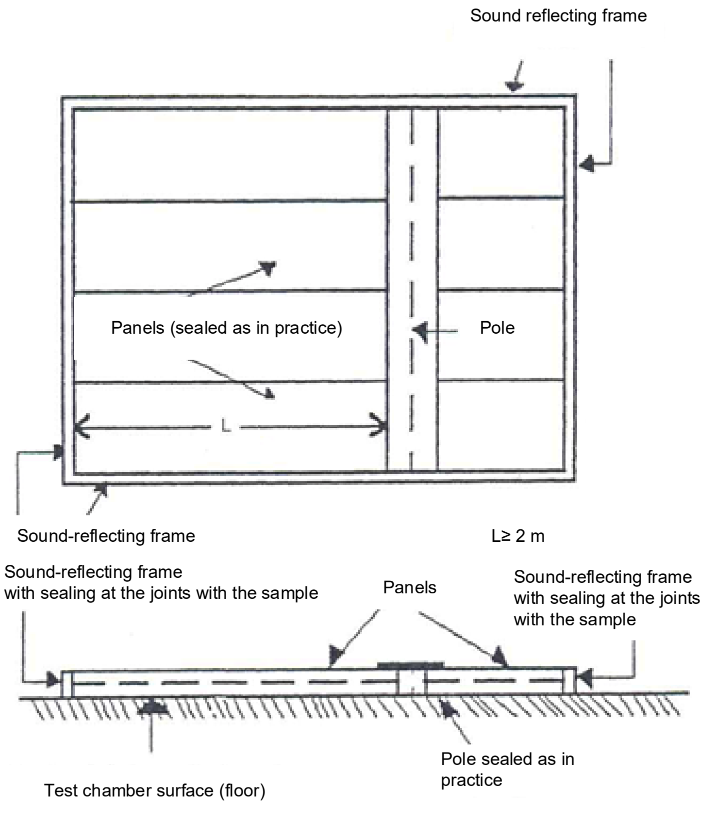

Figure 4. Schematic of the sample for the sound absorption index tests [6].

4. Research results

A reliable feature involving the evaluation of the acoustic properties of road noise barriers is the single-number sound absorption rating index $DL_{\alpha NRD}$, used to determine the absorption properties of the acoustic screen that in its design contains structural elements and filling elements. Laboratory tests carried out were the basis for determining the reverberation coefficient of sound absorption α_{si} and the single-number sound absorption coefficient $DL_{\alpha NRD}$. The summary of the obtained results is presented in the tables (Tables 1 and 2) and in the graphs (Figs. 5 and 6).

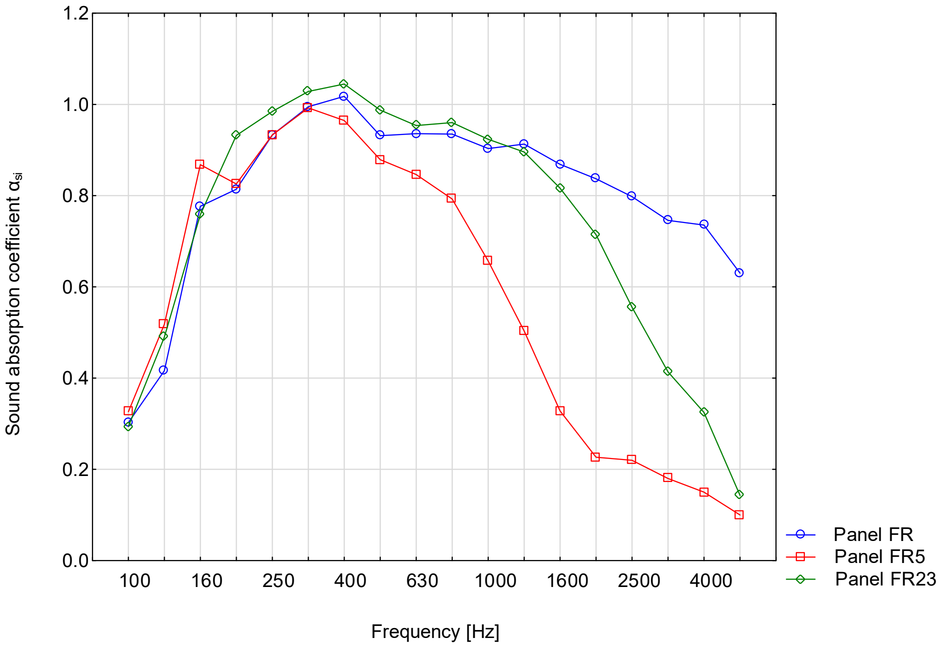

Figure 5. Sound absorption coefficient values for panels containing sound absorbing material FR without lining and with perforated lining of 5% and 23%.

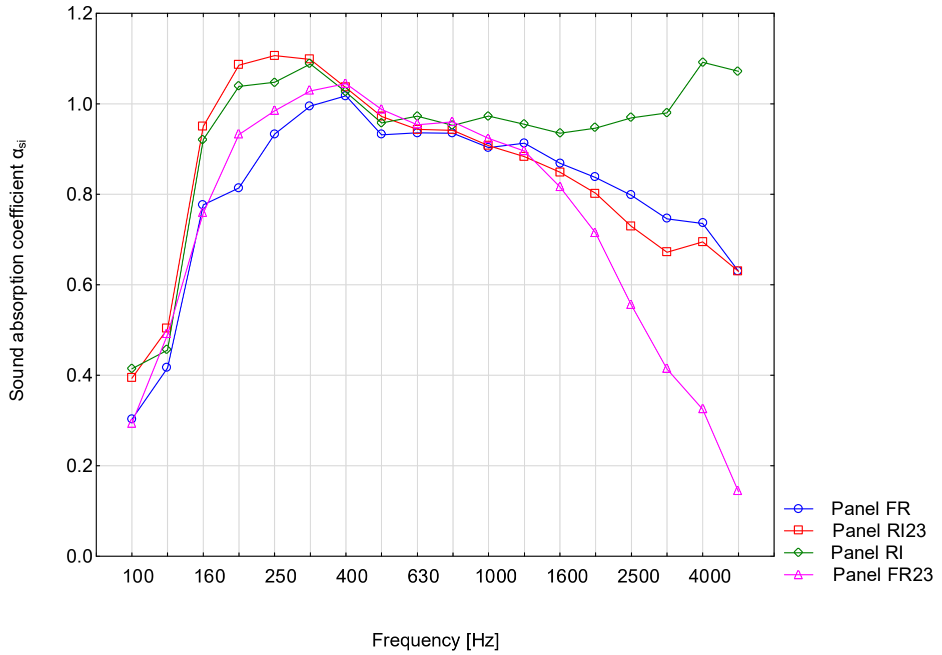

Figure 6. Values of sound absorption coefficient values for panels containing sound absorbing material FR and RI without lining and with lining with perforation of 23%.

Based on the graph presented in Fig. 5, it is clear that for a sample containing mineral wool FR with a density of 80 kg/m^3, for low frequencies in the range of 100 – 500 Hz, the coefficient values are similar, while for high frequencies in the range of 1000 – 5000 Hz, panels with perforations of 5% and 23% lose their sound-absorbing properties. A similar phenomenon occurs in the case of a sample containing RI mineral wool with a density of 31 kg/m^3, however, they are higher. An interesting phenomenon is the fact that the FR sample without the lining in the frequency range of 400 – 5000 Hz has similar absorption characteristics as the RI sample with 23% perforation. Therefore, it can be seen that the value of the absorption coefficient depends both on the type of mineral wool and the degree of perforation of the outer cladding, which can be seen in Fig. 6. This is also confirmed by the values presented in Tables 1 and 2, where the FR sample without the cladding reaches the value $DL_{\alpha NRD}$ = 9 and α_w = 0.85, while the RI sample containing 23% perforation $DL_{\alpha NRD}$ = 10 and α_w = 0.80.

Table 1. Results of the single-number sound absorption index $DL_{\alpha NRD}$.

Name	$D_{L\alpha NRD}$
PANEL FR	9
PANEL FR5	4
PANEL FR23	8
PANEL RI	15
PANEL RI23	10

Table 2. Results of the single-number sound absorption index α_w.

Name	α_w
PANEL FR	0.85
PANEL FR5	0.10
PANEL FR23	0.50
PANEL RI	1.00
PANEL RI23	0.80

5. Computer simulations

5.1. Characteristics of the analyzed noise source

A section of DK81 in Łaziska Górne (0.79 km long) was the transport corridor subjected to analysis. It is a fragment of an approximately 60 km long four-lane transit road, the so-called "Wiślanka", connecting the Upper Silesian conurbation with the Silesian Beskids, which starts in Katowice (from the A4 motorway) and ends at the intersection with the S1 expressway at Harbutowice, a village in the Skoczów municipality.

The transport corridor under consideration is an extra-urban two-lane dual carriageway with a median, in very good technical condition after the road pavement renovation, and has the following parameters:
a) technical class: GP (main road for accelerated traffic),
b) allowed speed: 70 km/h,
c) roadway width – 2 × 7.00 m,
d) the width of the median strip: variable, from 3.6 to 5.0 m, including reinforced shoulders of 2 × 1.25 m.

5.2. Characteristics of areas protected from noise

The vicinity of the DK81 road, in terms of planning conditions, was analyzed along the strip approximately 150 m from the edges of the road, based on the local spatial development plan approved by resolution of the City Council of Łaziska Górne [16]. Along the investigated section, the DK81 road is marked in the local development plan with the symbol: C1KDGP – main road for accelerated traffic, and in the vicinity of the road in the analyzed area, the following areas requiring protection against noise were identified: A95MU, A100MU, and A105MU, residential and service development areas. The acceptable standards based on the Regulation of the Minister of Environment of June 14, 2007 on acceptable noise levels in the environment [14] for areas with the symbol MU are as follows:
a) daytime (6^{00} – 22^{00}) – 65 dB,
b) night time (22^{00} – 6^{00}) – 56 dB.

5.3. Methods and assumptions adopted for calculations

To present the impact analyzed from the DK81 road section, a graphical representation of the distribution of acoustic climate in its vicinity was used. The impact on the acoustic climate of the DK81 neighborhood was developed based on simulation calculations, using the model of the existing terrain according to the resources of Head Office of Geodesy and Cartography, taking into account traffic factors (vehicle density, speed, and percentage of heavy vehicles), noise source geometry and the development state of the areas adjacent to the road in the 3D model. Numerical calculations were made using the SoundPlan package and the NMPB (Guide du Bruit) noise emission model based on the PN standard ISO 9613-2 'Acoustics.' Sound attenuation during propagation in open space [13]. The noise and traffic intensity measurements carried out at reference points for the existing transport system were applied to calibrate the adopted calculation model and were used to calculate the actual ranges of noise impact. Since there was no available national method for analyzing the acoustic climate, the French national calculation method "NMPB-Routes - 96 (SETRA-CERTU-LCPC-CSTB)" was applied, defined in "Arrêté du 5 mai 1995 relatif au bruit des infrastructures routières, Journal Officiel du 10 May 1995, art. 6 'and in the French standard "XPS 31-133" – in accordance with Annex II of Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 [12], pertaining to the assessment and management of environmental noise levels. The method uses the emission values from the "Guide du bruit des transports terrestres, fascicule prévision des niveaux sonores, CETUR 1980" as input data. The mentioned emissions comprise different traffic conditions both with steady traffic and when traffic accelerates or decelerates.

Sound emission is calculated on the basis of the formula:

$$E = (L_w - 10\log V - 50), \tag{1}$$

$$L_w = L_p + 25.5, \tag{2}$$

where: E – sound level, L_w – sound power level, V – vehicle speed. The sound power level L_w and the sound emission E used in the XPS 31-133 standard, as detailed in the "Guide du bruit 1980", are calculated as functions of the sound pressure level L_p and the vehicle speed V using formula (2).

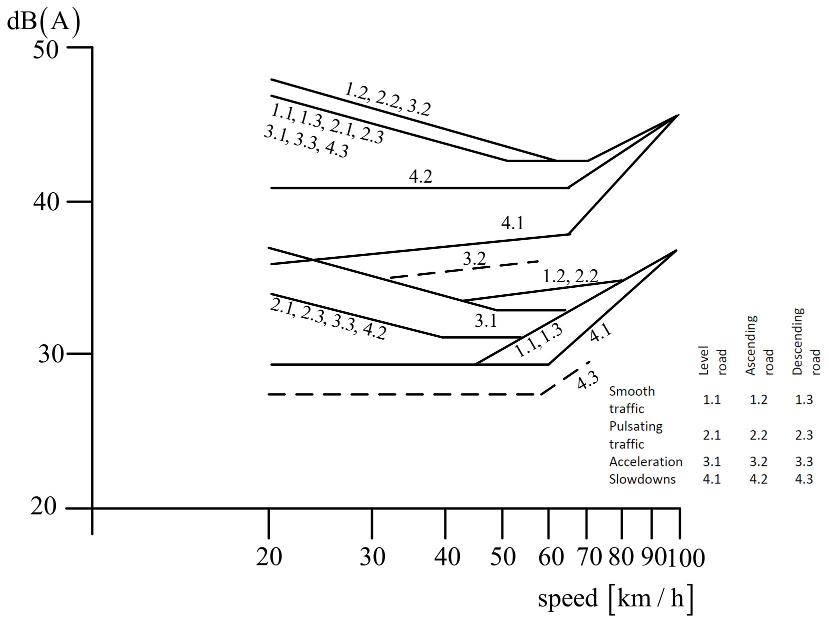

Figure 7. Nomogram to determine the input noise level according to the NMPB [15].

The "Guide du brutt 1980" contains nomograms showing the value of sound level L_{Aeq} (one hour) in [dB]. Quantity (A) specifies separately the emissions for light vehicles (E_{lv} sound emission) and heavy vehicles (E_{hv} sound emission) per hour. For these two categories of vehicles, E is a function of speed, traffic volume, and road gradient [11]. The L_{AWi} sound power level of an elementary source is calculated on the basis of the following:

$$L_{AWi} = [(E_{VL} + 10\log Q_{VL}) \oplus (E_{PL} + 10\log Q_{PL})] + 20 + 10\log(l_i) + R_{(j)}, \tag{3}$$

where: ⊕ – a symbol for adding sound levels, E_{VL} – sound level specified for light vehicles (Fig. 7), E_{PL} – sound level specified for heavy vehicles (Fig. 7), Q_{VL} – hourly flow of light vehicles for a given time period, Q_{PL} – hourly flow of heavy vehicles for a given time period, l_i – length of the line source section, representing a single point source, $R_{(j)}$ – road noise spectrum A determined on the basis of the European Standard EN 1793 - 3:1997, i – index of the point source, j – index of the spectrum band of road noise.

5.4. Calculation results

Acoustic calculations were carried out on a regular receptor grid with a side of 10 × 10 m at a height of 4 m above the ground level, which produced noise maps, and based on the obtained maps, for the current land development, the ranges of permissible noise levels (without protection) were plotted for daytime and nighttime. The calculation model was calibrated with the results obtained from the measurements, and the difference between the measured and calculated levels is within the range of 2.5 dB, which confirms the accuracy of the verification of the calculation model when using the theoretical calculation methodology according to the recommendations contained in the regulation [17]. The calculation results without acoustic protection and after its application (PANEL RI23) are presented in Fig. 8.

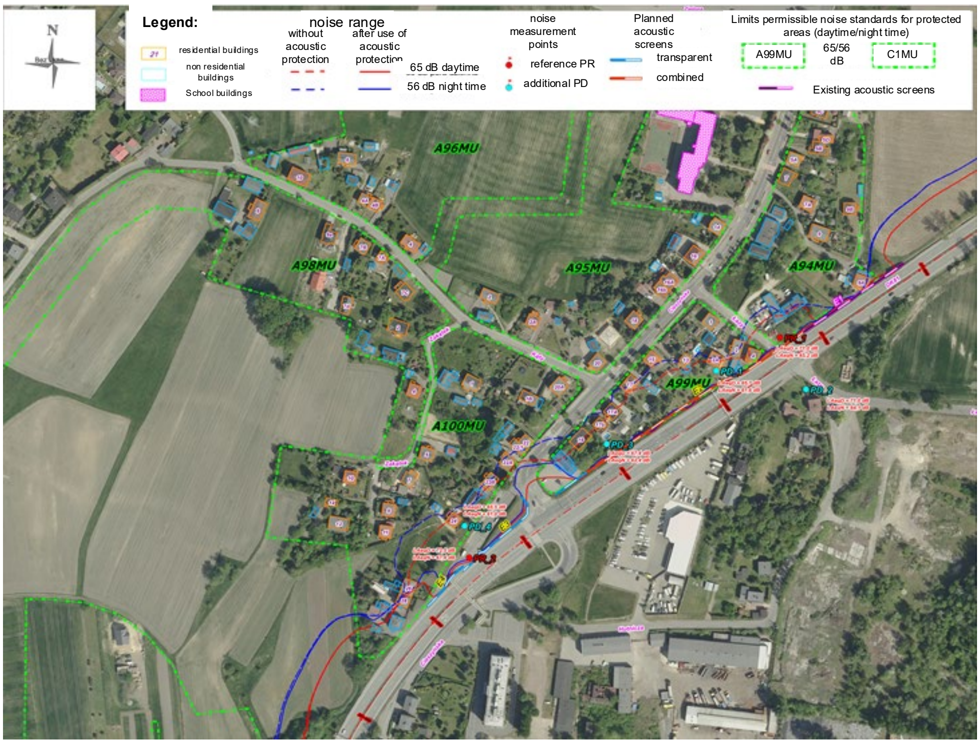

Figure 8. Map of noise impact ranges at a height of 4 m above sea level without and after the use of acoustic protection in the form of a combination of RI23 PANELS and TRANSPARENT PANELS.

6. Conclusions

The article presents research studies on acoustic panels made of sound-absorbing and reflective materials with holes. The adopted solution makes it possible to incorporate the pole into the structure, and the holes in the external lining allow the screen to be planted with vegetation, which means that this protection can be perfectly integrated into the surrounding environment. When analyzing the results obtained from laboratory tests, we can observe that the combination of sound-absorbing material encapsulated with perforated elements yields acoustic parameters obtained in the form of the single-number sound absorption index $DL_{\alpha NRD}$ ranging from 4 – 10 dB. A sample containing FR mineral wool with a density of 80 kg/m^3 for low frequencies in the range of 100 – 500 Hz, the coefficient values are similar, while for high frequencies in the range of 1000 – 5000 Hz, panels with 5% and 23% perforations lose their sound-absorbing properties. The FR sample without lining in the frequency range of 400 – 5000 Hz has absorption characteristics similar to the RI sample containing 23% perforation. Therefore, the value of the absorption coefficient depends on the type of mineral wool and the degree of perforation of the outer lining. This is also confirmed by the single-number values that describe the sound-absorbing properties. The FR sample without the padding achieves $D_{L\alpha NRD}$ = 9 and α_w = 0.85, while the RI sample with 23% perforation $DL_{\alpha NRD}$ = 10 and α_w = 0.80. Analysis of the results obtained from numerical calculations, after application of such a solution, confirms that it is possible to implement screens that effectively protect protected areas from the impact of traffic noise. The effectiveness of the acoustic screen depends primarily on the mutual location of the noise source, the reception point, i.e. its height above the ground level, distance from its plane, and geometric shape.

Additional information

The author(s) declare: no competing financial interests, and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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