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Effectiveness of the Simulation of Acoustic Protection for a Specific Urban Situation

Artur Nowoświat[1*], Rafał Żuchowski[1], Bartłomiej Pudełko[1]

[1] Department of Building Processes and Building Physics, Faculty of Civil Engineering, Silesian University of Technology, Akademicka str. 5, 44-100 Gliwice, Poland
[*] Corresponding author, e-mail: artur.nowoswiat@polsl.pl

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Abstract
The present article is addressing the problem of street noise investigation in urban agglomeration and the simulation of protection devices against noise. Noise levels were measured in the vicinity of the national road in Bieruń, Silesia in Poland. The publication attempts to assess the acoustic climate between a roundabout and an intersection. Based on the measured noise, the acoustic mapping was made in the SoundPlan program. The range of noise impact from the examined road section was determined. Finally, two concepts of preventive measures limiting the excessive impacts on the environment were presented, along with the indication of the impact on building development, business operations as well as transport links and traffic.
Keywords
traffic noise, noise pollution, noise mapping, acoustics screens

1 Introduction

Noise pollution in urban agglomerations is associated, among others, with the rise of urban population and the resulting increase in the number of vehicles (Mohammadi, 2009, Zannin et al., 2013). The spectrum of noise emitted by a vehicle depends on the type of vehicle and its speed (Yang et al., 2020). Traffic has a significant impact on noise level in the vicinity of building facades (Nowoświat et al., 2018).

In the analysis of noise pollution and during the design process of noise reduction devices, a great role is played by noise mapping (Guedes et al., 2011). To ensure reliable prediction of acoustic comfort, simulation programs of appropriate accuracy are indispensable (Janczur et al., 2009). Many countries and regions are developing their own models for predicting road noise. One of the first models was developed in 1952 by Bolt et al. (Bolt et al., 1952). Since then, many other noise models have been developed and then optimized and improved (Li et al., 2016, Estévez-Mauriz and Forssén, 2018, Gardziejczyk and Motylewicz, 2016). To estimate sound quality in the environment, street noise models are applied (Di et al., 2018, Hou et al. 2017), which indicate the exposure level of residents to such noise (Cai et al., 2019). The calculation models take into account the speed of the vehicle or traffic intensity, while the dynamics of vehicle traffic on the roads are ignored, which is often replaced by a correction factor (De Coensel et al., 2007). In many studies noise from several sources is examined (Aletta and Kang, 2015, Aumond et al., 2018) as a sampling at the measurement site of real sources in the urban environment (Chew and Wu 2016). With respect to noise mapping which is based on measurements, it is necessary to perform spatio-temporal sampling (Quintero et al., 2019). Therefore, in order to improve the sampling process, the literature offers techniques for estimating long-term noise levels based on short-term measurements (Safeer et al., 1972, Gaja et al., 2003, Quintero et al., 2018). In view of the problems of noise pollution generated by transit road systems, the present article proposes noise protection solutions in a typical Polish town without a beltway, being part of the Silesian agglomeration with a population of about 4.5 million.

2 Materials and methods

The Silesian agglomeration has the largest concentration of people in Poland. This agglomeration is located in the southern part of the country (Fig. 1).

The investigation involved a section of the national road DK 44 in Bieruń, about 2 kilometers long.

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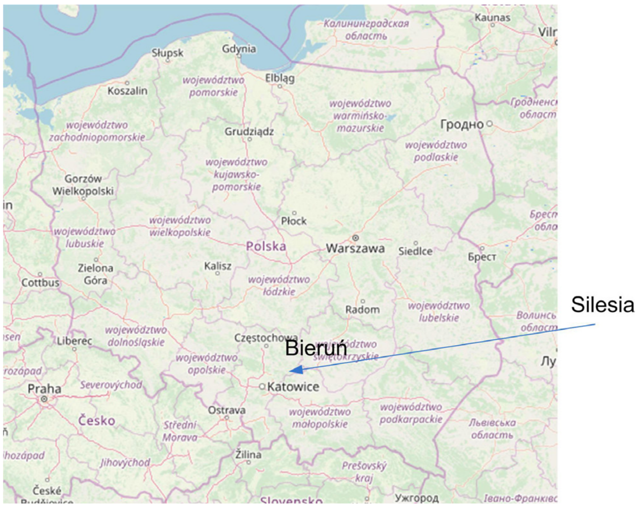

Fig. 1 Silesian agglomeration against the background of the map of Poland

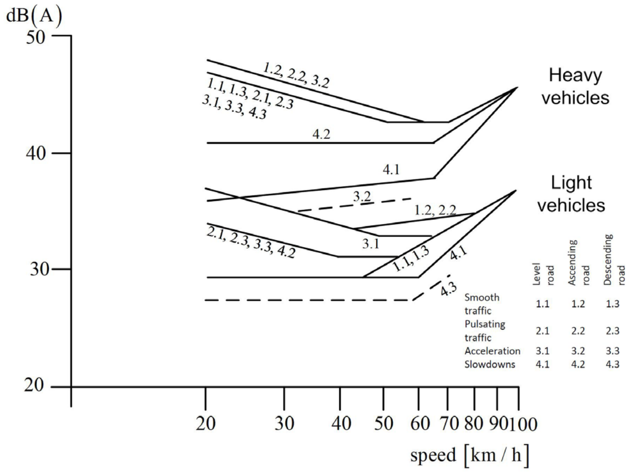

Fig. 2 Nomograph used to determine the level of input noise acc. NMPB (Lebiedowska, 1988)

2.1 Acoustic map

Acoustic maps are very important tools for analyzing environmental noise (Lee et al., 2008, Tsai et al., 2009, Bunn and Zannin, 2016). Noise maps were calculated using SoundPlan software (Szwarc et al., 2011). Simulation calculations were developed using the existing terrain model, in line with the resources of the Main Office of Geodesy and Cartography in Warsaw, including traffic factors (intensity of vehicle traffic, speed and percentage of heavy vehicles) and noise source geometry. Numerical calculations were made using the Guide du Bruit NMPB noise emission model. To calibrate the adopted calculation model and to calculate the actual ranges of noise impact, we applied the measurements of noise, traffic intensity and speed at the reference points for the existing communication system (Fig. 2). In line with the said method, the emission of sound was calculated based on the following formula:

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

where V – speed of vehicle [km/h].

The level of acoustic power L_w and the emission of sound E are calculated, depending on the level of acoustic pressure L_p and vehicle speed V, using Eq. (2):

$$L_W = L_p + 25\,. \tag{2}$$

The level of acoustic power L_{AWi} of the elementary source is calculated from the following relation:

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

where:

$\oplus$ – a symbol used for adding up the levels of sound,
E_{VL} – sound level defined for light vehicles,
E_{PL} – sound level defined for heavy vehicles,
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_j – length of the section of linear source, representing a single point source,
$R(j)$ – spectrum of traffic noise A, defined on the basis of the European norm.

The SoundPlan program used to perform computational simulations is equipped with modules for 3D modeling of the environment, for calculations and presentation of the acoustic field distribution in the form of noise maps. The calculations are carried out using the assumed meteorological conditions that affect the propagation of environmental noise. The algorithm for finding the paths of sound wave propagation between the source and the recipient is based on the assumption of a linear noise source.

2.2 Description of noise source and its neighborhood

2.2.1 Characteristics of noise source

The investigated transport corridor is a municipal single-carriageway road, being a section of about a 100 km-long transit GP-class two-lane road, running through the Śląskie and Małopolskie voivodships, connecting Upper Silesia with Krakow, having the following parameters:

- technical class: GP class road,
- admissible speed: 50 km/hour,
- road width –2 × 3.5 m,
- reinforced shoulders: 2 × 0.5 m.

Fig. 3 Map with the location of the national road and neighbouring areas

The location of the analyzed section of DK44 and the adopted noise measurement points are presented in Fig. 3.

2.2.2 Characteristics of the existing development

The investigated section of DK44 running along the direction north-west - south-east is located in the southern part of the town. The areas adjacent to the discussed section are primarily of housing and service building development types. There are also educational areas in the immediate vicinity of the road. The existing buildings have a street-along layout, which sometimes turn into a dispersed layout, they are directly adjacent to DK44 and to cross streets in the vicinity of intersections, or they are further away from the road. In terms of elevation, DK44 along this section runs at the level of the neighboring areas, in places on a small embankment and has direct connections with the local road network:

- km 7 + 750 intersection in the form of a roundabout with the streets Granitowa and Węglowa - beginning of the section,
- km 8 + 330 left-hand-side intersection, entry/exit Dąbrówki Street,
- km 8 + 330 intersection entry/exit with Węglowa and Solecka Streets - the end of the section.

2.2.3 Acoustic characteristics of protected areas

The neighborhood of the DK44 road in terms of planning determinants was analyzed in the 300m buffer, about 150 m away from the edges of the road, within which there are areas defined in local land use plans and approved by the resolutions of the Bieruń City Council:

- Resolution No. V/4/2007 of the City Council in Bieruń of 29.05.2007, *on the adoption of the local spatial development plan for the area located in the vicinity of streets Warszawska, Węglowa and Mieszko I*,

The section from the roundabout to the DK44 intersection with Solecka Street is defined in the Local Spatial Development Plan with the symbol: 1GP - as the area of main class public roads. In the immediate vicinity of the road, in the analyzed area, the following areas requiring noise protection were identified:

- (MN/U) - areas of single-family housing and service building development,
- (MN) - areas of single-family housing,
- (MW) - areas of multi-family residential development,
- (UO) - areas of education services.

2.2.4 Traffic characteristics

The traffic volume on the DK44 national road was measured simultaneously with the noise measurements in the period of 27–28 February, 2019 and 6–7 March, 2019. The measured daily traffic volume and the percentage of heavy vehicles on individual days are as follows:

- 27/28.II.2019 - **18,413 PR/day**, **11.7%** share of heavy vehicles (PPH_1/2),
- 06/07/07/2019 - **18,499 PR/day**, **12.2%** share of heavy vehicles (PDH_4/2).

Based on the document "Developing a program framework for the project ref. as Construction of the S1 express road", the traffic forecast for 2023 was adopted at **12900 PR/day**, with the **12.3%** share of heavy vehicles. The value of average daily traffic volume was determined on the basis of Fig. 4. Traffic distribution on the nodes was presented for the peak hour. The share of peak time in the average daily traffic was determined for 50 hours

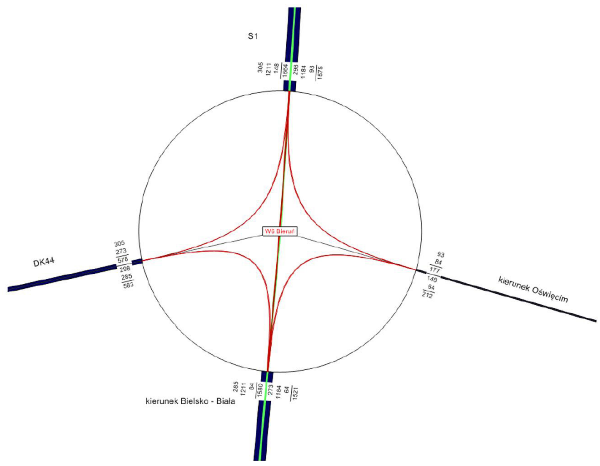

Fig. 4 Traffic volume distribution at the Bieruń node per veh/hour for the traffic forecast in 2023 after the construction of road S1 along the section from the node Kosztowy II in Mysłowice to the node Suchy Potok in Bielsko-Biała

a year, and it amounts to 9% of daily traffic. The analysis of the changes in traffic intensity on the analyzed section of DK44 was based on the comparison of the current traffic measurements in 2019 at PPH_1/2 with the results obtained in 2015. In the GPR measurement on this section, SDR was **16,998 veh./day** with the 19.1% share of heavy vehicles (3246 veh.), which demonstrates that within 4 years the traffic volume increased by approx. 7%, with a slight decrease of heavy vehicles.

2.3 Measuring method

Noise measurements in the vicinity of DK44 in Bieruń were carried out using the direct method of continuous measurements for a limited time of one day. Two categories of measuring points were adopted: reference (PPH_) and additional (PDH_). The run of the instantaneous sound level A with the sampling time of 1 second in time-based mode was recorded in the memory of the measuring instrument. During the measurements, the volume and structure of vehicle traffic on the DK44 road were measured, the prevailing weather conditions were recorded, and the speed of passing vehicles was measured. The acoustic signal recorded for storage, covering the period of 24 h, after being downloaded to a desktop computer, was processed with proprietary software used for precise elimination of acoustic events not related to the measured source of noise (e.g., noises made by people, passage of privileged vehicles, etc.), and then, for the material prepared in that way, daily noise indicators L_{AeqD} and L_{AeqN} were calculated.

3 Results and discussion

A summary of the measurement results and their comparison with the permissible sound levels in Poland is presented in Table 1. At the measurement points, which were located in the vicinity of building facades, the final result was reduced by a correction value of 3 dB. To protect the areas located in the vicinity of DK44, two concepts of acoustic protection were developed in the following variants:

- **VARIANT 1** - construction of **1425.5 m** of new acoustic screens of the height of **5.0 m ÷ 8.0 + 1.5 m (45°)** of straight and bent geometry, including **609.0 m** of full screens from absorbing panels, **776.5 m** of combined screens from absorbing and transparent panels, and **40.0 m** of reflecting screens from transparent panels, in the locations in line with the list in Table 2.
- **VARIANT 2** - the use of quiet asphalt pavement BBTM8-B of the total length of **840.0 m** and relevant speed adjustment of vehicles, in locations in line with the list given in Table 3.

The exceeding of permissible sound levels indicates that newly constructed screens should, in line with the standards [1, 2, 3, 4], be characterized by a single-number indicator of the assessment of acoustic insulation from air sounds ($D_{LR} \geq 30$ dB) which are contained within B3 airborne sound insulation class, while the absorbing screens should have the highest absorption properties - a single-number indicator for the assessment of sound absorption contained in class A4 ($D_{Lα} \geq 12$ dB). These parameters apply to the entire screen structure.

The acoustic calculations were carried out in a regular receptor grid of a side measuring 10 × 10 m at the height of 4 m above the ground level, which yielded noise maps, based on which, for current land use, ranges of noise levels (without protection devices) for daytime and nighttime were plotted, as presented on the maps in the scale 1: 2000.

Fig. 5 presents the map of noise impact ranges in 2019 before and after the application of acoustic protection - daytime and nighttime - **VARIANT 1**.

Fig. 6 presents the map of noise impact ranges in 2019 before and after the application of acoustic protection - daytime and nighttime - **VARIANT 2**.

Table 1 Summary of measured noise levels at reference points and at additional points in the vicinity of DK44 in Bieruń, including correction due to the location of the measuring point neat building facade

Point No	Location	Type of area acc. to local spatial development plan	Permissible level day/night	Values (measured) of the equivalent sound level *LAeq*, [dB]		Exceeded permissible limit Δ*L* = *LAeq* − *LAdop* [dB]	
				day	night	day	night
PPH_1/2	Reference point	1GP	-	68.6	64.8	–	–
PDH_1/2	Warszawska 226	D6.MN/U	65/56	60.6	56.7	–	0.7
PDH_2/2	Warszawska 236	D9.MW	65/56	65.2	61.5	0.2	5.5
PDH_3/2	Warszawska 223	B13.MN	61/56	62.8	59.2	1.8	3.2
PDH_4/2	Warszawska 258	D16.MW	65/56	66.2	62.9	1.2	6.9

Table 2 Summary of the proposed acoustic screens in the vicinity of DK44 in Bieruń - VARIANT 1

Screen No	Road side	Mileage		Screen parameters		Screen type - filling
		Start of screen [km]	End of screen [km]	Summary length of screen [m]	Height of screen (*) [m]	
EL - 10	left	7+831.6	7+870.6	39.0	5.0	Absorbing - full
EL - 11	left	7+878.2	7+932.2	53.8	5.0	Absorbing - full
EL - 12	left	7+942.0	7+960.2	18.5	5.0	Absorbing - full
EL - 13	left	7+973.3	8+014.7	40.0	5.0	Reflecting - transparent
EL - 14	left	8+020.6	8+039.9	18.5	5.0	Absorbing - full
EL - 15	left	8+044.0	8+061.5	17.5	5.0	Absorbing - full
EL - 16	left	8+067.2	8+079.3	12.0	5.0	Absorbing - full
EL - 17	left	8+086.8	8+102.8	16.0	5.0	Absorbing - full
EL - 18	left	8+111.1	8+206.5	87.3	5.0	Absorbing - full
EL - 19.1	left	8+219.5	8+251.5	32.1	5.0	Absorbing - full
EL - 19.2	left	8+258.5	8+269.8	11.3	5.0	Absorbing - full
EL - 19.3	left	8+277.5	8+287.7	10.6	5.0	Absorbing - full
EL - 20	left	8+290.6	8+322.2	31.6	5.0	Absorbing - full
EL - 21	left	8+328.6	8+344.8	25.5	5.0	Absorbing - full
EL - 22.1	left	8+354.5	8+404.0	51.6	5.0	Absorbing - full
EL - 22.2	left	8+409.3	8+450.9	41.6	5.0	Absorbing - full
EL - 23	left	8+456.8	8+470.6	14.0	5.0	Absorbing - full
EL - 24	left	8+478.4	8+504.9	28.8	5.0	Absorbing - full
EL - 25	left	8+510.5	8+525.2	14.6	5.0	Absorbing - full
EL - 26	left	8+533.9	8+614.9	84.7	5.0	Absorbing - full
EP - 4	right	7+788.4	7+821.4	38.5	5.0	Absorbing - Combined
EP - 5	right	7+827.6	8+021.0	191.0	5.0	Absorbing - Combined
EP - 6	right	8+031.6	8+125.6	92.7	6.5	Absorbing - Combined
EP - 7	right	8+165.0	8+202.1	28.5	6.5	Absorbing - Combined
EP - 8.1	right	8+203.3	8+313.5	11.,5	6.5	Absorbing - Combined
EP - 8.2	right	8+319.8	8+325.8	6.0	6.5	Absorbing - Combined
EP - 8.3	right	8+328.5	8+429.3	100.3	6.5	Absorbing - Combined
EP - 8.4	right	8+421.5	8+511.2	88,.5	5.0	Absorbing - Combined
EP - 8.5	right	8+516.0	8+538.2	23.5	6.0	Absorbing - Combined
EP - 8.6	right	8+532.5	8+614.5	81.5	8.0 + 1.5 m /450	Absorbing - Combined
EP - 8.7	right	8+608.0	8+614.2	13.5	8.0 + 1.5 m /450	Absorbing - Combined

(*) height is counted from road level.

Table 3 Summary of the proposed sections with the quiet pavement on the DK44 in Bieruń - VARIANT 2

Section No	Mileage		Pavement parameters		Type of quiet pavement	Speed Light veh. [km/h]	Speed Heavy veh. [km/h]
	Start of section [km]	End of section [km]	Summary length [m]	Reduction of acoustic power level [dB]			
DK44	7+780.0	8+620.0	840.0	- 6.0	BBTM8 - B	40.0	40.0

The calculation model correlates well with the results obtained from the measurements (Table 4), and the measurement uncertainty is ≤2.5 dB.

In the protected areas in the vicinity of the DK44 national road, its excessive impact currently comprises 47 (22 + 25) residential buildings located in the areas with established noise standards.

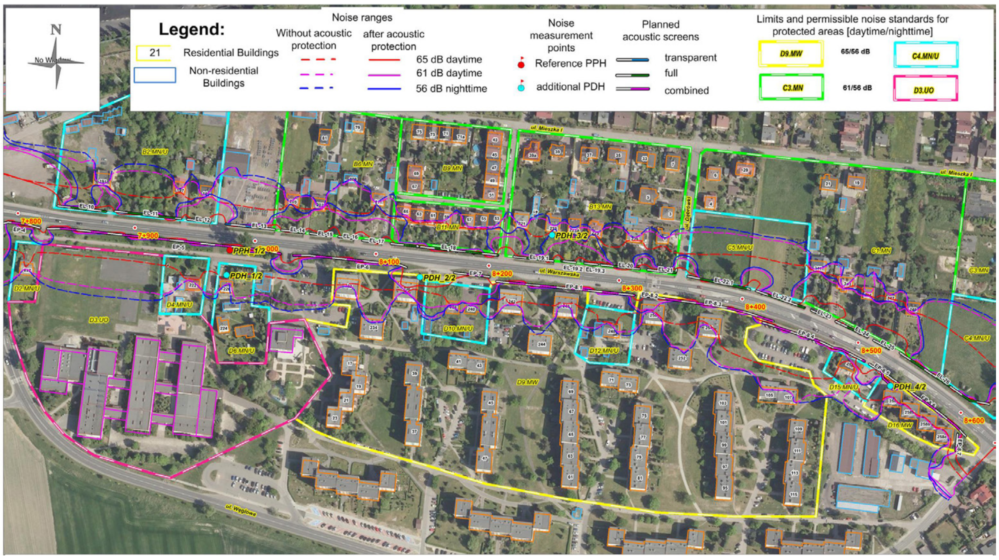

Fig. 5 Map of noise impact ranges at the height of 4 m above ground level before and after the application of acoustic protection in the form of screens

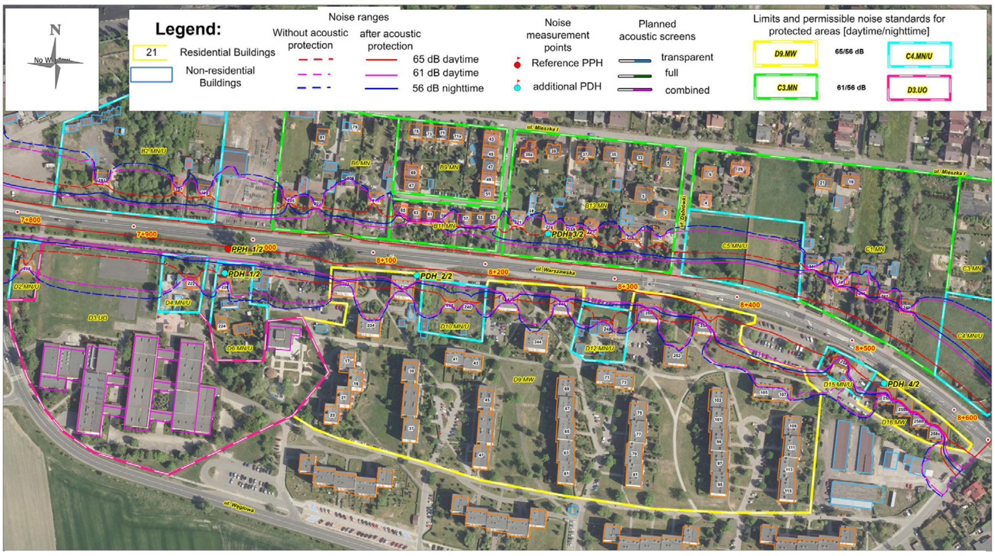

Fig. 6 Map of noise impact ranges at the height of 4 m above ground level without and after the application of noise protection in the form of a quiet pavement

Table 4 Summary of calculated levels at reference points and at additional points of DK44 in Bieruń - EXISTING CONDITION, YEAR 2019

Point No	Location	Permissible level day/night	Measured Values of equivalent sound level *LAeq*, [dB]		Calculated values of equivalent sound level *LAeq*, [dB] Year 2018		Difference of measured calculated noise levels [dB]	
			day	night	day	night	day	night
PPH_1/2	Reference point	-	**68.6**	**64.8**	**69.6**	**65.6**	-1.0	-0.8
PDH_1/2	Warszawska Street 226	65/56	**63.6**	**59.7**	**64.5**	**60.5**	-0.9	-0.8
PDH_2/2	Warszawska Street 236	61/56	**68.2**	**64.5**	**68.7**	**64.7**	-0.5	-0.2
PDH_3/2	Warszawska Street 223	65/56	**65.8**	**62.2**	**65.8**	**61.8**	0.0	0.4
PDH_4/2	Warszawska Street 258	65/56	**69.2**	**65.9**	**70.1**	**65.6**	-0.9	0.3

4 Conclusions

Analyzing the results of the performed acoustic analysis in the vicinity of the existing national road DK44 in Bieruń from km 7 + 780 to km 8 + 620, involving the impact on the acoustic climate of the areas and objects subject to protection in its vicinity and the concept of acoustic protection made in two variants, the following was found: along the examined section, the DK44 national road is a road having good pavement condition and one homogeneous traffic section. The development around the DK44 neighborhood is dominated by areas with existing residential and service buildings, but there are also service-commercial sites and educational areas. The town of Bieruń has binding local spatial development plans covering the entire area subjected to research, and based on those plans, locations of areas requiring noise protection were determined, and the required noise standards were established for them. Based on the carried out measurements, we can state that on the examined single homogeneous section of DK44, the measured traffic volume accounts for 18413-18499 vehicles/day. The percentage share of heavy vehicles in the total traffic flow reaches the value of 11.7–12.2%. The measured average speed of light vehicles was within 52.8–57.0 km/h and that of heavy vehicles within 47.1–50.0 km/h. In addition, the measured equivalent sound level at a distance of 10 m from the fringe lane at the height of 4.0 m was at the level of:

- in daytime: 68.6 dB,
- at night: 64.8 dB.

Taking into account the current traffic volume (2019), the excessive impact of DK44 includes 47 residential buildings (25 - left side and 22 - right side) located in the areas with established noise standards. However, with the forecast traffic volume (2023), the excessive impact of DK44 will include 46 residential buildings (21 - left side and 25 - right side) located in the areas with established noise standards. Therefore, to limit the impact of DK44 along the examined section on areas requiring protection against noise, two concepts of noise protection were developed. The developed concept proposes the location of technical protection devices (acoustic screens and quiet pavement) in two variants. **VARIANT 1** - construction of **1425.5 m** of new acoustic screens of the height of **5.0 m ÷ 8.0 + 1.5 m (45°)** of straight and bent geometry, including **609.0 m** of full screens made from absorbing panels, **776.5 m** of combined screens with absorbing and transparent panels and **40.0 m** of reflecting screens from transparent panels. For the current traffic volume (2019), in effect of the application of **VARIANT 1**, 23 residential buildings (located in the areas with established noise standards) remain within the scope of the over-normative impact of DK44. For the current traffic volume (2019), in effect of the application of **VARIANT 2**, 25 residential buildings (located in the areas with established noise standards) remain within the scope of the over-normative impact of DK44.

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