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Methodological basis of road acoustic researches

Transport is one of the most burdensome negative sources affecting the natural environment. Long-term exposure of the body to exhaust pollution can cause health problems and, in the worst case, even lead to death. In addition to exhaust emissions, traffic noise is another equally important issue. Due to its nature, variability over time or the design diversity of vehicles in the traffic flow, it is a phenomenon difficult to define. Like exhaust pollution, it affects people's health and quality of life. In addition to its direct impact on the human physical system, it can also cause psychosomatic disorders, which is why a detailed analysis of road noise taking into account the real operation of the vehicle is so important. The paper presents the basic concepts related to the problem of traffic noise in the world, determines the sources of noise in vehicles and the methodology of conducting acoustic road tests. At the final stage of the scientific paper, methods of reducing excessive noise levels in large urban agglomerations were also presented, and the effectiveness of using noise barriers on selected parts of the city road network using proprietary acoustic tests was assessed.

Key words: *acoustic screen, passenger car, combustion engine, health, noise assessment*

1. Introduction

The problem of air pollution by exhaust gases is a global problem that affects all developed countries in economic terms. The development of industry contributes to the increase in the share of road vehicles and thus to the increase of the generated harmful and toxic exhaust components. It is estimated that over 4 million deaths annually are related to the negative impact of exhaust gases on human health [18]. One of the main reasons for excessively high exhaust emission levels is the high proportion of vehicles exceeding the applicable exhaust emission standards. Like exhaust emissions, noise is another source of pollution that has a negative impact on human health. The source of noise with the greatest share in large urban agglomerations is the road noise, which has a negative impact on health, causes deterioration of the functioning of human organs, and affects the mental and emotional state. The impact of noise is a subjective concept, depending on the human sensitivity to noise, age or, for example, gender, it can cause and accelerate fatigue, distraction, headaches, and irritation, which may result in a collision or a serious road accident. Research on traffic noise and noise reduction methods are issues that are taken up by many scientists, both at home and abroad.

The authors of the paper [1] presented measurement methods for the assessment of the acoustic climate and indicated the relationships between urban noise and various aspects of urban planning. On the basis of the obtained results and the conducted analysis, they indicated the possibility of predicting the noise level in a given area depending on the selected urban elements. By modifying these elements, it is possible to reduce noise levels when developing new urban projects.

The negative impact of noise on the human body has been presented in publications [2, 13]. The authors reviewed the literature on the impact of noise on human health, taking into account both direct impact on the hearing organ and non-hearing effects. In the paper [13], a separate chapter was devoted to the impact of noise on the driver's body, focusing on the negative impact of infrasound and vibrations.

In the first part of the paper [3], the authors Bendtsen and Ellebjerg analyzed the relationship between a vehicle speed and generated noise. The analysis was based on the Scandinavian model and the Harmonoise model. In the second part of the publication, the literature was reviewed, and then recommendations for road managers concerning methods of reducing traffic noise in cities were described.

The measurement of traffic noise and the measurement methodology are presented in papers [15, 23]. The publications presented the results of measurements of the obtained measurement points, characterized by the high vehicle intensity, high share of heavy goods vehicles and high noise intensity. Based on the data, the acoustic state was analyzed. The scientific paper [15] presents technical solutions that could reduce the noise level occurring in these areas.

Paszkowski in his work [14] proposed an innovative method of road noise assessment. This method is based on a model representing both quantitative and qualitative noise risk assessment. The basis for noise assessment is the use of the existing quantitative indicators, technology of creating and using acoustic maps. The proposal of noise analysis is also based on the assessment of acoustic sensations by people.

Two mathematical models to determine the sound level were proposed in [17]. Their correctness was checked in the study by comparing the obtained results with the road noise measured directly. The obtained test results were described as relatively consistent. Therefore, the presented models can be used to predict noise on the surface, as their accuracy is in the range of about 1%.

In the discussed works on the problem of traffic noise, the authors took up the above issue by carrying out a literature review, including determining the negative effects of noise on the human and driver's body, determining specific relationships and developing innovative models for determining the noise level. All the authors of the publication noticed the essence of the problem of road noise, thus trying to reduce it to a level that would not adversely affect human health and the life quality.

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2. Environmental acoustics and sound parameters

Noise is any undesirable sound, which is a subjective feeling of the recipient, which may be perceived in a way that is burdensome or harmful to humans. Two parameters are used to describe the sound: frequency and sound pressure. The *frequency (pitch of the sound)* expressed in hertz [Hz], describes the number of vibrations per unit time – 1 s. The range of sounds received by the human ear is from 20 Hz to 20,000 Hz and is called the *range of audible sounds*. All sounds below 20 Hz (infrasound) and above 20 kHz (ultrasound) are sounds inaudible to humans. The second parameter is the *sound pressure* expressed in Pascals [Pa], which is a small change in the air pressure in which the sound is propagated. Due to the fact that the human ear is able to perceive a very large range of acoustic pressures (from the hearing threshold of 0.00002 Pa up to a pain threshold of 60 Pa), the *acoustic pressure level* is used instead of acoustic pressure, expressed in [dB] – formula (1) [19]. The above relationship is presented on a logarithmic scale, which means that an increase by 3 dB doubles the intensity of the sound.

$$L = 10\log\left(\frac{p^2}{p_0^2}\right) = 20\lg\frac{p}{p_0}\,[\mathrm{dB}] \quad (1)$$

where: p_0 – reference pressure, equal to $2\cdot10^{-5}$ Pa (hearing threshold).

The sounds with frequencies ranging from 1–4 kHz are best perceived by humans. To assess the impact of noise, the frequency correction is implemented by weighting (correction) filters: A (sound level from 20 to 55 dB), B (55–85 dB), C (above 85 dB) and correction D (for aviation noise measurements).

In order to define the intensity of a sound wave – a longitudinal wave propagating in gases, liquids and solids, the concepts of the pitch and loudness of the sound are used. *The sound pitch* is the subjective assessment of the sound frequency. On the other hand, the *loudness of sound*, expressed in sones, is the subjective impression of receiving the sound of a given intensity. It consists in comparing the received sound with the model sound (1000 Hz). The loudness level of a sound is a phenomenon that indicates that the sound has a loudness level of *n* sones when its loudness is equal to a simple sound whose frequency is 1000 Hz and the sound pressure is *n* dB. Another acoustic term is the *acoustic power*, which is the amount of energy emitted by a sound source. The range of the acoustic power is within the range from 10^{-9} W to 10^{7} W. In order to facilitate the comparison of two different noise sources, the concept of a *power level* is used – formula (2), with which the concept of *sound intensity* is related – formula (3), i.e. the direction of acoustic wave propagation (the ratio of the acoustic power of the sound wave to the surface of propagation of this wave) [19].

$$L_{N1} = 10\log\frac{N}{N_0}\,[\mathrm{dB}] \quad (2)$$

where: N_0 – the reference sound power, equal to $1\cdot10^{-12}$ W.

$$L = 10\log\frac{I}{I_0}\,[\mathrm{dB}] \quad (3)$$

where: I_0 – the reference sound intensity, equal to $1\cdot10^{-12}\,\mathrm{W\cdot m^{-2}}$.

3. Assessment of the traffic noise level

3.1. Noise assessment indicators

Traffic noise, as one of the most annoying types of noise, especially in urban agglomerations, has a negative impact on the shaping of the acoustic climate. Its variability over time is only one of the measurement problems, so it is important to use acoustic assessment indicators that take into account all data, such as the time of day/night, land development, demographic data or quantitative data of the population. The following values are used for the noise assessment (the reference time T can be freely adopted, e.g. 15 min, 1 h, 16 h, 8 h) [14]:

- L_A [dB] – the sound level using the A correction characteristic – formula (1).
- L_{AeqD} – the equivalent sound level for day time from 6 a.m. to 10 p.m.,
- L_{AeqN} – the equivalent sound level for night time from 10 p.m. to 6 a.m. – formula (4).

$$L_{Aeq} = 10\log\left[\frac{1}{t_2-t_1}\int_{t_1}^{t_2}\left(\frac{P_A}{P_0}\right)^2 dt\right], [\mathrm{dB}] \quad (4)$$

where: $(t_2–t_1)$ – the reference time interval T, P_A – the instantaneous value of the sound pressure, [Pa], P_0 – the reference sound pressure, equal to $2\cdot10^{-5}$, [Pa].

Directive 2002/49/WE defines the indicators used for the long-term assessment of the noise level [9, 14]:

- L_{DWN} – day-evening-night level, to determine all days of the year, where noise determinations must be specified for the time of day L_D (6 a.m.–6 p.m.), L_W (6 p.m.–10 p.m.) and L_{N2} (10 p.m.–6 a.m.) – formula (5),

$$L_{DWN} = 10\log\frac{1}{24}\left(12\cdot10^{\frac{L_D}{10}} + 4\cdot10^{\frac{L_W+5}{10}} + 8\cdot10^{\frac{L_{N2}+10}{10}}\right)[\mathrm{dB}] \quad (5)$$

- L_{N2} – night level, used to determine all nights of the year.

In addition to the basic noise assessment indicators, there are also complex indicators:

- L_{MZHk} – for the relative percentage of population of an area with high noise levels,
- T_{MZH} – for determining the ratio of the surface with excess noise levels to the total surface,
- M – specifying the amount of exceeding noise standards and the number of people exposed to high noise levels.

Permissible noise standards in Poland are included in the Regulation of the Minister of the Environment on permissible noise levels in the environment (Journal of Laws 2014, item 112). This regulation defines the permissible A-sound levels depending on the purpose of the area, both for the daytime L_{AeqD} and nighttime L_{AeqN}.

3.2. Factors influencing on traffic noise

The problem of road noise is a common phenomenon, to which mainly areas close to communication networks are exposed. A characteristic feature of road noise is the variability of noise sources (different designs, structure and vehicles categories) and the variability of traffic intensity. The main sources of noise generated by vehicles are [5]:

- operation of the drive source and its components (noise dominating during vehicle acceleration, operation at low gears),
- damage and hitting of body parts,

- noise generated at the contact of the tire with the road surface (prevailing at high speeds),
- aerodynamic noise.

Considering the noise generated by vehicles in the traffic flow, the following causes of its formation can be distinguished [5]:

- heavy traffic,
- large share of heavy duty vehicles,
- too high vehicle speeds,
- bad technical condition of vehicles,
- bad condition and wrong type of a road surface,
- lack of prioritization of the road network,
- large share of national roads running through residential areas and cities,
- no clear regulations regarding spatial planning taking into account the noise criterion.

However, in order to assess the noise level caused by the traffic flow on the road, many variables should be taken into account, including [20]:

- the number of vehicles passing in the adopted time unit,
- share of the number of intersections with traffic lights and taking into account the duration of the cycle of light signal change,
- type of vehicles and their technical condition,
- type and technical condition of the road surface,
- speed limits,
- the number of lanes,
- the location distance from the urban agglomeration.

3.3. Methods of traffic noise determination

Three measurement methods are used to determine the acoustic climate that takes into account traffic [11]:

- continuous measurement method, used for road noise tests (the direct method),
- a method of measuring single acoustic events, used in the measurement of the road, rail and air noise, in periodic tests (the indirect method),
- measurement method using sampling (the direct method).

In the method of direct continuous measurements, the measurement is performed for a minimum of 3 consecutive days. In this case, noise indicators should be determined on the basis of at least one continuous measurement for the selected road section. The obtained values are the result of multi-day or many-hour observations, while the values obtained at the moment when the requirements for atmospheric conditions were not met (the average wind speed not greater than 5 m/s, no precipitation) are eliminated from the entire period. The method of single acoustic events is based on measurement of a single event, which may be, for example, one journey of a vehicle, train, or flight of an airplane. The average exposure level is determined, also taking into account the standard deviation. The last method, the sampling method, consists in determining the equivalent sound level. When using this method, the value of traffic intensity on the tested section should not exceed 25% for each hour, and the share of heavy vehicles should not exceed 10%. This method is used when the share of all vehicles on the road does not exceed 300 units in 1 hour [11, 14].

4. Exposure to noise and its negative effects on human health

Noise sensitivity is a subjective feeling for every human being. Due to the harmful effects on the human body, noise can be divided into three areas:

- directly affecting the organ of hearing,
- indirectly affecting the nervous system and psyche,
- affecting other organs by reflex [13].

The harmfulness of noise depends on many factors, such as the intensity and sounds frequency, impact time, the nature of changes in sounds over time and inaudible components [13]. Long-term exposure to noise at the level of 70–80 dB, characterized by the dominance of medium and high frequencies, a short hearing renewal phase and impulse noise are features that may have a harmful effect on the human body.

4.1. Direct impact of noise on the human hearing organ

The hearing organ is the organ most exposed to noise in the human body. Due to its structure, prolonged exposure to noise can lead to irreversible changes in Corti's organ and increasing the hearing threshold. This process is a long-term phenomenon and takes place in a phased manner. The change in the hearing threshold begins after approximately 3–5 years of continuous exposure to noise and applies to higher frequencies at the level of 4 kHz, then until 10 years it covers the frequency at the level of 2 kHz. Complete and advanced deafness can occur after 10–20 years of exposure to excessively high noise levels. The consequence of shifting the hearing threshold may be speech incomprehensibility, caused by shifting understanding beyond the area of audible sounds. Figure 1 presents the area of audible sounds, music and speech of a healthy person as well as the area of audible sounds, music and speech of a person with hearing impairment. Particularly dangerous types of noise that can cause sudden and immediate hearing loss are impulse noises, characterized by a sharp increase to levels above 130 dB. Due to the impact on humans, audible noises can be divided into 5 groups:

- below 35 dB – harmless, sometimes causing nervousness, disrupting during work;
- 35–70 dB – causing nervous system fatigue, lowering the sensitivity of sight, hindering understanding speech and communication, adversely affecting falling asleep and resting;
- 70–85 dB – negatively affecting the work performance, harmful to health, causing hearing damage, headaches and nervous disorders;
- 85–130 dB – causing numerous disturbances, incl. cardiovascular and digestive systems, making it impossible to understand speech even from a distance of 0.5 m;
- over 130 dB – affecting the vibrations of some internal organs of a human being and causing their diseases, imbalance, nausea, changes in the content of components in the blood [13].

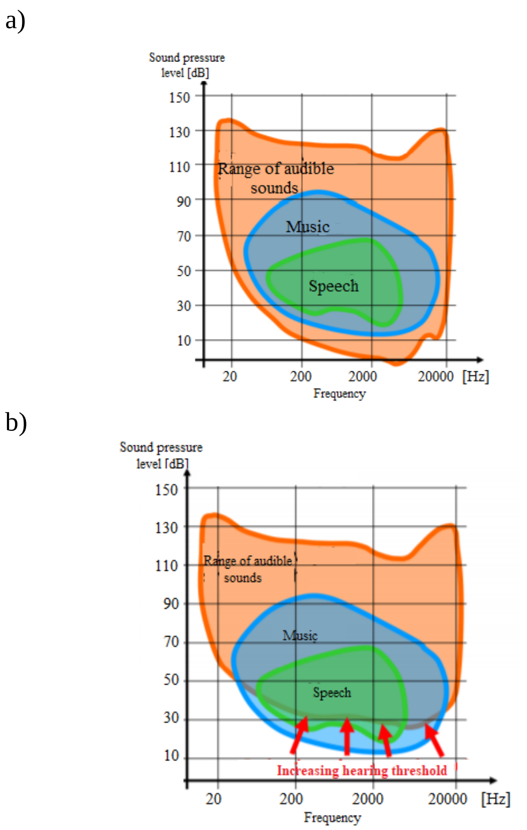

Fig. 1. The range of audible sounds, music and speech: a) a healthy person, b) a person with hearing impairment [24]

4.2. Non-auditory effects of noise on humans

In addition to the direct impact of noise on the hearing organ, there are also non-auditory effects, concerning both human health and well-being. The first group of non-auditory effects are psychological disorders: disturbances in cognitive and memory processes, difficulties in focusing attention, feeling tense, irritability, headaches and difficulties in focusing attention while performing work [2, 6]. The second group are physiological problems related to the proper functioning of the systems: cardiovascular (narrowing of blood vessels, arterial hypertension), digestive (possible ulcer), endocrine (hormonal changes) and nervous system. In addition to the effects described above, exposure to noise also causes psychological problems and early aging. Being in noise at the level above 75 dB triggers motor reflexes, e.g. contractions of: muscle, neck and head. After briefly exceeding this limit (75 dB), the electrical resistance of the skin changes, the rhythm of breathing changes and the circulatory system reacts differently (contraction of blood vessels and the increase in circulatory resistance). On the other hand, being in an acoustic climate of about 120 dB reduces the speed of the eyeballs, narrowing the field of view, and may also cause problems with distinguishing colors, which is especially dangerous when driving a car. The sound pressure level above 115 dB is a particularly dangerous level and there is a risk of hearing loss, even with short-term exposure. The levels of various sound sources and their impact on human health are presented in the Table 1.

Table 1. The sound pressure levels of various sources sound [dB] and their impact on human health [13]

Below 160 [dB]	**DEATH NOISE**
155–160	**NOISE CAUSING CONCUSSION BRAIN**
150–155	**PERMANENT NOISE DAMAGE TO HEARING**
145–150	A jet plane taking off from a distance of 10 m
140–145	Alarm siren from a distance of 1 m
135–140	Propeller plane engine
130–135	Hydraulic press from a distance of 0.5 m
125–120	**PAIN BORDER**
120–115	A machine gun from a distance of 0.5 m
115–110	Air hammer from a distance of 5 m
110–105	Disco
105–100	Metro from a distance of 3 m
100–95	Light music concert
95–90	Car horn from a distance of 5 m
90–95	Pneumatic drill from a distance of 2 m
85–90	The interior of the bus
80–85	A scream from a distance of 1 m
75–80	Phone ringtone from 2 m away
70–75	Passenger car engine from a distance of 6 m
65–70	Homemade sewing machine
60–65	Loud conversation from a distance of 2 m
55–60	The church bell from a distance of 400 m
50–55	A small office room, a small shop
45–50	Peaceful conversation
40–45	Quiet street
35–40	Tearing the paper from a distance of 1 m
30–35	Hospital, church, reading room
25–30	Very quiet room, clock ticking from 1 m away
20–25	Radio or movie studio
15–20	Average whisper from a distance of 2 m
10–15	A quiet whisper from a distance of 2 meters
5–10	Breath from the distance of 0.5 m
0–5	The murmur of leaves on a windless day from a distance of 3 m
0	**AVERAGE THRESHOLD OF HEALTHY HEARING**

4.3. Impact of noise on the driver's body

Excessive fatigue, drowsiness, discomfort, imbalance, psychomotor performance and physiological functions are the dominant effects of infrasonic noise on the driver. In addition to the changes described above, the driver's body is exposed to changes in the respiratory and cardiovascular systems, which is related to the reduction in the amount of adrenaline, cortisol and free fatty acids secreted. The effect of infrasound can be compared to the state after drinking a large amount of alcohol, i.e. decreased visual acuity, difficulties in maintaining balance and concentration, prolonged reaction time, increased symptoms of drowsiness and decreased cognitive functions. Accelerating and deepening sensory fatigue, impediment of speech understanding, audibility of warning sounds, worse vision, delayed reaction or mental fatigue negatively affect the possibility of causing a road accident [13, 22].

Apart from the infrasound noise, the driver is also exposed to the negative impact of vibrations, i.e. the transmission of mechanical shocks from a solid body to individual tissues of the human body or to the entire human body, bypassing the air environment [13]. The negative effect of vibrations is the resonance of human organs, which is manifested by strong irritation of the labyrinth in the form of, for example, jaw vibrations, changes in the tension of the larynx muscle, vibrations of the air column in the nasopharyngeal cavity. Other effects may be breathing problems, a feeling of pain around the heart, decreased visual acuity, which is also accompanied by a narrowing of the field of vision and a problem with distinguishing colors. A very popular effect of the vibration on the body is the seasickness, manifested by headache, dizziness, tinnitus, shortness of breath, stomach pain and nausea [22].

5. Methods of road noise reduction

One of the main sources of noise is the increased share of traffic flow in urban areas, especially heavy goods vehicles. An effective method to reduce the noise level in urban agglomerations is to transfer transit traffic outside the city. The ability to drive trucks only on city ring roads has a positive effect not only on the level of noise generated by vehicles in cities, but also allows to increase the capacity, especially during peak traffic hours.

The second method of reducing road noise is the design of circular intersections. This solution improves traffic flow, therefore the generated road noise is reduced by approx. 4 dB [16]. The biggest problem with standard intersections is sudden deceleration (braking) and acceleration of the vehicle and queues to enter the intersection. The increase in noise level depending on the acceleration or deceleration of various types of vehicle at 50 km/h is shown in the Table 2.

Table 2. Influence of delayed and accelerated motion on road noise [3]

Acceleration or delay [m/s^2]	Vehicle type	Increase of noise [dB]	Description of the movement
1.0	light	+1.7	medium acceleration
2.0	light	+4.5	hard acceleration
0.5	heavy	+2.1	medium acceleration
1.0	heavy	+4.5	hard acceleration
–1.0	light	–0.8	poor braking
–2.0	light	–1.2	hard braking
–1.5	heavy (two axles)	–4.5	medium braking

When assessing the noise level reduction at a circular intersection, many factors should be taken into account, which are influenced by, for example, the radius of the roundabout, the speed of traffic on the approach and departure from the roundabout, the distance of the observer from the roundabout [16].

Road noise resulting from the rolling of wheels on the road surface can be reduced by using surfaces with reduced noise emissions. This type of surface is called quiet road surfaces, characterized by a large number of pores (air-filled channels), whose task is to suppress noise. The best surface that fulfills the functions described above is a porous surface, with a pore content of about 20% and allowing noise reduction above 3 dB. Other materials with reduced noise levels used for road surfaces include: mastic asphalt and asphalt concrete, whose noise reduction efficiency is up to 3 dB. In addition to reducing rolling noise, another advantage of using the pavements described above is that accumulated water is drained more quickly to the lower layers. However, this is a problem when curbs cannot be reconstructed during road modernization (surface change). The use of the above-mentioned surfaces will not bring the expected result due to difficulties with water drainage and problems with cleaning the road [16].

Other methods of noise reduction are the so-called methods by propagation. The first and most frequently used method is acoustic screens. Their task is to create the so-called an acoustic shadow with a lower sound level than outside it. The condition for achieving the best effectiveness is to place the screen as close as possible to the noise source, taking into account the appropriate height and length.

Depending on the height, the following screens can be distinguished [4]:

– tall and very high above 6–7 m, reducing noise above 10 dB,
– medium, 5 m high, with a noise reduction of 7–10 dB (most often used in Poland),
– low up to 3.5 m, noise reduction up to 8 dB, used in uninhabited areas below the course of communication routes,
– very low with a height of 1 m, reducing the noise by about 3 dB.

Due to the principle of operation, there are two types of noise barriers: reflective and absorbing. The first of them are characterized by the sound absorption up to 4 dB, most often they are made of glass, plastic, wooden boards or concrete. Acoustic waves reaching the reflecting screen are almost reflected completely [16]. The second type of screens – absorbing (4–8 dB), reducing the acoustic energy reflected from the screen surface, are most often made of sawdust concrete or steel cassettes filled with sound absorbing material. In order to assess the effectiveness of the use of an acoustic screen, a quantity informing about the difference in noise levels in front of and behind the acoustic barrier is used – acoustic efficiency of sound – formula (6) [20].

$$\Delta L = L_{Aeq} - L_{AeqE}, \text{[dB]} \tag{6}$$

where: L_{Aeq} – equivalent sound level in front of the acoustic screen, L_{AeqE} – equivalent sound level behind the acoustic screen.

The other most common methods of reducing exposure to road noise along the propagation path are earth embankments – most often used along expressways or creating the so-called green walls, used mainly in places exposed to reflected waves that amplify noise from the source, e.g. among apartment blocks or in courtyards.

6. Assessment of the effectiveness of the acoustic screen application

To evaluate the effectiveness, an acoustic screen was used, located within the "big" city, due to the high traffic intensity, multi-path nature of the stream and high vehicle speed (Wincentego Witosa Street in Poznan). The road running at Wincentego Witosa Street is a provincial road No. 433, characterized by a high level of noise, within which there are apartment blocks, located approx. 15 m from the acoustic screen. As part of the research, a point measurement of noise generated by road vehicles in front of and behind the noise barrier was performed in two traffic rush hours: at 4:00 p.m. and 7:00 a.m. During these hours, there is the greatest accumulation of vehicles of people commuting to and returning from work. In addition to the point measurement, a frequency measurement was also performed. A certified Class I digital sound level meter (Bruel & Kjaer 2238) was used to perform the tests. The impact of vehicle traffic on the levels of generated noise in front of and behind the acoustic screen during two measurement hours was presented in Fig. 2. On the basis of the obtained test results, the highest noise level was noticed at the level of 89.5 dB at 4 p.m. and 92.8 dB at 7 a.m. The screen acoustic efficiency was calculated using the formula (6) and the obtained results are presented below:

$$\Delta L_{4\ p.m.} = 80.9\ dB - 74.4\ dB = 6.5\ dB$$

$$\Delta L_{7\ a.m.} = 82.6\ dB - 65.1\ dB = 17.5\ dB$$

a)

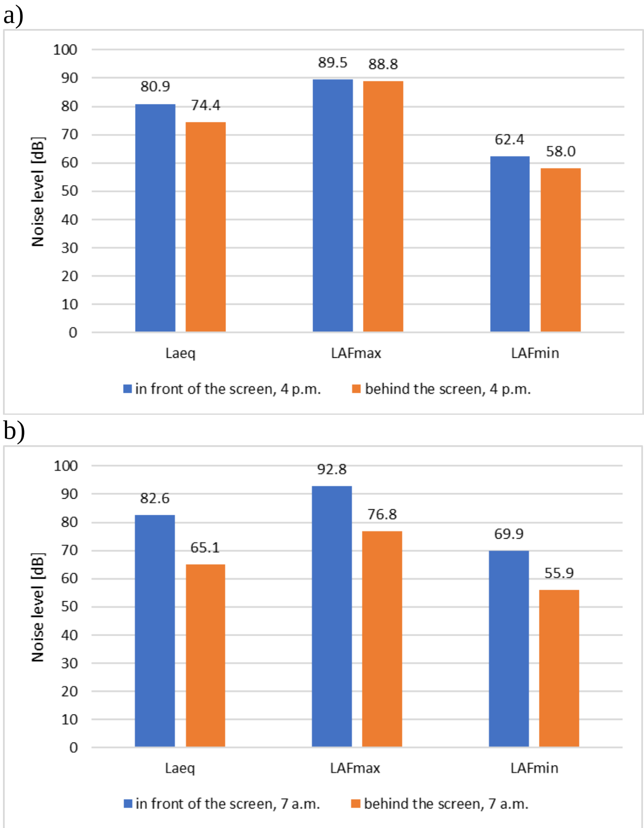

Fig. 2. The impact of vehicle traffic on the noise levels obtained in front of and behind the acoustic screen for the selected measuring section (Wincentego Witosa Street, Poznan) during the traffic rush: a) in the afternoon around 4 p.m., b) in the morning around 7 a.m. [20]

The use of an acoustic screen at Wincentego Witosa Street allowed to reduce the noise level from 6.5 to 17.5 dB. Lowering sound pressure levels has made it possible to reduce the risk of permanent hearing damage. The greatest noise reduction was recorded around 7 a.m. During the traffic rush hours around 4 p.m., exposure to noise is still very high and may have a negative impact on people living in the area near the acoustic screen, causing e.g. irritation, fatigue or e.g. headaches.

7. Conclusion

Traffic noise is a very dangerous civilization problem which, like exhaust emissions, requires a lot of research, analysis and activities aimed at reducing its nuisance. Exposure to noise carries the risk of hearing loss, problems with the proper functioning of many organs in humans, causes mental problems, and has a negative impact on the quality of life of people. It is especially dangerous when driving on the road, because its long-term impact on a person increases the risk of accidents. Noise is a problem that can be tackled at its source through the diagnostics of vehicles and its components, reducing rolling noise by using appropriate road surfaces, turning classic intersections into circular intersections, reducing vehicle speed or reducing noise along the path of propagation. The use of each of the noise reduction methods is extremely important for the natural environment, as there is no physiological adaptation to noise in humans [6]. Human is not able to get used to the acoustic state he is in, so it is necessary to counteract it, because in the worst case the noise can even lead to death. The research on the effectiveness of the use of an acoustic screen at Wincentego Witosa Street showed that the equivalent sound level for the acoustic screen at Wincentego Witosa Street was reduced by 6.5 and 17.5 dB. The differences between the achieved effectiveness of the acoustic screen were related to the variable intensity of vehicle traffic and participation in the traffic of vehicles of various categories. Despite noise reduction, noise exposure is still very high and adversely affects people's health and quality of life. Therefore, it is necessary to reduce noise at its source (in the vehicle) by actively assessing the noise level in traffic and reducing the main design sources and resulting from working processes generated in their propulsion sources (internal combustion engines, hybrid engines) and the drive system (feedback between continuous noise testing and design modifications and assessment of their effectiveness). In further stages of the research, it is possible to eliminate noise sources as a result of their real-time control at the level of a single vehicle. In this process, however, remember to separate the acoustic signal for a single vehicle and define the sound source from a specific component, taking into account external sound sources.

Nomenclature

I	sound intensity value, expressed in $W \cdot m^{-2}$
I_0	reference sound intensity, equal to $1 \cdot 10^{-12}\ W \cdot m^{-2}$
L	relative measure of sound pressure, sound intensity
L_A	sound level using the A correction characteristic
L_{Aeq}	equivalent sound level
L_{AeqD}	equivalent sound level during the day (6 a.m. to 10 p.m.)
L_{AeqE}	equivalent sound level behind the acoustic screen
L_{AeqN}	equivalent sound level at night (10 p.m. to 6 a.m.)
LAF_{max}	maximum sound level
LAF_{min}	minimum sound level
L_{DWN}	day-evening-night sound level
L_{MZHk}	relative share of the area's population, expressed in %
L_{N1}	sound power level

L_{N2}	Night sound level, to define all the nights of the year
ΔL	the effectiveness of the acoustic screen
M	the amount of noise standards exceeded and the number of people exposed to noise
N	sound sound power value, expressed in W
N_0	reference sound power, equal $1 \cdot 10^{-12}$ W
p	sound pressure
P_0	reference sound pressure equal to $2 \cdot 10^{-5}$ Pa
P_A	instantaneous value of the sound pressure, expressed in Pa
t_2–t_1	reference time interval T
T_{MZH}	the ratio of the surface area on which high sound levels occur

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