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THE RESEARCH ON THE EFFECTIVENESS OF THE INCLINED TOP TYPE OF A NOISE BARRIER

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Abstract. Now, it is normally agreed that noise barriers – shields with appropriate devices on the top edge – limit the diffraction of sound waves more effectively than the usual shields of the equal or in some cases even greater height. These barriers are referred to as “edge-modified” noise shields. The article describes acoustic field researches that estimate the impact of the slope of the upper edge of the noise barrier on the effectiveness of shielding from environmental noise. The article was drafted on the basis of methodical recommendations presented in the standard ISO 11821: 1997 “Acoustics – Measurement of the in situ sound attenuation of a removable screen”. While altering the slope angle, respectively to 90°, 120°, 150°, 180°, different noise barriers were formed: “L90” (slope angle 90°), “J120”, “J150” (slope angles 120° and 150°), and the usual “straight type” (slope angle 180°). The impact made by the form of the noise barrier on the spread of noise in the noise suppression area was observed at the areas of low (100–315 Hz) and high (2000–5000 Hz) frequency. The most effective form of a barrier in reducing the diffraction of low frequency sound waves was “J120”, whereas high frequency sound waves were most effectively reduced using a usual straight noise barrier.

Keywords: noise barrier, diffraction, top edge, traffic noise.

1. Introduction

Noise is often referred to as undesirable sound (Monsefi *et al.* 2011). It is a global problem encompassing all the spheres of human life and work (Baltrėnas *et al.* 2010; Brink 2011). Noise is one of the environmental pollutants, which creates interference in communication and health. The World Health Organization (WHO) considered noise as the third most hazardous type of pollution right after air and water pollutions (Agarwal, Swami 2011).

Motor vehicles and especially the road traffic are one of the main sources of environmental noise, which makes a negative impact on the environment and its components (Jagniatinskis *et al.* 2011; Paulauskas, Klimas 2011; Vaišis, Januševičius 2008). It is a growing environmental problem that is increasingly becoming an omnipresent, yet unnoticed form of pollution not only in developed countries but also in the developing countries (Firdaus, Ahmad 2010).

Various measures are being taken to reduce the acoustic environmental noise. It is usual that houses are built near noise sources, therefore taking into consideration the conditions of noise propagation, the existing relief is employed or artificial barriers are constructed to suppress the propagation of sound waves (Baltrėnas, Puzinas 2009).

In most cases, noise barriers in the form of screens are one of the most widely applied measures in cities to protect residential areas from undesirable traffic noise (Auerbach *et al.* 2010; Grubliauskas, Butkus 2009; Okubo *et al.* 2010). Barriers protect the receiver from direct airborne sound waves by reducing the noise level in the acoustic shadow zone. The noise reaches the receiver directly only through other indirect ways mainly due to the diffraction over the upper edge of the screen (Monazzam, Lam 2005; Monazzam *et al.* 2010).

It is known that the distance of a noise barrier from a noise source or a receiver and its geometry, especially its height, are important parameters in evaluation of the efficiency of a barrier. While increasing the height of a barrier, it is possible to improve its effectiveness as well; however, due to aesthetic reasons and the price of such construction, it is not beneficial to build very high barriers (Duhamel 2006; Naderzadeh *et al.* 2011). Many researches were carried out during the past two decades focusing on the noise diffraction around the barrier giving the priority not only to the enlargement of a barrier in height. Using experimental and numerical methods, it was examined how the shape of the top of the barrier influences the efficiency of noise attenuation (Baulac *et al.* 2007; Greiner *et al.* 2010; Mun, Cho 2009). Although a great number of researches were conducted concerning the design of the top of a barrier, in most cases usual straight barriers are still used (Kokavecz, Möser 2010).

Now, it is normally agreed that barriers with appropriate devices on the top edge limit the diffraction of sound waves more effectively than the usual barriers of the equal or in some cases even height. These screens are referred to

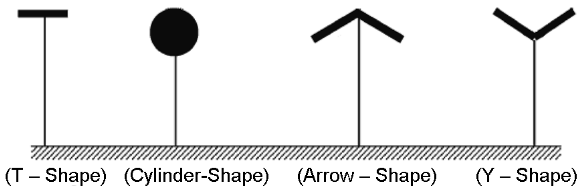

Fig. 1. Barriers with different top profiles (Monazzam, Lam 2005)

as "edge-modified" noise barriers (Okubo, Yamamoto 2007). Modified configurations are very diverse: T, Y, arrow, fork, cylinder shape and others (see Fig. 1) (Cianfrini *et al.* 2007; Jung *et al.* 2006; Monazzam, Fard 2011).

A great number of researchers described the effect of T and Y shape barriers. Japanese researchers determined that using T and Y shape barriers, the noise level was 3 dB lower than the noise level using a usual straight barrier of the same height. Some researches on the effectiveness of barriers with a sloping top (known as L and J shape barriers) were found as well. While applying a numerical model, Okubo and Yamamoto (2007), Murata *et al.* (2006) proved that barriers with sloping tops were superior to straight barriers of the same height. Chinese researchers Xintan *et al.* (2005) made theoretical calculations and described the effect of the inclined top on sound wave diffraction (while constructing the L shape barrier) as a factor for changing the position of a barrier in respect of the noise source. The inclined top type reduces the distance between the noise barrier and the noise source, thus increasing the shielding effect of the barrier.

The aim of this work is to estimate how the effectiveness of the noise barrier is changing depending on the angle of the inclined top type.

2. Methods

The research on the constructed removable screen is carried out in natural (field) conditions. The methodology for the research was framed according to the methodical recommendations presented in LST EN ISO 11821: 1997 "Acoustics – Measurement of the in situ sound attenuation of a removable screen".

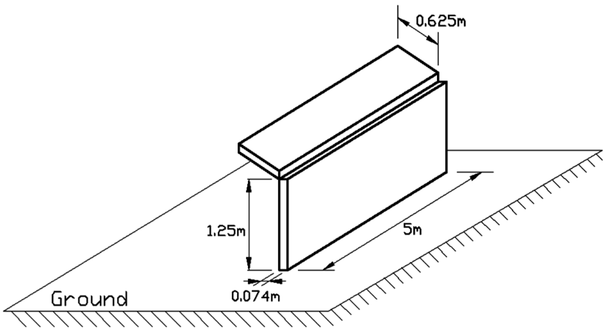

Fig. 2. Schematic image of the removable screen constructed for the research on the acoustic features of an inclined top type

The construction reducing noise consists of oriented strand boards (OSB) and rock wool (thickness 0.1 m). The external dimensions of the screen are: length – 5 m, height – 1.25 m, and screen thickness – 0.074 m. In order to form an inclined top, the 0.625 m high panel corresponding to the structure and geometry of the screen (see Fig. 2) was fixed on the upper edge of the barrier using flexible consolidation. The slope angle of the top of the screen was adjusted by metal supports.

The equipment made in Denmark was used to study the acoustic features of the construction (see Fig. 3):

- Omnipower sound source, which uses a cluster of 12 loudspeakers in a dodecahedral configuration – "Bruel & Kjaer" (frequency response: 50 Hz–10 kHz);
- Audio power amplifier – "Bruel & Kjaer" (power of 300 W);
- Precision sound level meter – investigator "Bruel & Kjaer mediator 2260";
- Microphone type 4189 – "Bruel & Kjaer".

The equipment used in the research meets the requirements of IEC 651 and IEC 804, the international electrotechnical equipment standards set out in the LST EN ISO 11821: 1997 standard.

The dodecahedral sound source – one of the newest products of the Danish company "Bruel & Kjaer" – creates standardized constant noise. The levels of noise generated by the device increase over the whole frequency range depending on the values: Gain 40, Gain 20, Gain 16, Gain 12, Gain 10, Gain 7, Gain 5, Gain 3, Gain 1, Gain 0, set on the power amplifier; here Gain stands for the index of noise source power. Noise source can be either mounted on a tripod stand whose adjustable height ranges from 1.3 to 2.0 m, or it can be placed on the ground.

The precision sound level meter – investigator "Bruel & Kjaer mediator 2260" – performs statistical processing of measurement results as it has an integrated central processing system and specialised software programmes. The relative measuring error of this device is ±1.5%, the noise level is recorded from 6.3 Hz to 20 kHz. The software "BZ 7210 Qualifier" was used for the processing of data obtained from the sound level meter during the research.

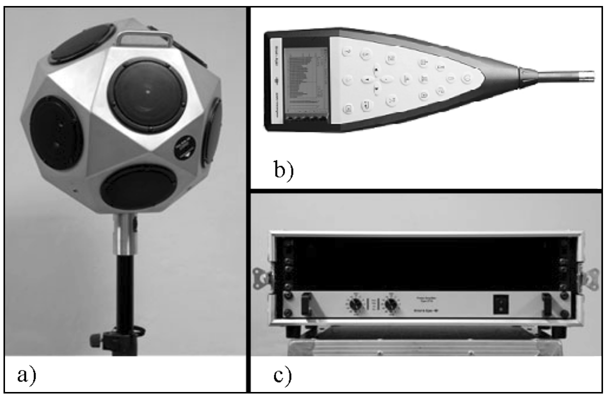

Fig. 3. The equipment system "Bruel & Kjaer" used for the research: a) OmniPower Sound Source Type 4292; b) Sound level meter type 2260 investigator; c) Power Amplifier (Settore... 2009)

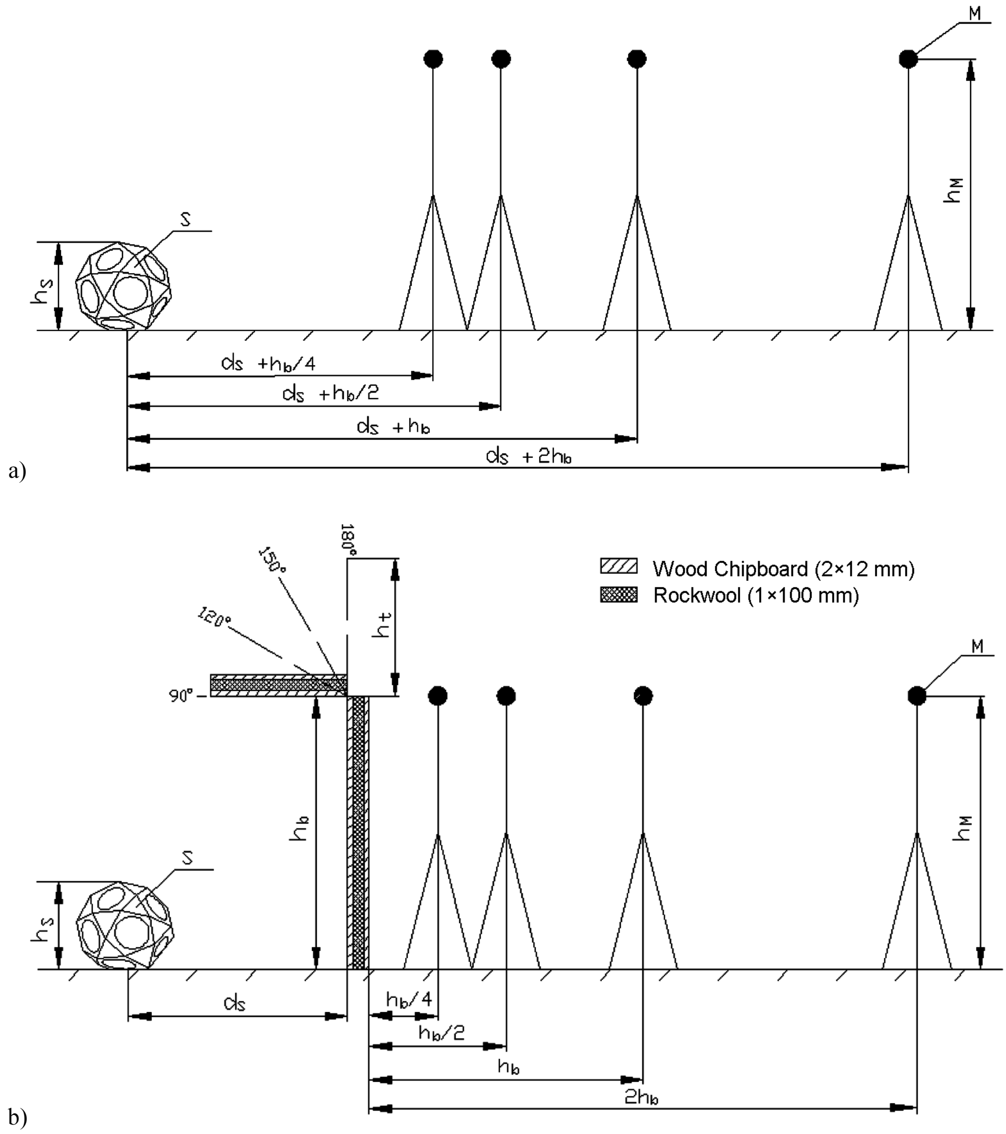

Fig. 4. Research situations: a) measurement of the level of noise coming out of the noise source in an open field; b) measurement of noise levels when noise coming out of the noise source is being suppressed by a noise attenuation screen-barrier: S – noise source; M – microphone, h_b – barrier height; h_M – microphone height; d_S – distance between the barrier and the noise source; h_S – height of the noise source; h_t – height of the flexible top

An open space was chosen for the research making sure that the surrounding surfaces, which had an influence on noise reflection and absorption would be fixed in respect of an object being studied.

The noise level generated by the omnidirectional noise source was estimated by carrying out measurements of the noise level in an open field without noise attenuation. The noise level while shielding the noise source was also estimated (see Fig. 4a, b).

Sound attenuation (D_p) in the studied noise damping environment was estimated by the formula:

$$D_p = L_{p1} - L_{p2}, \quad (1)$$

here, L_{p1} and L_{p2} – sound pressure levels in 1/3 octave bands respectively while measuring the noise level in open space and when the noise barrier is used to suppress the level of noise coming out of the noise source.

At the beginning of the experiment, the level of background and environmental noise was estimated. As it is stated in the methodical recommendations of the LST EN ISO 11821 standard, the artificial dodecahedral sound source creates such an acoustic field where the difference between the level of the noise coming out of the noise source and the level of the background noise is more than 10 dB in all dominant frequency bands.

During the research, the noise source and the microphone were placed in one straight line. While shielding the noise source with a noise barrier, the equipment used in the research (noise source, microphone) was placed perpendicularly to the main line of the barrier and appears at the point of the geometric centre of the screen.

Omnipower Omnidirect dodecahedral sound source was placed on the ground at 1 m away from the barrier (the height of the source is 0.4 m). Taking into consideration the methodical recommendations stated in the

LST EN ISO 11821 standard, four places for arranging microphones and carrying out measurements were chosen: 0.32 m, 0.64 m, 1.24 m and 2.5 m away from the barrier. The microphone, which was in the noise damping area, was mounted on a tripod stand in such a way that the height difference between the microphone and the ground surface amounted to 1.25 m.

The acoustic features of the inclined top of the barrier in the previously mentioned positions of microphones were examined while changing the slope angle of the top of the barrier. In each position of the microphone, four slope positions of the top of the barrier were measured while changing the slope angle respectively to 90°, 120°, 150°, 180° (as it is shown in Fig. 4b). In the places where airborne sound waves were recorded, the research was repeated for 3 times (the duration of one measurement is 30 s). The values of the noise level are the values of the arithmetic average of these quantities.

3. Results and discussion

A typical situation was simulated to study the features of the inclined top type barriers:

- the level of noise created by the artificial point noise source was estimated;
- the noise level was estimated in the area where the noise source was shielded by the noise barrier.

Noise measurements in the open field as well as while shielding the noise source with a barrier were conducted retaining the same sound level measuring conditions, i.e.:

- the adjustment of the research field (surfaces, which have influence on noise reflection and absorption would be fixed in respect of the object being studied);
- the operating conditions of the noise source (constant power, standardised constant noise level);

In measuring positions the noise level was recorded on 1/3 octave bands, the studied frequency range was 100–5000 Hz.

During the research using the "Bruel & Kjaer" power amplifier (power 300 W) the index of noise source power Gain 7 was identified, i.e. the level of the noise created by the omnidirectional noise source exceeded the estimated background noise level in the studied frequency range of 10 dB and even more.

While altering the slope angle of the inclined top, respectively to 90°, 120°, 150°, 180°, different noise barriers were formed: "L90" (slope angle 90°), "J120", "J150" (slope angles 120° and 150°), and the usual "straight type" (slope angle 180°).

The research based impact made by the inclined top of the noise barrier on the diffraction of sound waves over the upper edge of the barrier was observed in the areas of low (100–315 Hz), medium high (500–1600 Hz) and high (2000–5000 Hz) frequency.

Fig. 5 shows the results from the research on the low frequency noise level at the measuring positions of 0.32 m, 0.64 m, 1.24 m and 2.5 m away from the barrier.

In the studied low frequency range, the greatest impact on the diffraction of airborne sound waves in the noise attenuation area was made by the "J120" type barrier. Depending on the distance from the screen, it was determined that the shielding effect is 1–4 dB greater if compared to the other studied screen types. Similar regularity of the alternation of the noise level was obtained when the slope angle of the inclined top was equal to 150° (i.e. "J150" type barrier), however higher levels of noise were recorded in the studied frequencies.

The highest noise levels were estimated when the "L90" and the usual "straight type" barriers were used. Their impact on the diffraction of low frequency sound waves was similar (the variation of noise level alternation was obtained). At the studied points of 0.32 m, 0.64 m and 1.25 m away from the screen, the frequency response of the estimated noise levels using the "L90" type screen almost corresponded to the frequency response when "straight type" screen was used. However, when the distance as increased to 2.5 m, the obtained sound wave damping effect was more prominent while using the "L90" type barrier. It was estimated that at the frequency of 200 Hz and 250 Hz, the decrease of the sound level was 2 dB higher if compared to the usual "straight type" barrier.

Determined under the studied conditions, the effectiveness of the optimal "J120" type barrier to suppress low frequency sound waves in the noise attenuation area shows up at 160 Hz. The lowest noise level damping was estimated in all recording places when the frequency was at 100 Hz and 125 Hz.

The effective attenuation of low frequency noise in the entire studied frequency range, i.e. 100–400 Hz, was obtained at the research points, which were 0.32 m, 0.64 m and 1.25 m away from the screen.

Moving away from the screen, the acoustic shielding effect decreased. The obvious decrease of the shielding effect was observed at the measuring position of 2.5 m away from the screen. The results of the noise level research became distinct at the frequency of 100 Hz, 125 Hz and 160 Hz. At the mentioned frequencies, 0.32 m away from the barrier, the noise damping of 9, 7 and 16 dB was estimated but when the distance increased to 2.5 m, the noise damping decreased to 3, 5 and 7 dB, respectively. The decrease of the acoustic effectiveness could be explained by the fact that while moving away from the noise barrier, the effect of the diffraction of low frequency sound waves over the edges of the screen becomes more prominent, thus decreasing the acoustic shadow zone of noise damping.

Fig. 6 shows the results of the research on the noise level of medium high frequency (500–1600 Hz). It was estimated that in the areas of medium high frequency, the shielding effect, depending on the inclined top of the barrier, is insignificant. In the studied frequency range, the "J120" type screen had a more significant superiority only over the "L90" type screen (using "L90" type screen the highest noise levels were estimated in the entire measuring position). The results of the research on noise levels were distinct at the measuring position of 2.5 m away from the barrier with the frequency of 1250 Hz. Here, the noise damping effect was even 6 dB lower if compared to "J120" type barrier.

The frequency response of the studied "J150" and "straight type" barriers, which was obtained at the areas of medium high frequency of 0.32 and 0.64 m away from the barrier was almost the same as of "J120" type barrier. At the studied conditions at the mentioned noise level recording positions, the medium high diffraction of sound waves is not influenced by the construction of different types of noise barriers, namely, "J120", "J150" or "straight type". A more significant advantage of "J120" is estimated only at the research positions of 1.25 m and 2.5 m away from the barrier when the frequencies were 630 Hz and 1250 Hz, respectively. The effect equalled to 2 dB at 1.25 m away from the barrier at 630 Hz; whereas at 2.5 m away from the barrier at 1250 Hz, it reached 3 dB.

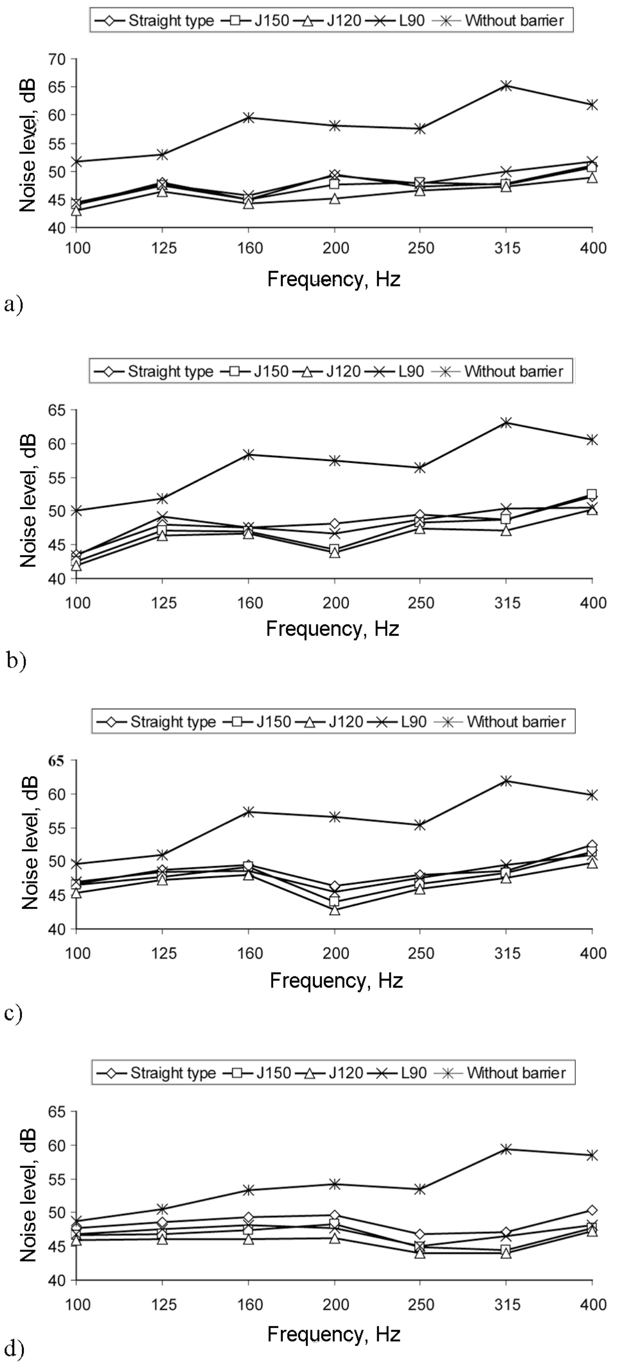

Fig. 5. The results of the noise level research in the low frequency areas (100–315 Hz): a) measuring position of 0.32 m away from the barrier; b) measuring position of 0.64 m away; c) measuring position of 1.24 m away; d) measuring position of 2.5 m away

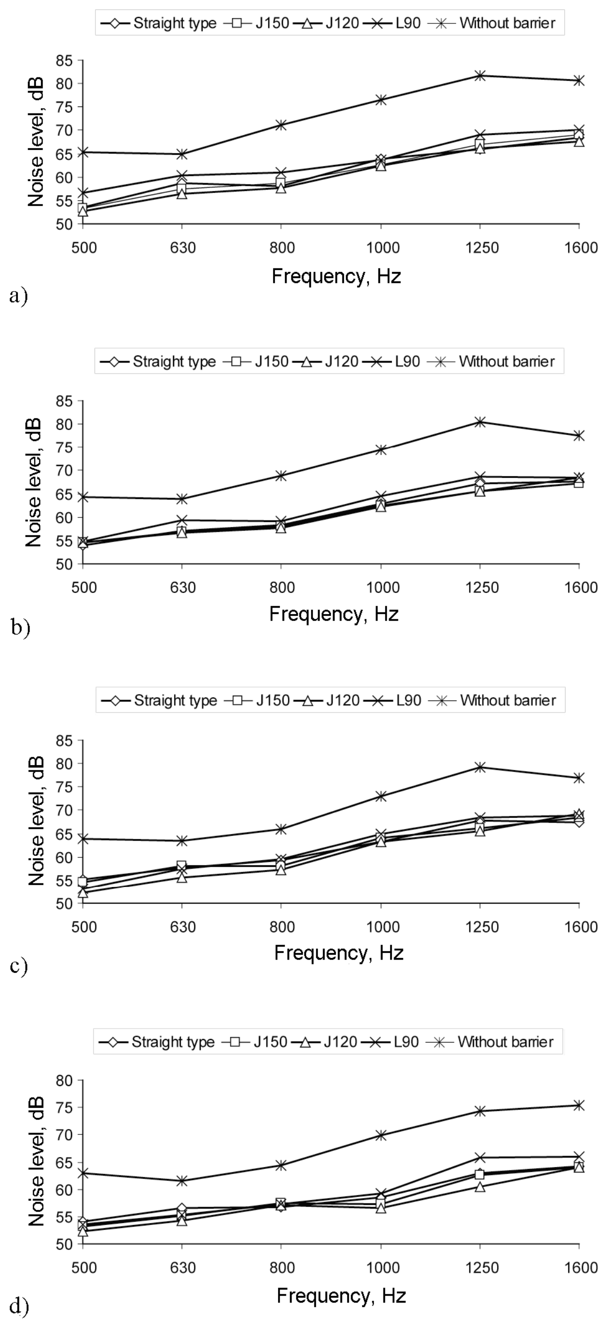

Fig. 6. The results of the research on the noise level of medium high frequency (500–1600 Hz): a) measuring position of 0.32 m away from the barrier; b) measuring position of 0.64 m away; c) measuring position of 1.24 m away; d) measuring position of 2.5 m away

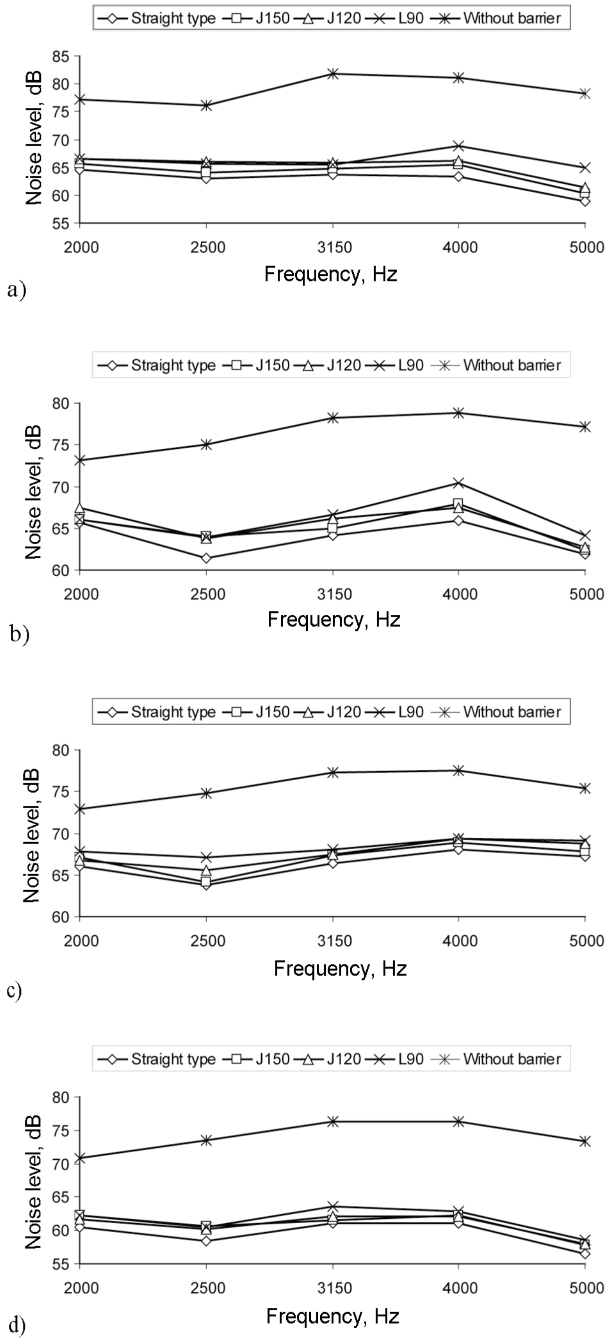

Fig. 7. The results of the research on high frequency noise level (2000-5000 Hz)**:** a) measuring position of 0.32 m away from the barrier; b) measuring position of 0.64 m away; c) measuring position of 1.24 m away; d) measuring position of 2.5 m away

Fig. 7 shows the results of the research on high frequency noise level. It appears that the diffraction of high frequency sound waves was reduced most effectively with the help of the "straight type" noise barrier, i.e. when the height of the barrier was increased by the height of the flexible top of the barrier. While comparing its influence on the diffraction of sound waves over the upper edge of the barrier to "L90", "J120" and "J150" type barriers at all noise level recording positions, it was estimated that the shielding effect was 3 dB higher.

The smallest effect of noise level attenuation, just as in low and medium frequency range, was reached while shielding the noise source by the "L90" type barrier. If compared to the usual "straight type" barrier, the estimated high frequency noise levels were 3–6 dB higher in all noise recording areas. The disadvantage of shielding effect in the studied frequency range was regularly decreasing when the "J120" and "J150" type barriers are used.

As shown in Figs. 6 and 7, the examined noise barrier was most effective in reducing the diffraction of medium high and high frequency sound waves. With increasing distance from the barrier to the measuring position, the noise damping effect was slightly decreasing in medium high and high frequency range.

The estimated weaker shielding effect of the "L90" type barrier in the studied 1/3 octave frequency bands might be interpreted using the results of the calculations carried out by the Chinese researchers Xintan *et al.* (2005), i.e. the effectiveness of the "L90" type barrier was equal to the effectiveness of the usual barrier of the same height if the screen was moved towards the noise source at the distance of the inclined top. In this case, it appeared that the increase of the height of the barrier was a more important factor than the decrease of the distance between the noise source and noise barrier.

4. Conclusions

1. The most effective form of a barrier in reducing the diffraction of low-frequency sound waves is "J120". Depending on the distance from the screen, it was determined that the shielding effect is 1–4 dB greater if compared to other studied screen types.
2. Moving away from the screen, the acoustic shielding effect decreases. When the distance increases from 0.32 m to 2.5 m and the frequency is equal to 100 Hz, the effect decreases from 9 to 3 dB respectively if the optimal "J120" type barrier is used.
3. In the medium high frequency range, the diffraction of sound waves is not influenced by the construction of different types of noise barriers, namely "J120", "J150" or "straight type".
4. When the "straight type" barrier was used in high frequency range, the shielding effect was estimated 3 dB higher in all noise level recording positions as compared to the "L90", "J120" and "J150" type barriers.
5. The examined noise barrier is most effective in reducing the diffraction of medium high and high frequency sound waves. With increasing distance from the barrier to the measuring position, the noise damping effect is slightly decreasing.
6. The smallest sound damping effect in the examined 1/3 octave frequency band was estimated while shielding the noise source by the "L90" type barrier.

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TRIUKŠMO SLOPINIMO SIENELĖS VIRŠUTINĖS DALIES POLINKIO EFEKTYVUMO TYRIMAI

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Santrauka

Paprastai pripažįstama, kad triukšmo slopinimo sienelės-ekranai su atitinkamais įtaisais ant jų viršutinio krašto efektyviau riboja garso bangų difrakciją, palyginti su įprastiniais tokio pat aukščio, o kai kuriais atvejais ir aukštesniais, ekranais. Ekranai su įtaisais vadinami „modifikuotosios briaunos“ triukšmo slopinimo ekranais. Atliekant akustinius natūrinius tyrimus vertinta triukšmo slopinimo sienelės viršutinės dalies polinkio įtaka aplinkoje sklindančio garso bangų ekranavimo efektui. Tyrimų metodika parengta pagal EN ISO 11821:1997 „Akustika. Natūrinis kilnojamo ekrano garso silpninimo matavimas“ standarte pateikiamas metodines rekomendacijas. Polinkio kampą keičiant atitinkamai 90°, 120°, 150°, 180°, formuota „L90“ (polinkio kampas 90°), „J120“, „J150“ (polinkio kampas 120° ir 150°) ir įprastinio „tiesiojo tipo“ (polinkio kampas 180°) triukšmo slopinimo sienelės. Triukšmo slopinimo sienelės formos įtaka triukšmo sklaidai stebima žemojo (100–315 Hz) ir aukštojo dažnio (2000–5000 Hz) srityse. Žemojo dažnio garso bangų difrakciją efektyviausiai sumažina „J120“ formos ekranas, aukštojo dažnio srityje didžiausias ekranavimo efektas pasiektas taikant įprastinę „tiesiojo tipo“ triukšmo slopinimo sienelę.

Reikšminiai žodžiai: triukšmo slopinimo sienelė-ekranas, difrakcija, viršutinė dalis, polinkio kampas.

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