EVALUATION OF THE EFFECTIVENESS OF SCREENING WITH NOISE BARRIERS WITH ACCOUNT TO AN EDGE NOISE REDUCER

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Received: 01.06.09; Revised: 16.06.09; Accepted: 06.07.09

A b s t r a c t

The paper presents results of the experimental testing compared to theoretical results obtained based on computational methods. Site investigation of the effectiveness of road noise barriers screening have been carried out for two situations, with and without an edge noise reducer, whereas theoretical calculations of the effectiveness have been based on a few computational models as well as SoundPLAN software. Results of experimental-theoretical testing obtained in this way allowed to evaluate the range of the theoretical methods use in the established geometrical conditions: source of sound – noise barrier – observer. The paper presents evaluation of the effectiveness of noise barrier screening with the use of an edge noise reducer in the site investigation conditions as well as in numerical calculations. Obtained results of "in situ" screening effectiveness were compared with the results of theoretical calculations by means of a reducer simulation as a flat extension of tested noise barrier of height corresponding to the height of a reducer for calculations in the frequency function as well as cuboidal element fixed on the upper edge of the noise barrier in numerical calculations.

S t r e s z c z e n i e

W pracy przedstawiono wyniki badań doświadczalnych, które porównano z wynikami teoretycznymi otrzymanymi na podstawie metod obliczeniowych. Badania terenowe skuteczności ekranowania akustycznego ekranu drogowego wykonano dla dwóch sytuacji, bez i z uwzględnieniem krawędziowego reduktora hałasu, natomiast obliczenia teoretyczne skuteczności oparto na podstawie kilku modeli obliczeniowych i oprogramowania komputerowego SoundPLAN. Uzyskane w ten sposób wyniki badań doświadczalno-teoretycznych pozwoliły na ocenę zakresu stosowalności metod teoretycznych w ustalonych warunkach geometrycznych: źródło dźwięku – ekran – obserwator. W artykule przeprowadzono ocenę skuteczności ekranowania ekranu z zastosowaniem krawędziowego reduktora hałasu w warunkach badań terenowych i obliczeń numerycznych. Otrzymane wyniki badań efektywności ekranowania „in situ" porównano z wynikami obliczeń teoretycznych poprzez symulację reduktora jako przedłużenie płaskie badanego ekranu o wysokość odpowiadającą wysokości reduktora dla obliczeń w funkcji częstotliwości oraz jako obiekt prostopadłościenny zamontowany na górnej krawędzi ekranu w obliczeniach numerycznych.

K e y w o r d s: **Environmental acoustics; Sound barriers; Sound screening; Effectiveness of sound screening by sound barriers.**

1. NOISE BARRIER AS AN ELEMENT OF THE ENVIRONMENT SOUND PROTECTION

Each obstacle on the way of sound wave propagation causes disturbance to sound field, resulting mainly from the reflection and diffraction phenomenon. In relatively big calculation distances, a vehicle being a source of noise represents a point source, whereas communication route is modeled as a series of point sources along the roadway axis. Sound wave emitted by a source (a vehicle) undergoes reflection off ground it is moving on, off a noise barrier surface as well as facades of the buildings located in the vicinity of the observation points. It needs to be noted that some noise emitted by a source undergoes reflection off and noise barrier surface whose size depends on the absorption properties of panels, then filtrates through a noise barrier (of the finite insulating power) and reflects off the buildings façade surfaces as well as ground to get to the protected area (behind a noise barrier).

Total consideration of the phenomena of sound diffraction, reflection and filtration through the noise barrier is theoretically quite difficult issue. For this reason computational methods recognize only influence of phenomenon of the sound diffraction on the upper edge of a noise barrier.

Therefore, basic factor limiting effectiveness of a noise barrier, being half plane, in the assumptions perfectly insulating located in the freedom field, is diffraction of a sound wave on the upper edge of a noise barrier [4].

According to the definition acoustic effectiveness of a noise barrier is determined based on the dependency:

$$\Delta L_E = 10\log\frac{p^2(P)}{p_E^2(P)}, \quad [dB] \qquad (1)$$

where:

$p^2(P)$ – square of the direct wave acoustic pressure in observation point P, with no noise barrier,

$p^2_E(P)$ - square of the direct wave acoustic pressure in observation point P, with a noise barrier,

As a result of diffraction phenomenon diffraction waves get to geometrical shadow causing the fact that noise barrier effectiveness reaches a finite value. Based on the theories of diffraction developed on the geometrical optics ground, sound field can be determined in the area of shadow behind a noise barrier [1, 2].

Table 1 presents mathematical dependencies based on which sound effectiveness of a noise barrier, treated as half plane of infinite length, can be calculated.

2. TESTING ACOUSTIC EFFECTIVENESS OF A NOISE BARRIER

The test of noise barrier effectiveness with the use of a noise reducer on the top edge of a noise barrier was carried out in the field conditions. Testing was carried out in two stages with the use of measurement method included in the standard PN-ISO 10847:2002 Acoustics. "In situ" determination of all types of external noise barriers effectiveness [5]. First stage of testing included determination of noise barrier effectiveness without reducer measuring levels of noise without a noise barrier and after its installation.

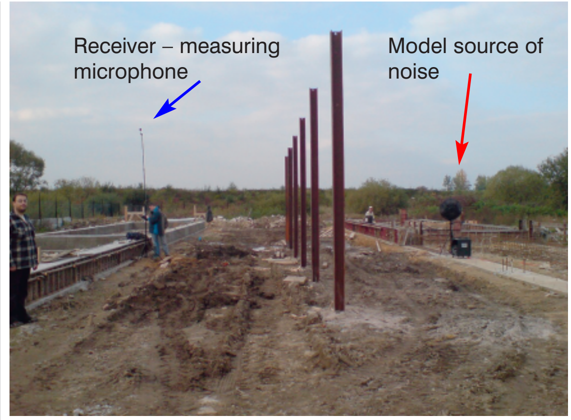

Figure 1.
Measurement system showing location of a model noise source and a receiver without a noise barrier

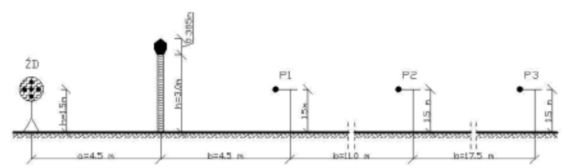

Figure 2.
Layout of the measurement system showing location of a model source of noise, a noise barrier and receivers

In the second stage measurements were carried out after installation of an edge noise reducer on the top edge of the noise barrier. One of the methods of testing noise barrier installed in the area is a direct method giving a procedure of carrying out measurements of sound pressure level in situation "before" or "after" installation of a tested device. Effectiveness of a noise barrier determined as D_{IL} is determined based on the dependency:

$$\mathbf{D_{IL} = (L_{ref,A} - L_{ref,B}) - (L_{r,A} - L_{r,B}), \ [dB]} \qquad (2)$$

where:

$L_{ref,B}$ – level of sound pressure „before" installation, in the reference point;

$L_{r,B}$ – level of sound pressure „before" installation, in the reception point;

$L_{ref,A}$ – level of sound pressure „after" installation, in the reference point;

$L_{r,A}$ – level of sound pressure „after" installation, in the reception point.

2.1. Description of a measuring stand

Effectiveness testing was carried out for one type of a noise barrier manufactured by "Gomibud" without and after fixing an edge noise reducer whose system,

Table 1.
List of computational models used to calculate sound effectiveness ΔL_E in the conditions of free sound field [3]

Author	Formula
Meakawa	$\Delta L_E = 10\log(20N+3)$, dla $N<1$ $\Delta L_E = 10\log(20N)$, dla $N \geq 1$ where: $N = \frac{2\delta}{\lambda}$ – Fresnel number, λ – length of the wave, $\delta = s + r - d$ – difference of ways of the wave getting to the observation point P directly and through a noise barrier edge, s – distance of source S from a noise barrier edge, r – distance of an observation point from a noise barrier edge, d – distance of an observation point from a source
Rettinger	$\Delta L_E = 10\log[(0.5-x)^2 + (0.5-y)^2 - 3$ $x = \int_0^v \cos\left(\frac{\pi v^2}{2}\right)dv$, $y = \int_0^v \sin\left(\frac{\pi v^2}{2}\right)dv$ $v = h_e\sqrt{\frac{s(s^o+r^o)}{\lambda s^o r^o}}$ s^o – distance of a source from a noise barrier r^o – distance of an observer from a noise barrier h_e – effective height of a noise barrier
Rathe	$\Delta L_E = 13 + 10\log N$, dla $N \geq 1$ $N = \frac{2\delta}{\lambda}$
Tatge	$\Delta L_E = 10\log(1+10N)$, dla $N > 0$ $N = \frac{2\delta}{\lambda}$

sound source – noise barrier – observer, geometry layout is presented in Fig. 2 and Fig. 1 whereas structure of an edge reducer in Fig. 3.

2.2. Results of tests and calculation of a noise barrier effectiveness

Results obtained based on the site investigation were compared to the results of theoretical calculations obtained based on Meakawa, Rettinger, Rathe and Tatge method (Table 1) as well as numerical calculations. Tests of a noise barrier sound effectiveness as well as theoretical calculations were carried out for three variants of an observer location towards a noise barrier in accordance with layout shown in Fig. 2.:

Variant I: layout parameters: a = 4.5 m, b = 4.5 m – **P1**, h = 3 m, h_o = 1.5 m.

Variant II: layout parameters: a = 4.5 m, b = 11 m – **P2**, h = 3 m, h_o = 1.5 m.

Variant III: layout parameters: a = 4.5 m, b = 17.5 m – **P3**, h = 3 m, h_o = 1.5 m.

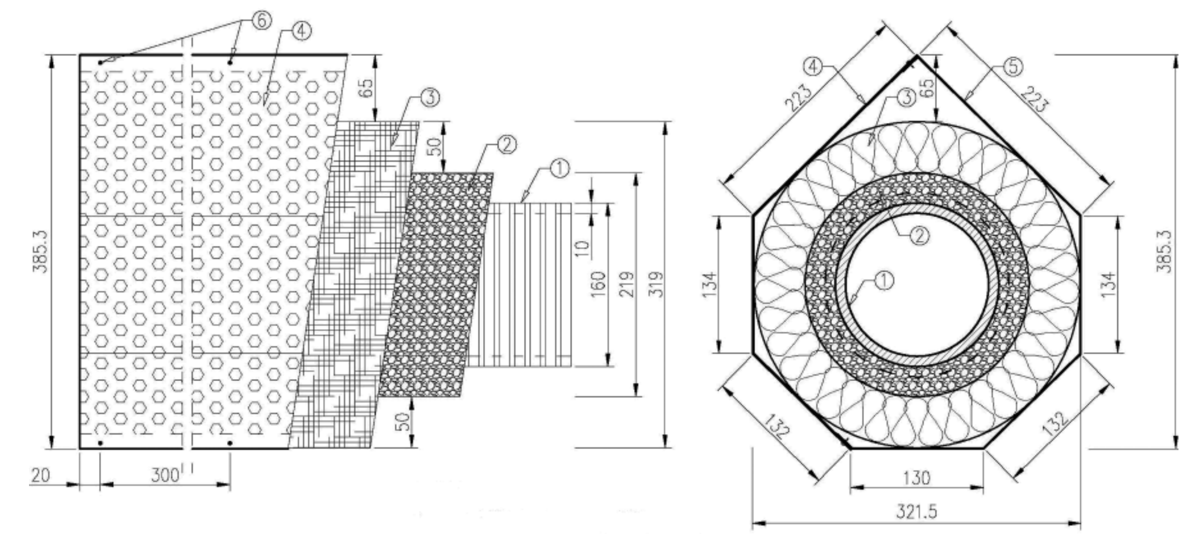

Figure 3.
Construction of the edge noise reducer manufactured by Gomibud subject to acoustic effectiveness testing. 1) PCV carbon pipe ø=160 mm, 2) mat SECUMAT ES 601 G4 30 mm, 3) mineral wool 75kg/m^3 50 mm, 4) aluminium sheet, perforated 1-1.5 mm, 5) aluminium sheet 1mm, 6) tinner's rivets ø=3-6 mm

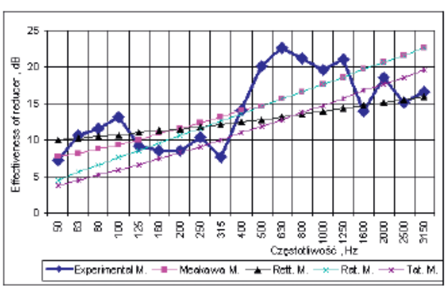

Figure 4.
Comparison of theoretical characteristics of screening effectiveness with empirical characteristic in marked octavo bands for VARIANT I

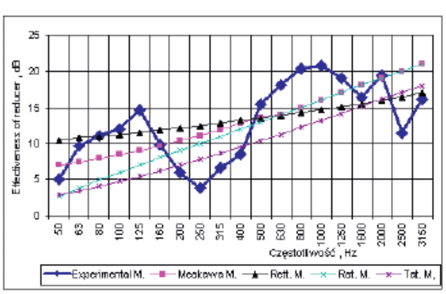

Figure 5.
Comparison of theoretical characteristics of screening effectiveness with empirical characteristic in marked octavo bands for VARIANT II

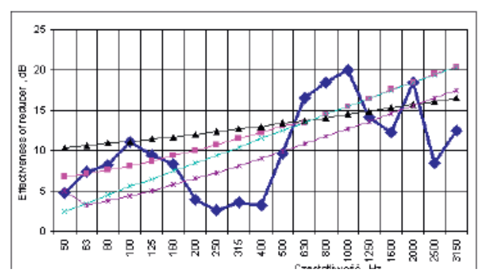

Figure 6.
Comparison of theoretical characteristics of screening effectiveness with empirical characteristic in marked octavo bands for VARIANT III

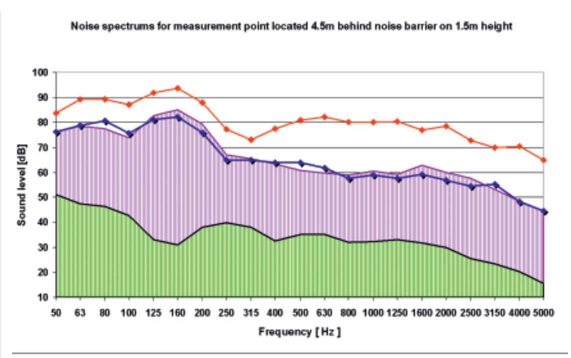

Figure 7.
Results of comparison of sound pressure level in measurement point located 4.5m from a noise barrier at the height of 1.5 m with a noise barrier and after installation of an edge noise reducer

Table2.
Value of acoustic parameters in a system with a reducer on the upper edge

f, [Hz]	Acoustic parameters for system : noise barrier – sound source – observer in [dB]								
	L_{2I}	L_{3I}	$(L_2\text{-}L_3)_I$	L_{2II}	L_{3II}	$(L_2\text{-}L_3)_{II}$	L_{2III}	L_{3III}	$(L_2\text{-}L_3)_{III}$
50	73.2	74.0	-0.8	71.9	70.0	1.9	69.0	68.4	0.6
63	77.0	77.5	-0.5	72.7	71.1	1.6	70.0	67.4	+2.6
80	75.9	75.6	+0.3	75.1	74.7	0.4	75.3	74.8	+0.5
100	72.7	75.0	-2.3	74.1	76.2	-2.1	71.8	74.6	-2.8
125	**74.5**	**75.3**	**-0.8**	**73.6**	**76.5**	**-2.9**	**70.6**	**70.5**	**+0.1**
160	82.9	79.4	+3.5	74.8	74.5	0.3	72.1	73.6	-1.5
200	79.7	75.1	+4.6	72.1	69.4	2.7	66.9	64.8	+2.1
250	**70.1**	**67.6**	**+2.5**	**60.3**	**58.4**	**1.9**	**60.7**	**58.4**	**+2.3**
315	69.5	68.0	+1.5	59.3	60.2	-0.9	57.1	56.2	+0.9
400	69.6	65.7	+1.6	60.1	61.0	-0.9	59.0	59.1	-0.1
500	**62.0**	**64.9**	**-2.9**	**55.4**	**56.8**	**-1.4**	**54.9**	**56.5**	**-1.6**
630	61.6	61.5	+0.1	54.9	53.4	1.5	52.3	50.6	+1.7
800	63.5	60.4	+3.1	58.4	54.8	3.6	56.7	50.7	+6.0
1000	**64.9**	**61.3**	**+3.6**	**57.3**	**53.0**	**4.3**	**56.5**	**52.2**	**+4.3**
1250	63.9	60.4	+3.6	55.6	53.4	2.2	55.4	50.9	+4.5
1600	65.4	62.4	+3.0	55.2	53.8	1.4	54.8	51.9	+2.9
2000	**64**	**60.0**	**+4.0**	**53.1**	**54.1**	**-1.0**	**50.8**	**49.0**	**+1.8**
2500	61.0	55.3	+5.7	51.6	49.9	1.7	51.1	47.0	+4.1
3150	53.8	55.8	-2.0	46.8	46.8	0	46.5	44.7	+1.8

$$\frac{1}{19}\sum_{50}^{3150}(L_2-L_3)_I=1.5\ \mathrm{dB} \qquad \frac{1}{19}\sum_{50}^{3150}(L_2-L_3)_{II}=0.75\ \mathrm{dB} \qquad \frac{1}{19}\sum_{50}^{3150}(L_2-L_3)_{III}=1.6\ \mathrm{dB}$$

Designations :
L_{2I} – sound level in third bands in the reception point with a noise barrier without reducer, for the observer's distance from a noise barrier amounting to b_1 = 4.5 cm,
L_{3I} - sound level in third bands in the reception point with a noise barrier with reducer, for the observer's distance from a noise barrier amounting to b_1 = 4.5 cm,
L_{2II} - sound level in third bands in the reception point with a noise barrier without reducer, for the observer's distance from a noise barrier amounting to b_2 = 11 cm,
L_{3II} - sound level in third bands in the reception point with a noise barrier with reducer, for the observer's distance from a noise barrier amounting to b_1 = 11 cm,
L_{2III} - sound level in third bands in the reception point with a noise barrier without reducer, for the observer's distance a the noise barrier amounting to b_2 = 17.5 cm,
L_{3III} - sound level in third bands in the reception point with a noise barrier with reducer, for the observer's distance from a noise barrier amounting to b_1 = 17.5 cm

Figures 4-6 list results of experimental testing and theoretical calculations in accordance with the methods specified in Table 1 as well as numerical calculations, respectively for variants specified above.

Analyzing obtained characteristics of the screening effectiveness for the examined geometrical conditions, there are discrepancies between experimental and theoretical results. These discrepancies are particularly noticeable in the range of medium frequencies 400-1600 Hz. Fig. 7 presents results of the measurements of sound pressure level in the reception point P1 with account to tested noise barrier before and after installation of a noise reducer.

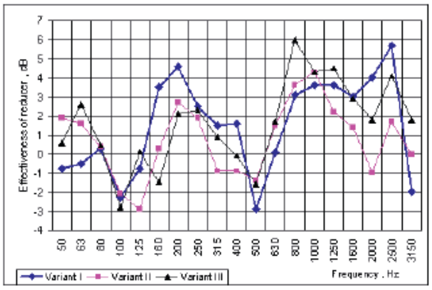

Figure 8.
Relative evaluation of the effectiveness of an edge noise reducer screening in relation to a noise barrier without a reduce $\Delta L_{ER} = L_2 - L_3$ depending on the location of an observer towards a noise barrier in the marked third bands

2.3. Evaluation of the effectiveness of an edge noise reducer screening

Screening effectiveness tests were carried out for three versions of an observer location towards a noise barrier with remaining geometrical parameters unchanged after installation of a noise reducer on the upper edge of a noise barrier. Obtained for this situation results of screening effectiveness with installed reducer and without it have been listed in Table 2.

To evaluate impact of an edge noise reducer on the effectiveness of acoustic screening effectiveness values were determined for the differences in screening effectiveness of a noise barrier with installed edge reducer and without it.

$\Delta L_{ER} = L_2 - L_3$ in the frequency bands from 50-3150 Hz, correspondingly for a receiver distance b = 4.5m; 11.0m; and 17.5 m, using the same remaining geometrical parameters of the system.

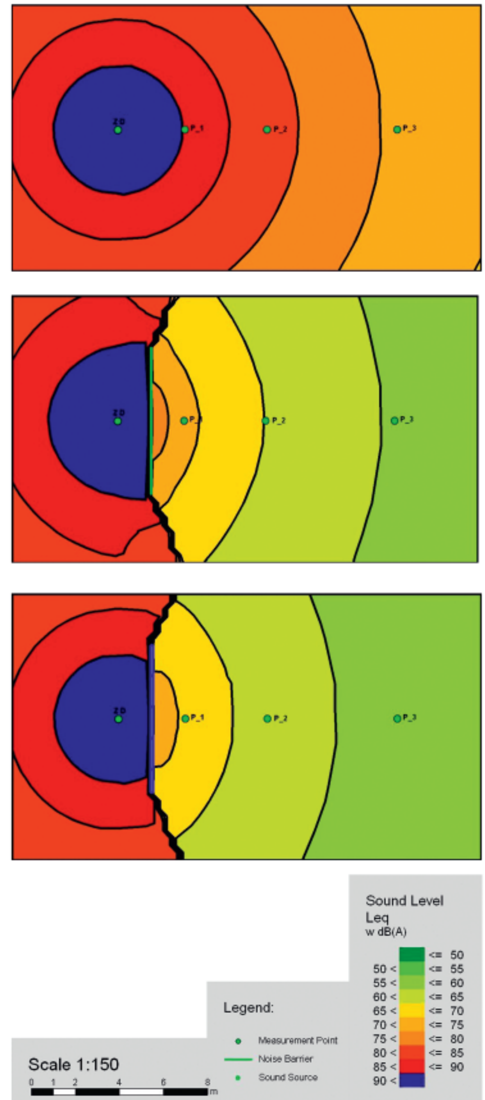

Figure 9.
Acoustic map without a noise barrier and after its installation with and without an edge reducer

Table 3.
Effectiveness of a noise barrier and an edge reducer obtained based on the testing results and numerical calculations for reception points

Number of point	Level of noise in [dB]				
	Without a noise barrier	After a noise barrier installation	After a reducer installation	A noise barrier effectiveness	An edge reducer effectiveness
Results obtained based on the measurements					
P1	89.5	75.6	73.6	13.9	2.0
P2	84.3	68.4	67.9	15.9	0.5
P3	80.8	66.4	65.4	14.4	1.0
Results obtained based on the numerical calculations					
P1	89.5	72.8	70.7	16.7	2.1
P2	81.3	65.6	63.9	15.7	1.7
P3	73.3	60.0	58.4	13.3	1.6

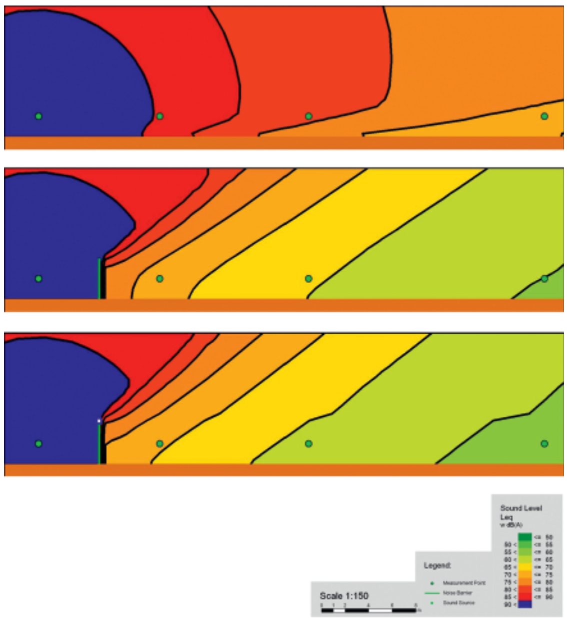

Figure 10.
Acoustic map in the cross-section without a noise barrier and after its installation with and without an edge reducer

2.4. Numerical calculations of screening effectiveness

Calculations were made with the use of SoundPLAN packet to compare carried out analyses of experimental investigation and model calculations with currently available computer tools used for modeling and calculating noise propagation. Obtained results have been presented in the form of noise maps in Fig.9 for situation without a noise barrier, after its installation and after installation of an edge reducer. Calculations were made for the same situations in cross-section perpendicular to a noise barrier and their results have been presented in Fig. 10. Table 3 presents results of calculations in points for:

Variant I : layout parameters: a = 4.5 m, b = 4.5 m – **P1**, h = 3 m, h_o = 1.5 m.

Variant II : layout parameters: a = 4.5 m, b = 11 m – **P2**, h = 3 m, h_o = 1.5 m.

Variant III: layout parameters: a = 4.5 m, b = 17.5 m – **P3**, h = 3 m, h_o = 1.5 m.

3. COMMENTS AND FINAL CONCLUSIONS

Testing a noise barrier without an edge noise reducer and then after its installation enabled both practical analysis of the range of applicability of the employed computational methods used for acoustic effectiveness as well as the evaluation of additional screening resulting from the use of an edge noise reducer.

Based on carried out investigation of the sound field distribution without a noise barrier and then after its installation with and without an edge noise reducer it has been noted that:

– Acoustic effectiveness of a noise barrier without an edge noise reducer very clearly depends on sound frequency and within medium and high frequencies is within the range of **10.7-14.6 dB**, however, it decreases substantially for low frequencies within the range of **50-250 Hz**, which is confirmed also by the results of theoretical calculation;

– Results of theoretical calculations of a noise barrier acoustic effectiveness without a noise reducer are generally not compliant with the experimental investigation results, only in some frequency bands compliance of these results can be found to be satisfactory;

– The greatest compliance of experimental and theoretical results of the investigated noise barrier acoustic effectiveness is obtained in accordance with Rettinger method in low frequencies band **50-125 Hz** as well as high frequencies band **1600-3150 Hz** for the examined geometrical variants;

– The use of an edge noise reducer causes random change of screening effectiveness substantially dependent on the sound frequency as well as distance of an observation point from a noise barrier;

– Averaging obtained results of a noise barrier acoustic effectiveness measurement with a noise reducer within the whole scope of measured frequencies would allow quantitative evaluation of a reducer suppression effectiveness which amounts to:

– for location of a microphone from a noise barrier in the distance b = 4.5m around ΔL_{ERI} = 1.5 dB,

– for location of a microphone from a noise barrier in the distance b = 17.5m around ΔL_{ERIII} = 1.6 dB,

– for location of a microphone from a noise barrier in the distance b = 11m around ΔL_{ERII} = 0.75 dB,

– for location of a microphone from a noise barrier in the distance b = 17.5m around ΔL_{ERIII} = 1.6 dB,

– Despite obtaining very good compliance between measurements and the result of measurement in point P1 without a noise barrier, there are discrep-

ancies noticeable in the farther distance from a source;
- Close values are typical of the effectiveness of a noise barrier itself and a noise barrier with installed edge reducer;
- An edge reducer is characterized by insignificant increase of screening effectiveness and it depends on the reciprocal location of a noise source and reception point.

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