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The Comprehensive Research of the Road Acoustic Screen with Absorbing and Diffusing Surface

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The paper presents the new solution to a road acoustic screen consisting of elements which are highly diffusing and simultaneously resistant to weathering, but also characterised by a sound absorption. There is described the comprehensive research of such the road acoustic screen with absorbing and diffusing surface. The study includes screen's resistance to wind load and snow removal, impact tests and measurements of some acoustic parameters.

Keywords: acoustics, mechanical strength, environmental actions, sound reflection, sound diffusion.

1. Introduction

The development of the automotive industry, road construction and environmental protection against noise caused that the thoroughfares require the equipment in acoustic screens. The method of construction of these devices depends mainly on their functions, but their implementation is also connected with the aesthetics, costs, durability and the possibility of recycling. The required acoustic characteristics represented by the insulation and sound absorption shall be determined on the basis of laboratory measurements of screens' elements (EN 1793-1:1997, EN 1793-2:1997). However, it is not considered the sound diffusion coefficient which has a significant impact on the acoustic screen's effectiveness.

The road acoustic screen with a flat reflective surface may direct a large amount of energy towards the protected objects, thereby reducing its effectiveness. Whereas, the screen with the sound diffusion surface reduces the amount of acoustic energy propagating in the direction of reflection so its effectiveness is higher (Fig. 1). The reduction of the reflected sound level can also be obtained by using elements characterized by high sound absorption, but these elements are usually expensive and undurable. Therefore, it is justified to construct the road acoustic screens using elements which are highly diffusing, but also having a sound absorption.

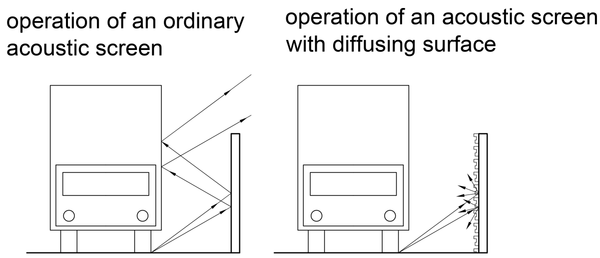

Fig. 1. Operation of an ordinary acoustic screen and a screen with diffusing surface (Kamisinski *et al.*, 2010).

2. New solution to road acoustic screens

Owing to the participation in a grant: "The measurement setup and procedures used during the research of sound diffusing structures" (No N R03-0036-06/2009), the scientists and employees from: Moller-Polska Sp. z o.o. company, AGH University of Science and Technology, University of Technology and Life Sciences in Bydgoszcz proposed the new solution to a road acoustic screen working on the basis of sound scattering and absorbing (Okręglicki *et al.*, 2008). The prototype of the designed acoustic screen is shown in Fig. 2.

Fig. 2. The prototype of the designed acoustic screen.

The panel was made in PVC extrusion technology with the addition of wood dust. It has two surfaces different in terms of some acoustic parameters, which allows to adapt the designed acoustic screen to the specific needs. On one side there is a Schroeder diffuser. A typical Schroeder diffuser (Fig. 3) consists of the wells with a given width ($2h$) and depth (l_k) due to the pseudorandom sequence. The wells are separated by vertical dividers with a width of w. The basis of its operation is to change the phase of the reflected sound thereby causing sound diffusing (Cox, D'Antonio, 2009). On the other side of the panel, there is a cylindrical diffuser. It could be perforated to increase sound absorption (Fig. 4).

The designed structure is double-sided and may be arranged alternately to allow different configurations of the road acoustic screen. Moreover, the panels might be mounted at the screens as a finial (Fig. 5). Finals made from a diffusion element increase the screen's efficiency allowing to reduce its height. Such panels with Schroeder diffuser sometimes are also used in some interiors, as they affect the room acoustic parameters (Kamisiński *et al.*, 2010).

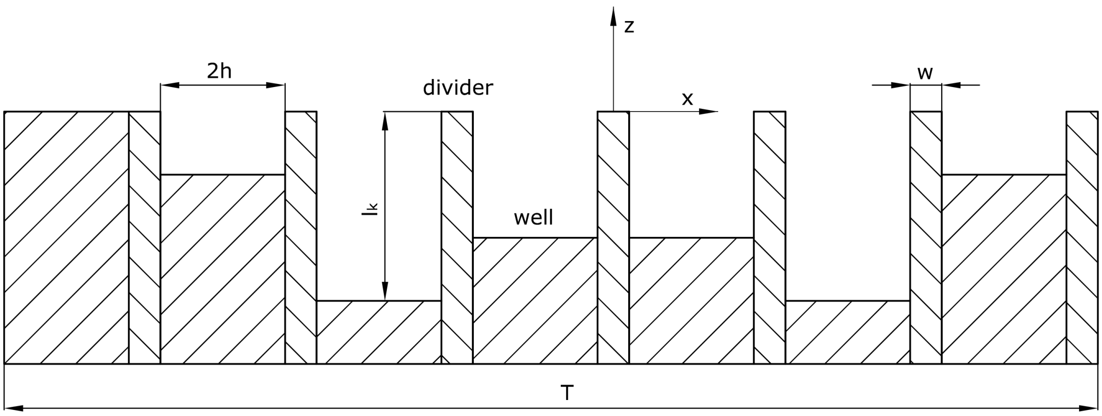

Fig. 3. The construction of Schroeder diffuser.

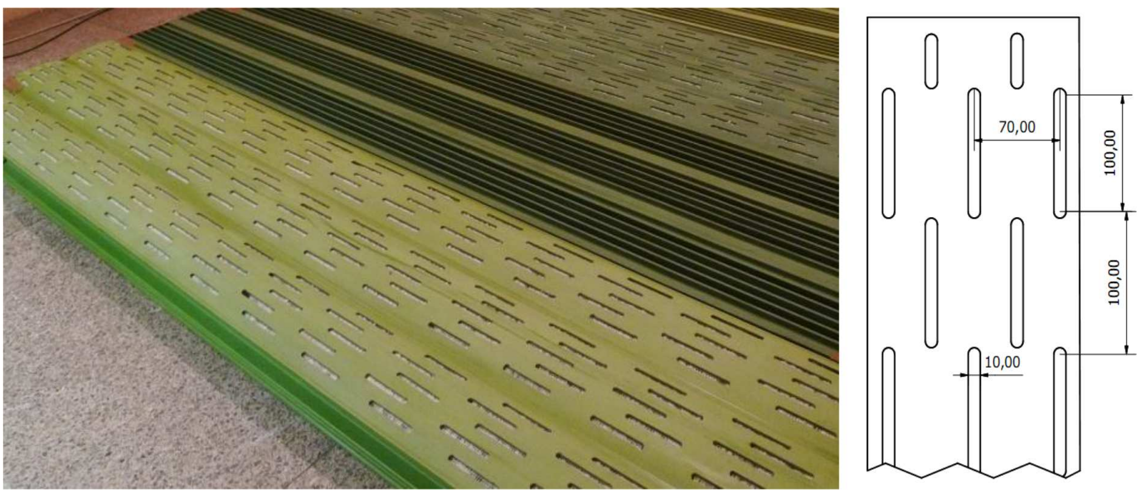

Fig. 4. The cylindrical diffuser – perforated and filled with an absorbing material.

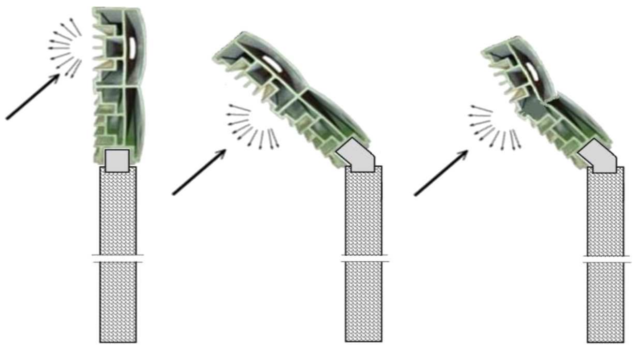

Fig. 5. The designed panels mounted at the screens as a finial.

The designers claim that such a road screen has distinguished acoustic parameters, which can be properly shaped depending on the screen's function. Moreover, it is easy to mount, durable and recyclable. To prove this statement there were carried out the comprehensive research of the designed screen.

3. The experimental studies of the designed road acoustic screen

3.1. The research program

The study of road acoustic screens aims at the verification not only of acoustic parameters but also the resistance to wind load, snow removal or stroke of stones thrown from the roadway. Thus, the acoustic screens should be highly resistant to such impacts and only their superficial damages are permit. Therefore, the research program include:

- Study of the resistance to wind load and snow removal according to standards: EN 1991-1-4:2005 and EN 1794-1:2011 (Germaniuk *et al.*, 2013);
- Study of some screen's mechanical properties including impact or hardness tests (ISO 179-2:1997 and EN 1794-1:2011) (Śliwa, Zimniak, 2010);
- Laboratory measurements of acoustic parameters: sound scattering and diffusion (ISO 17497-1:2004, ISO 17497-2:2012), sound absorption (EN 1793-1:1997), sound insulation (EN 1793-2:1997);
- "In situ" measurement of the external acoustic screens' effectiveness (ISO 10847:1997).

3.2. Study of screen's mechanical properties

3.2.1. Screen's resistance to wind load and snow removal

To study the panels' resistance to wind load and snow removal, there were carried out measurements using three different samples (Fig. 6). The first one consists of two panels arranged in alternating order and feathered. The sample width was about 6 m (It is the longest dimension as the screen panels are arranged horizontally). The second sample was additionally strengthened by pipe with dimensions: 60×60×3 mm and two C-sections with dimensions: 60×30×3 mm. The third sample was similar to the second one but it was about 1 m narrower.

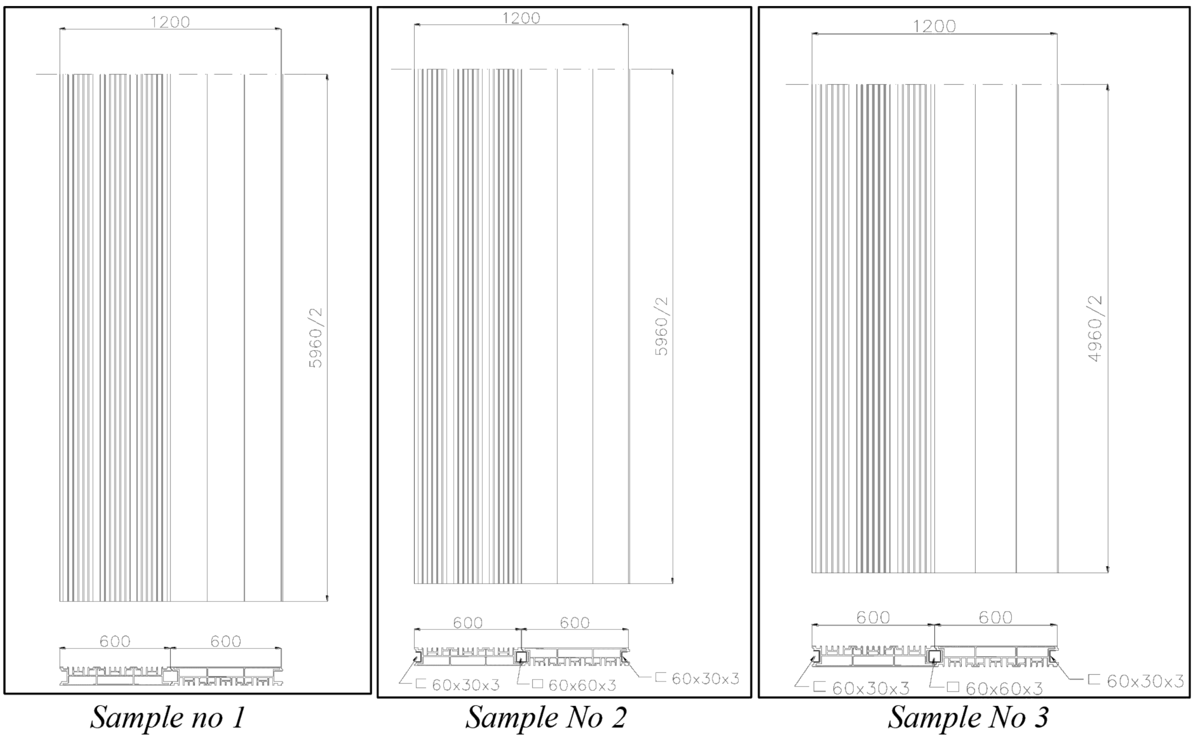

Fig. 6. Three different samples to study the panels' resistance to wind load and snow removal.

Table 1. The permitted and measured values of deflections for tested samples.

	Reversible deflection		Permanent deflection	
	Permitted values [mm]	Measured values [mm]	Permitted values [mm]	Measured values [mm]
Resistance to wind load				
Sample no 1	39.7	53.7	11.9	5.1
Sample no 2	39.7	24.3	11.9	0.3
Resistance to snow removal				
Sample no 3	33.1	27.9	9.9	1.4

The research was carried out in accordance with the standards EN 1794-1:2011 and EN 1991-1-4:2005. The permitted and measured values of deflections for tested samples are shown in Table 1. Based on the performed studies it was found that the first sample did not meet the requirements for the resistance to wind load and snow removal. Therefore, it was necessary to examine the second sample which proved to be resistant to wind load but not to snow removal. The third sample, narrower than the other, met all the requirements. Finally, it was assumed that the design panel should have a width up to 5 m and it must be strengthened.

3.2.2. Impact and hardness tests

The road acoustic screens must be largely resistant to impact. Their superficial damage is only allowed. Therefore, it was essential to carry out the research of screen's mechanical properties including:

- an impact test – using Charpy's hammer (ISO 179-2:1997);
- an impact test – simulating the impact of stone (PN-EN 1794-1:2011);
- a hardness test – basing on Brinell's method.

Based on the research the following conclusions can be drawn. Firstly, determination of impact resistance using Charpy's hammer is not possible because samples were destroyed. On the other hand, the impact resistance while simulating the impact of stone meets requirements. Moreover, the panel's hardness strongly depends on the sampling site.

3.3. The research of some acoustic parameters

3.3.1. Sound scattering and diffusion coefficients

The measurements of sound scattering and diffusion coefficients were made according to the standards: ISO 17497-1:2004 and ISO 17497-2:2012, respectively. The sample used to study sound scattering coefficient was circular with a diameter of 2.7 m (Kamisiński *et al.*, 2012). On the other hand, the sample for research of sound diffusion coefficient had a rectangular shape and dimensions of 1000×800×120 mm. The measurement of sound scattering coefficient was carried out in a reverberation chamber, whilst the measurement of sound diffusion coefficient took place in an anechoic chamber (Fig. 7) (Felis *et al.*, 2012). The research results are shown in Fig. 8.

The research has shown that the scattering and diffusion coefficients of the tested samples are very high

Fig. 7. Tested samples on the measurement setups: the sample used to study sound scattering coefficient (on the left) and the sample used to study sound diffusion coefficient (on the right).

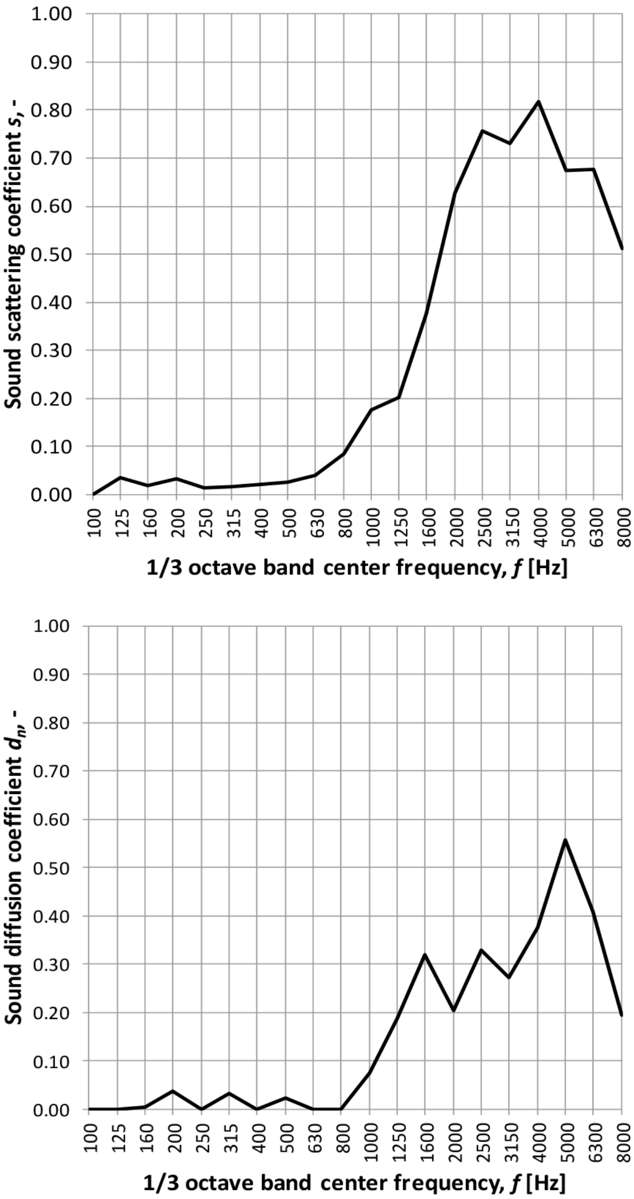

Fig. 8. Sound scattering (top) and diffusion (bottom) coefficients as a function of the sound frequency.

for the frequency range above 1600 Hz, which confirms the usefulness of this type of structure to build road acoustic screens. Nevertheless, due to the possibility of adverse interference of reflected waves occurring around this type of repetitive structures, it is preferred to disturb such a sequence by another sound absorbing and diffusing structure.

3.3.2. Sound absorption coefficient

The measurement of sound absorption coefficient was performed according to standard ISO 354:2003. The study for fifteen different samples was conducted in a reverberation chamber. The samples differed in respect to the arrangement of tested profiles (Schroeder diffuser, cylindrical profile), the type of perforation and the filling (mineral wool, granulate of polyurethane foam). The exemplary sample on the measurement setup is shown in Fig. 9.

Fig. 9. A sample consisting of alternate panels: a perforated Schroeder diffuser and a perforated cylindrical profile.

Based on the performed studies of sound absorption coefficient for fifteen measurement samples, it can be concluded that the proposed panels can provide onenumerical absorption index DLα even equal to 7 dB. Asignificant impact on the panels' absorption have a surface perforation and the filling. Among the all tested samples, the best result was achieved for a perforated panel (cylindrical) filled with mineral wool having a density of 50 kg/m^3 and 30 mm thick.

3.3.3. Sound insulation

Nowadays the European standards allow to conduct the measurements of airborne sound insulation of acoustic screens both by "in situ" and laboratory tests. According to the articles by Watts, Morgan (2006) and Garai, Guidorzi (2000) these two methods show a high degree of correlation for timber, metal and concrete noise barriers. Thus, the authors decided to carry out only the laboratory measurements of sound insulation of proposed road acoustic screens in accordance with standards: ISO 10140-2:2010 and EN 1793-2:1997. The sample on the measurement setup is shown in Fig. 10, whilst Fig. 11 illustrates the airborne sound insulation of tested sample as a function of the sound frequency.

The conducted measurements of screen's airborne sound insulation showed that the designed screen's onenumerical index DL$_R$ is equal to 33 dB. This value provides the proper operation of such an acoustic screen for all typical acoustic situations. The increasing of panel's sound insulation for such applications has no economical justification. Moreover, it is worth adding that after applying the surface perforations to increase panel's sound absorption, the index DL$_R$ does not decrease below 24 dB.

Fig. 10. The sample on the measurement setup intended for determination of elements' sound insulation.

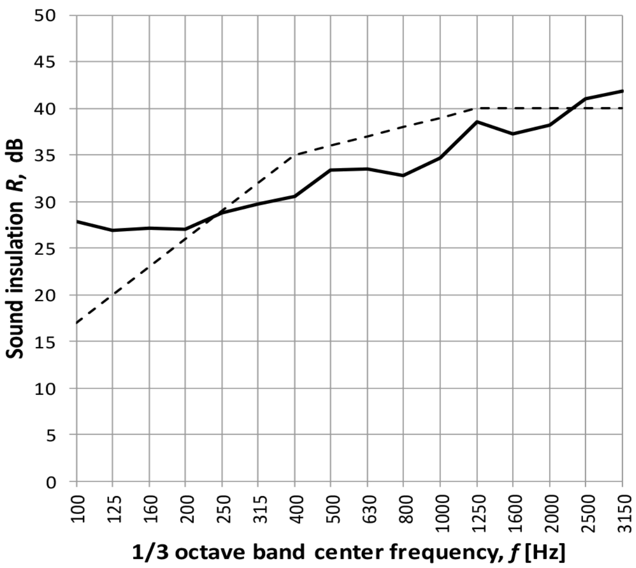

Fig. 11. Airborne sound insulation of tested sample as a function of the sound frequency.

3.3.4. "In situ" measurement of the external acoustic screens' effectiveness (insertion loss)

The major parameters with respect to acoustic properties that characterised noise barriers in "in situ" tests are insertion loss as screens' effectiveness, insulation index for airborne sound insulation and reflection index for sound reflection. The last two indices can be measured following the method described in CEN/TS 1793-5 standard. Nevertheless, as was mentioned in Subsubsec. 3.3.3, the screen's airborne sound insulation was determined only in laboratory studies. Moreover, the reflection index also was not measured as the scattering surface of the acoustic screen could falsify obtained results (Tronchin, 2013a; 2013b). As a consequence, the only determined in in-situ measurement parameter was the screen's acoustic effectiveness.

The produced panels were used to build experimental acoustic screen with a length of 10 m and a total height of 4.50 m, in the version with alternating panels of sound diffusing and absorbing surface. The insertion loss was measured for two variants of slanted final. Figure 12 illustrates screens with the diffusing (top) and reflecting (bottom) final.

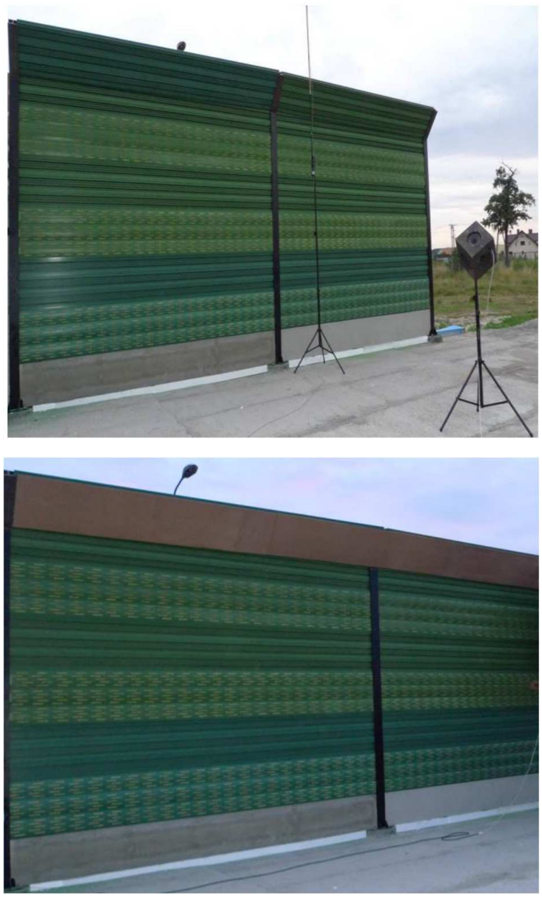

Fig. 12. The studied acoustic screen composed of alternating diffusing and absorbing panels, with the diffusing (top) and reflecting (bottom) final inclined in the direction of the sound source.

The study was carried out according to standard ISO 10847:1997 Acoustics – In-situ determination of insertion loss of outdoor noise barriers of all types. An equivalent of the sound source was a cubic omnidirectional speaker and the measurement signal was white noise. Signals' analysis was carried out in 1/3 octave bands in the range of 100–10000 Hz. A scheme of the measurement stand is shown in the following figure (Fig. 13).

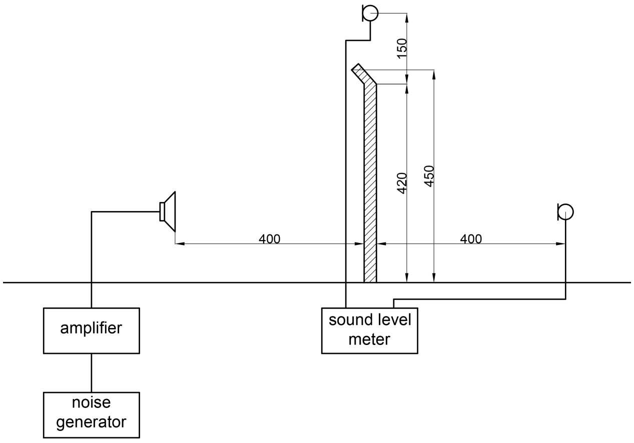

Fig. 13. Scheme of the measurement stand.

On the basis of the carried out measurements the acoustic effectiveness D_{IL} was calculated. The obtained results are shown in graph below (Fig. 14).

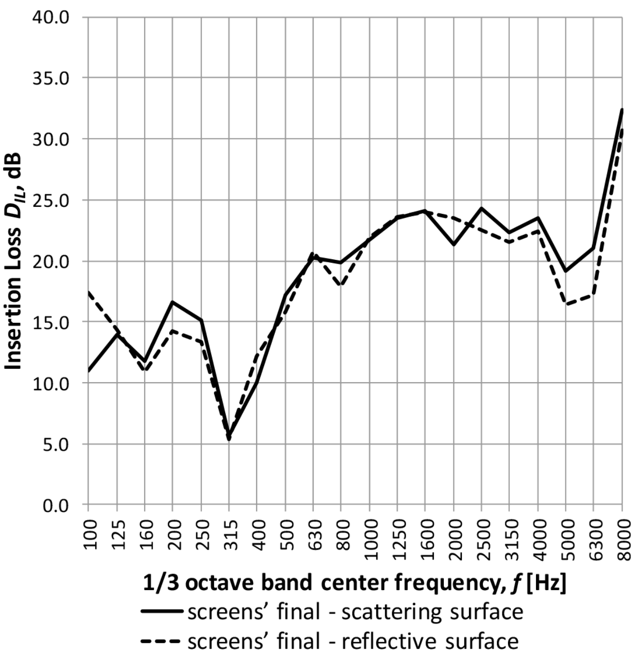

Fig. 14. The acoustic effectiveness D_{IL} calculated for two versions of screens' final.

On the basis of obtained results it could be concluded that for high frequencies the diffusive final has greater efficacy than the reflective one. The increase in acoustic effectiveness of the screen occurs in the usefulness frequency range of designed diffuser. The use of scattering element as a culmination of the screen may increase its effectiveness in the field of the frequencies range scattered by diffuser. For presented configuration it was proved that the acoustic effectiveness of described screen's configuration has grown from $D_{IL} = 17$ dB to $D_{IL} = 18.3$ dB after using designed diffuser. This value is classified as a very high.

4. Summary and conclusions

The examined new acoustic screen with absorbing and diffusing surface is a result of the progressive process to improve the design of noise barriers. Based on the comprehensive research and calculations carried out in accordance with some standards for the road acoustic screens, it can be concluded the studied acoustic screen meet the requirements of EN 1794-1:2011 for snow removal and wind load in the first load zone described in EN 1991-1-4:2005. Furthermore, the results of tests carried out under simulated impact of stones thrown from the roadway are positive. The pestle strokes on the screen's walls formed small cavities, which are within the limits specified in EN 1794-1:2011. There were also examined some acoustic parameters of the studied screen. It's insertion loss (ISO 10847) may even reach a value of 18.3 dB. The scattering (ISO 17497-1:2004) and diffusion (ISO 17497 2:2012) coefficients of the tested sample are very high for the frequency range above 1600 Hz (up to 0.6 and 0.8, respectively). The sound absorption index DLα is in the range from 4 to 7 (EN 1793-1:1997), depending on the sample type, while the sound reduction index DL_R (EN 1793-2:1997) is equal to 33 dB if there is no screen's perforation or in the case of perforated panels, it is greater than 24 dB.

Summing up, the presented acoustic screen can effectively compete with the structures currently used for traffic routes. It is distinguished by significant acoustic efficiency, easy assembly, high durability or the possibility of recycling. Moreover, the screen's acoustic parameters might be formed depending on its designed function. The application of the diffusing structure causes the considerable reduction of the sound level on the direction of reflection, however, this effect is not commonly considered during the design of acoustic screens. Therefore, it is reasonable to use such highly diffusing elements to the construction of noise barriers. Furthermore, the sound scattering and diffusing coefficients should be placed in the manufacturer's catalog data.

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