

LOUVRED NOISE BARRIER FOR TRAFFIC NOISE REDUCTION

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Abstract. Environmental issues near roads become more and more important in our society daily life. One of the most critical environmental issues is traffic noise. The present paper study louvred noise barrier designed by authors. The louvred noise barrier provides sound attenuation while allowing airflow and sunlight through it. Since the airflow resistance of the barrier is low, it requires a shallow foundation compared to conventional noise barriers. The sound attenuation performance of the louvred noise barrier was tested experimentally in a sound transmission chamber. Airflow resistance simulated using a computational fluid dynamics model. The simulation and experimental study were done with different louvred noise barrier setup: change of louvre blade angle and sound-absorbing material thickness. The results showed potential for future development for the field testing. Sound attenuation was highest in 2500 Hz and 3150 Hz octave frequency bands. Depending on the louvred barrier

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setup, sound attenuation was up to 28 dB(A) in mentioned frequency bands. The equivalent sound pressure level reduced up to 17 dB(A). The results showed that an increase in the louvre blade angle increases sound attenuation and increases airflow resistance.

Keywords: airflow, louvred barrier, mineral wool, noise barrier, sound-absorbing materials, sound attenuation.

Introduction

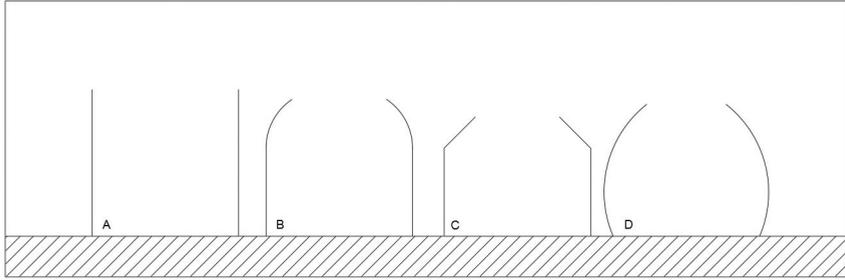
Traditionally noise is described as any intrusive or disruptive sound (Monsefi et al., 2011). A sound becomes intrusive when it disturbs people everyday activities, such as sleep, conversations or deteriorates the quality of life (Baltrėnas et al., 2010; Gražulevičienė & Bendokienė, 2009; Zavadskas et al., 2009). As reported by the World Health Organization, 20% of the European Union population is exposed to noise exceeding 65 dB(A), and 30% of the population exposed to noise exceeding 55 dB(A). Extended exposure to such noise level may cause health problems. The most frequent noise-related diseases are sleep disorders, cardiovascular and mental diseases. People who regularly exposed to 85–90 dB(A) noise at factories or industrial premises are at risk of progressing loss of hearing or hyperacusis (World Health Organization, 2011).

One of the solutions to reduce environmental noise pollution is to use noise barriers. Their shape could classify noise barriers (Figure 1) and the materials used. The barriers, which have perforated plates with absorbing material inside classified as absorptive, are made of brick or plastics classified as purely reflective—noise barriers classified using those parameters (Table 1).

One of the most critical parameters of traditional noise barrier design is the shape. Different shapes of barrier provide better sound screening geometrically. Several studies are done to test the performance of different shape of noise barriers. Such studies focus on inclination

Table 1. Classification of various noise barriers (Yoon & Pyo, 2019)

Shape	Material	Type regarding sound absorption	Fillers
plane, vertical	metal	no absorption	mineral wool
plane, inclined	concrete	integrated	chip wood
plane, curved	ceramic bricks	absorption	clay or other
plane, bent	wood or board	additional absorption	ceramic grains
embankment	transparent glass or plastic		plastic or rubber foam



Note: A – vertical, B – curved, C – inclined, D – bent.

Figure 1. Different shapes of noise barriers

angles of noise barrier rooftop shield (Figure 1, C) (Defrance & Jean, 2003; Venckus et al., 2012; Voropayev et al., 2017). Such devices on noise barriers are needed to change the sound diffraction wavefield.

Recently designs with air gaps become more attractive in the research of noise barrier development. Several designs of noise barriers with air gaps have been proposed. Noise barriers with air gaps could be attractive to constructors because it requires a shallow foundation since airflow resistance of such barriers are close to zero (Dimitrijević et al., 2019). Often such systems use sonic crystals to scatter the sound energy (Figure 2). Studies show that sound barriers using sonic crystals attenuate sound levels up to 16 dB(A). However, the reported results do not show the broadband attenuation (Dimitrijević et al., 2019). The distinct design sonic crystal noise barrier reaches up to 25 dB(A) (Sánchez-Pérez et al., 1998). Such a noise barrier is designed with channels inside the columns to create resonant elements (Radosz, 2019).



Figure 2. Noise barrier with air gaps (Dimitrijević et al., 2019)

Sound-absorbing materials coverings in such noise barriers usually used to achieve more broadband sound attenuation (Engel, 2014; García-Chocano & Sánchez-Dehesa, 2013; Romero-García et al., 2009; Umnova et al., 2006).

Louvred noise barriers used as a structural element that controls noise and, at the same time, enables the airflow and lighting through the construction while attenuating the sound (Lee et al., 2020). Such noise barriers can be used in facades of buildings, as sound-attenuating jackets for engineering equipment that needs ventilation, e.g., air conditioners or near roads. Louvred barriers may also be used as a noise barrier on highways instead of traditional noise barriers. Compared to commonly used non-transparent shields, louvred noise barriers increase the flow of natural light onto the road surface and allow the travellers to see the surrounding areas while travelling (Viveiros et al., 2002; Watts et al., 2001). Louvred barriers could also be used as an alternative to currently commonly used traditional noise barriers. The noise barrier effectiveness mainly depends on its height, the shape of the top and the place of installation (Duhamel, 2006; Naderzadeh et al., 2011; Venckus et al., 2012).

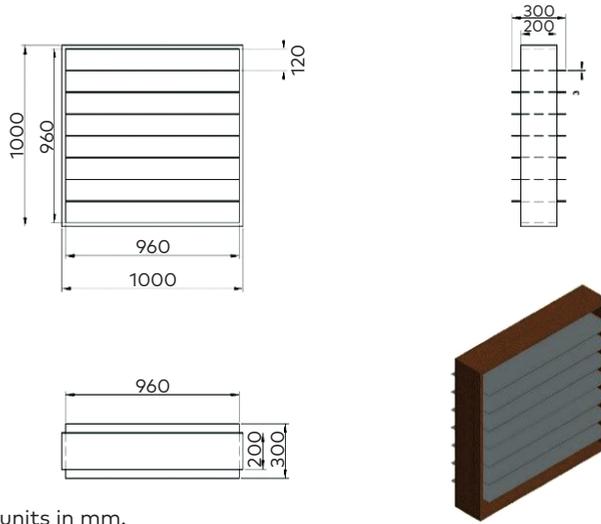
This article aims to propose a design for a louvred noise barrier with low airflow resistance. The paper organised as follows: in Section 1, the design of the louvred noise barrier and testing methods presented; in Section 2, the results of the study presented; in Section 3, the discussion and the conclusions presented.

1. Louver design and testing methods

Figure 1 presents the designed louvred noise barrier. The presented design provides high ventilation while diffracting the sound waves in the desired direction. The tested louvred barrier dimensions are 1.0 m × 1.0 m. A barrier made of 7 steel blades of 3 mm thickness equally spaced at 120 mm distances. The drawings with the indicated dimensions presented in Figure 3.

Every sound attenuation test has been done with louvre blades in a horizontal position and changing tilt angle from 0° to 45° with a step of 15° (Figure 4). All louvre blades tilted in parallel.

The sound absorption of such a barrier is linked to the sound absorption of mineral wool and the air permeability of the barrier. Since it is well-known that mineral wool shows high sound absorption, there was done several computational fluid dynamics (CFDs) simulation runs. The simulation investigates the correlation between air permeability and sound reduction of such barrier using “SimScale” modelling



Note: units in mm.

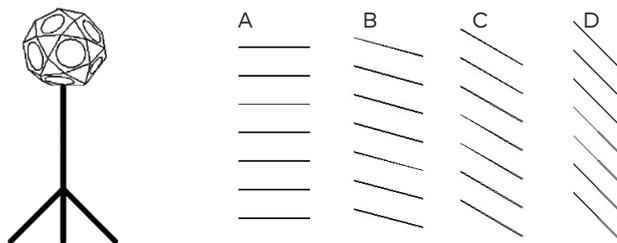
Figure 3. The design of the louvred noise barrier for laboratory sound attenuation tests

software. CFD simulation model was incompressible and steady-state flow.

The testing was done using different thickness mineral wools:

- covered with mineral wool on both sides: density 40 kg/m^3 , thickness 10 mm;
- covered with mineral wool on both sides: density 40 kg/m^3 , thickness 20 mm;
- covered with mineral wool on both sides: density 40 kg/m^3 , thickness 30 mm.

The transmission chamber used to determine the designed louvred noise barrier sound attenuation (Figure 5). The transmission chamber



Note: A – 0°; B – 15°; C – 30°; D – 45°.

Figure 4. Tilting positions of louvred barrier blades in measurements

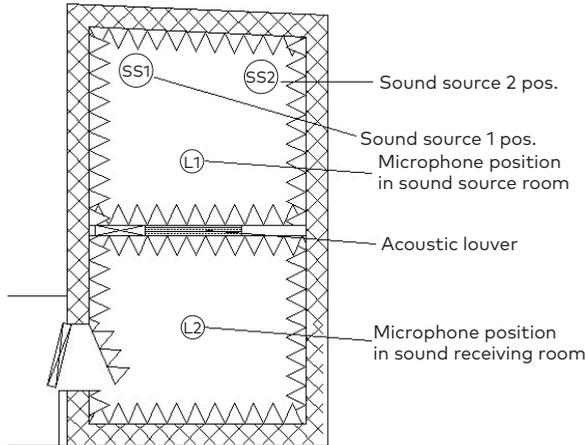


Figure 5. Equipment and tested louvre positions in the chamber

made of two rooms separated by an opening where the test specimen placed. The sound receiving room is semi-anechoic. The connecting partition of chamber rooms is soundproofed to reduce the indirect noise transmission (i.e., not through the opening where the test specimens are placed) and minimise the background noise sounds in the noise attenuation chamber. A louvred barrier tightly fixed in the wall opening for the test sample, with all edges insulated with soundproofing tape. Due to the limitations of the chamber, the lowest measured frequency was 500 Hz.

The tests were done following the methodology described in *ISO 10140-2:2010 Acoustics Laboratory measurement of sound insulation of building elements Part 2: Measurement of airborne sound insulation*. Sound attenuation was measured from 500 Hz to 8000 Hz using 1/3 octave band filtering (International Organization for Standardization, 2010).

$$D = L_1 - L_2, \text{ dB(A)} \quad (1)$$

where D is the sound level difference between chamber rooms, dB(A); L_1 is the sound level in the acoustic chamber room where the sound source located, dB(A); L_2 is the sound level in the other room of the acoustic chamber behind the louvred noise barrier, dB(A).

The experimental setup consists of two 1.27 cm (0.5 in) microphones and a sound source. White noise used for sound attenuation testing. The sound source and one microphone placed in the first room (the source room), the second microphone is placed in the other room (sound receiving room) and separated from the sound source by a louvred noise barrier. The sound attenuation measurements were done using

two sound source positions and one position for each microphone (Figure 3). Microphone positions limited due to possible adverse effects of interferences of reflected waves in the rooms. The averaging was done of 5 measurements with each 3 min long. Measurements were done with four different tilting angles of blades of a noise barrier regarding the sound source (Figure 2).

2. Results

At first, a sound attenuation test done with louvred barrier blades without any sound-absorbing material. The purpose of this test was to determine how much noise can be reduced with this type of barrier by merely diverting the sound by louvred barrier blades.

Figure 6 illustrates that sound insertion loss depends on the louvre blade angle in the frequency range from 500 Hz to 8000 Hz. The frequency range from 500 Hz to 630 Hz reduces from 1 dB(A) to 6 dB(A) depending on the blade angle. The sound level reduces from 1 dB(A) to 5 dB(A) in the frequency range from 630 Hz to 1600 Hz. The sound level reduces from 1 dB(A) to 11 dB(A) in the frequency range from 2 kHz to 8 kHz. The diagram shows that the higher sound attenuation achieved when louvre blades tilted at a 30° or 45° angle.

The computational fluid dynamic simulation shows a correlation with sound attenuation results. A relative increase of energy (k) is presented in computational fluid dynamic modelling figures while airflow conditions are applied. Where k is from 0 m²/s² to 50 m²/s². The highest air energy growth found when blades were tilted at 30° (Figure 7, C). Similar results found during the experimental sound attenuation study.

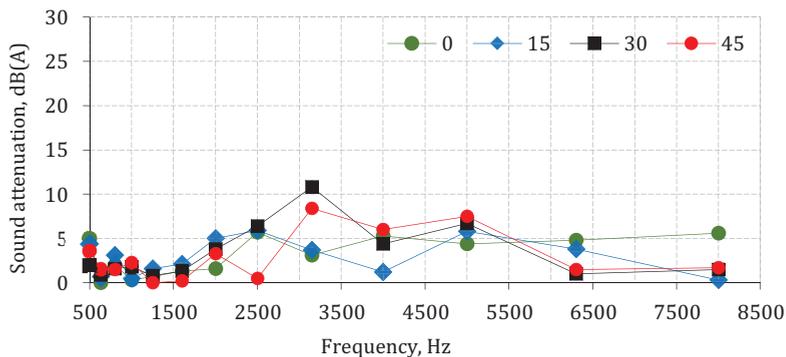
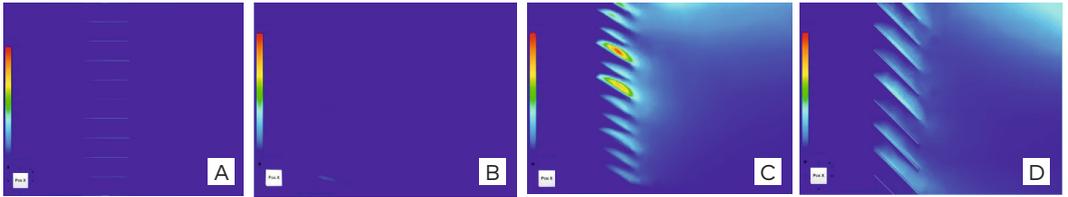


Figure 6. Test results with blades without sound any absorbing material



Note: A – 0°; B – 15°; C – 30°; D – 45°.

Figure 7. Energy growth per area of the barrier without sound-absorbing material

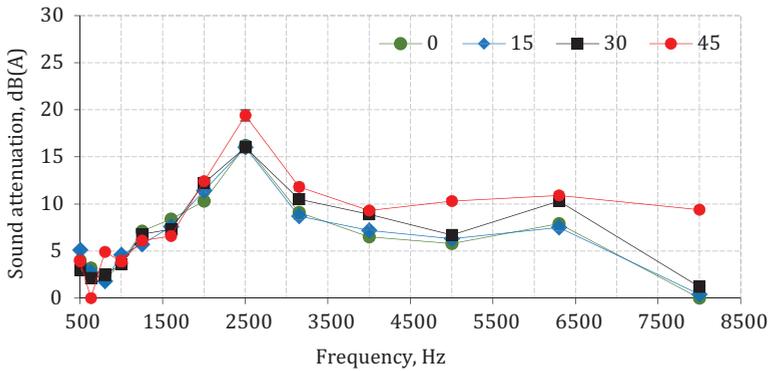
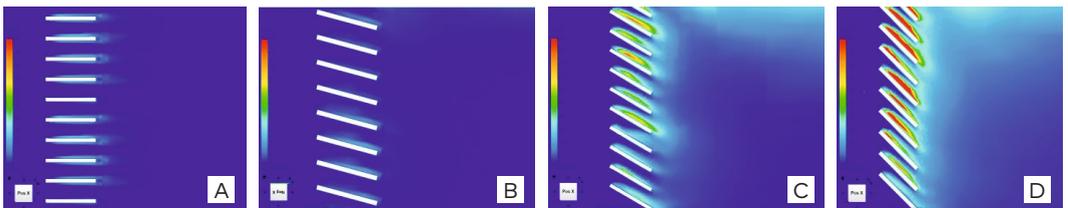


Figure 8. Test results with blades covered with 10 mm thickness of mineral wool on both sides

Figure 8 shows the sound attenuation of the louvre when its blades covered with a 10 mm thickness of mineral wool. Due to the wavelength of lower frequency sound waves, sound attenuation efficiency is noticeably lower in lower frequencies, and the difference between



Note: A – 0°; B – 15°; C – 30°; D – 45°.

Figure 9. Energy growth per area of barrier with 10 mm thickness of mineral wool

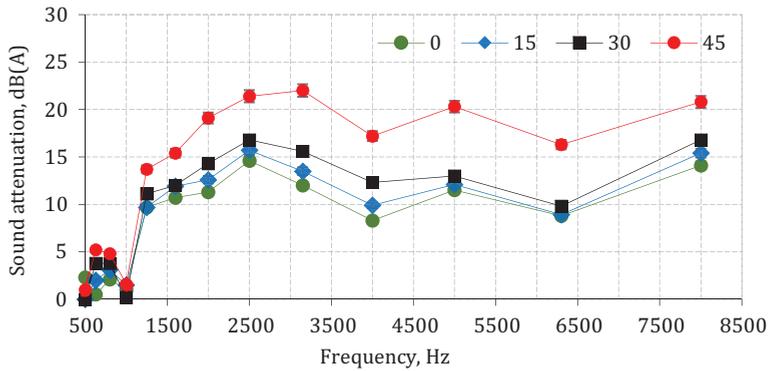
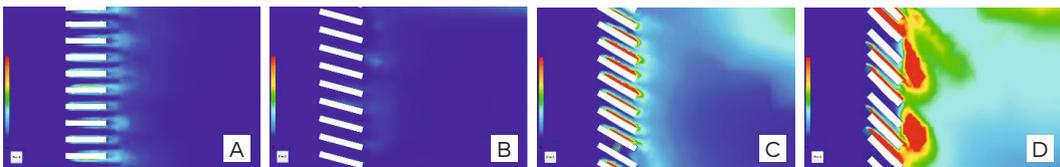


Figure 10. Test results with blades covered with 20 mm thickness of pressed mineral wool on both sides

barrier setups is insignificant (from 500 Hz to 2000 Hz). The sound level attenuation values reach from 5 dB(A) to 19 dB(A) in the frequency range from 1250 Hz to 8000 Hz when louvre blades tilted at a 45° angle. Figure 8 shows that with the increase in blade tilting angle, louvre barrier sound attenuation increases.

The computational fluid dynamic simulation shows a correlation with sound attenuation results. The highest energy growth was found then blades was tilted at 45° (Figure 9, D). The sound attenuation experimental results show that the highest sound reduction gained at a 45° barrier setup. Therefore 0° and 15° setup showed similar results after simulation and experimental study. The increase of airflow energy in those tilting angles are similarly low. A similar tendency also applies to sound attenuation results.

When barrier blades covered with a 20 mm thickness of pressed rockwool, sound attenuation is higher than the test results of a 10 mm



Note: A – 0°; B – 15°; C – 30°; D – 45°.

Figure 11. Energy growth per area of barrier with 20 mm thickness of mineral wool

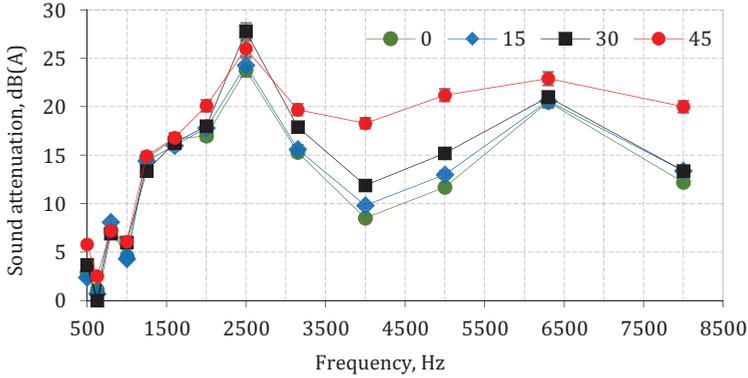
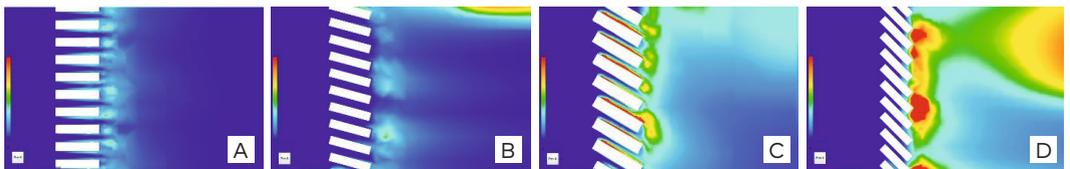


Figure 12. Test results when louvre blades covered with 30 mm thickness of pressed rockwool on both sides

thick mineral wool setup. In this case, sound attenuates in a wider frequency range from 1250 Hz to 8000 Hz (from 8 dB(A) to 22 dB(A) attenuation). As in the previous case, at lower frequencies, sound attenuations stay similar with blade tilting angle (from 500 Hz to 1000 Hz). The influence of the tilting angle is noticeable from 1250 Hz. Sound attenuation increases with blade angle inclination.

Figure 11 shows the energy growth per area increase with louvre blade inclination. The highest energy growth was found, then the blades were tilted at 45° (Figure 11, D), which means that this setup provides the lowest air permeability. The simulation results correlate with sound attenuation results.

In Figure 12, the results of sound attenuation using 30 mm thick mineral wool presented. Sound attenuation increased compared to other tested cases using this setup. As in previously presented cases, sound attenuation increases with blade angle. Peak attenuation gained at



Note: A – 0°; B – 15°; C – 30°; D – 45°.

Figure 13. Energy growth per area of barrier with 30 mm thickness of mineral wool

2500 Hz frequency (attenuation varies from 24 dB(A) to 28 dB(A)). Using this setup wider frequency range has no influence on lower frequencies than other setups (from 500 Hz to 2000 Hz).

Figure 13 shows the energy growth per area increase with louvre blade inclination. The highest energy growth was found then blades was tilted at 45° (Figure 13, D), which means that this setup provides the lowest air permeability. The simulation results correlate with sound attenuation results. Comparing to all CFD simulation runs, it is noticeable that energy air energy growth increases with the thickening mineral wool layer. Such phenomena occur because shrinking air gap when increasing the thickness of mineral wool.

Figure 14 illustrates the drop in equivalent sound level ($L_{A,eq}$) when louvre blades tilted at different angles. In most cases, the best sound attenuation results obtained when louvre blades tilted at a 45° angle, irrespective of the coating of the blades. The best sound attenuation result (17.3 dB(A)) achieved when louvre blades are covered with a 30 mm thickness of mineral wool and tilted at a 45° angle. The worst sound attenuation (1.8 dB(A)) was observed when louvre blades were without sound-absorbing materials and tilted at a 45° angle.

In the studies of other authors who used similar design louvred barriers, best results obtained when blades tilted at 45° and 60° angles (Januševičius, 2011; Matsumoto et al., 2004). Other researchers have also analysed sound attenuation by louvred barriers of other designs. At low and average frequencies from 100 Hz to 1000 Hz, sound attenuations differed insignificantly, irrespective of the louvred barrier blade tilt angle. Such a phenomenon occurs because there is only the effect of a mass layer in these frequencies. Other authors in their studies stated

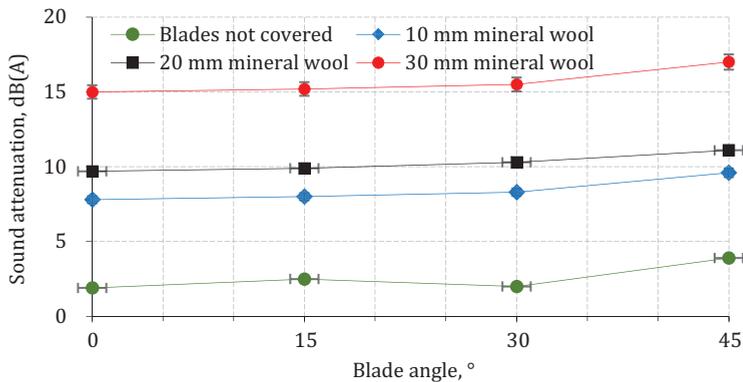


Figure 14. Comparison of the change in equivalent sound pressure level

that a louvre blade tilt angle does not influence the obtained results in these frequencies (Januėvičius, 2011; Matsumoto et al., 2004; Viveiros, 1998). At higher frequencies, sound attenuation caused by the absorption of sound-absorbing material and the diffraction of waves (Viveiros, 1998). Compared to other studies regarding open barriers, this design of barrier provides more broadband sound attenuation.

The limitation of this study is that such a louvred barrier design is not directly applicable for use by the roads due to humidity and possible rain effects on mineral wool. Materials with good sound absorption properties are recommended in future development because the principal barrier effectiveness comes from sound absorption phenomena. Based on laboratory tests presented, a live scale barrier could be developed and tested. For use near roads and railways, such a louvred barrier design could be used as a top part of the barrier to increase lighting on-road and decrease overall airflow resistance. Another possible way to use a louvred barrier is on viaducts. Therefore, it provides low airflow resistance, and it would not increase loads on construction significantly. In future studies, sound-absorbing materials that are more resistant to atmosphere conditions required. Due to barrier construction design, this barrier is almost non-existent to air, making the foundation cheaper than conventional noise barriers.

Conclusions

In this study, the design of an innovative open, louvred noise barrier proposed. After an experimental and computational fluid dynamic simulation study, found that sound attenuation increases with airflow resistance. The study shows that increasing blade angle increase sound attenuation as well as airflow resistance.

1. It was found that sound attenuation increases by increasing the blade inclination angle. The highest sound attenuation found at 45° louvre blade angle with all different louvred barrier setup. The highest sound attenuation achieved when 30 mm thickness of mineral wool used. Even though sound attenuation was the highest measured, computational fluid dynamic simulation results showed the highest air flow resistance, which could be a concern building such a noise barrier. Sound attenuation depending on different barrier setup varies between 2 dB(A) and 17 dB(A) in equivalent broadband sound level.

2. Sound attenuation increased with blade inclination angle. The highest sound attenuation values got when the blade inclined at 45° the equivalent sound attenuation was 17 dB(A). Barrier setup with mineral wool used most effective from 2500 Hz to 3150 Hz octave frequency bands. Depending on the blade inclination angle in those frequencies, attenuation varied from 14 dB(A) to 28 dB(A).

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