Lowering the noise level in the transport flows through reduction of the traffic barrier reflected noise

I Kralov and K Nedelchev
Technical University of Sofia, Department of Mechanics

E-mail: kralov@tu-sofia.bg

Abstract. Reflected noise from traffic barriers usually leads to increasing of the noise level excited by the automobiles and trains. This effect requires the design of transport noise barriers for effective noise reduction behind them as well as to produce small level of reflected noise in source direction. This will effect in better noise environment for many passengers especially in case of busy traffic in rush hours. People affected by this effect are usually far more than the affected ones behind the barrier. One of the existed solutions is the use of expensive combined noise barriers with high degree of absorption. In this study a new passive transport noise barrier is designed, tested and analysed for a good reduction level of the reflected noise. It is done by appropriate design of the barrier profile performing source and reflected acoustic waves interference in small volumes near the barriers. The barrier construction, made by repeated, equally profiled elements, allows even the existence of acoustic bandgaps especially behind the barrier.

1. Introduction
Acoustic noise reduction is a very important process due to its direct impact on the environment and people health. There are three main ways to reduce the acoustic noise: reduction of the sound power of the source, influence on the noise radiation and noise insulation of the working/living place. In many cases application of the second method includes typical solution for reduction of noise propagation by different types of barriers, absorbers or active noise control solutions. The enormous number of recent research works and publications in this area prove the actuality of this research field [10, 11, 12, 13, 16]. Usually, expensive and sophisticated solutions have to be created in order to meet the noise level standards. The noise barriers are mainly divided into passive, active and combined. Passive solutions mainly block the spreading of sound waves and decrease the noise levels by reflecting acoustic waves [1, 2, 3, 10, 11, 12, 13, 14, 15]. On the other hand, active methods input additional energy that is used to eliminate the acoustic energy of the source by propagation of sound waves of opposite phase, by conversion of the sound energy to electricity, etc. [1, 2, 13, 17]. Combined solutions include combination of the previously mentioned ones.

Main advantages of the passive noise barriers are the relatively low cost of manufacturing, assembly and maintenance due to the use of a few materials only, the use of assemblies of equally shaped elements, etc. This is proved by the huge number of patented solutions [4, 5, 6, 7, 8, 9]. A lot of studies show good acoustic efficiency of these barriers regarding the relation of the noise level behind the barrier with respect to the source noise level [1, 2, 13].

In case of higher level of noise reduction needed, the combined types of noise barriers are used.
They usually have additional closed space for spreading the sound waves and/or additional absorption materials are used. This type of barriers is relatively more expensive for manufacturing, assembly and maintenance. Its advantage is better noise energy absorption.

In case of noise excited by the transport flows, it is very essential noise to be reduced not only behind the barrier, but also the barrier reflected noise to be reduced. Reflected noise from traffic barriers usually leads to increasing of the noise level excited by the automobiles and trains. This effect insists transport noise barriers to be designed for effective noise reduction behind them as well as to produce small level of reflected noise in road direction. This will effect in better noise environment for many passengers especially in case of busy traffic in rush hours. People affected by this effect are usually far more than the affected ones behind the barrier. One of the existed solution is the use of the above mentioned expensive combined noise barriers of high degree of absorption.

The aim of this research study is to present a new passive transport noise barrier of high level of reduction of the reflected noise design, test and analysis. The reflected noise level is done by appropriate design of the barrier profile performing source and reflected acoustic waves interference in small volumes near the barriers. The barrier construction, made by repeated equally profiled elements, allows even the existence of acoustic bandgaps especially behind the barrier.

2. New transport acoustic barrier of low level of reflected noise
As a result of the analysis above the following principles for the new barrier synthesis were used:
- passive noise barrier for transportation and industrial noise;
- level of noise reduction equal or better to that of the existing barriers;
- relatively low costs of manufacturing, transportation, assembly and maintenance;
- relatively high level of reflected noise reduction.

The new acoustic noise barrier construction is shown on figure 1. Noise insulating panels are made of non-metal materials. They have a half-tube like form arranged one over the other, and all their concave arc profiles have one and the same direction – to the sound source waves. The essential characteristic of the barrier construction is that the concave profile is exactly semi-cylindrical and the border area between two neighbor channels is a sharp edge. These channels are arranged into H-shaped metal columns fixed to the ground. The channels are fixed vertically to the columns through non-metal semi-disks of external diameter, equal to the internal diameter of the channels. The semi-disks are fixed to the columns by bolt or stud connection [15].

![Figure 1. New acoustic barrier design [15]](image_url)

The main expected effect of the new barrier is that the interference between the source and reflected sound waves is close to the barrier. In this way the noise reduction by converting sound energy into heat will have lower effect over the noise level near the source. The degree of reflection depends mainly on the barrier material, sound waves frequency and acoustic pressure level. An important parameter of the barrier construction is the absence of reflecting surface, perpendicular to the source sound waves. The exact semi-cylindrical profile of the channels focuses reflected waves to
interfere with the source waves inside the profile of the channels.

To achieve better performance, geometrical parameters of the barrier can be designed for specific cases. Varying the width of the profile and the radius of the channel according to the sound power and frequency is a successful way of improving the acoustic efficiency of the barrier.

The presented construction has a lot of advantages. First, the non-metal channels are technologically easy for manufacturing. The uniform shape of elements allows big manufacturing series and reduction of production costs. Second, the elements are easy to be transported, assembled and maintained. Assembly does not require neither special machines nor expensive equipment. There is no need for the working team to possess any special skills. Third, the modular construction gives the possibility to vary easily the height of the barriers.

More advantages and areas of application of new barrier could be found in [15].

3. Simulation, test and analysis of the acoustic efficiency of new passive transport noise barrier

The main investigation of the acoustic properties of new barrier will be made by numerical simulation using a professional software for acoustics – COMSOL Multiphysics®. To verify some numerical results, a laboratory experiment using a scaled prototype of the barrier is made.

3.1. Experimental test of the scaled prototype of the new acoustic barrier

To produce some laboratory experiments a scaled prototype of the barrier is made. The prototype is shown on figure 2a and its main parameters are given in Table 1. The test is shown on figure 2b.

![Figure 2. a) the scaled prototype of the new acoustic barrier; b) acoustic test of the prototype](image)

| № | Parameter                                    | Value  |
|---|---------------------------------------------|--------|
| 1 | Diameter of the channel profile (internal), mm | 76     |
| 2 | Number of channels                         | 7      |
| 3 | Width of the profiled channels, mm         | 8      |
| 4 | Material                                   | HDPV   |
| 5 | Material density, kg/m³                    | 970    |

The experiments were performed in a semi-anechoic chamber. A 40 dB chamber was used. The sound system of sound generator, amplifier and specialized sound source, inside the chamber, is used to generate the noise level needed. First the noise level inside the chamber as well as at the receiving position were measured. The open side of the chamber was closed by the barrier prototype. Again the noise level inside the chamber and the noise level at the receiving position /behind the barrier/ were measured.
The acoustic measurement and analyzing system PULSE 3560B of the Bruel&Kaer equipped with the OEM software and microphone 4516A is used. Before measurements, all the standard procedures for calibration and estimation of the environmental noise influence are proceeded.

The results from the experiment are given in the table 2 and in figure 3. The following notations are used:
- $L_{fon}$ – level of the surrounding noise, dB;
- $L_s$ – noise level of the source, dB;
- $L_{RP}(A)$ – A-weighted noise level at the receiving point without barrier, dB;
- $L_{RP,bar}(A)$ – A-weighted noise level at the receiving point with new barrier, dB;
- $Eq$ – equivalent noise level for all the treated octaves, dB.

**Table 2. Results from experimental test of the scaled prototype of the barrier under study**

| Octave, Hz | $L_{fon}$ | $L_s$ | $L_{RP}(A)$ | $L_{RP,bar}(A)$ |
|------------|-----------|-------|-------------|-----------------|
| 63 Hz      | 19.7      | 67.9  | 48.2        | 41.8            |
| 125 Hz     | 22.1      | 68.1  | 54.3        | 47.2            |
| 250 Hz     | 23.0      | 68.2  | 58.9        | 51.2            |
| 500 Hz     | 19.6      | 68.2  | 62.8        | 49.1            |
| 1000 Hz    | 21.5      | 68.2  | 65.7        | 50.2            |
| 2000 Hz    | 16.7      | 68.2  | 66.4        | 46.6            |
| 4000 Hz    | 15.7      | 68.3  | 66.2        | 44.3            |
| Eq         | 28.3      | 76.0  | 71.8        | 56.5            |

**Figure 3. Results from experimental test of the scaled prototype of the barrier under study**

The results show an A-weighted noise level reduction in case of use of the barrier prototype between 16 dB and 22 dB.

3.2. **Numerical simulation and test of the scaled prototype of the new acoustic barrier**

Numerical simulation of the same scaled barrier prototype is made in COMSOL Multiphysics®. The process of model building, model mesh, type of analysis and boundary conditions are the same as in [15]. Comparative results of the new barrier acoustic efficiency are presented in Table 3 and on figure...
4. Here the following new notations are used:

\( L_{RP, bar, n} (A) \) – A-weighted noise level at the receiving point with new barrier, numerically found, dB;

\( L_{RP, bar, e} (A) \) – A-weighted noise level at the receiving point with new barrier, experimentally found, dB;

**Table 3.** Comparative results from experimental and numerical test of the scaled prototype of the barrier under study

| Octave, Hz | \( L_{RP, bar, n} (A) \) | \( L_{RP, bar, e} (A) \) | \( L_{RP, bar, n} (A) \) - \( L_{RP, bar, e} (A) \) | % |
|-----------|----------------|----------------|----------------------------|---|
| 63 Hz     | 39.6 dB        | 41.8 dB        | -2.2 dB                    | -5.3% |
| 125 Hz    | 48.4 dB        | 47.2 dB        | 1.2 dB                     | 2.5% |
| 250 Hz    | 47.1 dB        | 51.2 dB        | -4.1 dB                    | -8.0% |
| 500 Hz    | 56.7 dB        | 49.1 dB        | 7.6 dB                     | 15.5% |
| 1000 Hz   | 59.1 dB        | 50.2 dB        | 8.9 dB                     | 17.7% |
| 2000 Hz   | 54.6 dB        | 46.6 dB        | 8.0 dB                     | 17.2% |
| 4000 Hz   | 53.7 dB        | 44.3 dB        | 9.4 dB                     | 21.2% |

**Figure 4.** Comparative results from experimental and numerical test of the scaled prototype of the barrier under study

Results show relatively good relevance of the experimental and numerical results for the scaled prototype of the new barrier acoustic efficiency. Differences are less than 30% for different octave bands which is appropriate for such basic research problem and is similar to the known results in the literature. Based on this conclusion next step of investigation is done.

3.3. Numerical investigation of the acoustic efficiency of the new barrier

In this section an investigation of the noise level distribution on the both sides of the new acoustic barrier is presented in the vertical plain of a small source of spherical noise waves. The studied acoustic barrier as well as the environment around it, are modelled as a "tridimensional" 2D
axisymmetric object [15]. For the present study a Frequency Acoustic Analysis - Pressure Acoustic, Frequency Domain is used. Again the COMSOL Multiphysics® is used. The process of material parameters, model building, model mesh, type of analysis and boundary conditions are the same as in [15].

To compare the influence of the reflected noise over the sound level in the area of the source (traffic flow) as well as the level of noise reduction behind the barrier, a comparative analysis is made. The results of noise distribution on both sides of new barrier and those of an often used combined barrier are compared. Second barrier consists of a perforated flat metal surface, directed to the source, mineral wool of density 170 kg/m$^3$ and another flat metal (aluminum) surface on the rear side. Part of the sound waves passes through the perforated screen and are absorbed form the mineral wool inside the panel of the barrier. Other part of the waves is reflected from the non-perforated part of the front panel, while relatively small amount of sound energy passes behind the barrier. This barrier has common acoustic effect: reflection and interference between source and reflected waves, and relatively good level of absorption inside the panel. Serious disadvantage here is bigger manufacturing cost due to presence of different materials, bigger transport and technological expenses etc. Schemes of the numerical tests for both type of barriers are given on figure 5. Figure 6 shows the noise distribution at 1 kHz and 2 kHz without barrier.

![Figure 5. Schemes of the numerical tests for both type of barriers](image)

![Figure 6. Source noise level distribution without barriers at frequency octave bands 1kHz and 2 kHz](image)
Figure 7. Noise level distribution for both types of barriers at frequency octave band 1000 Hz

Figure 8. Noise level distribution for both types of barriers at frequency octave band 2000 Hz

Some comparative results of the both barriers noise level distribution are presented on figures 7 and 8.

The source is in the middle of the graphs and represents the transport unit noise source. The vertical plain of the source is bounded at the bottom from the road, modelled as more than 90% reflection barrier surface. On the right side at 4 m from the source, the investigated noise barrier is modelled as described above.

It could be seen from these figures that the bandgaps exist due to reflection from of the road. In case of noise barrier there is additional interference in radial and obtuse angle directions. This makes the picture much more complicated. It is obvious that the sound distribution depends on the frequency range, source noise level, distance between the source and barrier etc. To make an approximate comparison of the acoustic efficiency of both barriers, the following procedure is used. For both cases (barriers) the equivalent level of the sound pressure level is found from the measurement points (MP) of vertical lines at different distance \( L_2 \) from the source. Three lines are between the source and the barriers, while other three lines are behind the barriers. Results are presented in table 4.

### Table 4. Equivalent noise level form all the points in vertical lines at given distances from the source

| Leq | 0.5 m | 3.45 m | 4 m | 4.1 m | 4.3 m | 8 m |
|-----|-------|--------|-----|-------|-------|-----|
|     | SPL, dB | SPL, dB | SPL, dB | SPL, dB | SPL, dB | SPL, dB |
| Source without barrier | 69.9  | 66.2  | 66.0 | 66.0 | 65.7  | 64.0 |
| Perforated combined barrier | 71.0  | 68.6  | 68.4 | 49.1 | 48.7  | 47.9 |
| New type barrier | 70.5  | 67.4  | 67.1 | 47.0 | 46.4  | 46.1 |

The results show that the new barrier has similar and even better acoustic efficiency both for the noise level distribution behind the barrier and for the area near the source. The results are very interesting for the distance of 4 m and 4.1 m. They show that the combined barrier excites the level of noise which is bigger than the level excited by the new barrier. This could be explained by the relatively big flat reflecting area of the front panel directly to the source area. Another interesting fact
is the presence of bandgap regions behind the barriers. May be this is due to the periodic structure of the sound barrier panel shapes. This will be a new investigation task in a future work.

4. Conclusions
An investigation of the acoustic efficiency of a passive traffic noise barrier was made. Numerical simulation, verified by experiments, is used to find the noise level distribution on both sides of the barrier. The searched effect is the barrier to produce small level of reflected noise in source direction. This will effect in better noise environment for many passengers especially in case of busy traffic in rush hours which makes the number of people affected by this effect usually many times bigger than number of affected people behind the barrier. A comparative analysis with noise level distribution in case of use of expensive combined noise barriers of high degree of absorption is done.

Results and their analysis shows better acoustic efficiency of the new barrier. The barrier construction, made by repeated equally profiled elements, allows even the existence of acoustic bandgaps behind the barrier. This effect could be used for optimization of the acoustic barrier characteristics.

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References
[1] Banov S and Kralov I 2003 Noise in Transportation Technics (Sofia: Technical University of Sofia (in Bulgarian)) p 134
[2] Nikolov N, Benov D and Shubin I 2014 Acoustic Design of Transport Noise Insulating Barriers, (Sofia: ACMO Academic Press (in Bulgarian)) p 241
[3] Patent № UD 96/16230 – 30.05.1996.
[4] Patent № US № 6305492 B1 / 23.10.2001.
[5] Patent № US 7789193 B2 / 07.09.2010.
[6] Patent № AT 513615 A4 2014-06-15.
[7] Patent № 89203035.4 / 29.11.1989.
[8] Patent № DE 42 20 547 A1 / 07.01.1993.
[9] Patent № 10 2014 2017 767.7 / 10.03.2016.
[10] Kralov I, Terzieva S and Ignatov I 2011 Analysis of methods and MEMS for acoustic energy harvesting with application in railway noise reduction Bucharest. Proc. MECAHITECH’11. 3 56-62
[11] Kralov I, Sinapov P, Nedelchev K and Ignatov I 2012 Friction induced rail vibrations, AIP Conf. Proc. 1497 19-25.
[12] Trevor J and D’Antonio P 2009 Acoustic Absorbers and Diffusers (Taylor & Francis)
[13] Thompson D J 2009 Railway Noise and Vibration (Elsevier)
[14] Gieva E, Ruskova I, Nedelchev K and Kralov I 2018 An investigation of the influence of the geometrical parameters of a passive traffic noise barrier upon the noise reduction response, AIP Conf. Proc. 2048 020020
[15] Kralov I 2017 New solution for transport and industrial noise protection through reflective noise barriers Matec Conf. Proc. 133 DOI: https://doi.org/10.1051/ mateconconf/ 201713306001
[16] Ivanova Y, Vassilev V, Djomdorov P and Djourjaliisky S 2015 Experimental-Theoretical approach to the identification of effective sound attenuation panels from recycled materials, J. Bul. Chem. Comm. 42 1–8
[17] Aleksandrova M 2018 Spray deposition of piezoelectric polymer on plastic substrate for vibrational harvesting and force sensing applications AIMS Mat. Sci. 5(6) 1214-22