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EFFECTIVENESS OF THE CONSTRUCTION OF SOUND BARRIERS ON TWO HIGHLY BUSY ROADS IN BELGRADE

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Abstract. *The application of sound barriers is considered to be one of the important environmental and occupational noise protection measures, especially when it comes from noise sources such as road traffic. It represents a secondary measure of noise protection, because it is applied on the path of propagation of sound waves from the sound source to the place of immission, while the primary measure is applied at the source itself or its immediate surroundings. In this case, the place of immission is the place where a person resides as the main subject of noise protection. In this paper, the efficiency of this application of protection is discussed on the example of two sections of extremely busy traffic roads in Belgrade: a) Arsenija Čarnojevića Boulevard along UHMC Bežanijska kosa (former section of highway E-70 Belgrade-Zagreb) and b) Franše d'Eperea Boulevard along the building of the City Institute for Medical Emergency (former section of the E-75 Belgrade-Niš highway).*

Key words: *sound barrier, noise, sound, sound insulation, noise level, sound attenuation, efficiency.*

1. INTRODUCTION

Protection of the population from environmental and occupational noise that originates from sources of noise such as traffic, whether it is road, rail, air or river traffic, is certainly one of the significant needs in modern living conditions, especially since there is a constant tendency to increase both the number of inhabitants and the number of vehicles used in traffic.

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The application of sound barriers, especially when it comes from noise sources such as road traffic, is a secondary measure of protection against noise because it is applied on the path of propagation of sound waves from the sound source to the place of immission, which in this case is the place where the human lives and works as the main protection subject. At the same time, as a primary noise protection measure, it is carried out at the source itself or its immediate surroundings, which in the case of road traffic, at least in our area, is carried out by moving traffic or making roundabouts instead of classic intersections with traffic lights.

This paper presents the effectiveness of sound barriers installing as one of the ways to protect against road traffic noise, on two sections of the busiest and noisiest traffic roads in Belgrade: a) Arsenija Čarnojevića Boulevard (former section of the E-70 Belgrade-Zagreb highway) and b) Franše d'Eperea Boulevard (former section of highway E-75 Belgrade-Niš). These are the sections of the traffic road that stretch along the UHMC Bežanijska kosa and next to the building of the City Institute for Medical Emergency near Mostar Interchange. At the selected measurement points near the facades of the selected buildings along these sections, noise level measurements were made before and after the construction of sound barriers. The estimated height of the sound barriers along both sections is 5 m, while the length of the barrier on the section along UHMC Bežanijska kosa is about 650 m and on the section next to the building of the City Institute for Medical Emergency is about 350 m.

2. Description of the Measurement Procedure

As an immission place on the section along UHMC Bežanijska kosa, the Pulmonology building was chosen, that is, the principal's room on the high ground floor, which is directly oriented towards the road that is, the subject of the investigation. This measuring point is marked with MM1.

As an immission place on the section along City Institute for Medical Emergency, Hall A on the 1st floor was chosen, which is directly oriented towards the road that is, the subject of investigation. This measuring point is marked with MM2.

The measuring points MM1 and MM2 are shown with black dots in Fig. 1 where estimates are given at what distances these measuring points are located in relation to the constructed sound barrier. These measuring points are at different distances from the noise source, that is, roads with mixed road traffic that takes place in four traffic lanes in both directions.

a) b)

Fig. 1 Measurement points and their distances from sound barriers: a) the section along UHMC Bežanijska kosa and b) the section next to the building of the City Institute for Medical Emergency

3. Measurement Results

The paper presents noise level measurements at selected measuring points before and after the construction of sound barriers along traffic roads, which were carried out by the Laboratory for Acoustics and Vibrations of the IMS Institute in Belgrade.

The measurement of the noise level at the selected measuring points MM1 and MM2 was carried out according to accredited methods [1,2], which were valid at the time of measurement, in the outdoor environment. The measuring point MM1 was chosen to be located in front of the window of the principal's room of Pulmonology of UHMC Bežanijska kosa on the high ground floor at a height of about 3 m from the ground, and it is about 187 m away from the center axis of the road [3,4], while the measuring point MM2 was chosen that it is located in front of the window of Hall A of the City Institute for Medical Emergency on the first floor at a height of about 6 m from the ground, that is, about 3 m from the level of the road, and it is about 40 m from the center line of the road [5,6].

Noise level measurements were made using a windscreen. Meteorological conditions did not affect the measurement results, except on the third day of measurement at measuring point MM1 after the construction of the sound barrier, when the wind speed exceeded the value of 5 m/s. Those results were not considered in further analysis.

The dominant noise source on the subject sections is road traffic originating from traffic from the roads Arsenija Čarnojevića Boulevard and Franše d'Epere Boulevard. Also, the impact of other activities is evident at the measurement points, and given that the measurement points are defined within the hospital or medical emergency, including local parking lots and access roads in the further vicinity.

During all the measurements, the traffic was counted against the measuring point for 15 minutes, for each direction of the road separately, according to the classification of traffic into light vehicles, heavy vehicles and motorcycles. The traffic count will not be shown separately in the paper, but it was estimated that on average around 1800 vehicles pass by the measuring point MM1 in the daily measurement period in an interval of 15 minutes, and around 2100 vehicles pass by the measuring point MM2, while it was stated that the traffic flow during practically unchanged by all measurements.

Noise level measurements covered a continuous period of time within five days including weekend days on MM1 and within three working days on MM2 and included monitoring of statistical parameters: A-weighted equivalent continuous sound pressure level $L_{Aeq,15min}$ and percentage levels $L_{AF5,15min}$, $L_{AF10,15min}$, $L_{AF50,15min}$, $L_{AF90,15min}$ and $L_{AF95,15min}$. determined in successive 15-minute intervals during a period of 93 h at measuring point MM1, that is, 47 h at measuring point MM2. The paper will show only the A-weighted equivalent continuous sound pressure levels $L_{Aeq,15min}$ as a representative parameter that will be used on both sections when comparing the results obtained before and after the construction of sound barriers.

Calculated A-weighted equivalent continuous sound pressure levels values L_{day} for the daily measurement period, $L_{evening}$ for the evening measurement period and L_{night} for the night measurement period, as well as the value of the noise level for day-evening-night L_{den} were done with a software SLC ver 4.1 (2008).

The measurement results are tabulated with the calculated A-weighted equivalent continuous sound pressure levels for the day L_{day}, evening $L_{evening}$ and night L_{night} during the measurement period of 24 h, their average values during the entire measurement period as well as the average noise level for day-evening-night L_{den} during the same measurement period.

At the measuring point MM1, these values are given in Tab. 1 before the construction of the sound barrier and in Tab. 2 after its construction, while at the measuring point MM2 they are given in Tab. 3 before the construction of the sound barrier and in Tab. 4 after its construction.

Table 1 Calculated values L_{day}, $L_{evening}$, L_{night} and L_{den} at the measuring point MM1 before the construction of the sound barrier

No.	Day L_{day} (dB (A))	Evening $L_{evening}$ (dB (A))	Night L_{night} (dB (A))	Day rec.no.	Evening rec.no.	Night rec.no.
1	55.1	58.8	55.2	25	16	32
2	55.3	57.2	54.0	48	16	32
3	54.3	55.8	51.0	48	16	32
4	57.3	55.9	52.7	48	16	32
5	58.1	–	–	14	–	–
Average	56.0	57.1	53.5	183	64	128
L_{den} = 61 dB(A)						

Table 2 Calculated values L_{day}, $L_{evening}$, L_{night} and L_{den} at the measuring point MM1 after the construction of the sound barrier

No.	Day L_{day} (dB (A))	Evening $L_{evening}$ (dB (A))	Night L_{night} (dB (A))	Day rec.no.	Evening rec.no.	Night rec.no.
1	53.5	52.2	50.7	25	16	32
2	53.0	51.0	48.1	48	16	32
3	–	–	–	–	–	–
4	54.5	51.7	47.8	48	16	32
5	56.7	–	–	13	–	–
Average	54.1	51.7	49.1	134	48	96
L_{den} = 57 dB(A)						

Table 3 Calculated values L_{day}, $L_{evening}$, L_{night} and L_{den} at the measuring point MM2 before the construction of the sound barrier

No.	Day L_{day} (dB (A))	Evening $L_{evening}$ (dB (A))	Night L_{night} (dB (A))	Day rec.no.	Evening rec.no.	Night rec.no.
1	67.3	66.8	62.6	19	16	32
2	67.1	66.8	62.5	48	16	32
3	65.4	–	–	29	–	–
Average	67.3	66.8	62.6	96	32	64
L_{den} = 70 dB(A)						

Table 4 Calculated values L_{day}, $L_{evening}$, L_{night} and L_{den} at the measuring point MM1 after the construction of the sound barrier

No.	Day L_{day} (dB (A))	Evening $L_{evening}$ (dB (A))	Night L_{night} (dB (A))	Day rec.no.	Evening rec.no.	Night rec.no.
1	57.3	57.5	53.6	19	16	32
2	57.6	57.5	54.6	48	16	32
3	58.6	–	–	29	–	–
Average	57.9	57.5	54.1	96	32	64
L_{den} = 62 dB(A)						

Measurements both before and after the construction of sound barriers at the measuring point MM1 began on Friday at 12.00, and the value L_{day} for the first daily period was calculated from 23 data for A-weighted equivalent continuous sound pressure levels measured in 15-minute intervals. Value L_{day} for the last daily period was calculated from 13 data for A-weighted equivalent continuous sound pressure levels measured in 15-minute intervals, considering that measurement ended on Tuesday at 9.00.

Measurements both before and after the construction of sound barriers at the measurement point MM2 began on Wednesday at 1:30 p.m, and the value L_{day} for the first daily period was calculated from 19 data for A-weighted equivalent continuous sound pressure levels measured in 15-minute intervals. Value L_{day} for the last daily period was calculated from 29 data for A-weighted equivalent continuous sound pressure levels measured at 15-minute intervals, because the measurement ended on Friday at 1:15 p.m.

In both cases, the average values for L_{day}, $L_{evening}$ and L_{night} as well as the average value L_{den} for the entire measuring period of 93 h at the measuring point MM1, that is, 47 h at the measuring point MM2.

The calculated values of A-weighted equivalent continuous sound pressure levels were made for the correct belonging of the measurement interval to the day, evening, or night time measurement period. During all calculations, local effects were taken into account as they appeared in the record and were not specially corrected. However, due to unfavorable weather conditions on the third day of measurement at measuring point MM1 after the construction of the sound barrier, the results are not relevant, so they were not taken into account during the calculation L_{day}, $L_{evening}$, L_{night} and L_{den}, and in the corresponding diagram below they will be blurred.

2.1. Comparative results

The measurement results are shown in diagrams as comparative results of A-weighted equivalent continuous sound pressure levels $L_{\mathrm{Aeq,15min}}$ at 15-minute intervals before and after the construction of sound barriers at each of the measuring points. In the tables, the average values for L_{day}, L_{evening} and L_{night} as well as the average value for L_{den} before and after the construction of sound barriers and according to the measurement point.

At the measuring point MM1, the comparative results are shown in the diagram in Fig. 4 and in Tab. 5, and at measuring point MM2 in the diagram in Fig. 5 and Tab. 6.

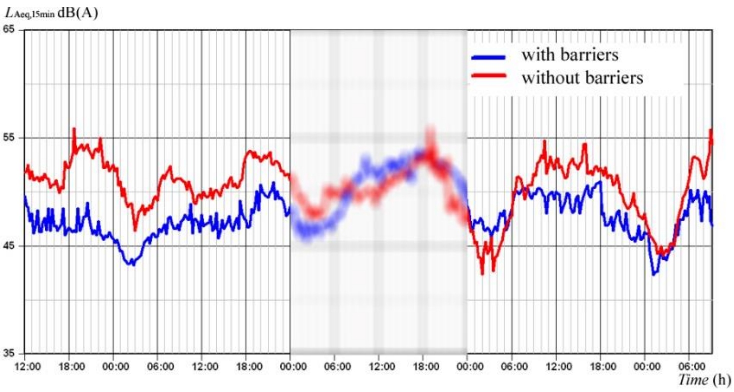

Fig. 4 Comparison chart of A-weighted equivalent continuous sound pressure levels $L_{\mathrm{Aeq,15min}}$ before and after the construction of sound barriers at the measurement point MM1

Table 5 Calculated values L_{day}, L_{evening}, L_{night} and L_{den} at the measuring point MM1 after the construction of the sound barrier

MM1	L_{day} (dB (A))	L_{evening} (dB (A))	L_{night} (dB (A))	L_{den} (dB (A))
Before	56.0	57.1	53.5	61
After	54.1	51.7	49.1	57
Difference	1.9	5.4	4.4	4

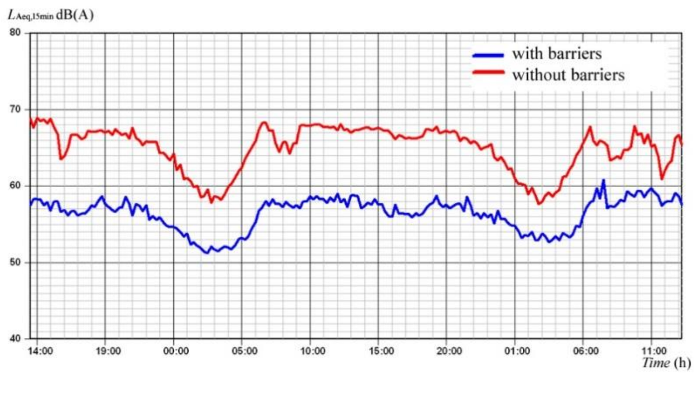

Fig. 5 Comparison chart of A-weighted equivalent continous sound pressure levels $L_{\mathrm{Aeq,15min}}$ before and after the construction of sound barriers at the measurement point MM2

Table 6 Calculated values L_{day}, $L_{evening}$, L_{night} and L_{den} at the measuring point MM2 after the construction of the sound barrier

MM1	L_{day} (dB (A))	$L_{evening}$ (dB (A))	L_{night} (dB (A))	L_{den} (dB (A))
Before	67.3	66.8	62.6	70
After	57.9	57.5	54.1	62
Difference	9.4	9.3	8.5	8

3. THE OBTAINED RESULTS COMMENT

From the presented comparative diagrams of A-weighted equivalent continuous sound pressure levels $L_{Aeq,15min}$ along two busy roads in Belgrade: a) on the section along UHMC Bežanijska kosa and b) on the section next to the building of the City Institute for Medical Emergency, and from the tables of calculated values L_{day}, $L_{evening}$, L_{night} and L_{den} it can be stated that the existing noise levels caused by road traffic decreased after the construction of the sound barriers, and that their construction is justified.

On the section along UHMC Bežanijska Kosa, which is far from the sound barrier, a trend of decreasing noise level values can be seen on average for L_{day} 1.9 dB (A), for $L_{evening}$ 5.4 dB (A), for L_{night} 4.4 dB (A), and for the overall level for day-evening-night L_{den} 4 dB (A).

On the section next to the building of the City Institute for Medical Emergency near Mostar Interchange, which is located near the sound barrier, a trend of decreasing noise level values can be seen on average for L_{day} 9.4 dB (A), for $L_{evening}$ 9.3 dB (A), for L_{night} 8.5 dB (A), and for the overall level for day-evening-night L_{den} 8 dB (A).

A rough A rough sketch of the measuring points showing the measuring points in relation to the road is given in Fig. 6 for both sections in question. In the sketch, it can be clearly seen that both measuring points MM1 and MM2 are largely protected from the direct propagation of sound (road traffic noise) by a sound barrier as a physical barrier, where the acoustic properties of the selected barriers play an important role, in the first place the single-number rating of airborne sound insulation DL_R and single-number rating

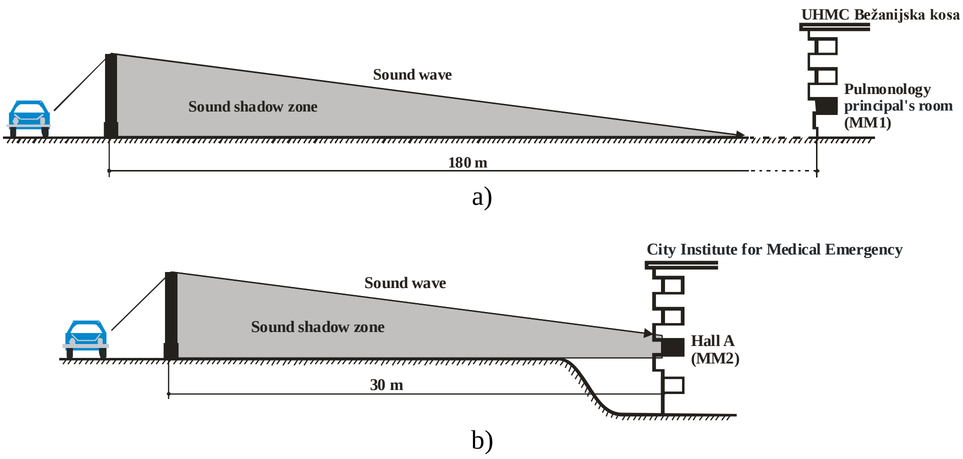

Fig. 6 A rough sketch of measuring points and their positions in relation to the sound shadow zone: a) at measuring point MM1 and b) at measuring point MM2

of sound absorption DL_α [7,8]. The same sketch also shows that the sound can reach the imission point via a detour, due to the diffraction phenomenon, but the measuring point MM2 on the section next to the building of the City Institute for Medical Emergency is largely in the sound shadow created by the constructed barrier because it is located directly behind it and that this is one of the main reasons why the noise level reduction values at that measuring point are much higher than in the case of the section along UHMC Bežanijska kosa where measuring point MM1 is significantly far from the road and is not in the sound shadow created by the barrier [9].

However, the reduction of the noise level by the construction of a barrier on the section along UHMC Bežanijska kosa is not negligible, because the facilities and population (citizens and staff) in the vicinity of the hospital, which are located at a high distance from the road, are still protected from the direct spread of the noise of the busy road, primarily bearing in mind that the traffic road belongs to acoustic zone 5, and the clinic-hospital center to acoustic zone 1 [10,11] where the required noise levels are far lower than the level near the road.

A similar situation is with the section next to the building of the City Institute for Medical Emergency, which is located right next to a busy traffic road, belongs to acoustic zone 5, and the City Institute for Medical Emergency to acoustic zone 1, where the required noise levels are far lower than the levels near the road. and citizens and staff staying in this building are particularly exposed to this type of noise.

4. CONCLUSION

Based on the presented measurement results, it is concluded that the effectiveness of the construction of sound barriers on the sections along traffic roads is sometimes less and sometimes more significant. Their construction is certainly justified at whatever distance the immission point is located, because based on the results obtained, no matter how much the noise reduction is (perhaps it seems that 4 dB or 8 dB is a small reduction in the noise level), it is very significant for the population which should be protected from excessive noise that harmful effects on human health first and then all aspects of human live and work, because these are not insignificant values.

From the technical point of view, the efficiency of the construction of sound barriers depends on the distance of the barrier from the point of immission. When the noise source is directly behind the barrier (case of road traffic noise) the following rule applies - the more distant the barrier is from the point of immission, the smaller the sound shadow is, and the diffraction occurrence and larger sound waves result in less protection efficiency, regardless of the barrier's acoustic properties.

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