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DESIGN OF NOISE PROTECTION IN URBAN AREAS-CASE STUDY OF AN ELEMENTARY SCHOOL

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Abstract – *The paper describes the activities to eliminate the impact of noise on the operation of an elementary school. By measuring the noise outside and inside the premises, values of noise levels were determined. On the basis of acoustical calculation software noise maps were drawn and used to design noise protection system. In this case the protection systems is designed as a sound barrier, and replacement of windows on the building was proposed. When designing the barrier, in addition to the acoustic requirements, aesthetic, urban and safety have been also considered and presented in the paper.*

Key words: *Noise mapping, Noise protection, Sound barriers.*

1. INTRODUCTION

Sound is of interest to many scientific disciplines, ranging from engineering to medical and human research. In the field of engineering dominate three aspects of interest:

- Sound as a mean of communication,
- Sound as a manufacturing tool,
- Sound as a noise.

The European Union defines noise as unwanted or harmful sound from external environment created by human activities. This usually refers to:

- Traffic noise,
- Noise generated by the industry in cities and towns,
- Street noise created by: construction machinery, music equipment in restaurants and other entertaining facilities, sporting events, other outdoor facilities, loading and unloading of various metal objects, etc.,
- Noise in households (from electrical and other appliances, from neighboring houses and similar).

Noise above the permissible limits, which occurs around the school facilities, negatively affects students and teachers, reducing their physical and mental abilities. Prolonged or loud noise may directly or indirectly cause not only hearing losses, but also other diseases and disorders, and here are presented only a few:

- Irregular heartbeat,
- Loss of appetite,
- Depression,
- Nervousness,
- Insomnia,
- Raised blood pressure,
- Raised level of sugar in the blood,
- Damages to the blood vessels,
- Damages to the nervous system,
- Irritability,
- Stress,
- Reduced ability to work,
- Chronic fatigue,
- Reduction of attention and memory.

All these symptoms indicate that exposure to noise above the permitted level are very dangerous for children in schools. Research of the Institute of Hygiene and Environmental Medicine, Faculty of Medicine in Belgrade, confirms that the noise in recent decades belongs to the most important causes of damage to the health of residents of Serbian cities [1]. Research has shown that, in comparison with children from suburbs, kids in central areas of cities have higher blood pressure because of the noise.

In this paper we analyzed the noise that affects the elementary school. The research consists of the following four phases:

- measurements of noise inside and outside off the school,
- analysis of the sources of the noise,
- drawing of the noise maps, and
- design of noise protection barrier.

2. NOISE SOURCES

Elementary school is located alongside the regional road Kraljevo-Kragujevac and close to the workshops of Automobile Association of Serbia (AMSS). On the opposite side of the road is a bus stop.

The main sources of the noise are:

- **Traffic on the main road** that has four lanes (two in each direction). All categories of road vehicles use the road and the speed limit is 40 km/h. A crossroad with traffic lights is only 50 meters from the school, so the limit is generally well respected. However, because of the high intensity of the noise that occurs when starting the vehicle at traffic lights turn on and the bus station.
- **Noise from pupil** in the schoolyard during classes in Gymnastics
- **Workshop of Automotive Association of Serbia**.

The measurement revealed that the dominant source of noise is the main road. Therefore, during drawing of the noise maps is taken into account only the noise generated by the traffic.

Fig.1. shows the location of the school and point sources of noise tagged with S1 to S15, simulating noise emission by the vehicles at the road. KT1 and KT2 labels the positions of the control points where the noise level was tested (Table 1).

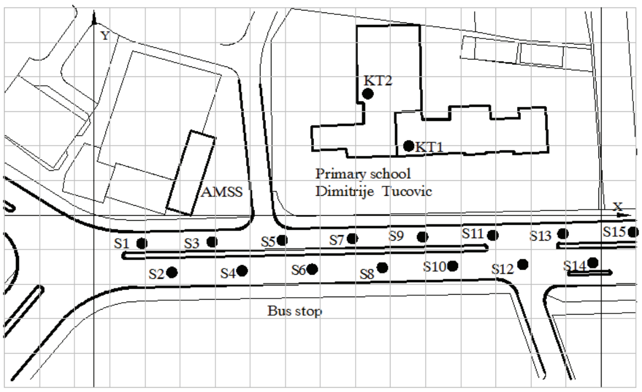

Fig. 1 *Position of the school and the point sources of noise.*

Besides, the measurements were taken outside and inside the school, in the classrooms given in the Table 1.

Table 1:

Measuring point	Buka	Vreme merenja	Ekvivale. nivo buke db	Ocena
Classroom no. 7 cabinet for mathematics (KT4)	Unutrasnja	10^{20}–10^{35}	**42.1**	Ne zadovoljava
Classroom no.7 cabinet for mathematics (KT1)	Spoljasnja	10^{40} – 10^{55}	**66.2**	Ne zadovoljava
Classroom no. 6 Cabinet of Physics (KT3)	Unutrasnja	11^{00} – 10^{15}	**44.6**	Ne zadovoljava
Classroom no. 6 Cabinet of Physics (KT2)	Spoljasnja	11^{20}–11^{35}	**57.6**	Zadovoljava

Data on the measured noise levels are given in the Table 2:

Table 2 *The measurement results*

Sources	X [m]	Y [m]	sound level L[db]
S1	12,89	8,22	75
S2	21,4	16,62	75
S3	32,97	7,76	75
S4	41,41	16,15	75
S5	52,89	7,29	75
S6	61,41	15,68	75
S7	72,9	6,83	75
S8	81,42	15,22	75
S9	92,90	6,36	75
S10	101,42	14,75	75
S11	112,9	5,9	75
S12	121,41	14,29	75
S13	132,42	5,43	75
S14	141,41	13,82	75
S15	152,91	5,96	75

On the basis of the measurement data and the modeling of the traffic noise by the point sources, noise maps of the current situation (Fig. 2) and the facade of the school (Fig. 3) are made.

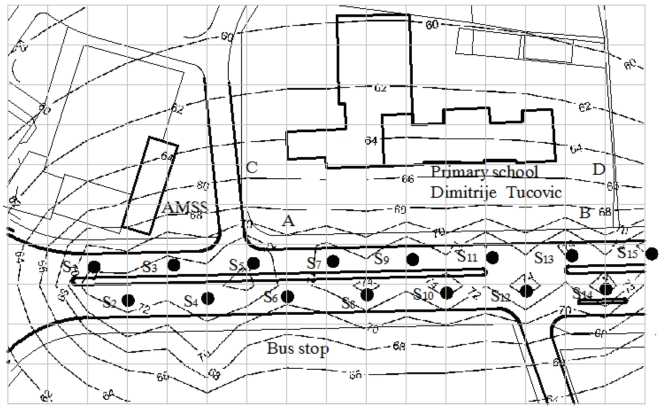

Fig. 2 *Noise map of the current state at the school*

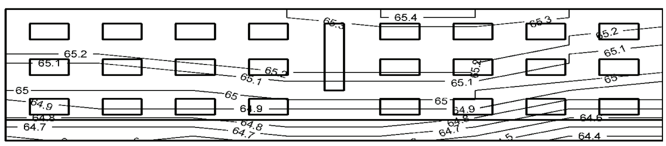

Fig. 3 *The noise level of the current situation on the facade of the school*

The figures show that the school is exposed to noise levels higher than it is allowed. Based on the above mentioned data and the noise maps were analyzed solutions for protection against the noise in the form of a sound barrier.

To this purpose were made noise maps which take into account the effects of a barrier with position as given to Fig.4.

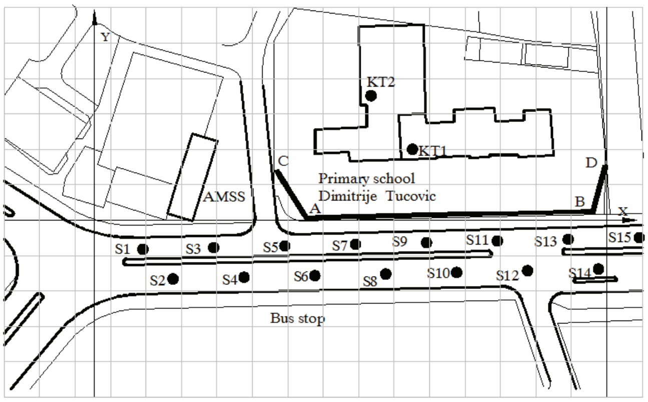

Fig. 4 *Position of the noise barrier and points A, B, C and D*

The respective noise maps with noise barrier are shown in the Fig. 5 and Fig 6. The noise barrier consists of three sections: AC, AB and BD. The coordinates of these points are given in Table 3.

To obtain the data that are used to draw the noise maps was used the software that was designed by the Faculty of Mechanical Engineering Kraljevo within the project TR 37020 of Ministry of Education and Science.

Table 3 *Data on barrier:*

	X [m]	*Y [m]*	*h [m]*
Barijera AB	$X_A = 57.93$ $X_B = 140.34$	$Y_A = 0$ $Y_B = 2$	7.3
Barijera AC	$X_A = 57.93$ $X_C = 50.11$	$Y_A = 0$ $Y_C = 14.23$	7.3
Barijera BD	$X_B = 140,34$ $X_D = 143,22$	$Y_B = 2$ $Y_D = 13.77$	7.3

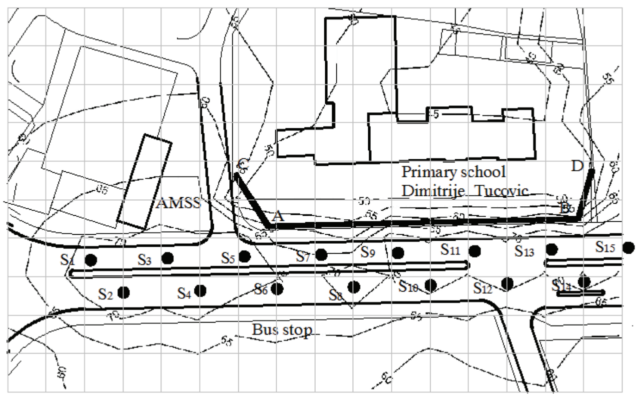

Fig. 5 *Map of the noise outside the school with the noise barrier*

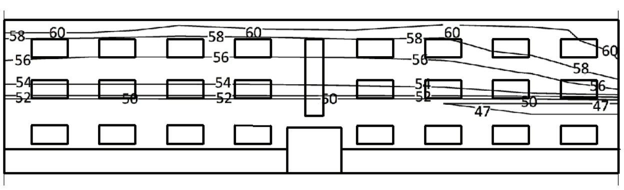

Fig. 6 *Noise maps of the facade of the school with the noise barrier*

3. DESCRIPTION TECHNICAL BARRIERS

Acoustic requirements, such as absorption capacity, efficiency, atmospheric effects, and size of the barriers, are of the primary importance in the design of the protective barriers. Length and height of the barriers are calculated to provide sufficient, that is the necessary, protective efficiency. In Fig.7 is shown the direction of the sound from the farthest vehicle lane to the school. The sound lines from other lanes are closer and the noise is more attenuated, and therefore, they have less impact to the noise affecting the school. Details of noise impact from the road to the school building are provided in versions with and without barriers in the previous chapter.

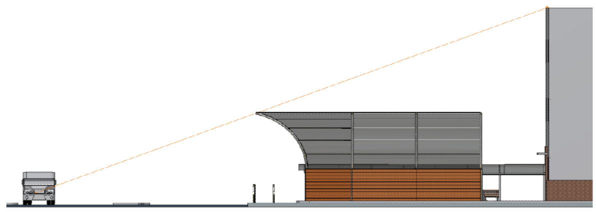

Fig. 7 *Profile of the noise barrier*

Raising of the barrier at the edges of the schoolyard reduces the wind force in the schoolyard, so the pupils will have comfortable walk and rest. As barriers have the form of a circular arc surrounding the sidewalk in the front of the school, they also protect the sidewalk from the influence of the rain. The slope of the barrier is made steep enough to provide safety against the load from snowfalls during winter.

Sound barrier is designed as a combination of sound absorption and sound reflection surfaces. The lower part of the barrier, up to the height of 2 m, is made of metal sandwich panels filled with mineral wool. The panels are perforated at one side and the side faces the sound source, in order to absorb the noise. The upper part of the arc is made of Lexan with thickness of 28 mm so that it reflects the sound towards the road, and not to the apartment buildings across the street.

Sound barrier, in full length of 100 m, with a projected height of 7.30 m, is slightly curved at the ends, which should eliminate the effect of sound diffraction of distant sound sources. Angle of distant sound sources to the facade of the school is less than $10°$.

Aesthetic requirements are met by construction of the barrier using modern materials and colors combination, with the aim to create attractive visual impression. The bottom of the barrier is made of metal panels allowing painting in various colors and leaving possibly for painting of murals or graffiti to match the needs of education process. Bearing construction is made from stainless steel and metallic materials that provide a nice look. At top of the barrier are mounted elements of transparent or slightly tinted Lexan. In this way, the schoolyard obtained a kind of intimacy, and on the other hand, views from the school, or the view from the road to the school remain open. The construction of the barrier did not comprise any damage to the trees in the park in front of the school.

Surroundings of the school, besides the road with four lanes, consists of the residential area and the new church on the same side of the road, while on the other side of the road are apartment buildings with commercial space. Configuration of the terrain is flat. Legislation would have to be explored in terms of covering the sidewalk on the street as part of the public area. Other parts of the barrier are in the school yard. Compatibility with local appearance is achieved using metal construction barriers, similar to the metal fence around the church. Barrier's compliance with the road alignment is complete, because the barrier and the school building are parallel to the axis of the road.

In addition to the protection against the noise, the barrier construction has other facilities. The area between the entrance to the schoolyard from the side of the road and the entrance to the school is made through the barrier so that it is covered by a roof and equipped with benches. The purpose of the passage is to get together the youngest pupils with teachers or parents before crossing the street (Fig. 8).

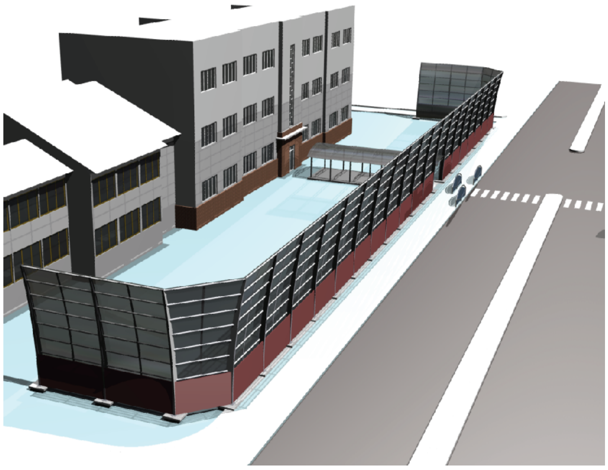

Fig. 8 *Noise barrier in the school*

Besides, on the sidewalk in front of the exit of the schoolyard is set a labyrinth with protective structure. It directs the flow of pedestrians from the street through a crossing, and prevents the unwary persons to get to the street (Fig. 9).

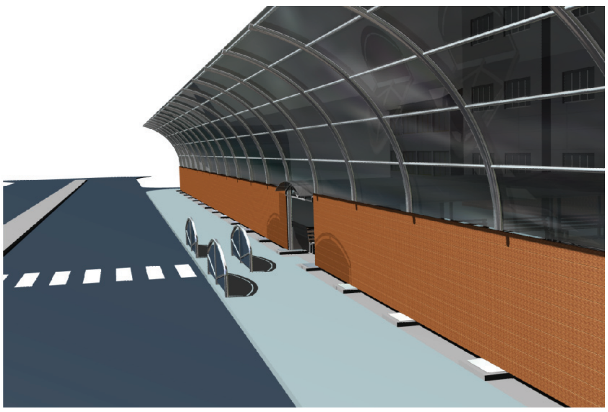

Fig. 9 *Look of the noise barrier*

The construction relies on the foundations below the columns, so to be resistant to temperature changes. Load capacity of the barriers is calculated considering the influence of weather, following the regulations in the field. The removal of water from precipitation running off barrier shall is made by a concrete channel placed below the construction in the schoolyard.

Pupil safety is increased by the barrier both in terms of traffic and possible people on the sidewalk. Sight distance for drivers and pedestrians is not reduced. The effects of light and shadows and the light reflections were considered. Visibility of animals and birds is provided by tinted Lexan. The materials used in manufacturing of the barrier are non-flammable and self-extinguishing.

Environmental factors of the barrier were considered by reducing the noise impact on pupils and school staff, as well as by the reduction of impact of exhaust gases from motor vehicles to the schoolyard and to the classrooms.

Maintenance of the barriers, in terms of atmospheric effects during long periods of use is easy because the barriers use materials resistant to the influence of rain, snow and wind. Transportation costs of materials, equipment and people are minimized and the construction work may be carried out during the school holidays, so as not to interfere education process.

The technology of the construction is devised so that all works on the barrier can be performed by the local contractors, without requiring special technologies.

3.1 Calculation of protection

The attenuation of the noise barrier is determined by the difference in the lengths of diffracted wave path and the direct wave path.

Attenuation of the barrier is calculated according to the standards for road traffic noise prediction (RSL 90) and industrial noise (ISO 9613), has the form:

$$C_B = -7 \cdot \log\left[5 + \left(\frac{70 + 0.25 \cdot s_\perp}{1 + 0.2 \cdot z_\perp}\right) \cdot z_\perp \cdot K_{w\perp}^2\right] \quad (1)$$

where $z_\perp -$ represents the path difference and $K_{w\perp} -$ the metrological correction.

The path difference between the length diffraction and direct path is:

$$z_\perp = A_\perp + B_\perp + C_\perp - s_\perp \quad (2)$$

Where are: $A_\perp -$ the source distance to the top of the barrier, $B_\perp -$ the distance to the top of the receiver barriers, $C_\perp -$ the sum of distances between the edges of the barriers, $s_\perp -$ the shortest distance to the receiving point of emission.

Metrological correction is determined based on the same parameters given by:

$$K_{w\perp} = \pi \cdot \left(-\frac{1}{2000} \cdot \sqrt{\frac{A_\perp \cdot B_\perp \cdot s_\perp}{2z_\perp}}\right) \quad (3)$$

Equation (1) gives the total attenuation of noise levels. The frequency characteristics of noise attenuation barriers can be determined by the equation:

$$C_B = \begin{Bmatrix} \left[-20\log\dfrac{\sqrt{2\pi N}}{\tanh\sqrt{2\pi N}} + 5\right] & N \geq -0,2 \\ 0 & N < -0,2 \end{Bmatrix}, \quad (4)$$

where N is the Fresnel-number, which is determined on the basis of ratio between the sound paths difference and their wavelength:

$$N = \pm\frac{2}{\lambda}\left(A_\perp + B_\perp + C_\perp - s_\perp\right) \quad (5)$$

4. CONCLUSION

This paper presents the protection against noise based on the construction of a barrier between a school and a road. The effects of the solution are reduction of the noise level and provision of improved environment protection of pupils and teachers. It also affects be the arrival and departure of pupils and parents from the school.

By comparing the maps with and without noise barriers, it can be seen that the noise levels are reduced by almost 20 dB around the school. At the street facade, the noise levels are reduced by 5 dB on top and 17 dB on the bootom. This shows that the use of barriers to reduce noise is effective and economic solution.

Structural barrier is rather simple, and therefore cost of construction of the structure is relatively small. It is easy to maintain and has a long life because of the materials that are resistant to corrosion and to the impact of the rain, snow and wind.

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