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The analysis and measuring the noise on the A2 motorway (E-65) "Mother Teresa" section: Skopje - Tetovo

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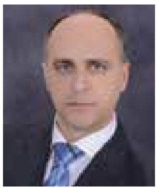

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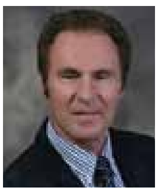

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Professional paper

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The analysis and measuring the noise on the A2 motorway (E-65) "Mother Teresa" section: Skopje - Tetovo

Traffic noise measurements on the Skopje – Tetovo Section of the Mother Teresa A2 Motorway in the Republic of Macedonia are presented in the paper. The first measurement was conducted in 2003 immediately after the motorway was opened to traffic, while the second one was conducted in 2014. Noise levels were estimated according to two calculation methods. After it was established that noise levels exceeded the legally allowed limits, appropriate protection measures were proposed and adequate conclusions for solving the noise problem on the section under study were adopted.

Key words:
road traffic noise, motorway, calculation methods, noise map, noise barriers, galleries

Stručni rad

Goran Mijoski, Darko Moslavac, Zoran Krakutovski, Todorka Samarđioska

Analiza i mjerenje razina buke na autocesti A2 (E-65) "Majka Tereza", dionica Skopje - Tetovo

U radu su opisana mjerenja razina buke u području autoceste A2 (E-65) "Majka Tereza", dionice Skopje - Tetovo u Republici Makedoniji. Prvo mjerenje provedeno je 2003. godine, neposredno nakon puštanja autoceste u promet, a drugo 2014. godine. Razine buke određene su primjenom dvije metoda proračuna. Nakon što je utvrđeno da su razine buke više od zakonski dopuštenih, predložene su odgovarajuće mjere zaštite te su donesene zaključci o tome kako na predmetnoj dionici riješiti problem bučnosti.

Ključne riječi:
prometna buka, autocesta, metode proračuna, karta buke, barijere za zaštitu od buke, galerije

Fachbericht

Goran Mijoski, Darko Moslavac, Zoran Krakutovski, Todorka Samarđioska

Analyse und Messung des Lärmpegels auf der Autobahn A2 (E-65) "Mutter Theresa", Teilstrecke Skopje-Tetovo

In der Abhandlung wird die Messung des Lärmpegels auf dem Gebiet der Autobahn A2 (E-65) "Mutter Theresa", Teilstrecke Skopje-Tetovo in der Republik Mazedonien beschrieben. Die erste Messung erfolgte 2003, unmittelbar nach Inbetriebnahme der Autobahn, und die zweite 2014. Der Lärmpegel wurde durch Anwendung zweier Berechnungsmethoden bestimmt. Nachdem festgestellt wurde, dass die Lärmpegel über den gesetzlichen Grenzwerten liegen, wurden entsprechende Schutzmaßnahmen vorgeschlagen und Schlussfolgerungen gezogen, wie man das Lärmproblem an der besagten Teilstrecke lösen soll.

Schlüsselwörter:
Verkehrslärm, Autobahn, Berechnungsmethode, Lärmkarte, Lärmschutzwand, Galerie

1. Introduction

Sound is a form of energy transmitted via sound waves that can be detected by human ear (sound pressure ranges from 0 to 120 dB, but human ear can detect sounds in the frequency band ranging from 20 Hz to 20 kHz). On the other hand, noise is defined as any unwanted sound. The intensity of sound is measured in decibels [dB], the frequency in hertz [Hz], and time changes are measured either in seconds [s] or in fractions of a second. The noise coming from road traffic is classified as a linear source of noise.

Alongside air and water pollution, noise pollution is considered to be one of the most harmful impacts on our environment. Noise levels in the order of 80 dB greatly affect the quality of human life (e.g. work performance, sleep) while psychological disturbances occur already at noise levels grater than 65 dB. Research conducted in EU countries shows that approximately 80 million people (20 % of the total population) live and work in areas with noise levels in excess of 65 dB, and that about 170 million of people live and work in the so called "grey zones" in which noise levels range between 55 and 65 dB [1]. Research results related to noise and its harmful impact are presented in the EU Directive 2002/49/EC [2]. The most frequent sources of ambient noise are: various types of construction works, various forms of road, rail and air transport, parking lots, facilities for sporting and other events, buildings for residential and other uses, household appliances, amusement parks, sports shooting ranges, industrial facilities, etc. Research conducted so far [3] has shown that traffic noise is represented with 81 %, and noise from all other sources (industry, construction, noise from leisure activities) with 19 %, in the overall noise generated by humans (Figure 1).

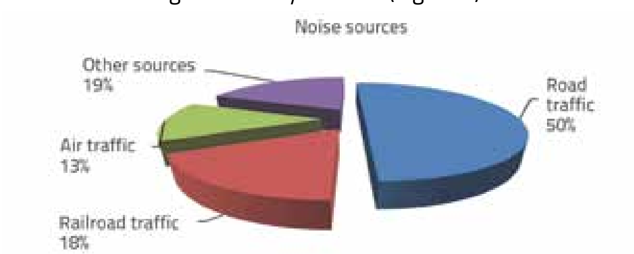

Figure 1. Sources of environmental noise

There are three types of traffic noise: noise from road, rail, and air traffic. The impact of noise on the quality of life can be very significant, which is especially due to constant development of transport systems. That is why monitoring activities must regularly be conducted and, when necessary, appropriate mitigation measures must be taken.

2. Background

According to Rochat J.L. [4], the spectrum of constant traffic noise on motorways most often ranges between 200 and 2,000 Hz. People can hear frequencies from 20 to 20,000 Hz, while human hearing is most sensitive in the frequency range from 1,000 to 6,300 Hz.

2.1. Factors influencing traffic noise

The noise caused by motor traffic, called traffic noise, results from the interaction between motor vehicles and pavement surface. It depends on the intensity, type, structure and speed, and regarding the type of road, the condition of the pavement surface and its longitudinal slope. The noise caused by motor vehicles can be divided into (Figure 2):

- Noise created by the working engine (engine noise)
- Noise generated by the tyres of the vehicle on the pavement surface, while the vehicle passes through the medium - air (rolling noise)
- Noise resulting from the turbulence of air that occurs during movement of vehicles (aerodynamic noise) [5].

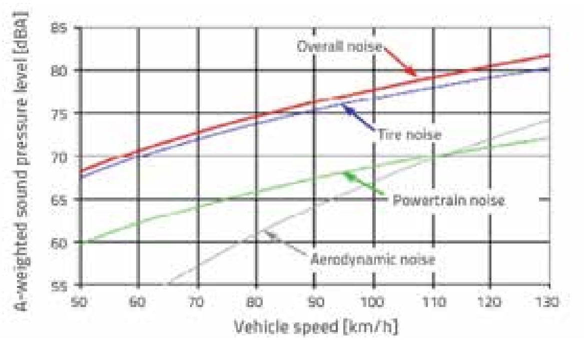

Figure 2. Types of traffic noise

2.1.1. Impact of pavement surface on traffic noise

The rolling noise generated by light and heavy vehicles moving at a certain speed on pavement surface is considered to be a dominant source of traffic noise. Such noise primarily depends on structural characteristics of the driving surface (depth of microtexture and macrotexture) and pavement irregularities, i.e. roughness of the driving surface expressed by the international roughness index - IRI [m/km] [6]. The influence of roughness depth on noise level (Figures 3 and 4) mostly depends on:

- selected type of asphalt wearing course (in terms of grain size and asphalt mix composition);
- pavement construction method applied;
- additional measures taken during road use (procedures for increasing road roughness) [7].

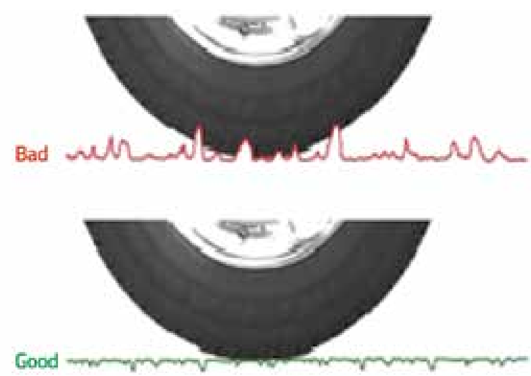

Figure 3. Good and bad texture

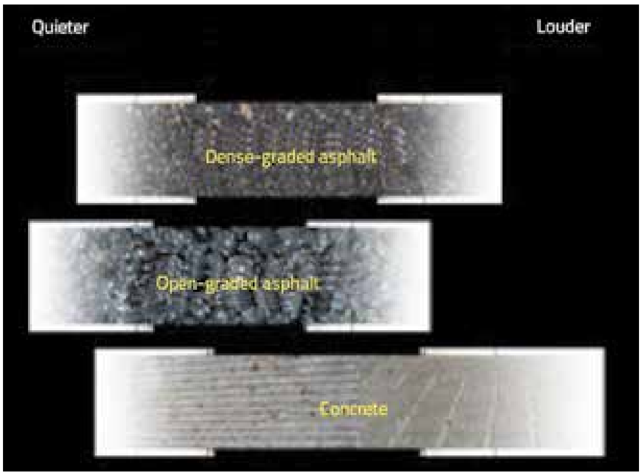

Figure 4. Impact of roughness on noise level

Previous research shows that there is relationship between the pavement roughness depth and traffic safety. Reduction of roughness leads to reduction of noise generated by wheel and pavement surface interaction, but also to lower stability of vehicles and to reduced traffic safety. It was established that noise emissions on concrete pavement surfaces (with final wearing layers) are greater compared to noise emissions on asphalt pavement surfaces with asphalt wearing layers. Properties of wearing courses are a factor that greatly influences traffic noise levels. Wearing course properties are defined differently in various calculation methods, such as those used in Germany and France [8, 9].

2.1.2. Impact of driving speed on traffic noise

It is important to note that, at low speeds, the engine noise is a more dominant source of noise compared to rolling noise. In case of speeds greater than 30 km/h for passenger cars, i.e. in case of speeds greater than 40 km/h for trucks, the rolling noise gradually gains in significance, while at speeds in excess of 50 km/h it becomes the dominant source of noise [10]. On roads destined for high speed travel, i.e. on motorways where maximum allowable speed is 130 km/h, the rolling noise is a dominant source of noise, while the effect of engine noise is almost negligible.

2.1.3. Impact of tyre properties on traffic noise

Noise caused by tyres depends on several factors: internal tyre pressure, contact surface, and tyre tread pattern. When rolling on pavement, worn tyres generate greater noise due to larger contact surface. It is important to note that rolling noise is greater in case of trucks, and that in case of passenger cars it becomes dominant only at very high speeds. The so called "quiet" tyres have recently been introduced and the level of noise generated by such tyres is much lower [11]. Due to increasing awareness about harmful effect of noise on the quality of life of people, the European Commission ordered the tyre manufacturers to conduct tests so as to define noise levels generated by particular tyre types, and to present these results to buyers during tyre purchase (Figure 5) [12]. The level of noise generated by tyre is expressed in decibels and is marked with black lines on the corresponding sticker (Figure 6):

- 1 black line - low noise tyre,
- 2 black lines - average noise tyre, and
- 3 black lines – high noise tyre.

Figure 5. Tyre according to Regulation EC 1222/2009

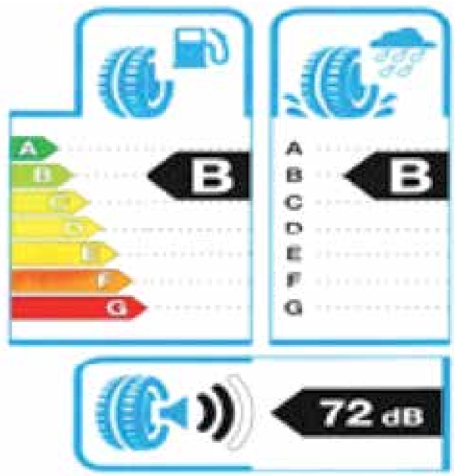

Figure 6. Tyre sticker

3. Noise analyses on A2 motorway (E-65)

According to the World Health Organisation, 210 million European citizens (44 % of the EU population) are subjected to harmful effects of traffic noise, which poses a significant risk to their health. Directive 2002/49/EC of the European Union applies to noise and problems associated with it. According to Paul de Vos (strategic advisor for engineering and consulting with Royal Haskoning DHV), the EU policy is to make local governments to invest large sums to reduce traffic noise. In this respect, European governments were required to spend hundreds of millions of euros by 2017 for noise barriers, quiet tracks and measures aimed at curbing negative effects of traffic noise on the quality of life and health of people [14].

In accordance with European trends and considering the importance of proper protection against traffic noise, appropriate noise measurements were made in the scope of this study on the Skopje – Tetovo Section of the A2 (E-65)

Figure 7. Position of measurement points along the A2 (E-65) "Mother Teresa" Motorway

Figure 8. a) Right side of motorway; b)Left side of motorway

Mother Theresa Motorway. The said section is located on the Skopje Bypass at the very entrance to the city of Skopje (Skopje West) (Figure 7). This motorway section (from km 0 + 980.04 to km 1 + 324.92) was selected as it is situated in the immediate vicinity of the bypass, and as residential buildings are located on both sides of the motorway (Figure 8). In addition, it is the same locality where noise measurements were also made in 2003. Noise level measurements were conducted at four measurement points. Control measurements of traffic noise on this section of the motorway were made at four measuring points.

Relevant noise protection legislation was also studied in collaboration with the Parliamentary Institute of Macedonia. The study results have revealed that: "The Republic of Macedonia, although still not formally a member of the EU, has fully implemented legal and technical regulations in this area" [19].

The issue of traffic noise protection on national roads (motorways, national and regional roads) in the Republic of Macedonia was not sufficiently addressed in the past. Thus, first traffic noise barriers (walls) were realized in this country no earlier than during construction of the road bypass around the capital city of Skopje (Figures 9 and 10). The reason for an insufficient activity in the area of noise protection include: insufficient funds for construction of roads in Macedonia, and absence of systematic monitoring of noise levels on existing roads. Other types of road noise protection measures (such as construction of "silent" road surfaces, etc.) have still not been implemented in the country [20].

Figure 9. Absorbent barrier

Figure 10. Reflective barrier

3.1. Noise level measurements

Noise measurements were conducted in accordance with requirements contained in the standard method MKS ISO 1996-2: 2010 Acoustics-Description, measurement and assessment of environmental noise - Part 2: Determination of noise levels from the environment (ISO ISO 1996-2: 2007), and also in compliance with the Noise Protection Act and relevant subordinate acts [15-17].
An appropriate set of instruments produced by Cirrus Research plc, UK, was used for measurements (Figure 11). The integrated sound meter type CR: 171B, Class1, was used as the main instrument for noise measurements. The instrument has: tube microphone-converter (capsule) 12.7 mm in diameter, tube preamp and reading login for audiotaping for 1:1 and 1:3 octave band filters.

Figure 11. Set of noise measuring instruments

The following three indicators are very important for measuring environmental noise levels: air temperature, relative humidity, and wind speed. These three components were measured on site using the Testo 435-2 device and special accessories: IAQ probes for ambient air temperature and relative humidity measurements, and Testo anemometer probe for measuring wind speed and air flow (Figure 12).

Figure 12. Measuring instrument Testo 435-2

The following four goals were set for this study:
- examine applicability of legal and technical regulations and EU recommendations,
- compare noise levels as determined according to European and Macedonian standards,
- compare noise measurement results with the results obtained in 2003 and 2014,
- propose measures for protection against noise if measured noise levels exceed the legally permitted values [18].

3.1.1. Research conducted in 2003

Table 4 shows average values of traffic (AADT, ASDT and AWDT, daily/hourly) for various vehicle categories. Speed of vehicles is as follows: for light vehicles $V_{1,\,max}$ =120 km/h, average V1 = 100 km/h, for heavy vehicles $V_{2,\,max}$ = 100 km/h, average V1 = 80 km/h.
The ambient temperature measured in November was: 5.8 °C, and the average humidity, also measured in November, was 84 %. The average annual air pressure measured in Macedonia was 98,1 (kPa). Noise level measurements were conducted with a properly calibrated phonometer type Bruel & Kjaer Investigator 2260. The calibration was performed with a high-precision Bruel & Kjaer Sound Level Calibrator type 4231. The results were processed with a specialized software Sound Analysis BZ 7210 Bruel & Kjaer [21]. A sound map of the first section was made for the purpose of the survey in 2003 (Figure 13).

3.1.2. Research conducted in 2014

The traffic count made in 2014 on the Skopje – Tetovo (A2) Motorway is presented in Table 2 [22]. Control measurements of noise levels were made on this section on 13 November

Table 1. Average daily/hourly flow of vehicles by categories (light and heavy) for 2003.

Traffic category	Sum		Light vehicle		Heavy vehicle	
	daily	hourly	daily	hourly	daily	hourly
AADT (average annual daily traffic)	8322	347	7407	309	915	30
AADT day	7184	597	6394	533	790	66
AADT night	1138	95	1010	84	125	10
ASDT (average summer daily traffic)	8722	364	7763	324	959	40
AWDT (average winter daily traffic)	7922	330	7051	294	871	36

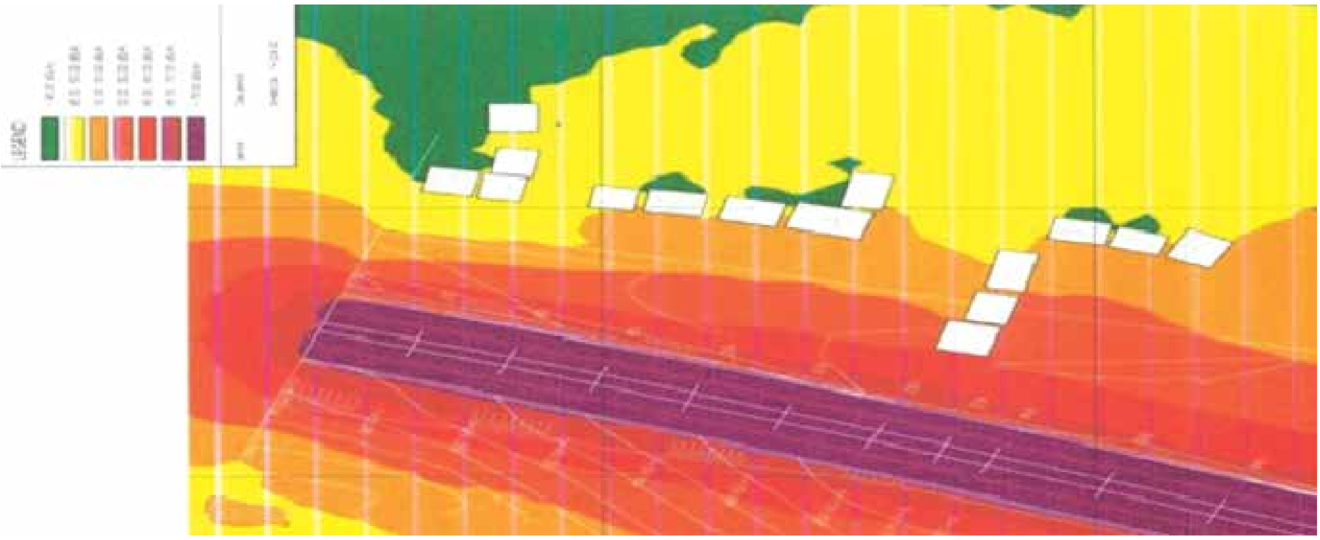

Figure 13. Sound map of the first section of the motorway

2014, from 7 a.m. to 7 p.m. in the daytime, and on 17 and 18 November 2014 in the night-time, from 7 p.m. to 7 a.m. [23]. Besides noise pollution measurements, average meteorological conditions were also measured: ambient temperature was 13.97 °C, relative humidity was 85 %, and the wind speed was 0.57 m/s.

Meteorological conditions at the selected measuring points during night-time measurements at the first section, with average speed of vehicles, were:

- ambient temperature 11.99 ° C
- relative humidity 82.9 %
- wind speed 0.19 m / s
- average speed of light vehicles V1 = 100 km/h
- average speed of heavy vehicles V2 = 80 km/h,

Traffic noise levels measured at four measurement points in the daytime and at night are presented in diagrams given in Figures 14 and 15.

Table 2. Average daily/hourly flow of vehicles by categories (light and heavy) for 2013 [22]

Traffic	Sum		Light vehicles		Heavy vehicles	
	daily	hourly	daily	hourly	daily	hourly
AADT (average annual daily traffic)	9829	410	9426	393	403	17
AADT day	8968	561	8600	538	368	23
AADT night	861	108	826	103	35	4
ASDT (average summer daily traffic)	10424	434	9997	417	427	18
AWDT (average winter daily traffic)	9230	346	8852	369	378	16

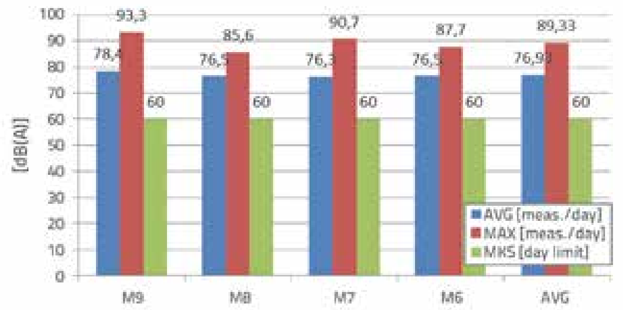

Figure 14. Results obtained in the daytime

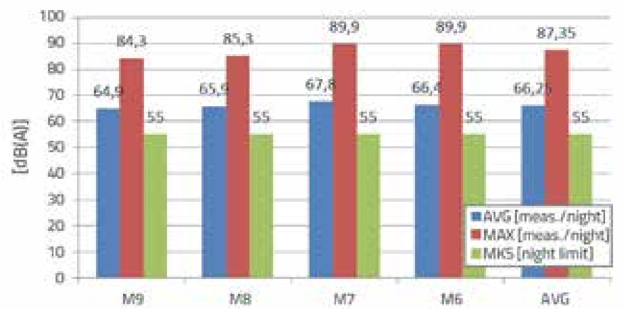

Figure 15. Results obtained in the nighttime

3.2. Noise level calculations

For further analyses, traffic noise levels were calculated according to two standards: German standard RLS 90 [8] and Macedonian standard ICC, the latter being actually a French standard applied in Macedonia according to an appropriate EU Directive [15-17].

3.3. Analysis of measurements and calculations results

Daytime and night-time research results for 2003 and 2014 are presented in Figures 16 and 17 [21, 23]:
- results according to German standard RLS 90
- results according to Macedonian standard MKS
- equivalent noise levels obtained by measurement
- maximum measured values
- maximum permitted values.

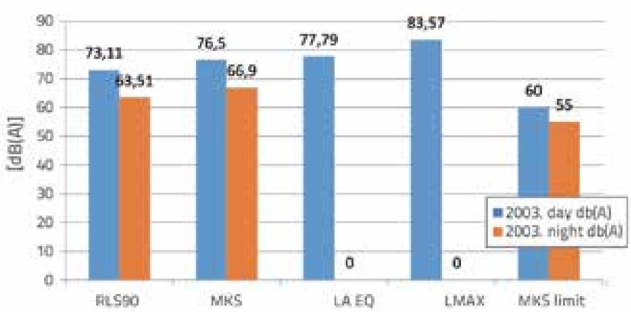

Figure 16. Total results - Noise in 2003

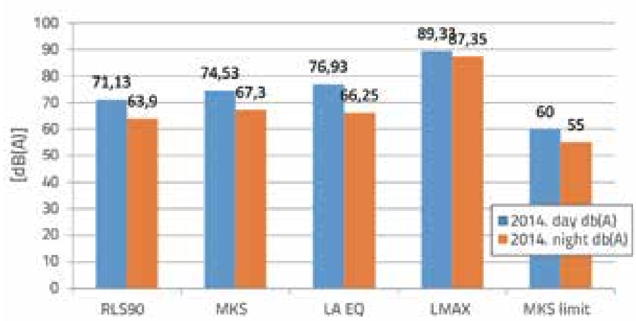

Figure 17. Total results - Noise in 2014

The following conclusions can be made based on results shown in Figures 16 and 17:
- noise values obtained by calculations (according to both standards) exceed maximum permissible values according to regulations (day and night)
- average measured noise values exceed maximum permissible values according to regulations (day and night)
- maximum measured noise values exceed maximum permissible values according to regulations (day and night)
- all values presented in the diagrams are significantly greater than allowable values [18].

4. Recommendations and solutions proposed for abatement of traffic noise

Based on the analysis and conclusions, it is evident that the analysed Skopje – Tetovo section of the A2 motorway exhibits high noise levels, which exceed permitted daytime and nighttime levels, and the recommendation is therefore to provide for appropriate noise protection measures. The best protection from excessive noise is to reduce noise level at source. Unfortunately, we can not influence the source, but we can influence the noise propagation. One of the ways to reduce noise is to provide adequate noise protection barriers. Taking into account features of the micro-location under study, several types of noise barriers can be recommended.

Traffic noise was constantly present on the analysed motorway A2, both in the nighttime and daytime, with dense traffic of light and heavy vehicles. Two solutions were suggested for this section: sound gallery and noise barriers.

The first alternative is to build a sound gallery, which would greatly reduce existing noise levels (Figure 18). This is one of the most effective solutions, but it is more expensive compared to conventional noise barriers.

The second alternative involves construction of noise barrier in one of the following ways:
- Option one is a transparent noise barrier with a steel structure and plexiglass panels, whose top is inclined toward the source – thus preventing reflection of noise from buildings situated on the opposite side of the motorway (this solution has been applied in some European cities) (Figure 19).
- Option two involves construction of a traditional noise barrier

Figure18. Sound gallery

Figures 19. Noise barriers in urban area (Switzerland)

Figure 20. Noise barrier at Skopje bypass

Figures 21. Transparent noise barriers

with transparent panels (made of plexiglass or acrylic glass) that would be placed on the bridge railing – 3.0 m in height plus 1.0 m for concrete – at the same motorway section (Figure 20).

These prefabricated transparent barriers are made of plexiglass and are placed onto galvanized steel structures. The posts are IPB14 hot-rolled profiles, placed at 3.0 m intervals. On the other side, before the bridge, two barrier types are to be assembled on the left side only (Tetovo – Skopje).

As on the bridge, the first solution could be a barrier with plexiglass panels 2.0 m in height. Its structure could be the same as to one on the bridge or as the one on the Skopje Bypass (Figure 21). The second solution is an absorbent protective barrier, such as the one that exists on the Skopje Bypass, with the height ranging from 2,0 to 3,0 m (Figure 22). A third solution is an environmentally-friendly highly absorbing noise barrier "Ruconbar", whose absorbing layer is made of recycled rubber and concrete. This would be the first barrier of this type ever applied in the Republic of Macedonia (Figure 23).

All proposed protection measures will certainly reduce the existing noise levels to allowed levels. However, adequate price and quality criteria must carefully be considered when choosing an optimum solution. According to the findings of this study and practical experience, the length of the protective noise barrier should be longer compared to the length of the existing roadside facilities.

Figures 22. Absorbent noise barriers

Figure 23. Noise barrier type Ruconbar (Croatia)

When choosing the type of noise barrier, it is certainly recommended to perform optimization by acoustic, technological and economic features in order to obtain the optimum sound barrier [24].

5. Conclusion

Based on the research described in this paper, it can be concluded that our environment is negatively affected by noise, and that the quality of human life is greatly impaired by noise. Numerous sources of noise are present in areas in which people stay, live, and work. Consequently, traffic noise should be considered as an important problem at all stages of development of transport systems, from the planning and design stages, to the construction and maintenance of transport facilities.

- The following conclusions can be made based on the analysis of the noise level calculation and measurement results obtained in 2003 and 2014 on the studied section of the A-2 (E-65) motorway: It can generally be concluded that daytime and nighttime noise levels exceed the allowed limits. Consequently, appropriate protection measures must be applied on the section under study. Most appropriate measures consist in noise abatement at the source, which involves installation of adequate noise barriers.
- Maximum noise levels measured in the nighttime are by approximately 30 dB (A) greater that the allowed levels. Considering that the night period is the time for rest and sleep of people living in close proximity, there is a need to urgently address the problem of noise and its harmful impact.
- According to the method and data from one year measurements, the calculated values of noise are higher than the permitted ones. According to Macedonian technical regulations, these levels are excessive in the daytime, and are even higher in the nighttime. Calculated noise levels are very similar to measured values – they differ by less than 5 dB(A).
- The quality of life of people is significantly impaired by noise, which is why appropriate protection measures must be applied during construction of new transport facilities. Several motorways and express roads are currently under construction in Macedonia and, at that, appropriate noise protection measures are planned. The results of the presented measurements will certainly represent a useful parameter for the construction of protective barriers on the newly designed roads.
- The main conclusion and recommendation is that competent bodies operating within the road management system should continuously conduct noise level monitoring operations in the scope of their professional activities. At critical localities, where noise levels exceed the allowed limits, various activities must be undertaken and appropriate measures should be applied in order to reduce current noise levels. The implementation of these measures will result in better protection against traffic noise.

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