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NOISE MAPPING IN AREA OF AN URBAN OVERPASS

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Abstract: *The paper presents the concept of noise mapping in an urban area around major overpass in city of Kraljevo. The overpass is used by road traffic and is built over a railroad track. The height of the overpass is variable, with one end in the foot, and with the other end at the top of a hill. On one side of the overpass is the hill, which is covered by vegetation. On the other side of the overpass is residential area with houses and multi-floor buildings. The dominant source of the noise is the road traffic on the overpass, and the railroad traffic represents secondary source of the noise. Uneven terrain and presence of complex concrete structure of the overpass represent a challenge for the calculation of the noise field. The concept of calculation is performed according ISO 9613:2, using both commercial and proprietary software tools.*

Key words*: Environment protection, Noise protection, Noise mapping*

1. INTRODUCTION

In June 2002, the European Directive on the Assessment and Management of Environmental Noise or Environmental Noise Directive 2002/49/EC [1], was accepted and came into force. The document represents the legal basis for implementation of strategy for combating noise in European Union. Under this directive, as a first step in the strategy, member states were obliged to produce noise maps of the major roads, railways, airports and industrial activity sites as well as of large agglomerations by 30th of June, 2007. Noise maps are intended to describe the environmental noise levels caused by the previously mentioned sources in terms of the harmonized noise indicators L_{den} and L_{night}. From these noise levels, other indicators such as the total number of seriously annoyed residents may be derived. This information was to be submitted to the European Commission and made public. The next step of the strategy is drafting of Noise Action Plans, sets of measures for managing the noise issues and effects, including the reduction of noise if necessary. The Noise Action Plans are to be based on the noise−mapping results, drawn by competent authorities, with consultation of public on matters of priorities. One of important aspects of the strategy is harmonization of European noise legislation. The technical basis for the strategy is established through FP5 project "Harmonoise" [2], FP6 project "Imagine" [3], and FP7 project "Silence" [4].
While not a member of European Union, Republic of Serbia followed the developments of noise management strategy defined by the European Noise Directive. Government of Republic of Serbia passed in 2009 Law on environment noise protection [5] that addresses subjects in charge for environment noise protection, means and conditions for environment noise protection, measurement of environmental noise, access to information about noise, surveillance and other topics of relevance for environment and health protection. Further directions are defined by respective regulations, guidelines and standards that are relevant to environment noise protection and are in line with the European Noise Directive. The regulations determine the principles of assessment of noise impact, noise mapping and drawing of Noise Action Plans [6][7][8]. Overview of the valid regulations and standards relevant for environment noise protection is given in [9].
Majority of the measures prescribed by the regulations is still not supported by existence of a relevant accredited institutions and research groups, noise protection means available at market and adequate software support. The project "Development of methodologies and means for noise protection of urban environment" (acronym "UrbaNoise") [10] is a project financed by Serbian Ministry of Education and Science, aimed to facilitate solution of the present problems and deficiencies. The project is realized by three major Serbian state universities, University of Kragujevac, represented by Faculty of Mechanical and Civil Engineering in Kraljevo, University of Niš, represented by Faculty of Occupational Safety and University of Belgrade, represented by the Faculty of Traffic Engineering. The project goals are:

- development of national noise assessment methodologies harmonized with EU;
- development of national database of noise sources;
- development of software tools for local noise mappings;
- construction of laboratory facilities for testing of acoustic materials;
- design of modular noise barriers from waste materials.

This paper presents current phase in the development of software tool for drawing of local noise maps. The concept of the software is developed based on experiences in work with similar noise mapping tools and tested on

the problems from practice of noise protection. In this paper is described problem of the drawing of noise map in vicinity of an urban overpass in city of Kraljevo. The noise mapping was intended to be performed based on international standard ISO-9613:2 [11], and it turned out that the mapping represents a demanding task from the point of view of the standard, because the surroundings of the overpass contains all features that are considered within the standard.
The structure of the paper is the following: after this introductory paper follows the second chapter, where the object of the study, the surroundings of the overpass in city of Kraljevo, is described with the sufficient details to show the complexity of the task from the point of view of the standard ISO-9613:2. In the third chapter are presented measurements of the noise level at selected measurement points in vicinity of the overpass and the results of calculation of noise levels at the same points by application of various software packages. In the fourth chapter are presented analyses of the obtained results. Finally, the last chapter summarizes conclusions drawn from the described work and directions for the future actions.

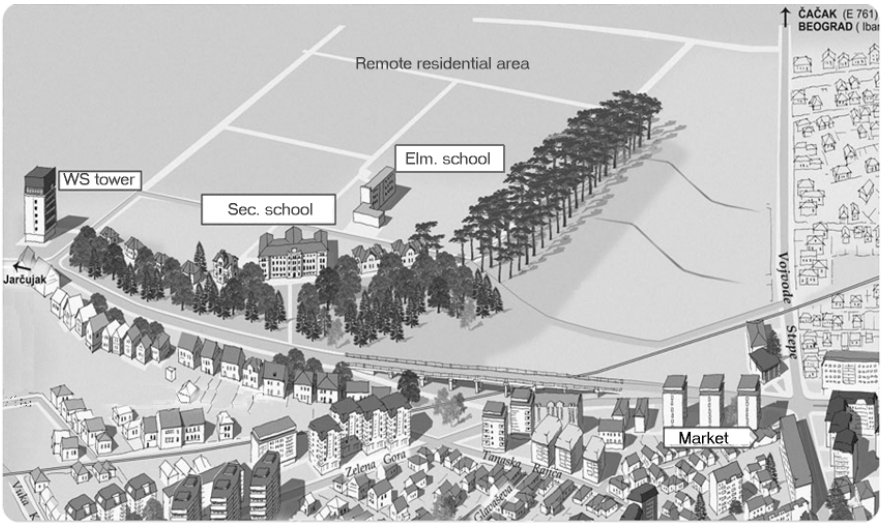

Figure 1: A drawing of the surroundings of the overpass studied in this paper

2. OBJECT OF THE STUDY

Kraljevo is a city in Central Serbia that represents an important crossing between North-South and West-East national roads and railroads. During 1980s, close to the large residential area near central part of the city was constructed major overpass that enabled passage of the road transport above the railroad line. In the Figure 1 is presented the overpass and elements of its surroundings. The overpass is pictured at the center of the figure, and it is shown that its left end is at a middle of a hill, while the right end is at the foot of the hill. The length of the overpass is 410 m, and the vertical difference between it ends is 8.33 m. The slope of the road varies from 1.5% to 5.2%. In the lower part of the figure is pictured a residential zone, with row of houses built along the higher part of the road that lead to the overpass. Along the lower part of the road is row of multistorey buildings. The rows of houses and buildings act as artificial barrier to noise propagation. In the higher part of the figure is shown hill above the road that is covered by vegetation that acts as a natural barrier to noise propagation. The foliage and the slope of the hill are providing a certain noise protection to houses and schools at the top of the hill and to remote residential area. Almost the whole surroundings is used as residential area and there are very few objects of other types, as it is the case with the elementary school and secondary school at the hill, water supply tower close to the upper part of the road, and a market close to the lower part of the road.
The elimination of the previous crossing between the railroad and the road made the overpass an attractive option for the truck, bus and car transport that is passing through the city. The increased traffic load led to significant increase of noise emission, and the nearby densely populated residential area soon became acoustically endangered zone. The main source of the noise was the traffic on the overpass, but important noise sources are also a wide street and the railroad line, both passing below the overpass. “Local ecology action movement” - municipal agency that deals with environment protection issues - is developing plans for noise protection of the surrounding of the overpass by a barrier constructed along the overpass. According to the practice prescribed by the law, as mentioned in the introduction, the first step in noise protection of a certain zone is drawing of the noise map of the endangered area. The concept of the noise mapping was to perform a series of measurements of noise levels, and then to draw noise maps by noise field calculations, using the various available commercial software packages that will be compared to the results of noise field measurements, in order to determine the best available noise map.

3. RESULTS

The experimental measurements were performed at ten measurement points. Noise level was measured using phonometer Bruel & Kjaer 2238 Mediator that has accuracy 0.1 dB. The measurement points were selected as shown in the Figure 2, with the aim to represent different configurations of surrounding objects around measurements points. The measured quantity was the A-pondered equivalent continuous sound level L_{eqA}, as defined by ISO-1996:1 [12]. Measurements were performed during the morning, day and evening. The results of the measurements are presented in the Table 1. With the aim to characterize the road as a noise source were performed measurements of noise level in points along the road, with distance between the two measurement points equal to 6 meters. Simultaneously with the noise measurements along the road was performed traffic counting, so the frequencies of light and heavy vehicles were determined in both directions.

In general, noise field calculations may be performed by the exact (so-called reference) and the approximate (so-called engineering) models. The exact methods are based on solving of differential equations of wave propagation, require considerable computer resources and time, and are suitable for accurate calculations of sound fields in acoustics, as it is the case with halls and theatres. The engineering models are much faster in implementation, but are considerably less accurate. They are suitable for noise mapping because noise maps essentially represent an estimation of the influence of the estimated noise sources in some longer period.

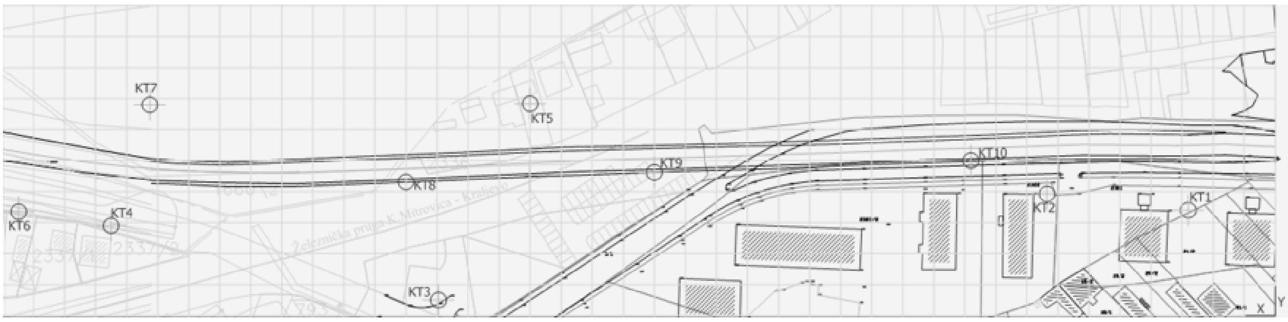

Figure 2: Positioning of the measurement points, marked by circles and numbered KT1-KT10

International standard ISO-9613:2 is adopted for the purposes of calculation of outdoor noise fields. The standard enables calculation of average downwind sound pressure level L_{AT}(DW) and long-time average sound pressure level L_{AT}(LT) at a receiver that is exposed to noise from multiple point-like sound emitters on uneven ground with varying hardness, in environment that consists of housings, industrial sites, foliage and noise-protection barriers. While the standard cannot describe many practical cases, and despite the presence of improved noise emission and propagation models, it remains the only internationally adopted standard.

At the market of commercial software are present several software packages for noise mapping, ranging from integrated software packages for strategic noise mapping to software for low-scale noise-field calculations intended as support tools for design of noise protection systems. The software packages differ in the models of sound propagation they use, ability to present various objects in noise maps and in the extent of the area that can be presented and processed.

Table 1: Results of the experimental measurements of the noise level at measurement points [dBA]

Measurement point	KT1	KT2	KT3	KT4	KT5	KT6	KT7	KT8	KT9	KT10
Morning	69.2	62.5	60.4	67.0	61.2	68.4	69.2	74.8	74.8	73.8
Day	69.3	65.4	60.8	66.2	59.2	67.8	69.0	76.5	72.6	74.5
Evening	63.7	58.9	55.3	60.0	55.8	63.3	61.7	70.8	69.5	65.3

As explained in the introduction, within the framework of the project “UrbaNoise” research team at the Faculty of Mechanical and Civil Engineering Kraljevo has been developing a proprietary methodology for noise mapping. Besides, for the calculations of the noise fields in surroundings of the overpass were used two evaluation versions of the software packages for noise mapping, SPM9613 [13] and OTL-Terrain [14].

Using the software SPM9613, the terrain in vicinity of the overpass was modeled as a mesh with 11x11 nodes and dimensions 410x100 meters. Each point of the terrain was described by its elevation and hardness of the ground. The noise of the traffic on the overpass was modelled by 42 point-like sources with noise power level of 76 dB over all third-octaves, uniformly distributed over the middle of the road at the overpass, with distance 10 meters. The park between the road and the secondary school was modelled as foliage. The buildings within the map were modelled as six horizontal barriers. However, the horizontal surface of the overpass was not modelled as a barrier to noise propagation, because the software package SPM9613 does not provide possibility for the modelling of horizontal surfaces. For that reason, the overpass was modelled as a hard terrain, without the free space below it. The results of the calculations are presented in the Table 2.

The software package OTL-Terrain has advanced capabilities for calculation of noise maps, including: Hadden & Pierce Diffraction 3D model implemented with finite impedances faces using Salomons semi-analytical method including ground effects; calculation of multiple barrier diffraction in a recursive way at any diffraction order; in-house sound path detection methods; incorporating of ground effect using the One Parameter Theory of Chessell based on Delany and Bazley; inclusion of reflections from finite surfaces based on Clay–Medwin's work to include Fresnel zones contribution at any order level; atmospheric absorption based on ISO-9613:1 and inclusion of turbulence coherence factor based on WP3 of the project "Harmonoise". Besides, the software package also enables much simpler calculation of the noise fields according to the ISO-9613:2 standard, and this was exactly the option that was used for calculation of the noise field in the vicinity of the overpass, for the sake of comparison with the results of other software packages.

Table 2: Results of the calculations of the noise level at measurement points [dBA]

Measurement point	KT1	KT2	KT3	KT4	KT5	KT6	KT7	KT8	KT9	KT10
Experiment	70.7	65.7	62.1	68.0	62.0	69.7	70.4	77.3	75.5	75.3
SPM 9613	68.3	70.4	74.9	68.7	69.3	67.8	67.3	66.1	65.9	76.2
OTL Terrain	67.0	69.2	73.6	65.5	67.0	65.6	67.0	73.3	74.9	76.7
BelCho	72.0	74.1	64.3	68.8	69.2	70.2	70.0	73.0	72.9	75.9

The basis for the model was the imported 2D image from the Google Earth web-based application, but the 3D modelling of the terrain was not available. For that sake, the hill above the overpass was modelled as Δ-barrier, and the overpass was modelled as a set of interconnected I-barriers. The buildings along the road were modelled as 18 structures with four walls and a flat roof. However, the remaining terrain was modelled as a flat ground with the appropriate acoustic hardness expressed by airflow resistivity. The results of the calculations performed using OTL-Terrain software are presented in the Table 2.
Besides the two trial versions of the commercial packages, noise field was also calculated by application of the software modules developed within the project "UrbaNoise". The software modules implement noise field calculations based on ISO-9613:2, with the basic objects being point-like sources, ground, foliage, housing, industrial sites and vertical barriers, but also proprietary objects like individual buildings and horizontal barriers which are suitable for modelling of bridges, platforms and various types of ceilings. The software has three main components: geometric library, ISO-9613 library and model implementation library. The geometric library implements geometric objects and geometric operations, the ISO-9613 library implements spectra, spectral operations and the effects of sound propagation, and the model implementation library implements the acoustic field and the objects within it, and performs calculations of noise levels in the acoustic field. The results of the calculation of the noise field by the software modules (in the development phase referred as "BelCho"), are also shown in the Table 2 for the sake of comparison.

4. ANALYSIS

The results listed in the Table 2 are shown in the Figure 3. The presented results will be considered from the point of view of predicted trends and magnitudes.
Before any other analysis, it is important to stress that noise mapping is essentially has statistical nature, and it requires acquisition of data in statistically meaningful amounts and periods. Both statistical requests are not satisfied with the experimental data provided in this paper, because they represent just a beginning of a planned systematic measurement of noise in the studied area. Therefore, the results of the provided analysis, as well as the derived conclusions, have only limited validity, and represent just directions for the future actions.

It can be observed that the results obtained by SPM9613 do not agree in trends with experimental observations in points KT5, KT6, KT7, KT8 and KT9, predicting also approximately 5 dB lower values than the other software packages for noise field calculations. Being that the distance to the overpass decreases from KT5 to KT9, the result obtained by SPM9613 raises suspicions and demands further study of the model applied with the software package.

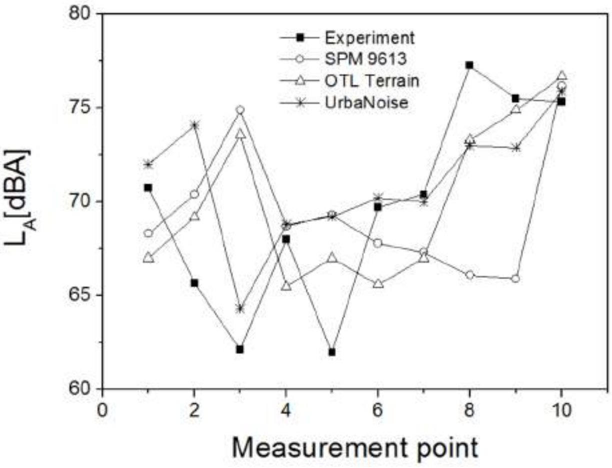

Figure 3: Graphical presentation of the experimental data and results of numerical calculations

The predictions of both SPM 9613 and OTL-Terrain disagree with the observed trend in the measurement point KT3, predicting also almost 10 dB lower values than those estimated by the experiment. The point KT3 is located between the buildings behind the first row of houses; it seems that the simple model, which includes just limited number of buildings besides the road, is not sufficient for description of the noise field at the measurement point KT3. The conclusion is further facilitated by the fact that the surrounding of the KT3 is modeled with more details in the model used with software modules developed within the project "UrbaNoise".

The most striking difference between the observed and the calculated trends is in the point 5, where all three software packages predicted higher values then in the points 4 and 6, and the experimental measurements indicated lower values. Considering that the measurement point KT5 is also between houses, the observed behaviour may be as well attributed to the insufficient description of the surroundings used for calculations.

The statistical analysis of the difference between the experimental and numerical estimations of the noise field is shown in the Table 3. It is obvious that the best agreement with experimental results show results obtained by the modules developed within the project "UrbaNoise". However, it should be stressed again that the results do not have enough statistical reliability, especially considering that the models of the studied area that were used in calculations were not the same for the three software packages used.

Table 3: Statistical analysis of differences between the experimental and numerical estimations [dBA]

Model	Mean	Dev.	Min.	Med.	Max.
SPM9613	5.5	4.5	0.7	3.9	12.8
OTL-T	4.0	3.0	0.6	3.6	11.4
UrbaNoise	2.8	2.9	0.4	1.7	8.4

The noise map obtained by the application of the software modules developed within the project "UrbaNoise is presented at the Figure 4.

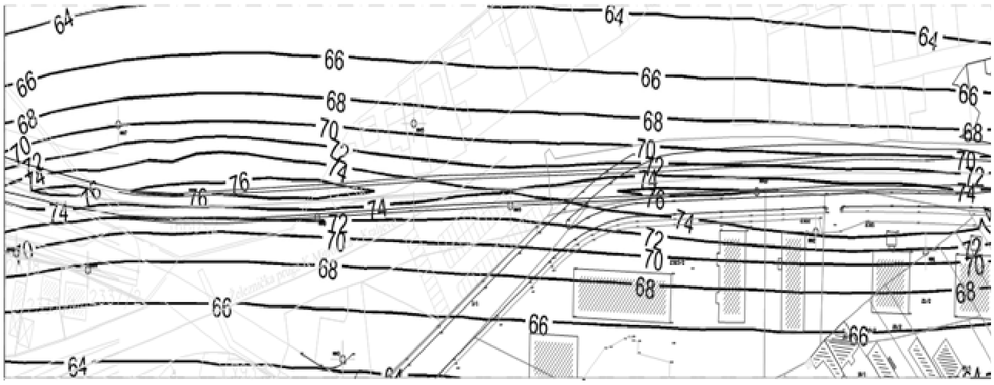

Figure 4: Noise map obtained by the application of the software modules developed within the project "UrbaNoise"

5. CONCLUSIONS

Two commercial software tools and software modules developed within the project "UrbaNoise" were used for drawing of the noise maps of the surroundings of the overpass. Each of the software tools has different set of limitations from the point of view of modelling the objects and space where the sound propagates and the noise levels are calculated. Therefore, the models of the object of the study area where not the same, but depended on the limitations of the respective software package. The software package SPM 9613 was not capable of modelling of the structure of the overpass, because it cannot describe horizontal barriers to sound propagation. The software package OTL-Terrain was not used up to its full potential because it was used in ISO-9613 mode, and the terrain was modelled by Δ-barriers, which did not allow for accurate modelling of the hilly terrain around the overpass. The software modules developed during the project "UrbaNoise" did not take into account influence of the reflections.

The obtained results were compared to the experimental measurements of noise taken at selected points near the overpass. The experimental results were taken at sufficient number of points that represent well the structure of the noise field that was studied. However, the measurements were taken during just one day and cannot be considered representative for noise level, because they do not represent variations of traffic intensity and weather conditions during seasons. Therefore, the derived conclusions may be only recommendations for future actions.

The obtained results have shown rather good agreement between the magnitudes of experimental and numerical estimations of the noise level fields, as evidenced by the Table 3. However, the trend analysis shows that the details of the model can significantly influence the obtained results.

The results suggest that the exact shape of the terrain is not of crucial importance for good agreement between experimental and numerical estimations of the noise level, because rough modeling of the terrain by Δ-barriers in OTL-Terrain model does not seem to have large influence on the results. On the other hand, inability to represent the overpass as a structure with openings seemed to have negative impact on ability of SPM 9613 model to comply with results of other models and experimental results.

Finally, all the models showed large discrepancy in comparison to the experimental results at the measurements points that were between buildings and houses. Due to the importance of residential areas for noise mapping, noise control and environment protection as whole, appropriate attention has to be devoted to the calculation of noise fields in spaces between buildings and houses. Therefore, such areas have to be described with as much details as possible, and further attention should be devoted to development of models of sound propagation in limited open space.

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