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TOWARD ENVIRONMENTAL NOISE ESTIMATION ACCORDING TO THE ROAD SURFACE CHARACTERISTICS AND TRAFFIC VOLUME

Ivica Stančerić, Vesna Dragčević, Saša Ahac

Preliminary notes

The paper gives the first results of the research aimed at analysing the possibility of the relevant estimation of the level of disturbance caused by traffic noise on the basis of parameters collected regularly by road administrations. For the description of road surface characteristics these are road evenness (IRI_{100}), road texture and visual assessment of pavement condition given by the PCI-index, as well as the traffic load including the structure of the traffic flow. When making a decision about the reconstruction, together with already included parameters, the environmental noise estimation should also be taken into consideration. In doing so, environmental noise conditions would, without altering standard procedure, become another important factor in deciding about the reconstruction of the existing roads.

Key words: *noise level, PCI-index, road evenness, road surface properties, road texture, traffic load*

Prilog ocjeni stanja bučnosti u ovisnosti o površinskim svojstvima kolnika i prometnom opterećenju

Prethodno priopćenje

U radu su dani prvi rezultati istraživanja koje ima za cilj analizirati mogućnost relevantne ocjene stupnja smetnji uzrokovanih bukom od prometa na osnovu parametara koje uprave za ceste redovito prikupljaju. To su za opis površinskih svojstva kolnika ravnost (IRI_{100}), tekstura i vizualni pregled stanja dan PCI-indeksom te prometno opterećenje koje uključuje i strukturu prometnog toka. Pri tome bi uz dosadašnje parametre pri donošenju odluke o rekonstrukciji bilo potrebno uključiti i ocjenu stanja bučnosti. Na taj način bi i stanje bučnosti u okolišu, ne mijenjajući uvriježenu praksu, moglo postati još jedan važan čimbenik prilikom donošenja odluke o rekonstrukciji postojećih prometnica.

Ključne riječi: *PCI-indeks, površinska svojstva kolnika, prometno opterećenje, ravnost, razina buke, tekstura*

1 Introduction
Uvod

In the last ten years more and more attention in Europe has been paid to the protection against environmental noise. Its harmful effects on human health are well-known and, in addition to workplace noise which was emphasized a lot earlier and which is connected to professional illnesses, extremely harmful environmental noise effects are emphasized [1]. The dominant role, with regard to other environmental noise sources among which traffic and industry are the most important ones, is attributed to the traffic, especially road traffic. In spite of the fact that other sources cause bigger disturbances, the number of people exposed to road traffic noise is significantly higher, so, in the long run, health problems caused by road traffic noise imply considerable expenses for the health system. An especially large number of those exposed to road traffic noise live in urban areas, big cities where population density is high and very loaded city roads pass close to residential buildings.

Noise level measurements in Zagreb, the capital and the biggest cultural, economic and industrial centre of Croatia, started in the 1970s. The results showed that the maximum noise level values were not lower than 70 dB(A) in neither part of the city, and they rose as high as 85 dB(A), [2]. According to the European Commission data peak noise level values in urban areas do not, as a rule, increase further since the vehicles are newer and technologically more advanced, but the period of exposure to noise is prolonged [3]. That is also the case of Croatia.

The complaints by Croatian citizens directed to the authorities regarding the disturbances caused by high levels of noise are more and more frequent and numerous. The reason for that lies, on the one hand, in the prolongation of the time of exposure to high levels of noise and, on the other hand, in raising consciousness about disturbances caused by noise which are clearly stated in innovative and ever growing regulations in this field as well as in the media. The Republic of Croatia has almost completely harmonized its regulations with those on the European level based on European Directive 2002/49/EC. It prescribes the continuous assessment of environmental conditions regarding noise pollution, making noise maps and designing action plans, with the aim to improve the situation in high exposure areas as well as to protect the quiet ones.

In spite of that the protection against traffic noise in urban areas in Croatia is carried out sporadically and refers mostly to those areas along roads where levels of noise are extremely high, local residents repeatedly direct objections to city authorities, and efficient protection can be carried out by barriers. There is a years-long experience in the construction and application of noise protection barriers. Along with the newly constructed highways intensively built in Croatia in the last decade, protection has been carried out by the construction of different types of noise protection walls. Other measures of the protection against noise, such as the application of low-noise pavements, speed and traffic limits for certain types of vehicles or traffic redirection, have been neglected. Due to high density of buildings in urban areas, these very measures are sometimes the only possible solution. The reason for such a situation is partly insufficient knowledge about other protection measures, and partly the fact that systematic implementation of efficient protection would require significant financial resources which are usually limited. Generally it can be said that systematic monitoring of the situation on the part of road administration does not in fact exist, but the wish to change such a situation is increasingly expressed. The research presented in this paper is a contribution to these efforts.

2
The aim of the research
Cilj istraživanja

The desire of city administration to improve environmental noise situation which citizens are exposed to, either by decreasing the exaggerated noise levels to the levels prescribed by the regulations or by decreasing it to the lowest achievable levels if the regulations cannot be met, has been more pronounced recently. The overall improvement of the situation would require significant funding which has not been planned for this purpose and it is not realistic to expect that the situation will change in the future. Thus, efforts are being made to determine whether this situation can be influenced within the regular maintenance of city roads. Can the situation be improved and how much by timely and regular maintenance with the application of the usual ways of road driving surface improvement?

Every year significant funds are invested into traffic infrastructure development in the city of Zagreb. Special importance is given to interventions to improve road infrastructure, especially those referring to regular maintenance of the existing roads. The standard planned maintenance of the most loaded city roads comes down to the following: the replacement of the existing asphalt layers by the new base course of asphalt stabilized base and wearing course of asphalt concrete; the construction of a completely new road structure with a granular base layer, cement stabilized base, asphalt stabilized base and wearing course of splitmastic asphalt or asphalt concrete.

In addition to that, regular efforts are being made to improve the existing traffic regulation or a new one is often introduced. The basic goal is the decrease in traffic jams, i.e. the increase in comfort as well as safer and faster traffic flow and, consequently, the increase in city life quality. In areas where roads pass through business and residential areas citizens' petitions and complaints addressed to city administration regarding disturbances caused by road traffic noise are very frequent. These facts have motivated this research with the aim of determining the degree of noise level decrease by timely road maintenance, that is, by environmental noise condition assessment on the basis of parameters collected regularly by road administrations.

The selection of streets for driving surface reconstruction is done on the basis of road evenness evaluation, visual survey of road damage and the planned annual amount of funding for repair and reconstruction. The environmental noise situation is secondary in this respect. However, if the decision regarding this maintenance was made considering the improvement of environmental noise situation, that would be the first step in efforts to paying more attention to this segment. This does not require the change in the manner of performance of works, the introduction of new technologies or the increase in costs, but only a more careful selection of sections.

This research would like to determine, on the basis of relatively easily measured parameters describing the road surface, road evenness, road texture and PCI index, which have influence on the decision making regarding the road driving surface improvement, how much the improvement of these parameters (by reconstruction) would improve environmental noise conditions.

The aim of the overall research is to create the data base which would be the foundation for making correlative models between the measured parameters of road surface properties, traffic load and noise level. Similar types of research in the world have been carried out mostly on test sections and not in real traffic conditions. This research is based on monitoring the behaviour in real conditions in the city of Zagreb and is carried out as a part of the wider project "Road Traffic Noise - Monitoring and Protection Measures" started at the Faculty of Civil Engineering of the University of Zagreb approved by the Ministry of Science, Education and Sport.

3
Research plan and description of the locations
Plan istraživanja i opis lokacija

The planned research is divided into three phases:

I phase – measurement on chosen locations of the parameters which describe the road surface: road evenness (IRI), road texture (MPD), visual assessment (PCI) as well as the levels of noise, driving speed and traffic load;

II phase – measurements of all the parameters listed in the first phase for the condition after driving surface improvement was carried out;

III phase – the longest phase comprising the measurements which will take place once in three years during construction exploitation.

In the first phase locations had to be selected carefully. Locations where the driving surface was repaired only on a part of carriageway (e.g. only one lane on a three-lane road) were not chosen but only those where it was repaired on the whole carriageway. The choice was additionally limited to the roads with the data known from the previous period (the first phase listed parameters), or it was known that they would be planned for the reconstruction in the course of the following three years (the necessary data for the period before the reconstruction can be collected). The data regarding citizens' complaints were respected in location selection.

The first phase of research has so far been carried out on several locations. The second phase has been completed on three locations described in the paper. For other locations where the first phase was finished the second could not be conducted because their reconstruction was not finalized.

On the described locations in the first phase before the reconstruction and then in the second phase after the reconstruction there have been extensive measurements of noise level, driving speed, road evenness, road texture and traffic load as well as visual assessment of pavement condition to determine the age, type and state of road driving surface, the width and number of lanes and the longitudinal slope.

The paper shows the results of the research on three locations situated in the mixed, mostly residential area of the city of Zagreb (Fig. 1). These are three-lane one-way major city roads [4] passing through the centre of the city connecting the western and eastern part of the city with the traffic load of 30 000 vehicles daily.

The existing driving surface on all observed locations consisted of the wearing course of asphalt concrete AC11, which was 4 cm thick, of unknown age, in some sections covered by patches of different types of asphalt, of different surfaces and of unknown thickness and age. They were submitted to the reconstruction on the whole carriageway, and the wearing course of the driving surface was layered by 4 cm thick splitmastic asphalt SMA11 on locations L1 and L2 and 3 cm thick SMA8 on location L3.

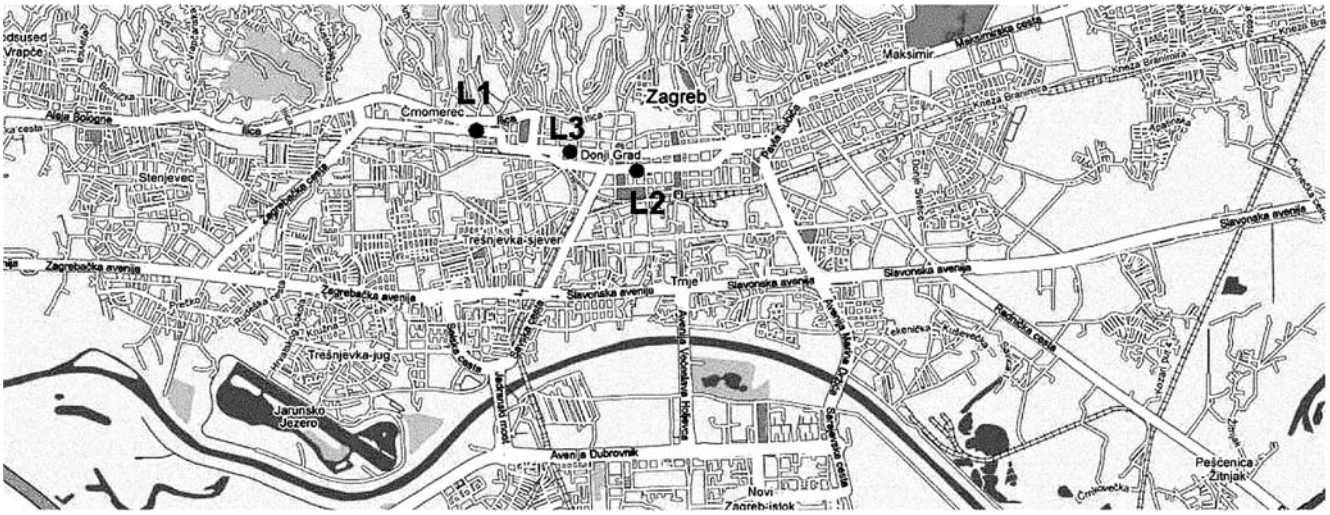

Figure 1 *The observed locations on the map of the city of Zagreb*
Slika 1. *Prikaz promatranih lokacija na planu grada Zagreba*

The existing driving surface on all observed locations consisted of the wearing course of asphalt concrete AC11, which was 4 cm thick, of unknown age, in some sections covered by patches of different types of asphalt, of different surfaces and of unknown thickness and age. They were submitted to the reconstruction on the whole carriageway, and the wearing course of the driving surface was layered by 4 cm thick splitmastic asphalt SMA11 on locations L1 and L2 and 3 cm thick SMA8 on location L3.

4
Noise measurement
Mjerenje buke

Short-term (15 min) noise level measurements were done by precise sound level meters Brüel &Kjaer 2260 and 2250 at favourable meteorological conditions, at the height of 1,2 m above the surface of the ground and the distance of 7,5 m from the axis of the lateral lane. On each measuring spot the measurement was repeated 4 times in the period "day" and "night". Noise measurements were conducted between 9 and 10 am and between 10 and 11 pm when traffic flow is continuous. Measurements during peak hour traffic were avoided because of frequent traffic congestions.

Fig. 2 shows mean values of the equivalent noise levels for the period "day" and "night" for the situation before and after the reconstruction. It is evident that the noise levels in the "day" period after the reconstruction are lower than those before the reconstruction from 0,9 to 1,5 dB(A).

In the period "night" the very improvement of the road driving surface (the situation after the reconstruction) led to the increase in the noise level from 0,5 to 0,9 dB(A). When traffic conditions allow it (traffic load is low) the driving on the repaired road is faster and the speed is frequently much higher than the allowed. The increase in the noise level was caused by the alteration of the traffic flow which was significantly changed compared to the situation before the reconstruction, so the results cannot be compared and have, consequently, been left out of further consideration. It is not the case for the period "day" when the cause of the noise level alteration, considering the situation before and after the reconstruction, is the change of the very parameters which describe the road driving surface.

In Croatian engineering practice in the selection of the type of road driving surface protection against noise does not have any significance. The wearing course of asphalt concrete or splitmastic asphalt is regularly applied. Some tests show that their acoustic properties are similar [5]. However, noise level measurements carried out in some European countries showed better results of SMA with regard to AC from 2 to 3 dB(A) [6].

5
Traffic measurement
Mjerenje prometa

Traffic measurement has been carried out simultaneously with noise measurement (between 9 and 10

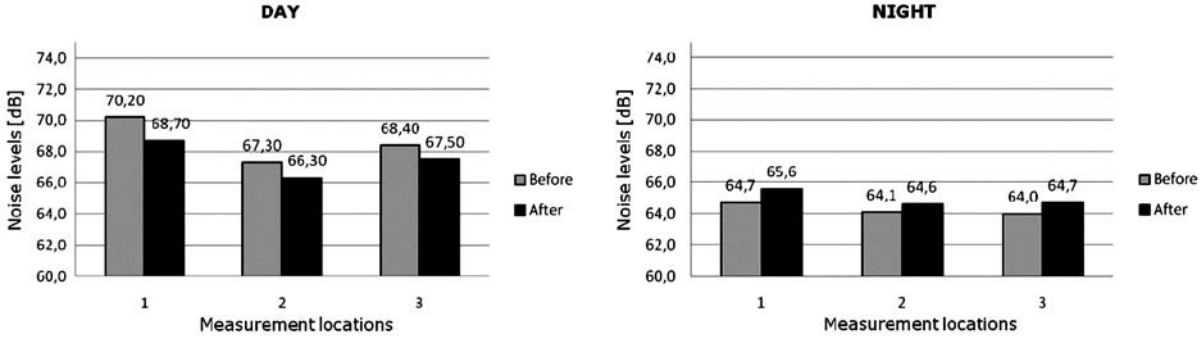

Figure 2 *Mean values of the equivalent noise levels before and after the reconstruction for the period "day" and "night"*
Slika 2. *Srednje vrijednosti ekvivalentne razine buke prije i poslije rekonstrukcije za period "dan" i "noć"*

am) by registering the traffic load by video-camera. Measurements during peak hour traffic were avoided because of frequent traffic congestions. Road vehicles have been divided into three categories: personal vehicles, light and heavy freight vehicles. Heavy freight vehicles include truck trailers, tractor semi-trailers and buses. The data are presented in Tab. 1.

Table 1 *Traffic measurement before and after the reconstruction on selected locations for the period "day"*
Tablica 1. *Mjerenje prometa prije i poslije rekonstrukcije na odabranim lokacijama za period "dan"*

Location	Before reconstruction			After reconstruction		
	Personal vehicles	Freight vehicles		Personal vehicles	Freight vehicles	
		Light	Heavy		Light	Heavy
L1	1654	139	11	1785	150	11
L2	1604	115	31	1692	136	25
L3	1680	131	39	1703	145	27

It is evident that traffic load is approximately the same on all three locations, that personal vehicles make up for 90 % of vehicles in traffic flows. After the reconstruction there was no change regarding the traffic load, thus the traffic flow conditions in the period "day" show similar properties.

Field measurement determined the average vehicle speed assuming that they move at unvaried speed by measuring the time of passing at known length. It corresponds to the allowed speed on the observed roads and amounts to 50 km/h.

6
Road surface characteristics measurements
Ispitivanja površinskih karakteristika kolnika

Measurements of road surface characteristics consist of: evenness measurement, texture measurement and road condition assessment described by PCI-index.

Evenness measurement. Previous research shows that the influence of road evenness on road traffic level is negligible. That statement is based on the results of a few researches within the European project TINO (Analysis, Measurement and Suppression of Tyre Noise, duration 1996 to 1999). The stated research included a small amount of different road surfaces, therefore, the reliability of these data is questionable [7].

The measurement of the (longitudinal) road evenness on all locations was performed on the whole length of the selected road section on the right and middle lanes by laser/inertial profilograph of Laserprof type produced by Greenwood Engineering. Since it is a double-sided cross slope it was supposed that the left road lane is symmetric compared to the right one.

The parameter of the road evenness (driving comfort measure) is IRI - International Roughness Index in metres per kilometre. It is mathematically determined on the basis of longitudinal profile values measured by profilograph. The measured longitudinal road profile is used as the base for quarter-car simulation model. The model includes all important dynamic elements determining the way in which uneven parts of the road surface influence the vehicle vibrations. IRI describes the reaction of the vehicle to the uneven parts on the driving surface, thus it is suitable for the assessment of the overall road condition, where smaller value indicates more comfortable ride and, therefore, "smoother" road.

The results of road evenness measurements on locations L1, L2 and L3 before (AC11) and after the pavement reconstruction (locations L1 and L2 SMA11, location L3 SMA8) are presented in Fig. 3.

For the damaged road before the reconstruction IRI values ranged from 4 to 11 m/km and from 2,4 to 3 m/km for the new road. The measured mean values of road evenness after the reconstruction (the new road) according to COST 354 project [8] would be considered acceptable regarding road evenness which for the group of other roads (all except motorways and state roads) ranges from 2,5 to 3,7. The reason for such a state of road evenness for the new pavement is the technology of paving asphalt layers with frequent interruptions of works and partial manual paving of the layer. In addition, during the paving the road pavers were not automatically led which would definitely give much better results.

Texture measurement. The macrotexture of the road surface as well as the road evenness were measured by the laser profilograph. The macrotexture of the road is described by the Mean Profile Depth - MPD. It is expressed in millimetres and the calculation of MPD (Fig. 4) is defined by ISO 13473-1:1997 standard [9].

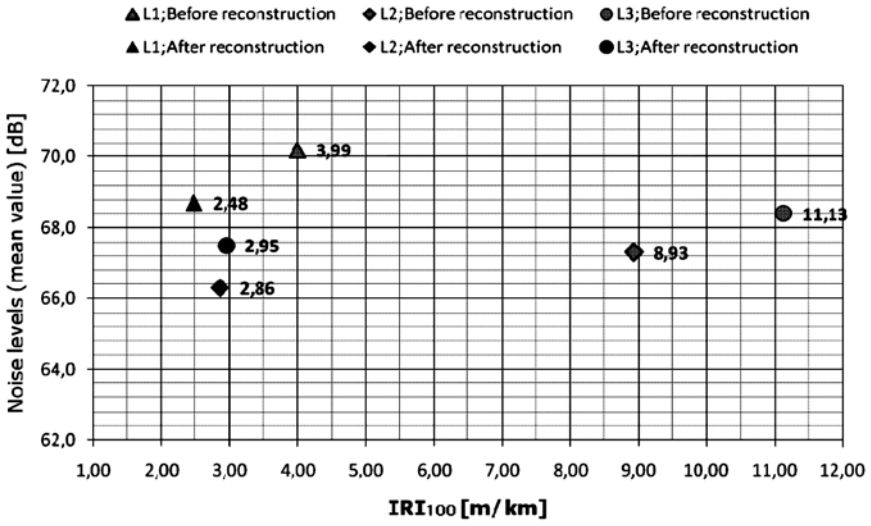

Figure 3 *The ratio of noise level and road evenness mean values on all three locations before and after the reconstruction*
Slika 3. *Odnos srednjih vrijednosti razina buke i ravnosti na sve tri lokacije prije i poslije rekonstrukcije*

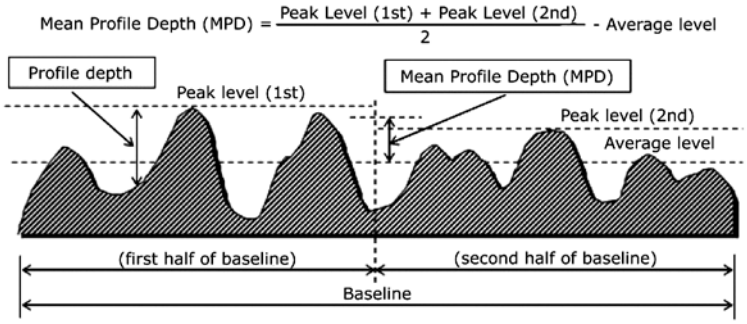

Figure 4 *MPD calculation defined by ISO/DIS 13473 standard*
Slika 4. *Proračun MPD-a definiran standardom ISO/DIS 13473*

The macrostructure consists of the size of large aggregate particles that «stick out» of the road surface and depends on the size, form and distance of aggregate particles on the road surface. Wave lengths of the macrotexture range from 0,5 to 50 mm. It is the conventional wisdom that the road macrotexture has a high level of influence on the road traffic noise [7], however, clear and unequivocal relationship between the macrotexture and noise has not been established yet.

Research of the influence of the road texture on the noise levels has demonstrated that there is a proportional relationship between the noise inside the vehicle and the road texture and that there is a weak proportional linear relationship between the noise outside the vehicle and MPD with certain types of tyres [7]. The noise level (Sound Pressure Level SPL) at lower frequencies (lower than 1 kHz) increases with the increase in texture amplitude (with wave lengths ranging from 10 to 500 mm) and SPL with frequencies higher than 1 kHz with the increase in the texture amplitude (with wave lengths ranging from 0,5 to 10 mm) decreases [10, 11].

The research [12] which included measurements of noise levels due to the test vehicle passing on test sections with the road surface AC11 and SMA8 for which the texture was measured (sensor measured texture depth SMTD), showed that the texture depth for SMA8 is bigger than the texture depth for AC11 (the mean value of SMDT for SMA8 amounted to approximately 0,54 mm while with AC11 that value was approximately 0,40 mm) and that the level of the emitted noise due to the interaction of tyres and the road surface of splitmastic asphalt (SMA) was lower than that on the surface of asphalt concrete (AB) ranging from 1,5 to 2 dB.

Fig. 5 shows mean values of road texture measurements on the observed locations. Results similar to those in previously mentioned extensive research were obtained for new surfaces. MPD values on reconstructed pavements, which wearing course was made of splitmastic asphalt, were 0,67-0,75 mm. MPD values for the pre-reconstruction conditions on the old layer of asphalt concrete ranged from 0,35 to 0,44 mm.

Road condition assessment. Visual surveys, although as a rule subjective, still represent the most reliable method of surface road damage observation. Objectification and interpretation of results obtained by visual observation are more difficult, however, efforts are made to lessen these difficulties by education and training of teams of observers. Visual assessment of pavement condition is described by PCI-index, numerical index presented by numerical measure ranging from 0 to 100. The stated number at the same time presents road structural integrity and usability, while higher values of PCI reflect better road condition.

For visual survey of pavement condition different observation methods can be used: by rounds (on foot) and visual observations from the car by (automatic) recording while driving. In Croatia there are instructions for visual assessment of pavement condition [13] which are primarily made for the observation method while driving. Since in this research the method of observation by rounds is used, it is more convenient to use ASTM regulations [14] in the interpretation of the road condition. According to ASTM regulations, before road condition estimation selected road section is divided into test samples (Fig. 6). The data regarding the damage are collected for the selected samples, (depending on the total observed surface) and after that PCI index of each observed test sample and of the whole section of the road is determined by computer program MicroPaver. The results of the visual observation and the evaluation of

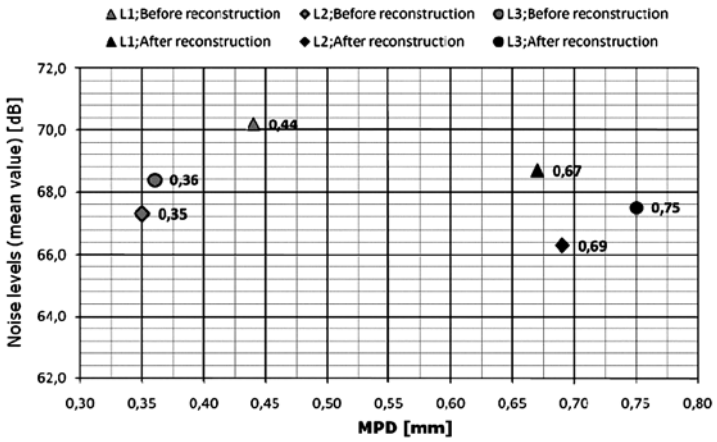

Figure 5 *Road texture measurements on selected locations*
Slika 5. *Mjerenja teksture kolnika na odabranim lokacijama*

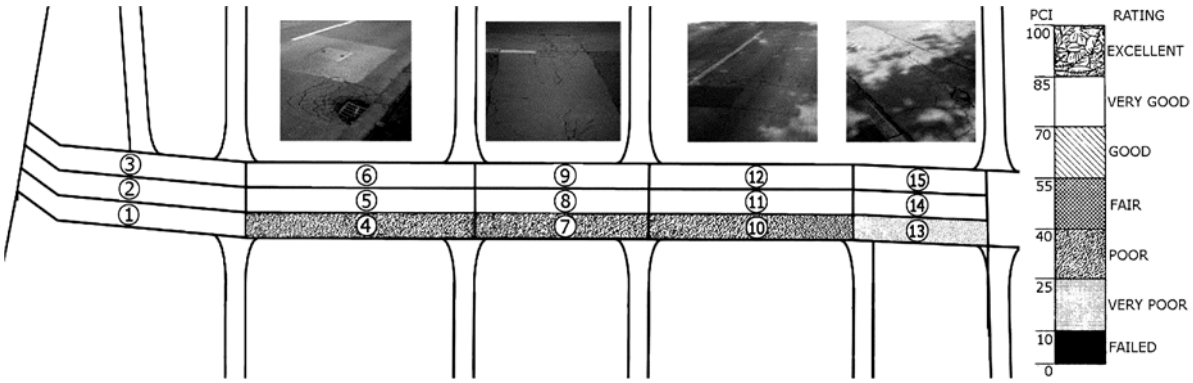

Figure 6 *The division into sections on the location L2 and the evaluation of conditions of each separate section*
Slika 6. *Podjela na odsječke na lokaciji L1 te ocjena stanja pojedinih odsječaka*

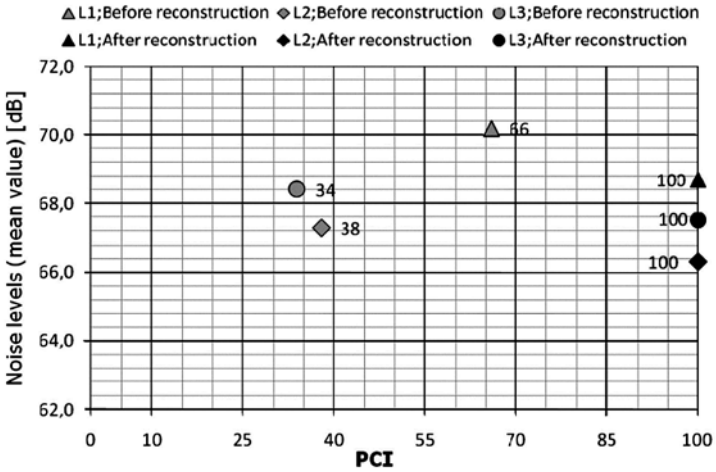

Figure 7 *Evaluation of pavement surface condition (expressed by PCI index) obtained by visual survey on selected locations before and after reconstruction.*
Slika 7. *Ocjena stanja kolnika (izražena PCI indeksom) dobivena vizualnim opažanjem na odabranim lokacijama prije i poslije rekonstrukcije*

pavement surface condition on the selected locations before and after the reconstruction are shown in Fig. 7. Before the reconstruction the pavement condition on the location L1 was good (PCI_{L1}= 66) and on the locations L2 and L3 poor (PCI_{L2}=38, PCI_{L3}=34). After the reconstruction the condition on all locations was excellent ($PCI_{L1,L2,L3}$ =100).

7 Conclusion
Zaključak

The reconstruction, i.e. the improvement of road driving surface condition on all three locations resulted in noise level decrease in the period "day" ranging from 0,9 to 1,5 dB.

Measurements on locations L2 and L3 show that, regarding the noise level decrease, SMA11 and SMA8 have similar properties. On these locations value differences in parameters describing the pavement surface conditions before the reconstruction are insignificant. This also refers to the condition after the reconstruction.

On location L1 there was greater improvement in noise level compared to locations L2 and L3. On this location the driving surface before the reconstruction was in better condition than on locations L2 and L3, after the reconstruction better road evenness and texture was achieved but the noise level was higher than on locations L2 and L3.

Testing low-noise surfaces (porous surfaces) on test sections shows that by the application of double layered asphalt on city roads where the speed is limited to 50 km/h it is possible to achieve noise level decrease of 3 dB (compared to the referent pavement covered by the wearing course layer of asphalt concrete of AB12t), while for low - noise thin layered surface this decrease amounts to 1,5 dB [15].

The technology and experience for making low-noise surfaces does not exist in Croatia, so it is not possible to influence the decrease in noise in this way. However, even if it was done on a small number of locations, this research shows that by applying the usual procedure it is possible to achieve a satisfactory improvement especially compared to the decrease achievable by applying low-noise thin layered surface. This research conducted in real conditions shows that it is roughly 1 dB. Should Croatia, along with the timely maintenance of the driving surface, positively affect the driving manners in order to reduce the driving speed, and to drive in lower gear, better results could surely be possible, more similar to those obtained by testing in ideal conditions.

Noise level measurements carried out in real traffic conditions indicate the complex relationship between road surface properties, traffic flow properties and noise levels. Improved road surface properties of new pavements, increased road texture, better road evenness and higher values of visual assessment of pavement condition index all point at the trend of noise level decrease. The analysis of the measured data of road surface properties and noise levels carried out within this project is still insufficient to determine clearer principle expected after the third phase of the research.

Additionally it turned out that reconstruction works should be carried out in a way to achieve lower initial road evenness of the new driving surfaces. It is evident that on

city roads it is not possible to achieve so good results as on those outside cities, but the present condition in this respect is worrying. Very good results are achieved on roads outside settlements so this knowledge should be applied to city roads as well.

It would definitely be useful, along with the usual practice of registering road surface properties, to include noise level measurements in data collection by road administrations. That would be another step towards the improvement of environmental noise.

8
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Authors' Addresses:
Adrese autora:

Ivica Stančerić, dipl. ing. građ.
prof. dr. sc. Vesna Dragčević, dipl. ing. građ.
Saša Ahac, dipl. ing. građ.
Sveučilište u Zagrebu, Građevinski fakultet
Kačićeva 26, 10000 Zagreb
e-mail:istanceric@grad.hr