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RECONSTRUCTION OF THE JARUNSKA ROAD IN ZAGREB AFTER THE EARTHQUAKE

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Abstract

The paper analyzes the condition of the road surface of Alley Matija Ljubek in the city of Zagreb, the road around Lake Jarun. The Jarun road was built as part of the development of the Jarun Sports and Recreation Center for the Universiade in 1987. It's 6.4 kilometers long and has one-way traffic for cars, a parking lot, as well as a separate path for bicycles and pedestrians. During 33 years of exploitation, a number of damages appeared on the roadway, which were further aggravated by seismic activities in the area of the city of Zagreb in 2020. As part of the preparation of the roadway renovation study, measurements of parameters were carried out: roughness index, route depth, macrotexture, cracks and patches on the pavement. After analyzing the measured characteristics of the driving surface, a proposal was made for the renovation of the Alley Matija Ljubek pavement. To apply for the allocation of non-reimbursable financial resources aimed at restoring the infrastructure to its proper condition, a detailed scope of work for repairing damages to the Alley Matija Ljubek road, funded by the European Union Solidarity Fund through Shoo, has been elaborated. The road was renovated in the spring of 2023 in agreement with the renovation project and with a high-quality approach to maintaining technical accuracy, safety and driving comfort. As a result, the road now has a new lifecycle for exploitation.

Keywords: road surface, seismic activity, safety and driving comfort

1 Introduction

Jarun is a residential area located in the southwestern part of the urban district of Trešnjevka, South in Zagreb. Positioned between Horvaćanska Street and the banks of the Sava River, the neighborhood encompasses the Jarun Lake [1]. The Lakes environment is arranged as a spacious recreational-sports center Jarun, a complex which abounds numerous sports facilities. The Matija Ljubek Alley, circling Lake Jarun with a length of 6.4 kilometres, was constructed as part of Recreational Sports Centre Jarun to accommodate the needs of Universiade in 1987. The pavement is in poor condition due to traffic loads, weather influence and lack of maintenance since its construction. The road surface's poor flatness and low-level of comfort in occasional driving, contributed to the rapid deterioration and overall poor conditions of the roadways constructions. The cause of poor roadway conditions is significant fragility due to tall modules stiffness in the asphalt layers and the lower wearable layers. The tall modules stiffness in layers appears from oxidation of binders, a natural aging process in asphalt layers during exploitation. On Figure 1 (left) is shown a part of the road with visible and typical damages in form of cracks and patches. Similar damage was along the entire length of roads, varying in intensity. On Figure 1 (right) is shown a section of the driving surfaces asphalt pavement, where rigidities are depicted in detail and marked with colours (red and orange colour represents deeper cracks while green and blue marked shallower cracks).

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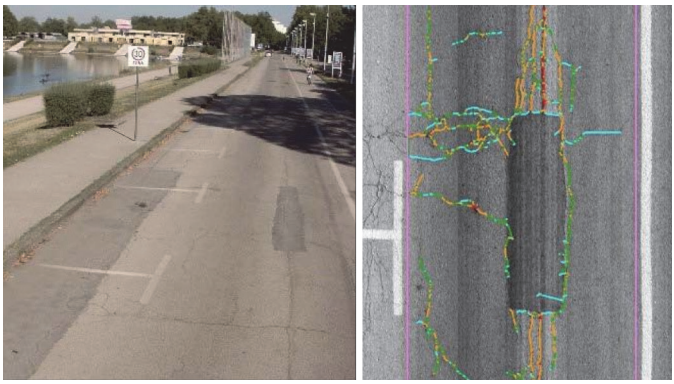

Figure 1 Damage on the pavement of Alley Matija Ljubek [2]

An earthquake magnitude 5.5 per Richter occurred on Sunday, March 22, 2020, at 6:24 AM. The earthquake affected the city of Zagreb and its wider territory, with the epicentre located 7 kilometres further north from the centre of Zagreb, code settlements Markuševac. It was the first larger earthquake since the major Zagreb earthquake of 1880, which had a magnitude of 6.3 per Richter and caused extensive damage to a large part of the city. The epicentre is located in Medvednica, near the neighbouring town of Kašina, at a depth of 12 kilometres [3]. After the intial shakes, a series of subsequent shakes followed, in total 57 of them within the next 24 hours and approximately 3200 shakes until the end of the year. The number of subsequent shakes and their magnitude exponentially decreased over the first seven days after the main earthquake. The earthquake affected the entire city and its surroundings, causing significant material damage to various objects. Residential buildings, family houses, medical facilities, schools, public facilities, bridges, and the city traffic infrastructure were all damaged. The earthquake also had a negative influence on state roadways. At the end of the year, on December 28th and 29th, 2020, several stronger shakes occurred in the area around the city of Petrinja, with the strongest magnitude of 6.2 on the Richter scale. The effects of the Petrinja earthquake were felt in the Zagreb area, causing damage to various objects and infrastructure. The existing bad state of the pavement in combination with the earthquake that occurred during low winter temperatures, resulted in additional damage to the pavement [4]. In cold conditions, the modules stiffness of the asphalt mixture is considerably larger than at warmer temperatures, leading to increased damage.

2 Characteristics of roadway driving surfaces

Faculty of Traffic science (FPZ) implemented measurements and recordings of characteristic driving surfaces on Aleja Matije Ljubek road, in July 2022. The following parameters were established:

- International roughness index - IRI
- Ruts (transverse roughness) - RD
- Macrotexture - MPD
- Cracks
- Patches on pavement.

The average speed of vehicle movements per route on the 6.4-kilometer subject road was recorded at 43.7 km/h, according to the occasionally shown measurements. The processed results of certain established parameters were represented in line graphs along the station and in bar graphs, with values divided in five groups (very good to very bad).

2.1 International Roughness Index - IRI

The parameter international roughness index (IRI) was measured on Aleja Matije Ljubeka using an inertial profilometer device, assembled on a measurement beam. The measuring beam contains multiple lasers, two of which are foreseen for measuring IRI. These lasers are positioned on the left and right sides, aligning with the trace wheels to capture the largest unevenness across the train surface. The measurement results contain IRI values for both the left and right trace wheels, along with other parameters necessary for data processing and assessing longitudinal surface equality. Referential values for border acceptability and border 'very bad' IRI, as well as borders group results are shown in the table below and are derived from the project COST 354 " Performance indicators for road pavements " [5] (Table 1).

Table 1 Groups index and values IRI

Groups	**Index IRI**	**IRI** [m/km] **highways and main roads**	**IRI** [m/km] **other roads**
Very good	0 - 1	‹ 1.1	‹ 1.2
Good	1 - 2	1.1 - 1.9	1.2 - 2.5
Acceptable	2 - 3	1.9 - 2.6	2.5 - 3.7
Bad	3 - 4	2.6 - 3.2	3.7 - 4.9
Very bad	4 - 5	› 3.2	› 4.9

Graphically, the determined values of IRI are divided in five groups. It is evident that the largest share from 56.25% of the findings, falls within the secondary group. This indicates the need for pavement reconstruction to prevent further increases in inequality (Figure 2).

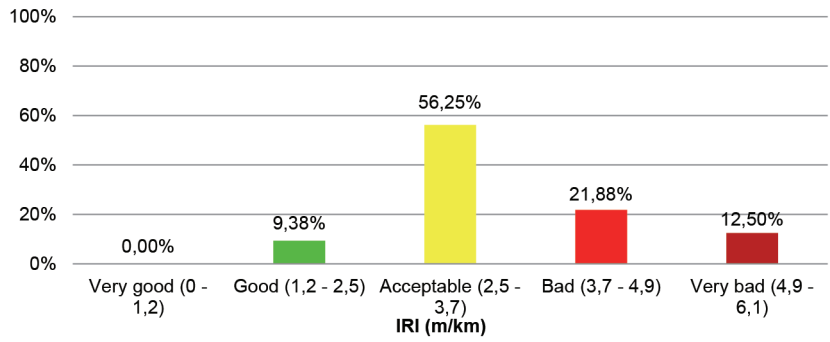

Figure 2 Distribution of IRI values by intervals

Through the analysis of public road surfaces from 2004 to 2007 in Croatia, average statistical values of IRI_{100} were obtained for various roadway categories. In Table 2 are findings for seven categories of asphalt roadways, with established borderline values for IRI.
According to Table 2, subject Aleja Matije Ljubek road falls under the category of class III city roads. It is visible that the tolerable marginal index equality (IRI_T) corresponds to the borders between the group values IRI 'good' and 'acceptable', as depicted in Figure 2. Considering that measured values of IRI exceed the acceptable borderline values, everything indicates a clear need for renovation of the roadway.

Table 2 Criteria international roughness index of surface asphalt pavements [6]

Road class	Asphalt pavement category	Designed roughness IRI_P [m/km]	Tolerant marginal roughness RI_T [m/km]	Unacceptable roughness IRI_N [m/km]
I-a	Highways - new pavement	$IRI_{PAN} \leq 0.90$	$IRI_{TAN} = 1.05$	$1.35 \leq IRI_{NAN}$
I-b	Highways - reconstruction	$IRI_{PAO} \leq 1.10$	$IRI_{TAO} = 1.30$	$1.70 \leq IRI_{NAO}$
I-c	Highways – rehabilitation	$IRI_{PAB} \leq 1.65$	$IRI_{TAB} = 2.10$	$2.45 \leq IRI_{NAB}$
II-a	State roads - new pavement	$IRI_{PDN} \leq 1.15$	$IRI_{TDN} = 1.35$	$1.65 \leq IRI_{NDN}$
II-b	State roads - reconstruction	$IRI_{PDR} \leq 1.40$	$IRI_{TDR} = 1.70$	$2.30 \leq IRI_{NDR}$
II-c	State roads – new layer	$IRI_{PDD} \leq 2.15$	$IRI_{TDD} = 2.55$	$3.00 \leq IRI_{NDD}$
III	City roads	$IRI_{PG} \leq 2.00$	$IRI_{TG} = 2.45$	$2.85 \leq IRI_{NG}$

2.2 Ruts

The resistance of asphalt to rutting is evaluated using the “wheel - tracking” method in accordance to norms HRN EN 12697-22. This method determines the occurrence speed of rutting and the depth on the load. The examination involves placing wheels with a load of 700N on the asphalt surface. The length of the wheel paths, on which rut measurements are made, amounts to 230 hmm, and the frequency of passage wheels on the asphalt is 26.5 transitions per minute. The temperature during the examination remains constant at 60°C, and the sample is maintained at the same temperature. The entire rutting examination procedure includes 20,000 transitions wheels.

For the analysis and renovation of the road around Lake Jarun, depth and the form of the route have been established along the entire route roads. Measurements are carried out with the help of a string laser attached to trace wheels positioned on a measurement beam. The lasers measure the depth of rut and determine the width and form of the route. In Figure 3, values of rut depth for the left and right trace wheels are shown in relation to the acceptable rut depth threshold. The rut depths are satisfactory, as both tracks’ wheels maintain uniformity along the entire length of the routes and significantly below the prescribed limits. The average rut depth is below 5mm.

The good condition of the driving surface roadway, particularly with consideration to the depth of rut, can be attributed to the fact that the road doesn’t experience difficult traffic, mostly consisting of personal cars.

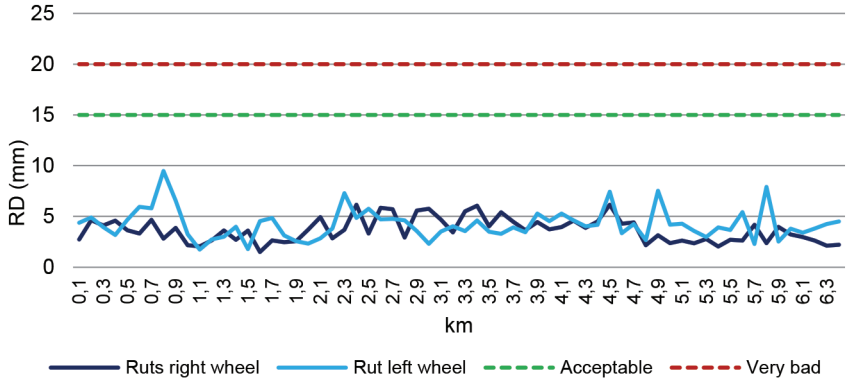

Figure 3 Measured values of the rut depth of the road surface

2.3 Macrotexture

Macrotexture is a property of the driving surface which involves the arrangement of grains in the aggregate within train surface roadway. It depends on the composition of the asphalt mixtures, and accordingly, it depends on the largest grain of the aggregate and the share of the individual grain size that is entered in the aggregates, the share and type bitumen and the share cavity in asphalt mixture. Macro textures connections are examined on two values; MTD (mean textures depth) medium depth textures and MPD (mean profiles depth) medium depth profile expressed in millimeters. ETD (estimated textures depth) is a calculated value derived using its formula [7].
In Table 3 are shown prescribed values of macro textures for highways (AC), state roads (DC) and respectively county roads (ŽC). The subject Jarunska road is classified as a county road. The measurement of macrotexture was conducted using high-frequency lasers (frequency measurements 62.5 kHz) which are located on the measurement beams with front sides of the measuring vehicles.

Table 3 Prescribed macrotexture values

Groups	**Macrotexture**	**MPD** [mm] **for AC and DC**	**MPD** [mm] **for ŽC**
Very good	0 - 1	1.25 - 1.06	1.01 - 0.87
Good	1 - 2	1.06 - 0.87	0.87 - 0.72
Acceptable	2 - 3	0.87 - 0.68	0.72 - 0.58
Bad	3 - 4	0.68 - 0.49	0.58 - 0.43
Very bad	4 - 5	0.49 - 0.30	0.43 - 0.29

The measured values of macro textures are divided into five groups using values from Table 3 (Figure 4). Group 'very good' and 'good' macrotexture contains 72% of the measured values which indicates a good macrotexture roadway on Aleja Matije Ljubek.

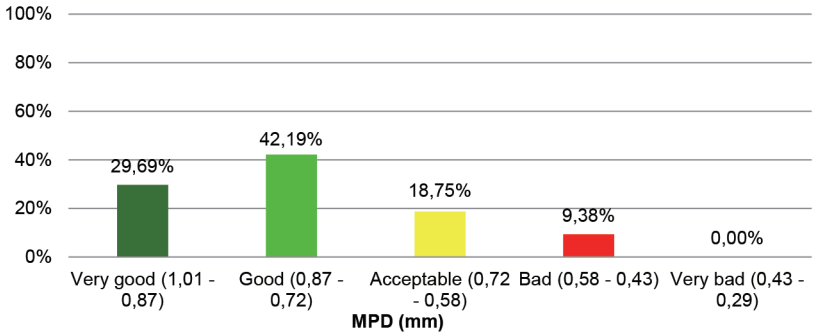

Figure 4 Depths of macro textures on road driving surfaces per groups

2.4 Cracks

By observation of acquired damages on the existing pavement, it's evident that certain factors have the biggest effect on deformation. Except for the intensity of traffic, it was observed that the type of soil has a substantial influence on duration of roadways constructions. The first damages that appears are cracks, deformations and irregularities. There are two fundamental causes to the origin of cracks in pavement - thermal influence and busy loads. Thermal stresses arise due to daily changes of temperature and sudden cooling of roadway layers, which negatively affect the aging of bitumen. While the structure is loaded with each passing vehicle, fatigue of the material and the formation of cracks occur. Cracks on the pavement surface often arise from the lower layers of the roadway or substrates. Therefore, it is essential to approach roadway renovation carefully, as existing cracks from the old pavement can quickly reflect on the new layers [8].

Cracks on Aleja Matije Ljubek are measured using a system with automatic crack detection, equipped with spectral cameras and lasers to determine the shape of the cracks. This system operates entirely automatically, capturing continuous sections of the roadway in one pass, and then analyzing and processing the data shown in Figure 1 (right). Cracks are classified according to their size, scope and type. Throughout the entire length of the driving surfaces, there is a noticeable percentage of crack occurrences above borders of acceptability, indicating a high level of pavement degradation (Figure 5). Specifically, 67.19% of the roadway surfaces falls within a group with a crack share exceeding 15%, which belongs to the 'very bad' condition of the driving surface. The average crack share in surface roadway for the group 'very bad' amounts to 42.23%, negatively impacting pavement roughness and accelerating the deterioration of the roadways constructions in the winter period due to the process freezing and defrosting.

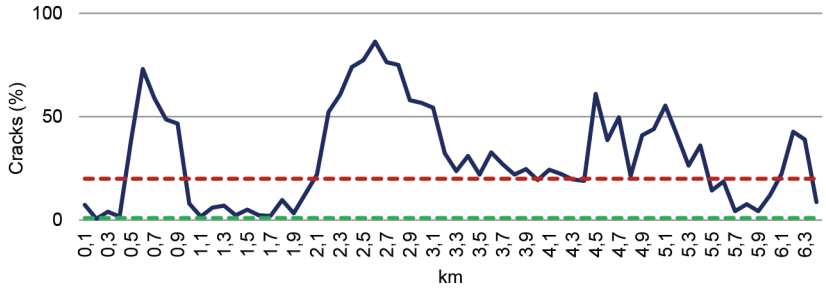

Figure 5 Cracks percentage in road surface

In Table 4, four main crack shapes observed along the entire length of the road in Aleja Matija Ljubek are presented. Out of a total of 7,514 cracks identified on the subject road, the majority are transverse cracks, accounting for 44.47% of the total. Longitudinal cracks comprising 29.78% of the total. Networked and flat cracks, on the other hand, rarely appear.

Table 4 Number and percentage of individual shape cracks

Crack shape	**Number of cracks**	**Cracks percentage** [%]
Longitudinal	2.238	29.78
Transversal	3.349	44.57
Networked	1.143	15.21
Straight	784	10.43
Altogether:	7.514	100

2.5 Patches on pavement

According to the Rulebook on road maintenance [9], patching involves repairing the road surface by making cuts in a rectangular form, parallel with the central line of the roadway with a minimal thickness of 50 mm. The final repair should not extend wider than the surrounding roadway and should not effect on drainage. The acceptable percentage of the patched area on the road surface is 0.3%, while exceeding 1% indicates a very bad state. Patching has been performed along the entire length of Jarunska road, with the patched area exceeding the acceptable value. In the last third of the road, it even exceeds border and height acceptability. The intensity of patching varies along the tracks, from the fourth kilometer to the end of the roadway the total of damaged surfaces intensifies and number of patches increases (Figure 6).

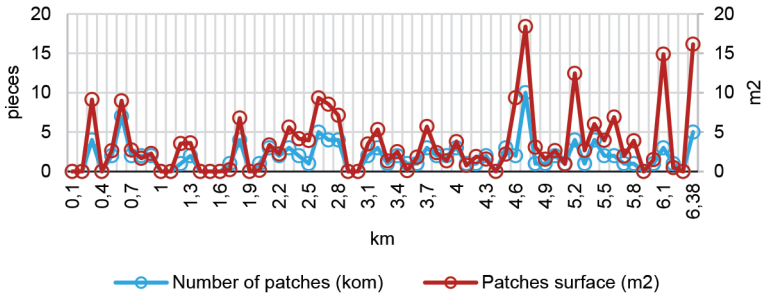

Figure 6 Patches on pavement

3 The extent of pavement renovation and earthquake damage

Within the framework of the roadway renovation project, an analysis of the existing road conditions was made, and based on the analysis, a remedial solution was proposed. The proposed renovation implies restoration of the entire asphalt pavement, and due to the complexity of the works and the length of the road, the renovation works are divided into three phases (Figure 7):

- I. phase from the Street Hrvatskog Sokola to the connection with Sava embankment (entrance in Baseball club Zagreb)

- II. phase from the connection with the Sava embankment (entrance in Baseball club Zagreb) to Petrina Street
- III. phase from Petrina Street to Hrvatskog Sokola Street.

The renovation of the damaged roadway includes cost estimates derived from the cost sheets of Zagreb Holding Company, the branch office Zagrebačke ceste, as of November 2022. These cost sheet are made for all three phases of the roadway renovation.
I. phase from Hrvatskog Sokola Street to the connection with the Sava embankment (entrance in Baseball club Zagreb), the length of the roadway is 1.800 m with a width of 8.50 m, and the length of the pedestrian pathway is 700.00 m and a width of 2.70 m.

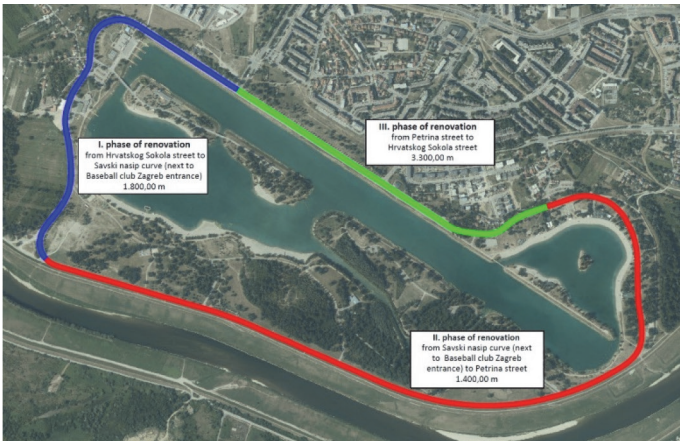

Figure 7 Renovation phases I – III

II. phase from the connection with the Sava embankment (entrance in Baseball club Zagreb) to Petrina Street, length of the roadway is 3.300 m with a width of 8.50 m, and the length of the pedestrian pathway is 2.000 m with a width of 2.20 m.
III. phase from Petrina Street to Hrvatskog Sokola Street, the length of the roadway is 1.400 with a width of 8.50 m, the pedestrian pathway is not a part of renewal.
The cost sheets contain basic groups of works by the type of work, which are further divided into subgroups:

- PREPARATORY WORKS; Milling existing one asphalt layers, Demolition of existing asphalt layers, Temporary traffic regulations
- LOWER STRUCTURE; Road bad and foundation layer
- PVEMENT STRUCTURE; Making of road bank, Making of cement stabilization layer
- ASPHALTS LAYERS; Cleaning existing asphalt layer or cement stabilization layer and spraying with bituminous emulsion, Placing of leveling asphalt layer, Placing of bearing asphalt layer, Placing of wearing asphalt layer, Placing of bearing asphalt layer on pedestrian paths, Placing of wearing asphalt layer on pedestrian paths
- FINISHING WORKS, Adaptation covers communal installation
- OTHER WORKS

4 Conclusion

After carried out recordings and measurements of the driving surfaces on the Matija Ljubek roadway in July 2022, an analysis of the results and photo documentation was carried out. The roadway was found to be in poor condition, with dominant damage including cracks, open longitudinal and transversal work connections on the pavement surfaces, and connections on patches. The age of the roadway, oxidation of binders in the pavement construction, and the influence of lower wearable layers and large modules of asphalt layers have contributed to the appearance of cracks, which were significantly increased during the earthquake. These cracks are caused by high irregularities of road maintenance, and its rapid deterioration significantly reduced safety and comfort of driving. The ruts and macrotexture were found to have satisfactory values due to the rigid pavement and the absence of heavy traffics loads on the road.

The total surface area of the road requiring reconstruction is 61.540 m^2. The earthquake that occurred in 2020 in the Zagreb area resulted in additional damage to the asphalt pavement constructions, further necessitating reconstruction. The earthquake directly influenced the occurrence of new cracks and the expansion of existing ones. With the reconstruction of the road at the Jarun sports and recreation center, safer and more comfortable traffic conditions have been achieved along Aleja Matija Ljubek.

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