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**EVALUATION OF LONGITUDINAL ROUGHNESS OF
PAVEMENT SURFACE ON THE HIGHWAY AND CITY ROADS**

Summary

The roughness of the pavement surfaces is one of the main indicators for usability of pavement surfaces, from aspect of fast, safe and comfortable transport. For that purpose, in the paper we analyzed the method and the causes for creation of the longitudinal unevennesses on the pavement surface at the highway sections. We analyzed the effects, criteria and types of measurement, such as the evaluation of the condition of the pavement surface. Also, there are recommendations for achieving the longitudinal roughness of the pavement surface on the highways, which came out from the analysis of the results from the experiment.

Key words

longitudinal roughness, international roughness index – IRI, pavement surface

**EVALUACIJA UZDUZNE RAVNOSTI VOZNE POVRSINE KOD
AUTOPUTEVA I GRADSKIH SAOBRAĆAJNICA**

Rezime

Ravnost vozne površine je jedan od glavnih indikatora upotrebljivosti vozničkih površina, sa aspekta brzine, sigurnosti i udobnosti transporta. U tu svrhu, u radu se analiziraju načini i uzroci stvaranja uzdužnih neravnina na voznoj površini autoputeva i gradskih tranzitnih saobraćajnica. U radu analiziran je utjecaj neravnina i kriterije i metoda mjerenja, kao i evaluacije stanja vozne površine. Dane su i preporuke za postizanje uzdužne ravnosti vozničkih površina, koje proizlaze iz analize rezultata eksperimenta.

Ključne riječi

uzdužna ravnost, međunarodni indeks ravnosti - IRI, vozna površina

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1. INTRODUCTION

For the participants in the highway traffic, the roughness is very important and it is one of the first characteristics of the road that they notice. The roughness¹ (longitudinal and transversal) (Fig.1), depending on the vehicle's speed and characteristics has a significant effect on the increasing on the oscillations of the vehicle. That increases the dynamical overload of the pavement surface on the highways, which impacts the transport economy. At the same time, reduced convenience and comfort is caused during the driving, and the most important thing – the safety in traffic is decreased. The unevenness of the pavement surface changes the conditions of contact between the wheels on the vehicle and the surface itself, so that bigger irregularities can cause changed conditions on the reliability of the wheels. That can lead to a significant decrease in the usage of the current capability of friction on the pavement, and also when dry pavement is present it can result with consequences.

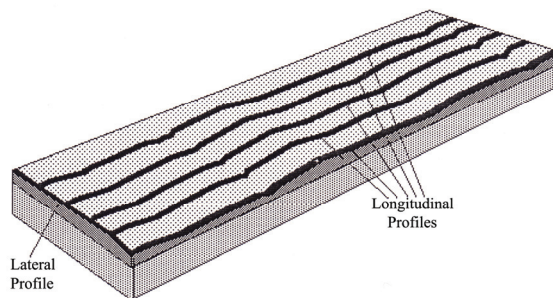


Fig. 1. Appearance of filmed longitudinal and transversal profiles on the pavement surface

The most inadequate longitudinal unevennesses is in the form of waves (wavy, actually amplitude unevenness). The degree of unevenness – evenness is measured by the length of the waviness (wave) between separate unevennesses. When the length of the waves between separate unevennesses $\lambda < 3$ cm, the pavement surface is rough (micro unevenness), and when the length of the waves is $\lambda > 3$ cm the pavement surface is wavy (amplitude unevenness). The amplitude unevenness of the pavement surface and the body of the road is characterised with elevations and depressions, which are repeated periodically trough the length of the road (called: wavy or amplitude unevenness), defined by its length and amplitude of the waves and with different shapes and sizes.

Because of all previously stated, it can be concluded that roughness, arises as one of the main indicators for usability of the pavement surface on the highways. For these reasons, we analyzed the manner and causes of creating longitudinal unevennesses on the pavement surface at highway sections, their influence and criteriums and the ways of measuring, so as the evaluation on the state of the driving surface. The purpose of the analysis is to give recommendations for achieving the longitudinal roughness of the road, that would make conditions for increasing the convenience and comfort when driving.

¹ Roughness is a vertical difference between elevations of projected and manufactured situation on pavement surface

2. EXPERIMENTAL PART

2.1. GENERAL AND CRITERIA

The measurements that were presented in this paper, were done continuously along the entire length of the two road sections of M-3, which are part of the international road E-65. The longitudinal roughness on the pavement surface was measured along with the longitudinal roughness on the objects on it and that was done on two of his sections: highway M-3 entrance in Skopje (M302R; L=3,9 km; $V_{\max}=120$ km/h) and the extension on the highway M-3 in an urban transit road boulevard „Alexander the Great –Macedonian“ (M303R; L=4,7 km; $V_{\max}=60$ km/h). The road M-3 has more specifications, a part is built as a highway (entrance in the capital city), a part goes through Skopje (transit road), and the third part is a national road, in which heavy traffic takes place (transport of military vehicles of the NATO alliance towards Kosovo).

The part of M-3 which was built as a highway solution, was projected in 1985 and was dimensioned with the following road construction:

- 6,5 sm ... AB 16 S (wearing course asphalt concrete)
- 7,5 sm ... AB 22 (binding course)
- 10,0 sm BNS 32 (bituminous bearing course)
- 30,0 sm mechanically stabilized crashed stone

54,0 sm Total thickness of the road structure, with improved liner of 30,0 sm with CBR > 10.

The measured traffic in 1985 is with AADT of 10.861 vehicles/day. According to the project, a calculation about the predicted traffic has been done for a period of 20 years in 2005 with two scenarios: optimistic and pessimistic. In the first scenario, the optimistic forecast of the traffic is with AADT of 23.696 vehicles/day, and in the second scenario, the pessimistic forecast of the traffic is with AADT of 19.283 vehicles/day. With a goal to visualize the furtherer influence of the traffic to the evenness on the pavement surface, in the next table i present the information about AADT (table 1) on the highway M-3 according to the annual newsletters - Data about the road traffic on the national and regional roads in Republic of Macedonia.

Table 1. Data about the AADT on highway M-3

Year	2005	2006	2007	2008	2009	2010
AADT	15.558	16.020	18.062	18.020	18.527	16.323

The measurements of roughness on the pavement surface, are done with help of a measuring device of the type of high-speed inertial profiler - The Dynatest Road Surface Profilometer[®] 5.051 Mark II (Fig.2). The studies were conducted in the USA (on three test sections with different length and different level of service, so as seven different types of measuring devices profiler, from which two on pushing and five inertial) from TxDOT (The Texas Department of Transportation), after the comparison of the results of the measurements it was established that convincingly most accurate results of the measuring profile from which we get the level of comfortable driving are received from a laser inertial profiler installed on vans. (Fig.3).



Fig. 2. The Dynatest Road Surface Profilometer[®] 5.051 Mark II

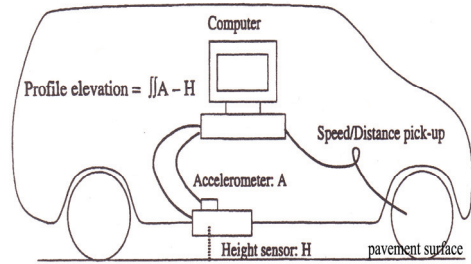


Fig. 3. A Schematic diagram of an „Inertial Profiler“

The criteria used while evaluating the state of the longitudinal roughness on the pavement surface on the road M-3, are according to the international index of roughness IRI [m/km] determined by The World Bank, as a main parameter for evaluation the state of the pavement surface (Fig. 3). The parameter IRI is used in most countries in the European Union and the US, there for it is essential to say that the values of IRI shown in [m/km], in separate countries are different. The classification of technical parameters IRI (International Roughness Index) is in 5 classes, those are: very good, good, average - acceptable, bad and very bad.

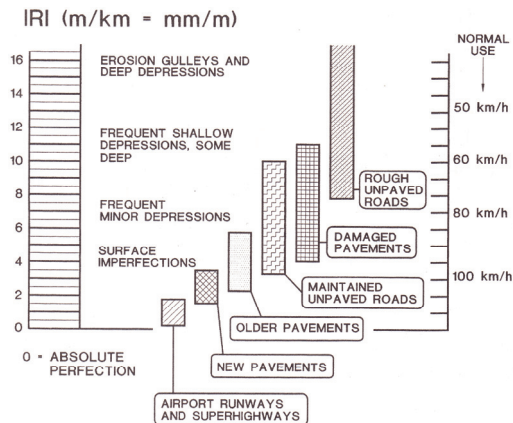


Fig. 4. The IRI Roughness Scale

When performing the measurements of roughness pavement surface of certain sections is calculated in the following statistical sizes: minimum, maximum and average index of evenness IRI_{100} (Min; Max; Avg) and 80% and 95% appearance on the index of evenness IRI_{100} (0,80 and 0,95).

The criteria used while evaluating the state of the longitudinal roughness on the pavement surface on the road M-3, are according to the class – rang of roads expressed by AADT for roads in exploitations, regarding the international index of roughness IRI [m/km], according to table 2 (regulations of the R. of Slovenia - Technical specifications for public roads), because the existing criteria in Republic of Macedonia for determination of the roughness on the pavement surfaces are according to the old JUS or current MKS

standards. According to the MKS standard, the roughness is expressed by measuring with a lath 4 m and the allowable deviation is 4 [mm] for roads with heavy and very heavy traffic and 6 [mm] for roads with lower traffic.

Table 2. Criterias for evaluation of the condition (IRI_{100})

Separation by size of traffic	Evaluation of the situation				
	Very good	Good	Average	Bad	Very bad
	Size of the index of roughness IRI_{100}				
Medium or high density of traffic (AADT > 2.000 vehicles/day) and medium or heavy traffic (> 80 NOO 82 kN/day)	< 1,2	1,2 - 1,5	1,5 - 2,2	2,2 - 3,1	> 3,1
Low density of traffic (AADT ≤ 2.000 vehicles/day) and easy traffic overload (≤ 80 NOO 82 kN/day)	< 2,6	2,6 - 3,5	3,5 - 4,3	4,3 - 4,9	> 4,9

2.2. MEASUREMENT AND EVALUATION OF THE SITUATION

The results of the measurements on highway M-3 „Interchange Hipodrom - Interchange Cento“ (M302R) are given in table 3 and the figures 5-7.

Table 3. Section M302R (S10)

	Min.	Avg.	Max.	St.Dev	80%	95%	Number of data
IRI_{25}	1.30	2.58	5.49	0.85	3.25	4.08	152
IRI_{100}	1.71	2.58	3.55	0.46	2.98	3.49	39

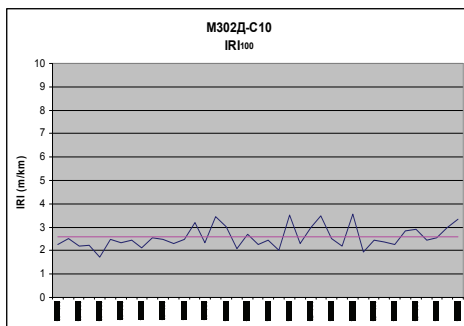


Fig. 5. Schedule for IRI_{100} for M302D-S10

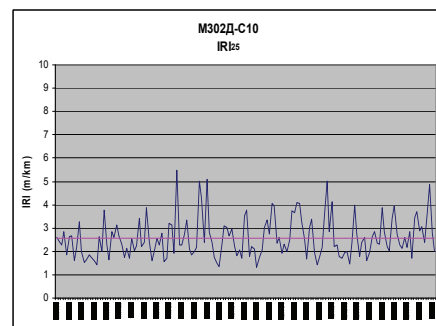


Fig. 6. Schedule for IRI_{25} for M302D-S10

The results of the measurements of roughness for the urban transit road boulevard „Alexander The Great - Macedonian“ (M303R) are given in table 3 and figures 8-10.

Evaluation of the level of state of both sections from M-3 regarding to the longitudinal roughness and according to the international roughness index IRI_{100} , compared to both sections (longitudinally in [m']), is shown in Table 5.

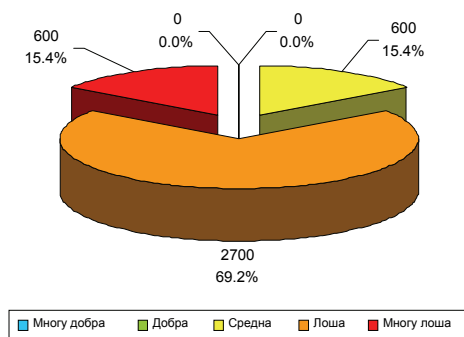


Fig. 7. Evaluation of the situation of M303R (IRI_{100})

Table 4. Section M303R (C10)

	Min.	Avg.	Max.	St.Dev	80%	95%	Number of data
IRI_{25}	1.27	2.91	10.16	1.34	3.60	5.61	184
IRI_{100}	1.38	2.91	6.10	0.94	3.34	4.95	47

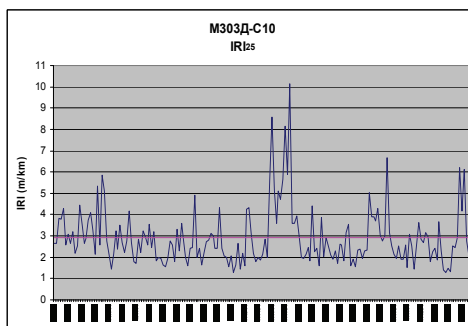
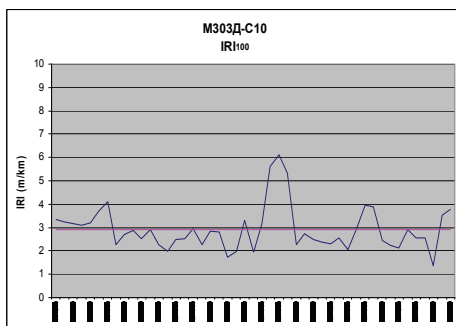


Fig. 8. Schedule for IRI_{100} for M303R-S10

Fig. 9. Schedule for IRI_{25} for M303D-S10

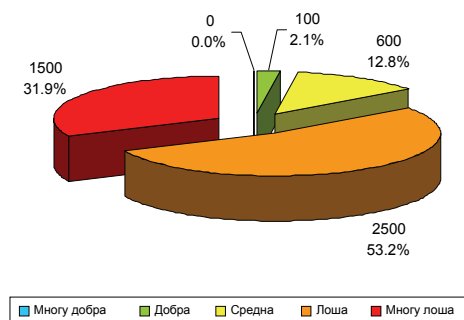


Fig. 10. Evaluation of the situation of M303R (IRI_{100})

Table 5: Evaluation of the situation of the two sections in [m']

IRI ₁₀₀	Very good	Good	Average	Bad	Very bad	Total length
1 Section	0	0	600	2700	600	3900
2 Section	0	100	600	2500	1500	4700
Total:	0	100	1200	5200	2100	8600

Fig. 11. Section of highway M-3
(M302R-S10)Fig.12. Section of transit urban road M-3
(M303R-S10)

2.3. ANALYSIS OF THE RESULTS

By analyzing the measured results for the state of the pavement surface, the following can be concluded:

- During evaluation of the roughness of the pavement surface, the higher the range of the road is, the profile is more even. For high-speed roads - highways ($V_{\max} = 130 \text{ km/h}$)¹ and AADT > 14.000 vehicles/day, the criteria for the pavement roughness is highest and the values of the indexes for roughness at highways should be reduced;
- At urban roads it is important to say that their corridors installations are placed regularly (for water, sewer, gas, electricity, telephone etc.), that makes the audits shafts to be placed on the pavement surface and directly influence on the level of roughness on the pavement surface, but they also have an indirect influence due to the heavy conditions in the building - paving the road structure;
- The influence on the dilatations from the objects (culverts, bridges, viaducts) is also inconvenient for the roughness on the pavement surface;
- From the comparison of the results entrance information is received for IRI₂₅ и IRI₁₀₀, you can notice that the results for IRI₂₅ are more accurate, actually the shorter measuring lengths (IRI₂₀ or in this case IRI₂₅) can be used for evaluating the status of newly built road sections, while the larger measuring lengths (IRI₁₀₀ or IRI₅₀₀), should be used for evaluating the status of roughness of the highways in exploitations;
- By evaluation the state of the road in sections you get a more precise image for the roughness of the pavement surface and analogly to that, higher standards for the index

¹ According to Changes of The Law for the traffic safety on the roads (from 04.08.2008), maximum speed on the highways is 130 km/h

of roughness IRI, while the expression of the situation in sections, or for the whole road, you get smaller values for the index of evenness IRI;

- From table 5 it can be concluded that on the analyzed sections, not one of the sections has a high enough evaluation of the state – very good, but the longest lengths on both sections are bad.

3. CONCLUSIONS

With the research done and the evaluation of the situation on the pavement surface on the two analyzed sections of the road M-3, it can be concluded that they will present a useful base of information for achieving longitudinal roughness of the pavement surface when construction of future roads, that will be used for making new criteriums, for measuring and monitoring the condition of the road exploitation.

Everything presented so far, imposes the need to introduce new modern technical regulations for roughness on the pavement surfaces of public roads in Macedonia as in most European countries and that would define:

- Basic procedures for measurement;
- Measuring equipment;
- The method of measurement and
- Criteria for assessment of the situation.

This technical regulations should provide suitable response to the current demands of transportation for speed, comfort and safety.

The permanent following of the roughness of the pavement surface expressed by the index of roughness IRI, is set to be one of the main indicators for expressing the overall condition of the pavement surface in terms of safety and comfort of transport.

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