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# ROUGHNESS OF THE MOTORWAY DRIVING SURFACE

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## Abstract

The motorway example illustrates the procedure of determining the longitudinal roughness as an important surface characteristic of asphalt pavement. Modern measuring devices and methods of collecting data for the driving surface profile have been described. The analysis of international longitudinal roughness index calculation IRI (International Roughness Index) has been conducted. In order to explain the expected pavement characteristic from the point of view of the driving comfort, parameters which influence the achievement of the motorway driving surface roughness have been discussed. Based on the statistic analysis of the measured values of IRI (m/km) for the constructed asphalt pavements of roads, the border values of roughness index have been established. The evaluation of the driving surface roughness includes a non-biased interpretation of established indices, determining acceptable deviation and defining border values.

*Keywords: longitudinal roughness, motorway, asphalt pavement, IRI (International Roughness Index), limits values*

## 1 Introduction

The diriving surface is the finishing surface of asphalt motorway pavement, intended motor vehicle traffic. Roughness is the indicator of the traffic surface deviation from the designed surface, defined by longitudinal and transverse gradients, as well as vertical and horizontal curvature of the level line. The level of roughness of the motorway driving surface also influences the passenger from the point of view of comfort, but also influences the durability of vehicles and the asphalt pavement structure. Passenger and/or car owner as well as the legal entity in charge of motorway management, have a common requirement, this being that the traffic surface is of acceptable roughness. There is a complex interdependence between the pavement traffic surface profile and the interaction of the vehicle wheels or tires. Determination of the roughness indicator includes the measurements of longitudinal profile of traffic surface and analysis of the roughness index value. When determining the longitudinal roughness criteria of motorways, all factors must be analyzed which limit the level of roughness [1].

## 2 Roughness measuring instruments

Modern electronic instruments are used today to measure the roughness of the motorway traffic surfaces. These instruments are profilers which gather data from the measuring profile through a mechanical foot or laser beam.

## 2.1 Walking Profilometer

With the Walking profilers, the main part of the device is the metal foot length 241,3mm, which is alternately placed along the measuring section line on to the traffic surface (Figure 1). An inclinometer, which measures the gradient or the azimuth, is fastened to the measuring foot. For each new step, the computer program computes a new reference height, as the reference height of the previous step increased by the relative height. Relative height is calculated from the inclination of the foot toward the vertical and length of the measuring section. The device registers the longitudinal measuring profile of the pavement surface by continuously lowered metal foot and for each measuring section (241,3mm) reregisters the summed height in relation to the initial point. Electronic walking profiler can graphically image the profile measuring results and automatically compute the value of roughness index IRI (International Roughness Index). During the measurement procedure the profiler is supported on the measuring surface by two auxiliary transporting wheels and two wheels which move the measuring section. Calibration from the initial point of the measuring section precedes the profiling, length 20 meters, and return to the initial position, while the speed of measurement is from 500 to 800 m/h [2]. The mechanism comes with a portable computer or a base unit which stores into a memory all of the measured height values of each measuring point, the number of measuring sections and the length of the measured section. Measuring with this type of equipment is defined in the Australian Technical Guidelines - AUSTROADS Pavement Test (PAT01: 2001) [3].

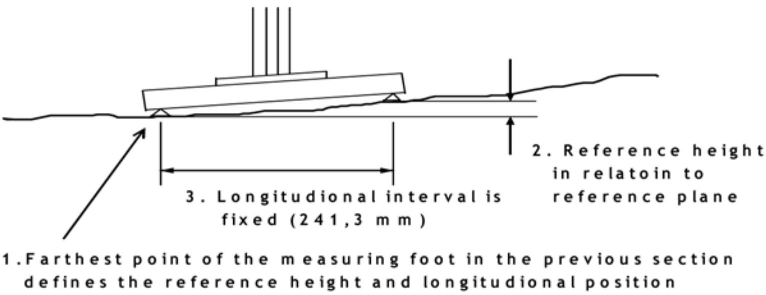


**Figure 1** Measurement principle of the Walking profiler

## 2.2 Inertial profilometers

In order to determine the roughness of the motorway surfaces during their operation period, General Motors Research Laboratories (G.M.R.L.) developed an Inertial Profilometer during the sixties of the past century. Profiling of the traffic surface with this type of device is done at normal traffic operation speeds. The measuring vehicle (a car or a site vehicle) has an accelometer which records the vertical vehicle acceleration during measurement at operating speeds. From the records on vehicle acceleration, by means of double integration the computer calculates the vertical displacement of vehicles in relation to inertial (fixed) reference plane, i.e. it defines the current height of accelometer placed in the vehicle (Figure 2). Relative height is the distance between the reference plane and the measuring section of the pavement structure surface registered under the accelerometer itself. Sensing the profile points whose frequency has previously been set is done by an optical or ultrasound laser. The longitudinal distances are recorded by means of a distance meter fixed on the measuring vehicle wheel. Operating speeds of profiling by means of an inertial profile meter are app. 30km/h, and can range up to 150km/h, depending on the road category. With sensors that have normal frequency values of 16kHz the length of measuring distance ranges between 25 millimeters and 25 centimeters, while with high frequency lasers (62,5kHz) the interval between two recorded points of the pavement surface ranges between 0,5 and 2,5 millimeters. High frequency lasers are used to measure the pavement surface texture.

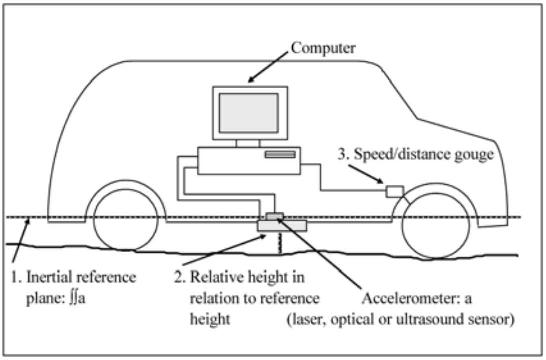


**Figure 2** Inertial profilometer

## 3 Longitudinal roughness IRI calculation procedure

Data on the measured longitudinal profile consists of numerous numbers collected at a determined measuring interval, showing height or elevation deviation of the profile points from the designed ideal situation. In order to present numerous collected data in a certain form, e.g. a graphical form or a wave spectrum, mathematical transformation – filtration is applied [5]. After filtration of the measured traffic surface section, an analysis of the indicators of longitudinal roughness IRI - International Roughness Index is done. For the IRI calculation, a standard mathematical model is used, the quarter-car model, according to ASTM E 1926-98(2003). Mathematical model of a quarter of the standardized vehicle includes all dynamic elements of the vehicle – carriageway system, which define how the carriageway roughness acts on the vehicle vibrations (Figure 3).
The roughness index IRI variable is that of the realistic profile of driving surface, measured by electronic profilometer. The principle of computer algorithm is the virtual drive of standardized vehicle model at the speed of 80km/h through a filtered recorded longitudinal profile of pavement surface. The computer program sums up all relative suspension shifts of the standardized car model in relation to the car cabin, as an answer to all rough sports of the simulated drive over the measured section of the driving surface. IRI is calculated by adding the differences of vertical shifts between the vehicle mass carried by one wheel (Mv) and the wheel mass with tire and half of the suspension (Mk) normalized per length of measuring section L over time (dt):

$$IRI = \frac{1}{L}\int_0^{L/v} \left|\dot{z}_1 - \dot{z}_2\right| dt \qquad (1)$$

Where:
L = length of measuring section (m')
$\dot{z}_1$ = vertical speed of tributary vehicle mass
$\dot{z}_2$ = vertical speed of wheel mass with axle

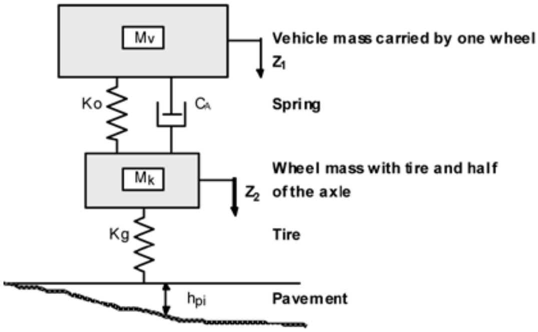


**Figure 3** Quarter-car model

Where:
$h_{pi}$ = height of filtered profile
$z_1$ = shift (vertical coordinate) of the vehicle mass carried by one wheel ($M_V$)
$z_2$ = shift (vertical coordinate) of wheel mass with tire and half of the suspension ($M_K$)
$k_g$ = coefficient of elasticity of the spring representing the car tire
$M_v$ = vehicle mass carried by one wheel
$M_k$ = wheel mass with tire and half of the axle
$k_o$ =coefficient of elasticity of the suspension spring
$c_A$ = coefficient of viscosity of shock absorber
The summed up, simulated vertical shifts of the typical vehicle suspension, divided by the length of the measuring section, give the roughness index value IRI in the measuring unit (m/km). The longitudinal roughness indicator IRI as part of the calculation, is based on the vehicle reaction passing over the pavement bumps and as such gives an realistic evaluation of the smoothness of the driving surface in the sense of passenger comfort.

## 4 Roughness parameters on motorways

The level of roughness of the motorway driving surface depends on the pavement structure, interruptions in the driving surface and conditions during placing of the asphalt course. The motorway pavement structure consists of asphalt courses (two or three) and base courses (cement stabilized course (CSS) and/or mechanically compacted course made of grained stone material without binder (MCC). The pavement structure has a subgrade made of earth material, mixed or stone material. Thickness of each course depends on the number of courses in the complete pavement structure and on the type of asphalt mixture, all of which influences the smoothness of the driving surface. Interruptions in the driving surface, like expansion joints and devices, water inlets, inspection manholes in tunnels, all influence the smoothness of the motorway driving surface [6]. The number of operating joints in the longitudinal and transverse direction must be minimized because they decrease the level of smoothness of the motorway driving surface and represent potential points of the deterioration of the roughness index IRI of asphalt pavements. The working speed of finishers must be determined, which actually achieve the required level of smoothness, the condition for this being a continuous, uninterrupted inflow of asphalt mixture, i.e. an optimal capacity of production and placing of asphalt, because every slow down or stop during placing of asphalt influences the undulation of the surface. Temperature of asphalt mixture during preparation, transport, placing and compaction must be in the range of equiviscous temperature of the binder. Climate has a direct influence on the asphalt temperature. Optimal temperatures of the environment and asphalt ensure a good asphalt course laying and satisfactory level of smoothness of the driving surface of motorways.

## 5 Analysis of measured values of the roughness index IRI on motorways

High levels of smoothness are a precondition on motorway surfaces since these roads have an Annual Average Daily Traffic (AADT) of over 14000 vehicles. Operating speeds of the traffic require a comfortable drive, which in turn influences traffic safety. The following was studied during analysis of the measured values of roughness index:

- Newly placed asphalt pavement structure as part of the new motorway construction (without structures; Class I-a,
- Newly placed asphalt courses as part of the motorway rehabilitation or improvement ( without structures); Class I-b,
- Newly placed asphalt surfacing on structures as part of new motorway construction and motorway rehabilitation or improvement; Class I-c.

The following statistical values were calculated for every measuring section:

- Minimum roughness index IRI100 (MIN); function MIN,
- Maximum roughness index IRI100 (MAX), function MAX,
- Average value of roughness index IRI100 (AVERAGE), function AVERAGE,
- 80% occurrence of the roughness index IRI100, function PERCENTILE (0,8),
- 95% occurrence of the roughness index IRI100, function PERCENTILE (0,95).

Average value of IRI100 (AVERAGE) represents an arithmetical average of the roughness index of driving surface of each measuring section. Analyzed roughness indices IRI100 occurring on half of the measured asphalt pavements are taken as target criteria of the motorway smoothness. The tolerance range of smoothness of the driving surface is between the statistical values: average value and 95% of the roughness index occurrence IRI100. This covers a wide range of index values IRI and has the elements of decreased but still acceptable and tolerated smoothness of the asphalt pavement. The value of 80% (PERCENILE 0,8) of the roughness index occurrence IRI100 divides the tolerance range in two, approximately equal intervals, representing the limit between the 1st and 2nd tolerance class. The first (I) tolerance class includes smaller deviations from the driving surface smoothness. The second class (II), above 80% of IRI index occurrence covers significant deviations from smoothness.

### 5.1 Smoothness of new motorway asphalt pavements – Class I-a

The data on average values of statistical roughness index from twenty sections of newly constructed motorways in Croatia are presented in the graph in Figure 4. A total of 2424 IRI100 values, i.e. 242.400 meters of measured sections (in the wheel marks) of traffic and acceleration lanes were analyzed.

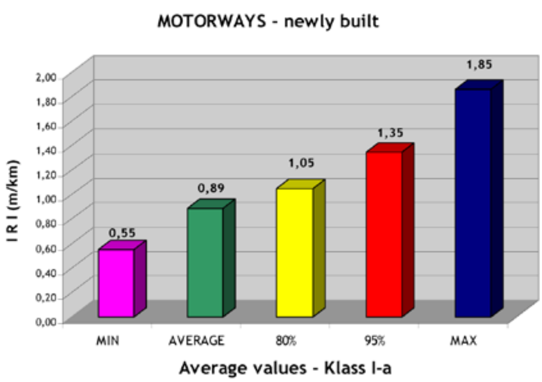


**Figure 4** Graph showing average statistical roughness index values IRI on motorways – newly built motorways

### 5.2 Smoothness of remedied or improved motorway asphalt pavements – Class I-b

The pavement structure rehabilitation almost always includes the replacement of the binder and wearing asphalt course as well as remediation of structural cracks in the pavement structure. New asphalt courses are placed according the reconstructed grade line, enabling significant improvement of the smoothness of driving surface in relation to the smoothness prior to reconstruction, but still one class lower than the smoothness achieved on newly constructed motorways. A total of 2481 IRI100 values, i.e. 248.100 meters of measured sections of traffic and acceleration lanes of remedied asphalt pavements were analyzed on ten rehabilitated motorway sections in the period between 2004 – 2007. Differences in the roughness index of remedied asphalt pavement surfaces in relation to the newly constructed motorways are presented in Figure 5. The increase in average values (AVERAGE) are as follows:

- Average value of IRI100 increased by 0,23 m/km,
- 80% occurrence value of IRI100 increased by 0,34 m/km,
- 95% occurrence value of IRI100 increased by 0,36 m/km.

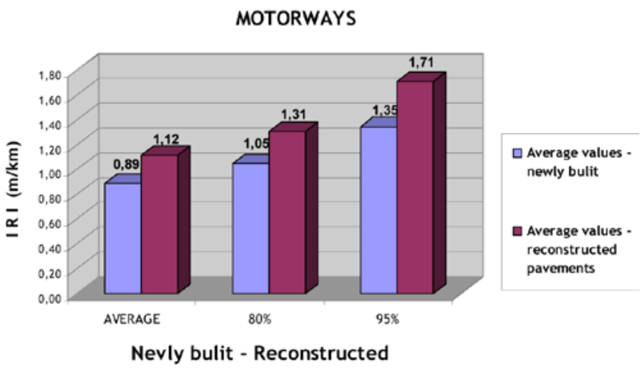


**Figure 5** Parallel graph showing average roughness index values IRI on newly built and reconstructed motorway pavements

### 5.3 Smoothness of newly placed asphalt surfacing on structures - Class I-c

Since thin course asphalt surfacing are usually placed on Croatian roads, complete replacement of asphalt courses must be done during rehabilitation of surfacing on structures, and this usually includes replacement of waterproofing. Tit can therefore be concluded that the extent of works on asphalt surfacing is equal during reconstruction as it is during construction of new motorways. This is why we will analyze together the smoothness of driving surfaces on newly built structures and the ones under reconstruction.
Parallel to the analysis of the roughness index of driving surfaces on structures, the following statistical values were analyzed as well:

- IRI on 109.800 meters of the motorway route without structures,
- IRI* on 123.900 meters of the motorway including structures,
- IRI** on 14.100 meters of measured profiles on driving and acceleration lanes - asphalt surfacing on structures.

Parallel analysis of statistical roughness index values on structures as compared to those on the route itself was done because it is expected that the same travel conditions prevail on the same motorway route, regardless of the fact that the vehicle is on the route or on the structure. Figure 6 shows parallel analysis of average statistical roughness index values of asphalt motorway pavements. Percentage of structures on such sections has a marked influence on the overall smoothness, therefore a separate roughness criterion is required for asphalt surfacing on structures, i.e. for road parts which include interruptions of the driving surface.

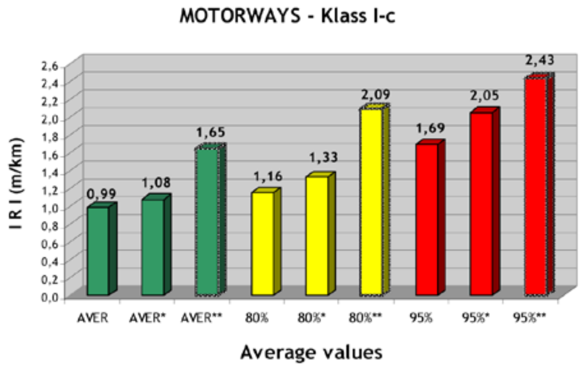


**Figure 6** Average roughness index values IRI on motorways, route only; route and structures(*) and structures only(**)

## 6 Smoothness criterion of motorway asphalt pavements

Statistical-probability analysis of the data on the roughness index values IRI100, measured on representative measuring sections of built motorway asphalt pavements, adopted the following: RIP – designed (expected) lower limit index, criterion defined on the basis of the average of mean values IRI100; IRIT – tolerance limit index, between two limit indices, criterion defined according to the average 80% roughness index occurrence value IRI100 and IRIN – unacceptable upper limit index (usability limit), criterion defined according to average 95% roughness index occurrence value IRI100. Table 1 presents the limit values of the accepted roughness index (IRIP; IRIT; IRIN) of driving surfaces, determined by analysis, for three categories of motorway asphalt pavements (I-a; I-b; I-c).

**Table 1** Criterion of limit roughness indices of motorway driving surfaces.

| ROAD CLASS | CATEGORY OF ASPHALT PAVEMENT | DESIGNED ROUGHNESS INDEX IRIP (m/km) | LIMIT TOLERANCE ROUGHNESS INDEX IRIT (m/km) | UNACCEPTABLE ROUGHNESS INDEX IRIN (m/km) |
|---|---|---|---|---|
| I-a | Newly built | IRIPAN ≤ 0,90 | IRITAN = 1,05 | 1,35 ≤ IRINAN |
| I-b | Reconstruction | IRIPAO ≤ 1,10 | IRITAO = 1,30 | 1,70 ≤ IRINAO |
| I-c | Structures | IRIPAB ≤ 1,65 | IRITAB = 2,10 | 2,45 ≤ IRINAB |

## 7 Conclusion

The value of roughness index IRI is the indicator of dynamic vehicle loads on the pavement driving surfaces. The level of smoothness determines the traffic operating speeds and gives an evaluation of the overall condition of pavement structure with regard to investments and maintenance. Smoothness of driving surfaces is satisfactory if the roughness index values IRI100 are lower than the designed values of the expected roughness index of asphalt pavements. Designed index (IRIP) can be taken as the contracted target value of smoothness of a built pavement on public roads. If the achieved values of the roughness index are in the range of lower roughness values IRIP, there is a justified reason to calculate the driving surface according to a higher price than the contracted price, as a reward to the contractor. The area where the reached values are being sanctioned is called the tolerance interval, which starts with the designed index (IRIP) or the limit tolerance index (IRIT) and ends with an unacceptable index IRIN). Acceptable – tolerance range of the smoothness of asphalt driving surface is relevant for the indices ranging between average values (AVERAGE) and 95% value of IRI of a certain motorway section. An 80% occurrence of IRI100 has been analyzed as part of the analysis of measured roughness indices, taken as the mean value of the tolerance range, and the determined values is taken as the tolerance limit index (IRIT) as follows:

- 1st tolerance stage ($IRI_{T-I}$), roughness indices $IRI_{100}$ are in the interval $IRI_P < IRI_{T-I} \leq IRI_T$ i
- 2nd tolerance stage ($IRI_{T-II}$), roughness indices $IRI_{100}$ are in the interval $IRI_T < IRI_{T-II} \leq IRI_N$.

The Ist tolerance stage interval refers to smaller deviations of the roughness index and can be used for lesser sanctioning of contractors or accepting the aggravating circumstances during placing of pavement structure. Second tolerance stage interval marks greater deviations of the index and contractor must be sanctioned when the quality of executed asphalt works are paid.

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# 5 ROAD MAINTENANCE