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ANALYSIS OF SELECTED PAVEMENT SERVICEABILITY PARAMETERS

The parameters of pavement serviceability have the notable effect to the road life time and to the conditions of safe and comfortable driving. The serviceability of flexible pavements is defined by three parameters: skid resistance, unevenness and pavement distress. The Slovak Road Administration observes 24 specific road sections on which the parameters have been measured two times per year since 1998. The obtained data should be used for determination of the degradation models that describe the qualitative decreasing of the parameters depending on time and traffic load. The functions are very important for definition of the optimal road maintenance and rehabilitation. The degradation models describing the parameters changes over time are the substantial research problem in dependence on many affecting factors.

The results of pavement serviceability parameters evaluation are presented in the paper. The basic functions are described and discussed.

1. Introduction

The pavement serviceability is defined as a complex of parameters affecting the drive of vehicles. The parameters have the notable effect to the road life time and to the conditions of safe and comfortable driving. The serviceability is defined by three parameters: skid resistance, unevenness and pavement distress. The skid resistance includes characteristics of microtexture and macrotexture and often is named like roughness. The unevenness includes two parameters – longitudinal unevenness and ruts as the transverse unevenness. The pavement distress describes the surface failures that decrease a quality of wearing course.

The Slovak Road Administration observed 24 specific road sections on which the parameters have been measured two times per year since 1998. The technical conditions are defined for measuring and evaluation of data. The observance of measured rules is not a simple process but it is very important for quality of results performance. The obtained data are used for determination of the degradation models that describe the qualitative decreasing of the parameters depending on time or traffic load. The functions are very important for definition of the optimal and effective road maintenance and rehabilitation. They also notably affect cost analysis of the pavement management system.

2. Pavement serviceability

The pavement serviceability is based on measurement and assessment of pavement surface characteristics. It quantifies overall performance of a pavement and is further used to manage a road network, called a Pavement Management System (PMS). The Slovak Pavement Management System (PMS) [8] is a tool for effective dividing of budget for the management of road rehabilitation. The system includes processes for effective maintenance, repairs and renewal of road surfaces and structures. The processes are based on the diagnostics of the pavement surface parameters (serviceability level of the road) and bearing capacity [1]. The pavement serviceability parameters are skid resistance, longitudinal unevenness, ruts, and surface distress. Pavement surface characteristics and their changes over time that are discussed in this article are the skid resistance, and longitudinal unevenness.

2.1. Friction, Skid resistance

Friction, in the context of tyres and roads, represents the grip developed by a particular tyre on a particular road surface at a particular time. The coefficient of friction is a measure of this, defined as the ratio of the load (the force applied in the vertical direction) to the traction (the force resisting movement in the horizontal direction). Friction is influenced by a large number of parameters relating to the road and the tyre but it is also affected by other influences that may not be directly attributable to them, such as the vehicle suspension, ambient conditions, speed and the presence of localised contaminants (including water) [2]. The mechanisms of tyre/road friction are not fully understood, but it is widely recognized that there are two main mechanisms involved: molecular adhesion and hysteresis losses, ideas proposed by Kummer in a unified theory of tyre/road friction in the 1960s [3], [4], and developed further by Moore a decade later [5]. The overall friction between tyre and road surface is the sum of these two components according to the following formula.

$$f_p = \frac{A \cdot S}{A_n \cdot p} + \frac{Q \cdot D}{A_n \cdot b \cdot p} \,. \qquad (1)$$

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Where:

f_p – coefficient of friction
A – sum of contact areas of each element – actual contact area, m^2
A_n – overall contact area, m^2
S – shear stress in the interface, MPa
p – tyre load, MPa
Q – deformed rubber bulk, m^3
D – energy losses due to damping in the rubber bulk, $M.J.m^{-3}$
b - slip distance, m

Skid resistance describes the contribution that the road makes to tyre/road friction. Essentially, it is a measurement of friction obtained under specified, standardised conditions, generally chosen to fix the values of many of the potential variable factors so that the contribution that the road provides to tyre/road friction can be isolated. Unless indicated otherwise, the term skid resistance applies to wet roads and measurements are made on a wetted surface [2].

Skiddometer BV-11 is a skid-resistance measurement unit that is used for observation by The Slovak Road Administration. It measures skid resistance using the longitudinal principle in one of wheel path. Measurements are done with wetting at about 17 % slip ratio. Vertical load is 1000 N, and a Trelleborg T 49 tyre with a size of 4.00-8 inflated at 120 kPa is used. The water film thickness is 1 mm [10, 11, 13].

There are many different devices throughout whole Europe for skid resistance measuring, and there is a new general effort to introduce a harmonised index with a complex process for calibrating the different measuring devices used in Europe, as well. This harmonisation process combines macrotexture measurement with measurement of pavement surface friction, which leads to determination of Skid Resistance index (SRI) computed by means of the following equations [19]:

$$SRI = B * F * e^{(S - S_R)/S_0} \tag{2}$$

where

B – parameter specific to the friction measuring device
F – measured friction coefficient at slip speed S, for Skiddometer BV11 it is Mu value
S – slip speed derived from the operating speed according to test principle
S_R – reference slip speed
S_0 – speed parameter, defined by equation:

$$S_0 = a \cdot MPD^b \tag{3}$$

where

a, b – parameter specific to the texture measuring device/method
MPD – mean profile depth obtained by processing the profiles recorded with a mobile profilometer.

The key to the harmonization process is the adequacy of the mathematical models used to represent the influence of road surface texture and slip speed or slip ratio on the measured values in combination with empirically-derived coefficients. It is clear that current models do not fully describe the behavior of all types of device across their practical operating ranges: in particular, some influence of speed remains even after harmonized values have been calculated [2]. There is a substantial influence of reference slip speed (SR) value, as well. The reference value was earlier set to 60 kph, and now it is 30 kph. The comparability influences of results related to test speed are illustrated in Figs. 1–3.

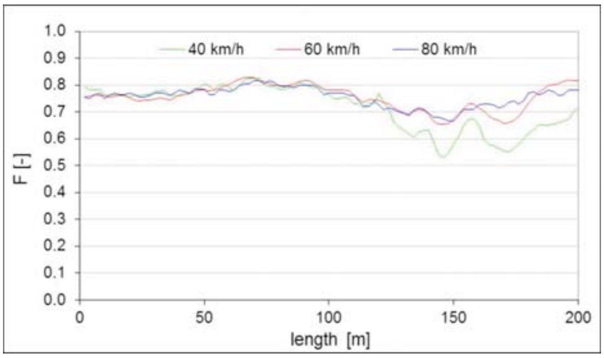

Fig. 1 Measured friction coefficient at different test speeds

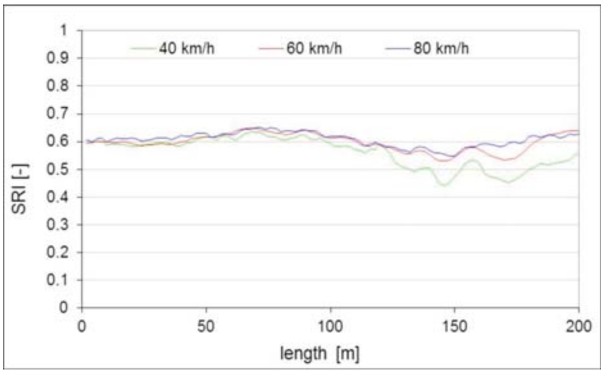

Fig. 2 SRI values for all test speeds computed for reference slip speed S_R = 30kph

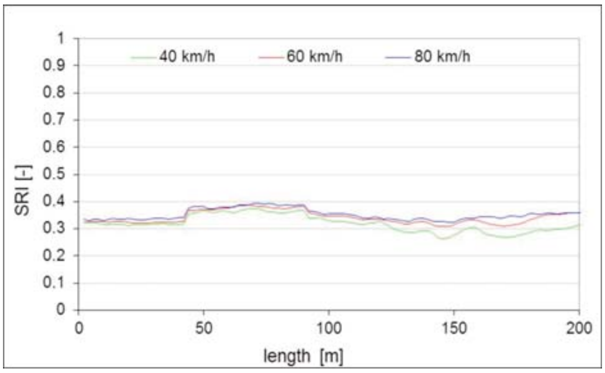

Fig. 3 SRI values for all test speeds computed for reference slip speeds S_R = 60kph

As shown in Figs. 2 and 3 a reference slip speed needs to be taken into account when the skid resistance measurement is harmonized. The reference slip speed S_R = 60 kph, by computing SRI, considers test speeds much better than if the value is set to S_R = 30 kph. For evaluation of skid resistance changes over time the reference slip speed S_R = 60 kph was used.

The skid resistance can alter for the first year or two as a result of traffic action before settling to an equilibrium value around which the skid resistance will fluctuate slightly. Once equilibrium has been reached, the skid resistance at any time may vary as a result of seasonal variation and a significant change in traffic level may alter the equilibrium level [2]. Because of seasonal variation changes of friction only spring measurements values were taken into account.

2.2. Unevenness

The road evenness is one of the basic factors of the pavement quality. It represents the characteristic of the road serviceability, and also road safety and comfort.

a) Longitudinal unevenness

The longitudinal elevation profile of a highway pavement refers to both grade and evenness in the vertical plane parallel to traffic flow. As a pavement develops distresses over time, its longitudinal profile can become altered by those distresses, leading to decreased smoothness and subsequently decreased wheel-pavement interaction, and increased noise, among other things. Longitudinal unevenness is described by International Roughness Index (IRI), which is obtained using the Reference Quarter Car Simulation (RQCS) according to [6, 11]. The ride comfort is described by vertical acceleration of sprung mass of testing vehicle (a_z), and the safety is described by vertical dynamic strength (F_z) at the contact of the wheel with pavement surface. How longitudinal unevenness influences ride comfort (and safety) is shown in Figs. 4 and 5.

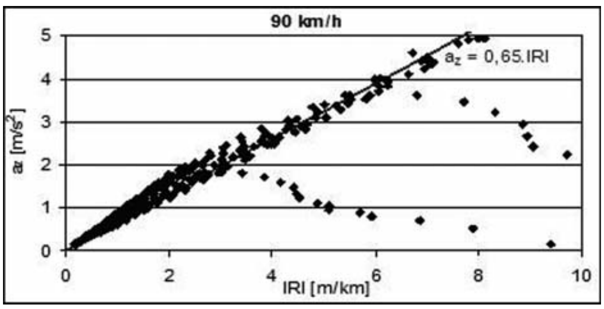

Fig. 4 Relationship between longitudinal unevenness (IRI) and ride comfort (a_z) at 90 kph

The relation tendency shows a mainstream of points that delimited an area of maximal discomfort by minimal IRI values. The line by basic points group was interleaved for determination of the relation between IRI and a_z. The other points lying below tendency are irrelevant from point of view of a comfort evaluation, because the bigger values of IRI respond the lower values of the response. Points lying out of mainstream confirm that one value of IRI can describe different unevenness with different car responses. These points have identical amplitude but different wavelength, which leads only to lower value of acceleration for even higher IRI. This fact is determined by overestimation of the short wavelengths and underestimation of the longer wavelengths by reference quarter car model.

The important characteristic of ride safety from point of view of longitudinal unevenness is the vertical strength Fz at the contact between vehicle and surface. The moment of minimal value was observed. The determined relation is presented in Fig. 5.

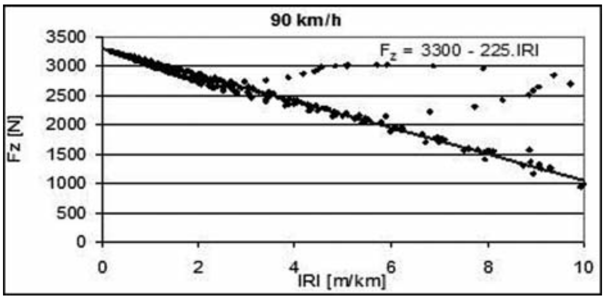

Fig. 5 Relationship between longitudinal unevenness (IRI) and ride safety (F_z) at 90 kph

The strength F_z has decreasing tendency with increasing IRI values. The different values of F_z for identical IRI value are possible to achieve alike for acceleration. The loss of contact does not occur by simulation with harmonic unevenness at speed 60 kph. On the other hand, at speed 90 kph and 130 kph the F_z achieved the zero value yet for low IRI values. The danger is not only a loss of contact but a low intensity of F_z, as well. An intensity of the vertical strength has influence on the stability of a car in horizontal curve and on the breaking distance, too. The differences are determined by characteristics of the reference model. In this case, the generally valid relation is not possible to establish because each vehicle has different weight so also different press strength of axle to the road surface.

3. The degradation functions

The methodology of the degradation functions creating includes two steps:

a. To create a degradation model that describes decreasing in the parameter quality.
b. To define the correlation function that describes a forecast of the parameter changes over time, and its value in particular time.

The model creation uses three research approaches:

1. The principles of the mechanics that use the regularity of structure degradation.
2. The empirical principles by using specific functions.
3. The combination of the mechanical and empiric approaches.

The degradation progress registers the basic tendencies of development, periodical changes based on climatic characteristics and traffic load, and non-regular changes affected by casual influences.

In practice, we evaluate the road degradation by two basic influences – time or traffic load. The mathematical formula of degradation model has an exponential shape (4) [18], (5) [20]

$$P(t) = 1 - \left(\frac{t}{T}\right)^a, \text{ or} \quad (4)$$

$$P(x,t) = 1 - A \times \left(\frac{n}{N}\right)^B \quad (5)$$

Where

$P(t)$ is the relative performance as a function of time

$P(x,t)$ is the value of a parameter "x" in time "t"

t – time of exploitation

n – number of traffic load (esal) during exploitation

T – time in which the parameter will be exhausted (the value will be 0)

N – overall traffic load (esal) till the parameter will be exhausted

a,A,B – shape parameters which value depend on the kind of effects that are considered.

The parameters A and B are dependent on materials of the road structure. The specific shape of the degradation model is shown in Fig. 6.

For determination of selected parameters changes over time the data measured between years 1998 and 2006 were processed. From all of measured sections were as an example chosen two of them – Poprad – Ganovce and Brodno – Zilina.

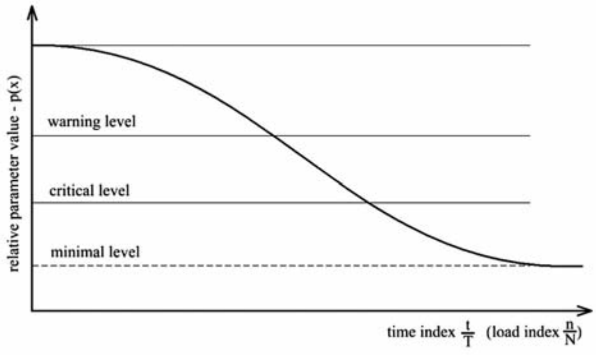

Fig. 6 The specific shape of the degradation model

3.1. Skid resistance

An evaluation of the skid resistance development over time is presented in Fig. 7. Depending on seasonal changes of friction only spring measurements values were taken into account.

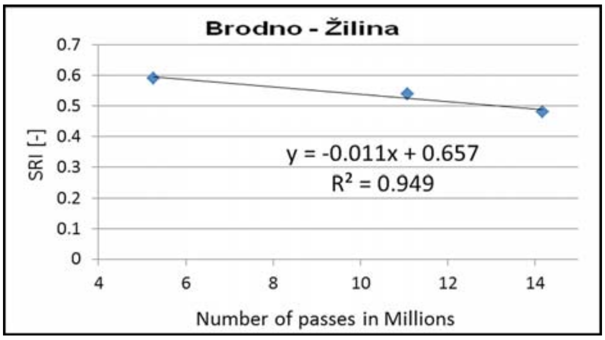

Fig. 8 Friction coefficient versus number of equivalent standard axle load passes

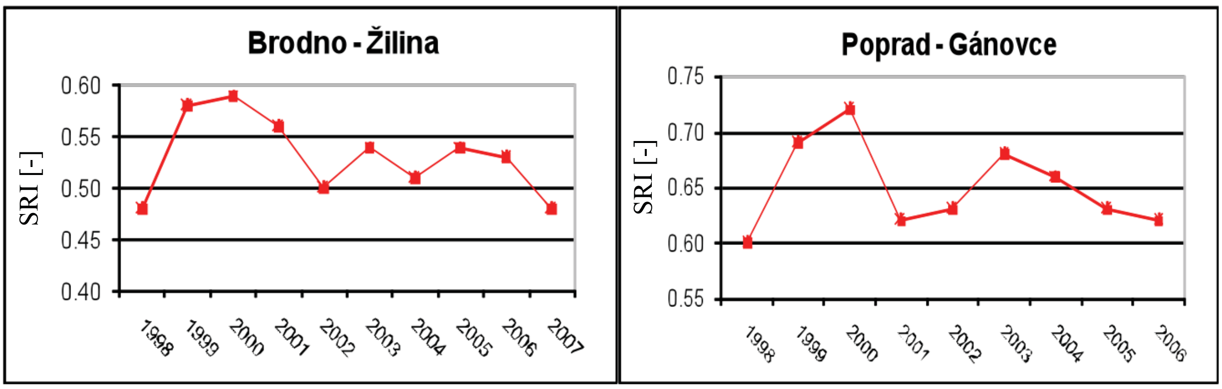

Fig. 7 Changes of SRI values over time

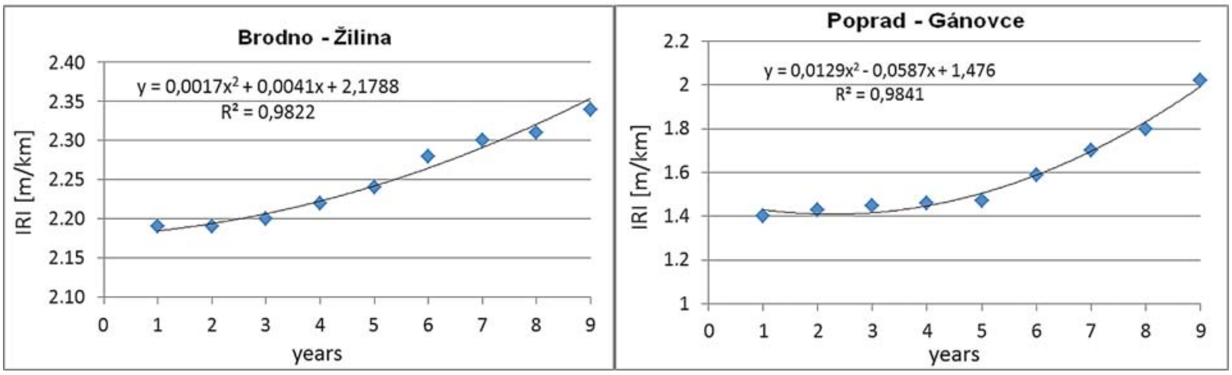

Fig. 9 Changes of longitudinal unevenness over time

Fig. 7 illustrates that there isn't any stable decrease of SRI values over years when friction was monitored. The same chaotic behavior appeared with the other sections. It may be caused by different test conditions every year, such as pavement surface temperature, test speed, measuring device calibration and keeping the same wheel path. Relationship between Skid Resistance Index and number of equivalent standard axle load passes is shown in Fig. 8.

3.2. Longitudinal evenness

An evaluation of the longitudinal evenness development over time is presented in Fig. 9.

As Fig. 9 shows, there is a clear evidence of IRI values increase during pavement usage over years. Increasing tendency is evident by all of the observed sections. All tendencies can be described by a quadratic regression line. Coefficients of the regression line may vary depending on number of passes, pavement construction and climatic conditions. Coefficients scale is very small because of weak unevenness changes over time, so it is possible to describe the tendency by linear equation as well. However, the question of describing life-cycle pavement surface characteristics changes should result from physical fundamentals, such as materials fatigue etc. Exact shape of tendency line is necessary to determine and verify after long-lasting observation on sections with different traffic load and pavement construction by unconditional considering its locality. Fig. 10 shows relationship between longitudinal unevenness and number of equivalent standard axle load passes.

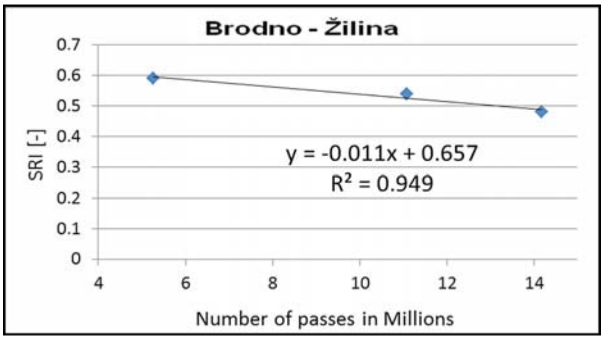

Fig. 10 Relation between longitudinal unevenness and count of equivalent standard axle load passes

4. Longitudinal unevenness and skid resistance interdependency

Can longitudinal unevenness influence the pavement skid resistance? Longitudinal unevenness induces a vehicle vibrating and subsequently vertical force (axle load) increase. On the assumption of increased tread pressure after passing unevenness and subsequently surface wearing and polishing, there were all sections observed from point of view of interdependency of longitudinal unevenness and skid resistance. A course of two mentioned parameters on selected sections (selected from road sections Zilina – STK and Rovensko – Senica) is shown in Fig. 11.

As is illustrated in Fig. 11 on some rough sections (described by higher IRI values) were measured lower skid resistance values, and on the contrary on smooth sections (described by lower IRI values) were measured higher skid resistance values. The assumption was confirmed on few sections but if the general relation of longitudinal unevenness to skid resistance was made, the correlation turned out as very weak. The speculation that the correlation is so weak because of generally low IRI values on observed sections (very smooth pavement surface from point of view of vibrating and tread pressure increasing) was contradicted by research published in [9].

5. Conclusions

There have been done a lot of research work in the field of flexible pavement parameters degradation. However, the question of accurate measuring and evaluating of the observed parameters is still open and the further research is needed. It has been found out that the reference slip speed S_R = 60 kph, by computing SRI, considers test speeds much better than S_R = 30 kph. In term of consideration of longitudinal unevenness influence to ride safety

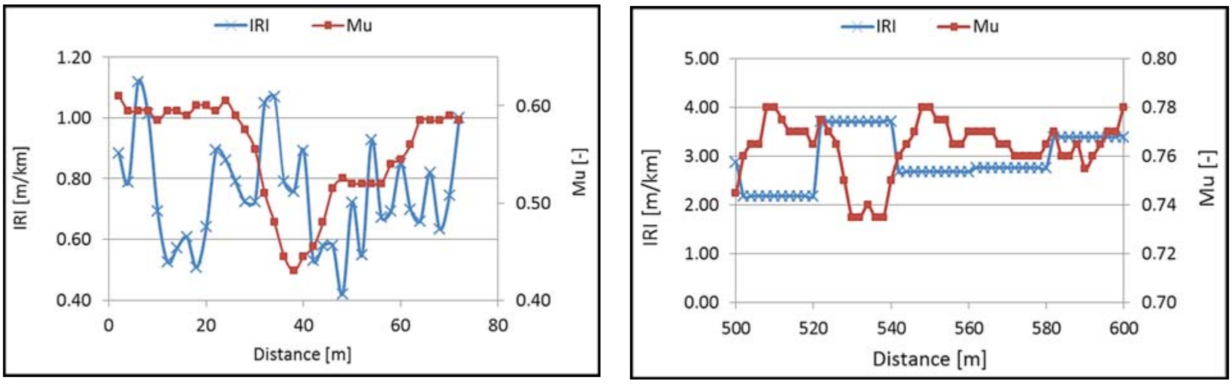

Fig. 11 Comparison of parameters by mutual dependency on 100m long section

(comfort) it is necessary to take into account the overestimation of the short wavelengths and underestimation of the longer wavelengths by reference quarter car model.

The analysis of serviceability parameters and their time and load development is very important part of PMS. It is not possible to choose an optimal time and technology of the road maintenance and repairing without the knowledge of the surface parameters development forecast. In addition, a determination of degradation functions is inevitable for specification of relationships between parameters as an important factor of the road safety increasing.

On the other hand, the analysis of degradation processes is very demanding to the exact observance of the same test conditions. The different climatic conditions and different driving traces are the basic sources of the measuring inconsistency. It is necessary to be aware of long time observation of the parameters for determination of developed functions, which can mean some decades.

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