

# Non-invasive diagnostic methods for investigating the quality of Žilina airport's runway

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**Abstract:** The Žilina airport was after almost 50 years of use measured by non-invasive methods including GPR and Profilograph GE in order to investigate the quality of the runway pavement at the chosen spots. Since it was just a pilot action, a sample of survey was carried out. The testing spots were placed where the geologic drill core J02 have been drilled out. The measurements performed by Profilograph GE were used to verify the quality of the pavement surface in term longitudinal unevenness by means of index IRI and C. The GPR survey was performed in 3D geometry, hence in the  $x$ - and  $y$ -direction. A horn type antenna with central frequency of 2 GHz was used on the test field in order to verify the thicknesses of pavement construction layers. Here, the result of a 3D survey is presented. The investigation confirms two sub-horizontal construction layers of the runway pavement. In some areas the GPR interpretation was not possible due to the signal attenuation. This significant signal attenuation is found mainly in the areas where the linear cracks are situated.

**Key words:** runway, pavement surface, unevenness, Profilograph GE, GPR, horn antenna

## 1. Introduction

One of the basic requirements of pavement quality is evenness of the pavement surface. As a result of dynamic load, improper structure of pavement

due to poor conditions and technology of pavement construction, deviations from the desired state in the form of unevenness may occur on the surface that become evident as unevenness. Unevenness adversely affects the rolling resistance, tires interaction with the pavement, pavement load and safety. Unevenness also quickens a damage to the pavement. When evaluating pavement unevenness, we must therefore perceive the pavement not as a self-contained phenomenon, but as a cause of various undesirable processes affecting its users in our case particularly crews or aircraft passengers. Apart from pavement unevenness the structure and condition of several layers of the runway pavement has also been monitored. GPR measurement was also used to achieve this. On the basis of these measurements we can determine the thickness of the construction layers, localized deformations in structure of the pavement and detect the risk of ground water. The objectification of pavement surface evenness and GPR measurements of the airport's runway were drafted in addressing the research project for "Evaluation of present state and proposal for reconstruction of the airport's movement areas" within the research activity of the Research centre of University of Žilina.

Airport Žilina is a public international airport. It serves for the region of northwest Slovakia with approximately 1.2 million inhabitants. The airport is used for the air transport of Slovak and foreign companies, flights of companies and private aeroplanes, flight training and sport flying, air ambulance flights, special flight works and activity of the Slovak republic.

Žilina airport at Dolný Hričov was built in the 1970s to replace the formerly Brazovský Majer Airport that had given ground to the developing Žilina city. Due to planned reconstruction, a diagnostic was done by non-invasive diagnostic methods. Since the runway covers a relatively large area, a few test fields were chosen to carry out the investigation (Fig. 1).

## **2. The objectification of longitudinal evenness of the airport's runway pavement surface**

A number of methods are available to detect unevenness in the longitudinal direction of a road. In general, equipment for measuring longitudinal unevenness could be divided into two basic groups:



Fig. 1. Satellite map of the Žilina International Airport with the schematic position of the Profilograph GE and GPR measurements.

- Profilometric equipment acquiring the direct image of the longitudinal profile of the roadway track, which is processed by various mathematical methods.
- The response apparatus acquiring the index of inequality using the measurement of the dynamic response of the vehicle or special measuring device.

Another criterion by which we can divide these devices, is the number of diagnosed parameters. Based on this criterion we distinguished:

- Single-diagnostic device following only longitudinal evenness.
- Multifunctional diagnostic devices analysing multiple parameters simultaneously.

Objectification of evenness of pavement surface in Slovakia is done by Profilograph GE, which is a profilometric multifunctional equipment to produce the reference line (Příkryl *et al.*, 2011; Pederson, 2007). The establishment of the reference line is based on the following principle: the vertical acceleration measured by the accelerometer is converted (with use of the relevant

algorithm) to the acceleration with respect to the reference plane (Inertial Reference) defined by the instantaneous position of the accelerometer in the vehicle (Fig. 2). The height of the road surface relative to the refer-

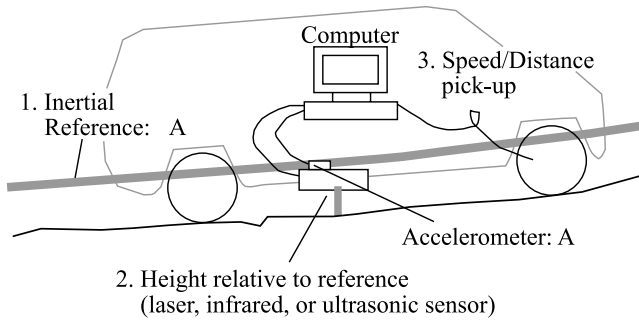


Fig. 2. The principle of creating a reference line for measuring the evenness of roads (Sayers and Karamihas, 1988).

ence plane is thus the distance between the accelerometer in a vehicle and the road surface below it (Fig. 2). This height is measured by contactless sensors which in this case are laser scanners.

### 2.1 International Roughness Index (IRI)

Currently, the world’s most used parameter to evaluate the quality of pavement surface in term of longitudinal unevenness is the International Roughness Index – IRI. This parameter is obtained by using a mathematical simulation of driving a reference quarter-car model (Fig. 3, Sayers et al., 1986; Gillespie, 1992; Molenaar, 1992) along measured surface irregularities. TP 4/2012 is valid for the evaluation of unevenness of road pavements in Slovakia (Decký et al., 2012). In accordance with the global trends in the diagnostics of pavement unevenness the fourth vehicle model is greatly used, commonly known as the “Reference Quarter-Car Simulation” (RQCS – reference model-quarters of passenger vehicles). The RQCS model (Fig. 3) can be mathematically described by two second order differential equations:

$$\ddot{z}_s m_s + C_s(\dot{z}_s - \dot{z}_u) + k_s(z_s - z_u) = 0, \tag{1}$$

$$\ddot{z} m_s + m_u \ddot{z} + k_t z_u = k_t y, \tag{2}$$

where:

- $m_s, m_u$  – the weight of sprung mass and unsprung mass [kg],
- $k_s, k_t$  – spring constants of springs and tires [ $\text{N m}^{-1}$ ],
- $C_s$  – linear damping coefficient shock absorber [ $\text{Ns m}^{-1}$ ],
- $z_s, z_u$  – vertical displacement of the sprung and unsprung masses [m],
- $\dot{z} = z(1) = dz_s/dt$  – the vertical velocity of the sprung mass [ $\text{m s}^{-1}$ ],
- $\ddot{z} = z(2) = d^2z_s/dt^2$  – vertical acceleration of the sprung mass [ $\text{m s}^{-2}$ ],
- $\dot{z}_u = z(3) = dz_u/dt$  – vertical velocity of the unsprung mass [ $\text{m s}^{-1}$ ],
- $\ddot{z}_u = z(4) = d^2z_u/dt^2$  – vertical acceleration of the unsprung mass [ $\text{m s}^{-2}$ ],
- $y(t)$  – input profile elevation road bumps [m].

This model can be applied to various types of cars, and it is possible to simulate running at any vehicle speed.

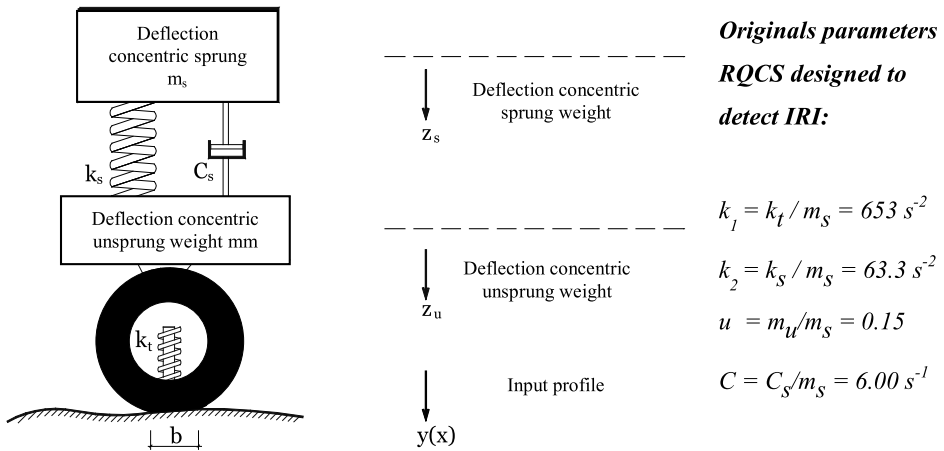


Fig. 3. The reference quarter-car model to estimate the index IRI.

## 2.2 The pavement unevenness index C

An assessment methodology for pavement surface unevenness based on the pavement unevenness C was created in former Czechoslovakia. This methodology enables us to quantify an effects of longitudinal unevenness of pavements on moving vehicles from the point of view of safety and passengers' comfort, and also in terms of the burden on the structural components of vehicles. This diagnostics methodology is still used for diagnostics

and assessment of runways (*Schlosser and Decký, 1998*). According to the methodology created by Procházka, Šprinc and Kropáč (*Procházka et al., 1980*) surface irregularities in the height of  $Z(l)$  can be expressed as the sum of the three typical components:

$$Z(l) = S(l) + H(l) + N(l). \tag{3}$$

Component  $S(l)$  represents the total progress (trend) of the routes given by the course of the vertical alignment longitudinal profile of the road or runway.

Component  $N(l)$  includes the individual local unevenness of the road surface, such as potholes, bumps, etc., which significantly impairs the smooth functioning of the level line and does not have a random character. It results from damage over time and should not appear with appropriate maintenance.

Component  $H(l)$  describes the random roughness of the longitudinal profile as deviations from the trend resulting from construction operations and traffic. This component produces a vertical vibration of vehicles and the character centred random function.

### 2.3 Evaluation of pavement unevenness using the unevenness index C and IRI

The classification of pavement surface unevenness in terms of TP 4/2012 (*Decký et al., 2012*) and by type of communication for a 20 m evaluating interval is presented in Table 1. The comparison of the previous classification with the one currently valid in Slovakia is shown in Table 2.

Table 1. Comparison of the classification scales for assessment of longitudinal unevenness according to *ČSN 73 6175 (1995)* and according to *Decký and Kováč (2014)*.

Classification level		Pavement unevenness index C [ $10^{-6}$ rad m]			
Level	Name	Roads I., II, III. class		Highways	
		Decký-Kováč	ČSN 73 6175	Decký-Kováč	ČSN 73 6175
I.	very high quality	< 2	< 5	< 1	< 2
II.	high quality	2–5	5–10	1–2	2–5
III.	Poor quality	5–10	10–20	2–5	5–10
IV.	Bad quality	10–20	20–50	5–10	10–20
V.	Unsuitable for traffic	> 20	> 50	> 10	> 20

Table 2. The comparison of classification scales according to TP 4/2000 and TP 4/2012.

Classification level		IRI [m/km]			
		Rural roads		Motorways	
		TP 4/2012	TP 4/2000	TP 4/2012	TP 4/2000
I.	very high quality	< 2.8	< 1.9	< 1.8	< 1.9
II.	high quality	2.8 – 4.4	1.91 – 3.3	1.8 – 2.7	1.91 – 3.3
III.	Poor quality	4.5 – 6.1	3.31 – 5.0	2.8 – 4.6	3.31 – 5.0
IV.	Bad quality	6.2 – 8.6	5.01 – 10.0	4.7 – 6.9	5.01 – 8.0
V.	Unsuitable for traffic	> 8.6	> 10.0	> 6.9	> 8.0

Classification level 5 represents threshold values in term of pavement serviceability. Upon reaching the IRI values corresponding to the upper limit of the classification level 4, i.e. at 8.6 m/km for rural roads and 6.9 m/km for the motorway, the road is unsuitable for traffic in terms of longitudinal unevenness. As warning thresholds are considered IRI values corresponding to the lower end of the classification level 4, i.e. with 6.2 m/km for rural roads and 4.7 m/km for the motorway. If these values are reached, it is recommended to adjust speed limits to 90 km/h on motorways and to 60 km/h on the rural road.

## Objectification of the unevenness of the airport runway pavement surface at Žilina Airport (Dolný Hričov)

### 2.4 International Roughness Index (IRI)

Based on the measurements of the longitudinal unevenness of airport's runway, situated in the cadastral area of Dolný Hričov, the results were based on 15 measurements carried out on this runway. Due to the wide range of data, the presented data are averaged values of the evaluations in 5, 10, 20 and 100 m evaluating intervals (Fig. 4).

### 2.5 The pavement unevenness index C

In previous works of authors in the field of evaluation of pavement surface evenness of RWY (Čelko *et al.*, 1996; Decký and Kováč, 2003) and in accordance with the conclusions of the work (Jareš, 1992) the following characteristics were used for evaluation:

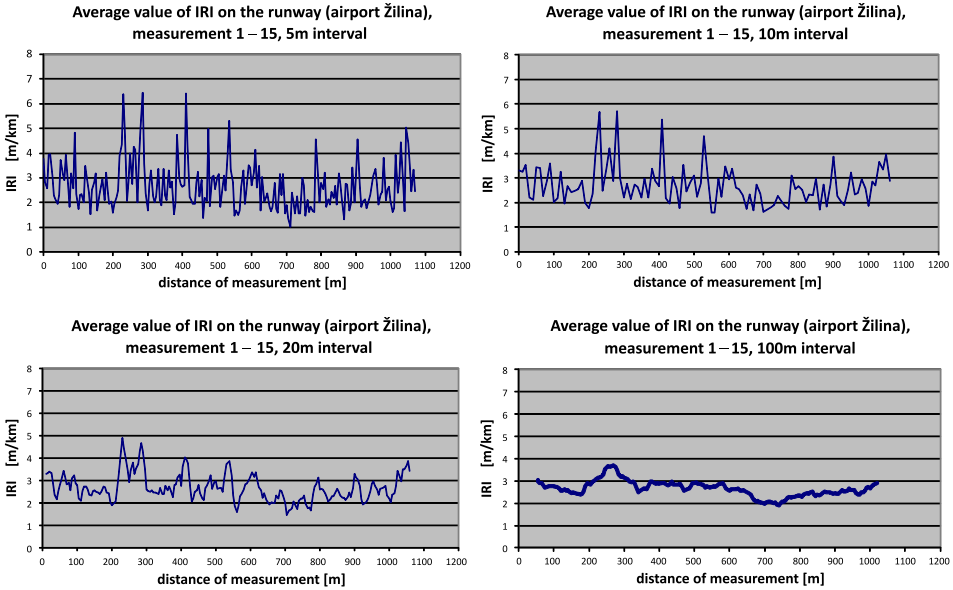


Fig. 4. Evaluation of the airport runway pavement surface in term of longitudinal unevenness using IRI, 15 – times of measurements.

- for evaluating technical condition, an evaluation interval of 10 m was used without moving the evaluation window,
- to evaluate the pavement surface in terms of comfort and driving safety, a 100 m interval with moving of the evaluation window has been used.

Correlation parameters depending on pavement evenness were objectified on the basis of long-term research activities, which the authors carried out through direct simulation methods and identification of dynamic system of vehicle – road – environment.

Due to the fact that the IRI values were in line with the original methodology (*Sayers et al., 1986*) evaluated for a reference speed of  $80 \text{ km h}^{-1}$ , a correlation formula between IRI and C will be used from which it is possible to express the pavement unevenness index C in accordance with the following formula:

$$C = \frac{1}{0.49} \sqrt{\frac{\text{IRI}}{1.99}} \tag{4}$$



The pavement unevenness index  $C$  has been drawn in Fig. 5 on the basis of formula (4) and the above-mentioned evaluation value intervals:

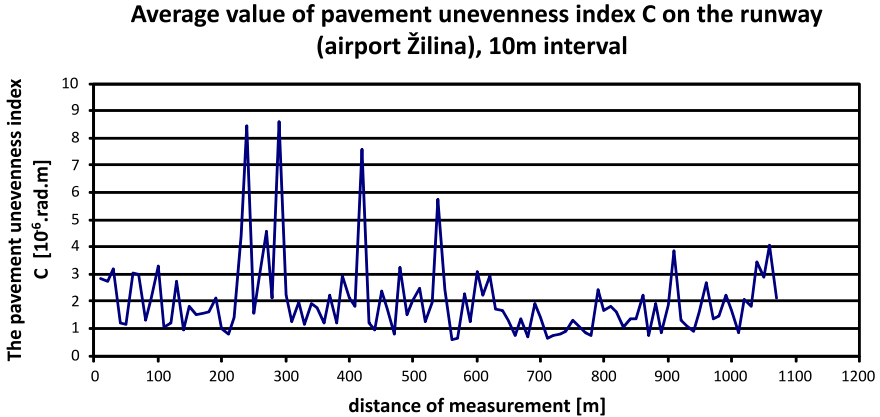


Fig. 5. Evaluation of the airport runway unevenness according to pavement unevenness index  $C$ , 10 m interval.

In this research activity “Evaluation and design of state reconstruction of the airport’s movement areas in Dolný Hričov”, evaluation of longitudinal unevenness of the runway was performed through:

- international index IRI (International Roughness Index),
- the pavement unevenness index  $C$ .

In the case of unevenness evaluation by means of the evaluation parameter IRI methodology TP 4/2012 was applied. According to it the values for the 20 m interval evaluation are crucial (Fig. 6).

In previous objectification of the unevenness of the runway pavement, the authors of the report used the evaluation in accordance with Table 3.

## 2.6 Results

On the basis of the realized measurements and evaluation of the pavement surface’s longitudinal unevenness of the airport runway at Dolný Hričov (Žilina airport) (Fig. 7 and Fig. 8) we can say that the pavement is considered low quality but sufficient to remain in use as a runway.

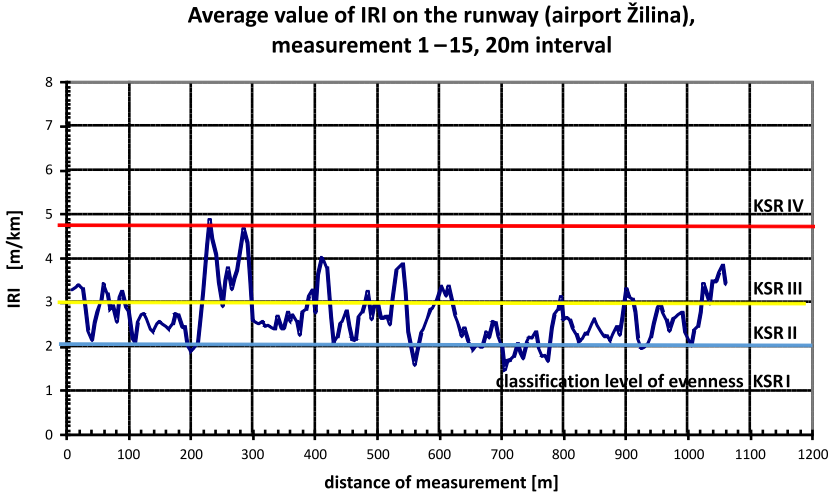


Fig. 6. Evaluation of longitudinal unevenness of the airport runway surface using IRI. Thresholds indicating the classification level of evenness (KSR) according to TP 4/2012 by Table 2.

Table 3. Classification scale for assessment of longitudinal unevenness (Decký and Kováč, 2014).

Classification level		Pavement unevenness index C [ $10^{-6}$ rad m] for evaluation	
Class	Name	Motorways	Rural roads
I.	very high quality	< 2	< 1
II.	high quality	2 – 5	1 – 2
III.	Poor quality	5 – 10	2 – 5
IV.	Bad quality	10 – 20	5 – 10
V.	Unsuitable for traffic	> 20	> 10

### 3. 3D GPR investigation

The GPR investigation was carried out in order to get more information about the construction layers of the Žilina airport runway pavement. The airport was built in the 1970s. The runway was not maintained on a regular base, therefore some issues concerning the quality of the pavement and subgrade base appeared.

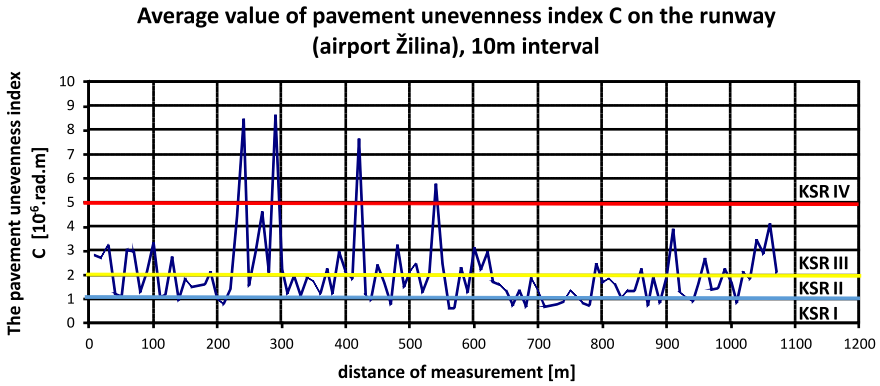


Fig. 7. Evaluation of longitudinal unevenness of the airport runway in terms of construction and technical state via pavement unevenness index C indicating the classification level of evenness (KSR) according to Table 3.

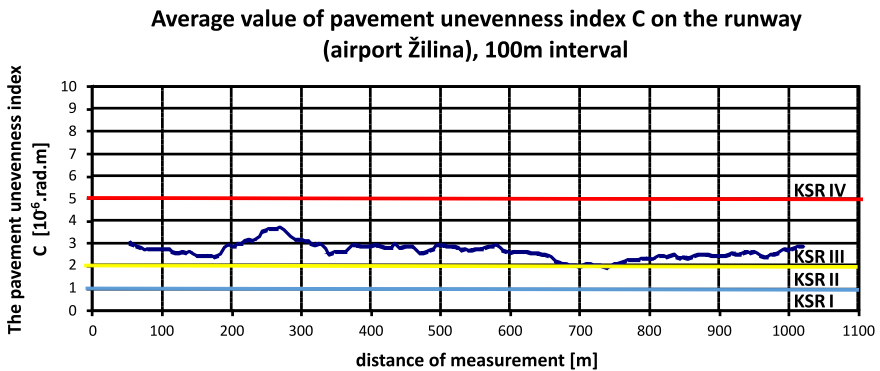


Fig. 8. Evaluation of longitudinal unevenness of the airport runway in terms of comfort and driving safety via pavement unevenness index C indicating the classification level of evenness (KSR) according to Table 3.

### 3.1 Methodology

The 3D investigation formed part of a comprehensive investigation of the Žilina Airport runway. Since it was only a sample of the investigation portfolio, a test field has been placed over the area, where the drill hole J02 has been made with a documented drill core (Záthurecký *et al.*, 2007). The stud-

ied GPR detail has been investigated by the GPR system SIR-20 (GSSI) in a 3D alignment (grid  $2.6 \times 1.4$  m with spacing of 0.2 m) and with the step of measurements of 0.01 m. In this study, a horn-type antenna with central frequency of 2 GHz was applied. The time record length of 20 ns was used. The manufacturer's specified depth range for this type of antenna is 0.75, which is sufficient for diagnosing the road condition and construction layers. The Radargram was processed by the special software package ReflexW (*Sandmeier software, 1997–2012*).

Since the 3D processing has some limits, it is more suitable to process data separately along the studied 2D profiles. 2D data processing offers more options how to treat raw data. Measured data were firstly processed in the following manner (*Daniels, 2004; Jol, 2009*);

1. 1D filtration – subtract mean (dewow)
2. Correction of maximum phase
3. 2D filtration – running average
4. Static correction – setting of the 0 value (the surface of the test field);
5. 1D filtration – bandpass frequency filter (400/600/3400/3600 – 2 GHz);
6. background removal;
7. spectral whitening (1500–2500 – 2 GHz).

Raw data, which were processed in this manner, were consequently interpreted and joined into the 3D data cube. Since the dielectric constant should decrease, positive peaks were considered as boundaries among layers. These positive peaks were detected semi-automatically in the ReflexW software (*Sandmeier software, 1997–2012*) package. Based on the data interpretation, two main boundaries were identified and more or less also interpreted on the 2D profile in  $x$  and  $y$  direction, in the case of obvious boundaries. The output of the investigation are the contour maps of the main boundaries in  $x$  and  $y$  directions.

### 3.2 Results

The results of the GPR survey were compared with the drill core *a priori* data. Consequently the GPR data were calibrated and dielectric constants were set up for both layers. The geophysical survey approach has a non-invasive nature, it does not necessarily require some obvious *a priori* data

such as drill cores. On the other hand the accuracy of the geophysical methods increases if more than one geophysical investigation approach is used. In this particular case, a geologic drill core was available (Fig. 1) which allows accurate identification of the pavement construction layers (Fig. 9) with the geophysical ones.

#### Geological drill core J02 – schematic description

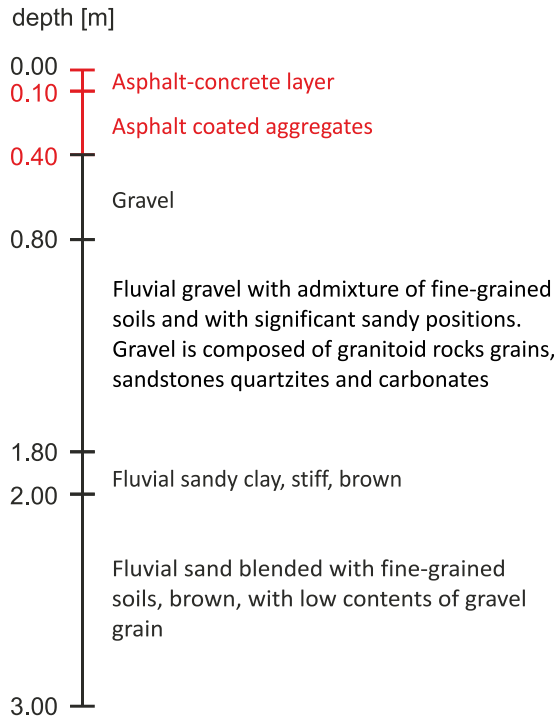


Fig. 9. Schematic description of the J02 geological drill core. For the purpose of the 3D GPR survey, the depth of the first and second boundaries (red font) was taken into account in order to determine the dielectric constant value.

At Žilina Airport, a GPR survey using a horn antenna with centre frequency of 2 GHz has been elaborated. Here, the results obtained by the interpretation of data are shown. As has been mentioned, two layers were already identified in both interpreted directions.

### 3.2.1 First Layer, directions $x$ and $y$

The first layer shown in (Fig. 10) based on the drill core comparison was identified as an asphalt-concrete layer. The result in the  $x$ -direction shows very good quality and almost on every single profile the course of the first layer can be tracked. On the other hand only the first half of the  $y$ -direction profiles can be well tracked. Here, if there was no possibility to distinguish any sharp boundary between the layers, the radargram stays un-interpreted (blank). The GPR interpretation error could be about 10–15% (Maser and Scullion, 1991; Morey, 1998; Matula, 2013), due to a non-unique dielectric constant value. In reality, the studied environment is not perfectly homogeneous, therefore the dielectric value may vary. Also, the electro-magnetic nature of the geological or anthropogenic environment that should have the same characteristics may vary in some intervals. Dielectric constant used in this survey was set based on the calibration with the geologic drill core J02, (Fig. 9) (Záthurecký et al., 2007). The dielectric constant value of 4 for the first Asphalt-concrete layer was used.

### 3.2.2 Second Layer, directions $x$ and $y$

The second layer shown in the (Fig. 11) based on the drill core was identified as asphalt coated aggregates. In both directions, the layer was tracked following the obvious boundary. Comparing results obtained from both directions, some differences can be seen. However, these differences are not quantitatively significant; they are within the standard error of interpretation, the central part of the contour maps report mismatch. The result in  $x$ -direction shows very good quality, the second layer can be well tracked on every GPR profile. The  $y$ -direction profiles can also be well tracked, except in the second half of the eighth profile ( $x = 1.4$  m) where the interpretation is missing. If there was no possibility to distinguish any sharp boundary among the layers, the radargram stays un-interpreted (blank) as it was in the previous discussed case. The dielectric constant value of 4.6 for the second asphalt coated aggregates layer was used. The dielectric constant value was determined based on the geologic drill core, as it was for the first layer.

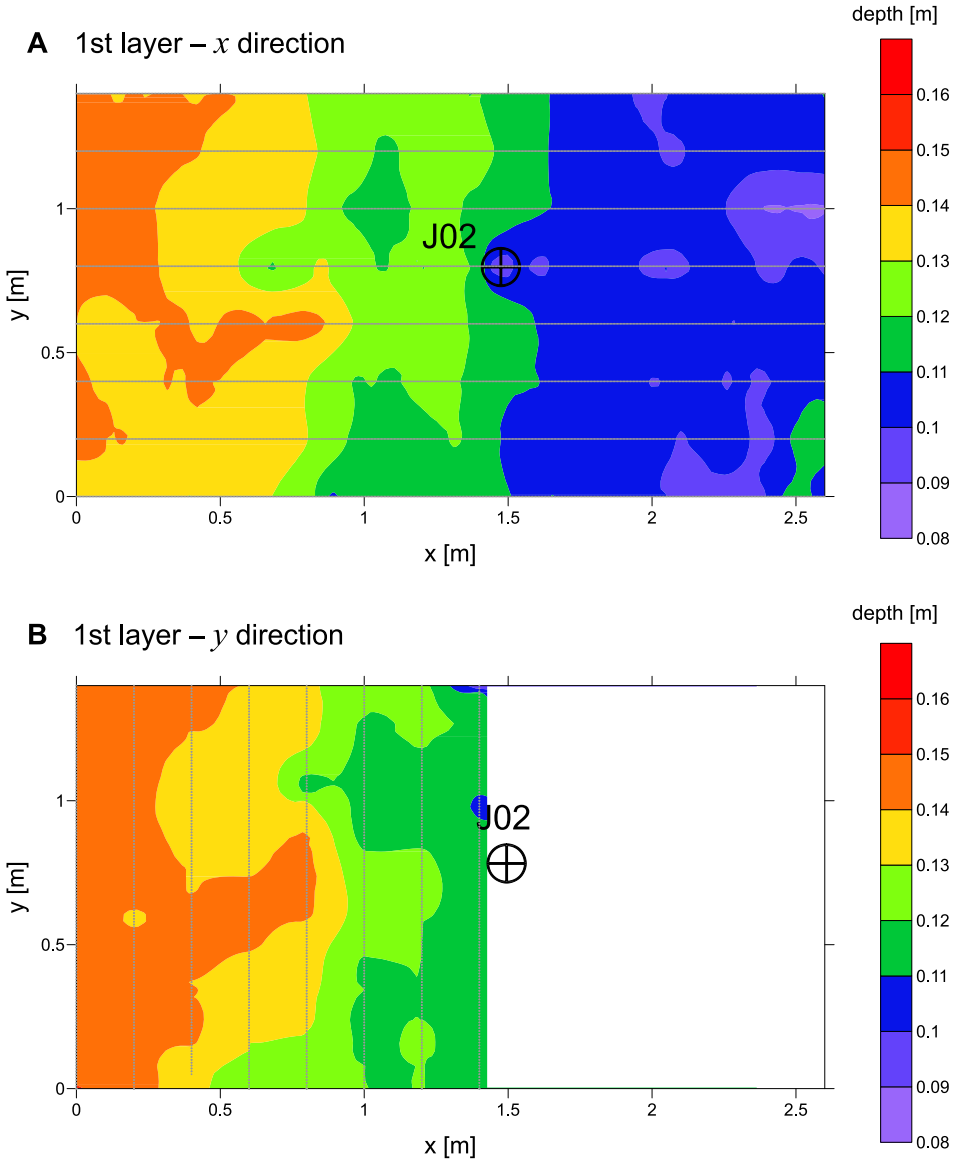


Fig. 10. **A.** The resulting contour map of the first identified layer in the  $x$ -direction. **B.** The resulting contour map of the first identified layer in the  $y$ -direction. Blank fields show areas where no data are available based on the interpretation. Grey lines show interpreted GPR profiles. Black cross in circle shows place where the J02 drill core was placed.

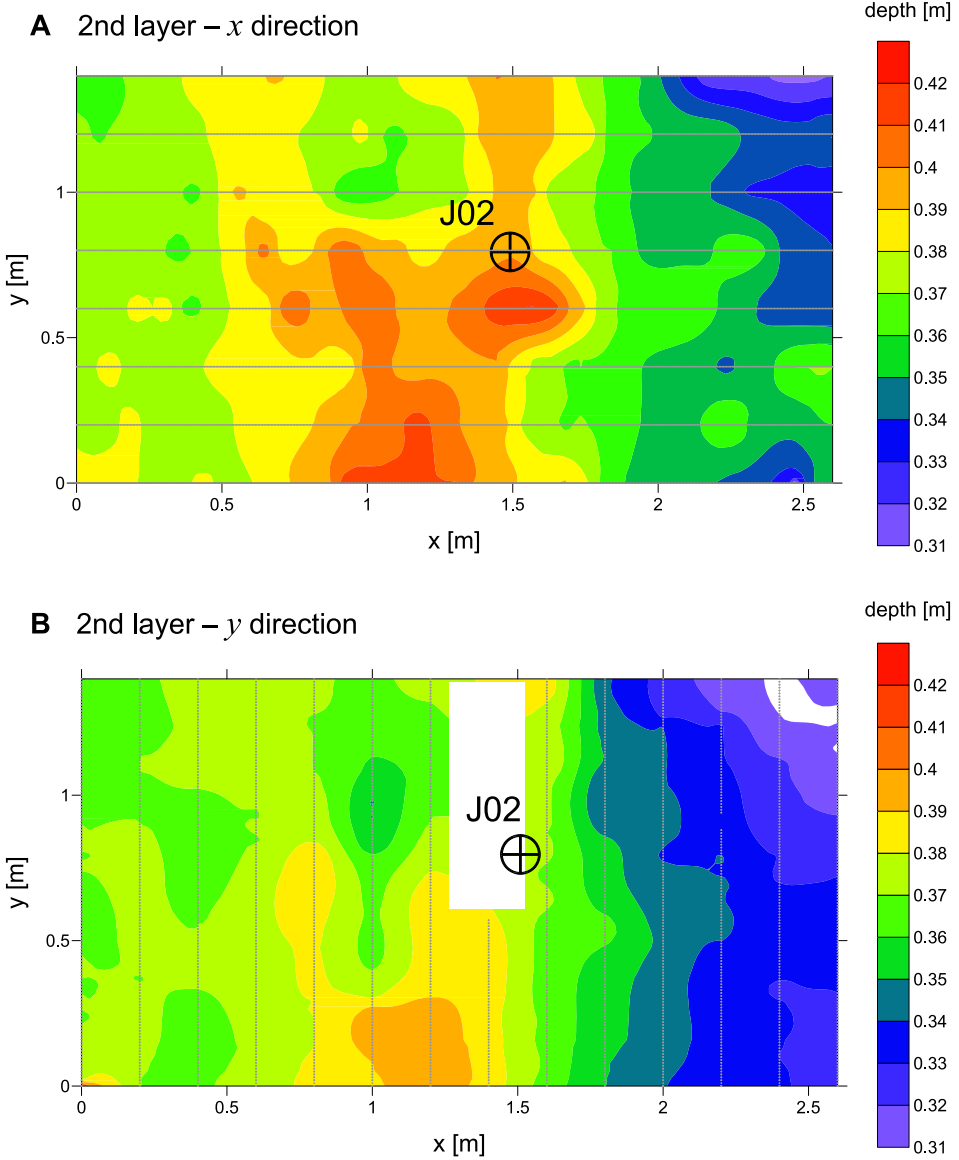


Fig. 11. **A.** The resulting contour map of the second identified layer in the  $x$ -direction. **B.** The resulting surface of the second identified layer in the  $y$ -direction. Blank fields show areas where no data are available based on the interpretation. Grey lines show interpreted GPR profiles. Black cross in circle shows place where the J02 drill core was placed.



## 4. Conclusion

With the arrival of new technologies, the process of data acquisition is simplified and the quality of data increases at the same time. Moreover it is possible to acquire data that could previously be obtained only by destructive interference to the pavement construction. An ability to measure more parameters and measure them faster, more accurately and safely at the same time allow us to get the desired and adequate amount of data for complex decision-making processes. Based on this it is possible to design suitable technology for maintenance, repair and/or reconstruction. Non-invasive GPR survey of the Žilina airport runway confirmed the validity of this kind of investigation. On the other hand, it is appropriate to complement such a survey by other methods of geophysical investigation, or support by drill cores.

The results and evaluation of longitudinal unevenness measurements and outputs of GPR measurements point to the fact that the airport's runway pavement is suitable for use by traffic. Although, the airport has been in use since the mid-70s, construction and the sub-base layers of the runway pavement are not significantly disturbed according to the survey results. On the other hand the eventual reconstruction would be useful in terms of comfort and safety of use.

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## References

- Čelko J., Schlosser F., Ďurčanská D., Komačka J., Decký M., Tabak M., 1996: Plány dlhodobého rozvoja letísk. Diagnostika dráh a plôch. Letiská Košice, Sliač, Piešťany. ŽU Žilina (in Slovak).
- ČSN 73 6175, Měření nerovnosti povrchu vozovek, 1995 (in Czech).
- Daniels J. D., 2004: Ground penetrating radar, 2nd. edition. Published by the Institution of Electrical Engineers, London, United Kingdom, p. 734.
- Decký M., Kováč M., 2003.: Rovnosť vzletovo-pristávacej dráhy letiska Sliač. Stavebná fakulta (in Slovak).

- Decký M., Kováč M., Čelko J., 2012: TP 4/2012 Meranie a hodnotenie nerovnosti vozoviek pomocou zariadenia PROFIOGRAPH GE. MDVRR SR (in Slovak).
- Decký M., Kováč M., 2014: Pozdĺžna rovnosť vozoviek pozemných komunikácií. Vedecká monografia. EDIS 2014, p. 222, ISBN 97880-554-0925-2 (in Slovak).
- Gillespie T., 1992: Everything You Always Wanted to Know about the IRI, But Were Afraid to Ask! Road Profile Users Group Meeting, Lincoln, Nebraska.
- Jareš J., 1992: Zjišťování parametru rovinatosti dopravních ploch metodou dynamické odezvy měřícího vozu. Závěrečná zpráva, Brno (in Czech).
- Jol H. M., 2009: Ground Penetrating Radar: Theory and Applications. Elsevier Science Amsterdam, First edition 2009. p. 509.
- Maser K. R., Scullion T., 1991: Automated detection of pavement layer thicknesses and subsurface moisture using Ground Penetrating Radar. Transportation Research Board Paper, p. 12.
- Matula R., 2013: Nedestruktivní diagnostika konstrukcí vozovek pozemních komunikací georadarem. Dizertačná práca, Univerzita Pardubice, Pardubice, p. 148 (in Czech).
- Molenaar A., 1992: Principles of Pavement Management Systems, Planning on Network and Project Level. Basic Steps in PMS, TU Delft, 02/1992. 7-92-411-1.
- Morey R., 1998: Ground Penetrating Radar for evaluating subsurface conditions for transportation facilities. Synthesis of highway practise 255, National Cooperative Highway Research Program, Transportation Research Board. National Academy Press. p. 39.
- Pederson N. J., 2007: Pavement Lessons Learned from the AASHO Road Test and Performance of the Interstate Highway System. Transport Research Board, 2007.
- Příkryl M., Kutil L., Žák J., 2011: 3D measurement technology of laser scanning (3D měření technologií laserového skenování), Švédsko, silnice 41 (väg 41) Bergham–Gullberg. Konference Asfaltové vozovky 2011, České Budějovice (in Czech).
- Procházka M., Šprinc J., Kropáč O., 1980: Teoretické základy klasifikace nerovností vozovek. Silniční Obzor, 7/1980 (in Czech).
- Reflex-Win PreVersion 7.0, 1997-2012, Sandmeier software, Karlsruhe, Germany.
- Sayers M., Gillespie T., Queiroz C., 1986: The International Road Roughness Experiment (IRRE): Establishing correlation and calibration standard for measurements. World Bank, Techn. Paper No. 45, Washington, D. C., 1986.
- Sayers M., Karamihas S., 1988: The Little Book of Profiling. Basic Information about Measuring and Interpreting Road Profiles, 1998.
- Schlosser F., Decký M., 1998: Analýza nerovností letiskových dráh a plôch. In: Silniční obzor, roč. 59, č. 6 (1998), s. 152-157, ISSN 0322-7154 (in Slovak).
- Záthurecký A., Lenková M., Frličková M., 2007: Dolný Hričov Airport, geological survey on account of aerodrome runway expansion (Letisko Dolný Hričov, geologický prieskum pre zväčšenie letiskovej dráhy) Final report. INGEO-IGHP, s.r.o. Žilina November 2007, p. 78 (in Slovak).