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3D GPR investigation of pavement using 1 GHz and 2 GHz horn type antenna – comparison of the results

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Abstract: Today, non-invasive, simple, safe, time efficient and traffic flow non-disturbing methods of the pavement diagnostics are requested. From this point of view a very convenient method seems to be the GPR investigation. The trial GPR survey of the Žilina airport was carried out in order to investigate the pavement of the runway. A testing field is placed where the geological drill hole has been drilled out. The GPR survey was performed in 3D geometry, hence in x and y directions. Two horn type antennas with central frequencies of 1 GHz and 2 GHz were used on the test field in order to verify thicknesses of pavement construction layers Here, the results of both 3D measurements are compared to each other However the investigation confirms two subhorizontal construction layers of the runway pavement, the results obtained in y-direction slightly differ at some areas. These errors are situated mainly in the areas where the linear cracks are found. On the other hand, results in x-directions are within standard error.

Key words: GPR, horn antennas, 1 GHz, 2 GHz

1. Introduction

First performed experiments using the ground penetrating radar (GPR) for the purpose of exploring road infrastructure took place in the mid-70's in USA (*Morey and Kovacs, 1977; Cantor and Kneeter, 1978; More and Erdhard, 1978*). The initial survey was focused mainly on applications in tunnels and later on bridges. These experiments investigated moisture and voids in concrete roads. The first measuring vehicle with mounted GPR system was developed in 1985 in the USA for efficient highways exploration (*Morey, 1998*). At the beginning of the 80's, the GPR began to be used

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for research purposes of road constructions (RC) in Canada and especially in Scandinavian countries (*Ulriksen, 1982; Manning and Holt, 1983; Carlsten, 1988; Carter et al., 1992*) In the second half of the 80's, it became a relatively fast tool concerning designing and restoring the RC after the initial test measurements, later also as a tool to control the quality of roads. The most common application of this type of non-invasive measurements consisted of determining the thickness of layers and subgrade structures, detecting cavities and voids risk-bearing areas in bridge constructions, identification of various armatures or buried objects in the RC. In the 90's, other European countries were joined (particularly England, France, Netherlands and others), where the non-invasive measurement methods classified as standard and routine tools of investigation, not only at the RC (*Saarenketo, 1992; Ballard, 1992; Ballard, 1993; Hobbs et al., 1993; Saarenketo and Roimela, 1998; Scullion and Saarenketo, 1998; Hopman and Beuving, 2002; Saarenketo et al., 2003; Pälli et al., 2005*). Presently the research in GPR systems for diagnosis and planning of the RC is focused mainly on automatization process of interpretation and processing the GPR records.

They put a considerable emphasis on diagnostic techniques abroad, are non-invasive, time-efficient, safe and convenient also in terms of minimum interference in which the traffic flow along the analyzed RC. Such a concept is fully in accord with the philosophy of the EuroRAP (European Road Assessment Programme). It aims to improve the road infrastructure and road safety, where the survey of the already existing infrastructure is inherent, with emphasis on the least possible risk to safety, efficiency and effectiveness without limiting the traffic. Among the methods that meet these requirements include the geophysical methods of GPR (ground penetrating radar) or optical technology of 3D scanner.

GPR is recently well accepted and known geophysical technique in many different applications (*Daniels, 2004; Jol, 2009; Pašteka et al., 2013; Putiška et al., 2013*). Originally this method had been applied to natural geologic materials for different structural and ore prospection. Now the method is well applied to other media including wood, concrete or asphalt. It is based on use of electromagnetic waves to probe the subsurface of lossy dielectric materials (*Jol, 2009*).

The Žilina Airport is an airport in the Dolný Hričov village, 10 km west of Žilina. The airport is used by foreign private flights and domestic flights, sports flights, ambulance and other types of special flights. The airport was built in the 70's of the 20th century Since the runway of the Žilina Airport was not maintained in a regular way, some issues concerned the quality of the pavement and subgrade base appeared (*Wikipedia, 2015*). The trial survey was carried out in order to test the 3D approach of GPR data acquisition, for processing and interpretation in real environment and also to compare results obtained, based on data interpretation concerning the 1 GHz and 2 GHz antennas.

2. GPR Theory and Principles

From the point of view of the current geophysical method survey, the most effective in terms of road construction diagnosis, except for the evaluation method of pavement strenght, is the GPR survey. The reasons for the growing popularity of GPR survey are several. It is in particular its non-destructive nature, high resolution, ideal investigation depth (depending on the transmitting antenna used), low price and high speed investigation that can be carried out during full traffic (*Daniels, 2004; Jol, 2009*). The data acquisition is performed in situ using GPR apparatus, consisting of the transmitter and the receiver antennas, the control unit and a digital recorder (e.g. laptop). The measurement is carried out directly on the surface. Transmitter and receiver of the horn type antenna are lifted above a surface at distance of about 0.45 m. The transmitting antenna transmits an electromagnetic pulse in regular intervals into the investigated environment of road construction. This signal is then spread within the investigated environment; some signal is reflected back and recorded by the receiving antenna (Fig. 1).

GPR systems transmit discrete pulses of radar energy These systems usually use a central frequency varying from 10 MHz up to 2500 MHz. GPR transmit short electromagnetic pulses into a medium and when the pulse reaches an interface with different electric properties, some energy is reflected back and the rest of it is proceeded forwards. The reflected energy is collected and displayed as a waveform showing amplitudes and time elapsed between wave transmission and reflection (*Saarenketo et al., 2003; Saarenketo, 2006*).

Several GPR time records (A – scan) at regular intervals along specified profile bound together give B – scan or a radargram. A radargram shows continuous record of measurements along a profile. Radargrams collected along given profiles in x and y directions can be stacked together and form a C – scan or a 3D radargram. Data processing is carried out in a specialized software system. Modified data is then interpreted and graphically processed in the end. Thicknesses of layers, possible delamination, also buried objects, inhomogeneities and other hidden faults can be calculated from the resulting travel times.

Every material is characterised by their physical properties. In the GPR survey, there are some very important variables of magnetic susceptibility, i.e. magnetism of the material, relative dielectric permittivity and electrical conductivity. Among these physical properties, the relative dielectric permittivity is essential for measurement of road materials (*Daniels, 2004; Jol, 2009*)

If the magnetic susceptibility is neglected the following simple formulae can be used in practical GPR surveys (*Jol, 2009; Matula, 2013*).

The road structural materials are distinguished on the basis of their relative dielectric permittivity (known also as the dielectric constant or dielectric value) most often for the GPR survey purpose:

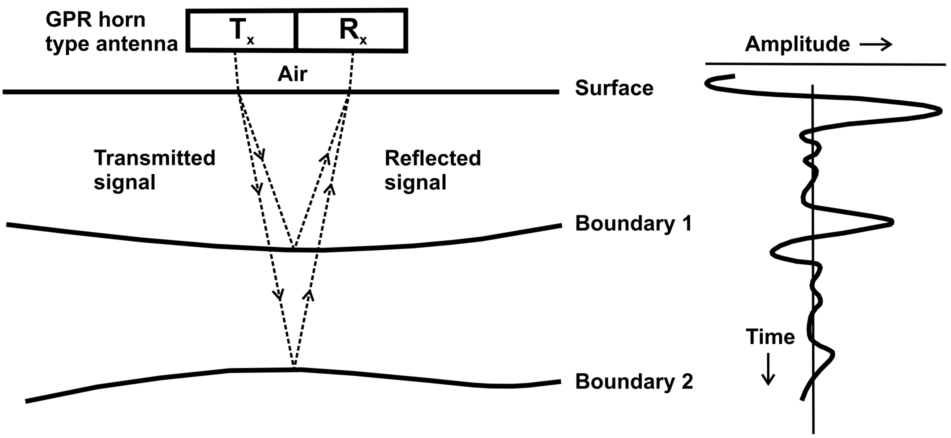

Fig. 1. Principle of GPR investigation (modified according to *Matula (2013)*). T_x is transmitting antenna and R_x is receiving antenna.

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}\,, \tag{1}$$

where ε_r is the relative dielectric permittivity of a material, ε is is the permittivity of a material and ε_0 is the permittivity of the vacuum (8.85×10^{-12} Fm^{-1}).

The velocity (v) of radar signal propagation in a medium is directly influenced by the relative dielectric permittivity (ε_r):

$$v = \frac{c_0}{\sqrt{\varepsilon_r}}\,, \tag{2}$$

where c_0 is the speed of light (2.997×10^8 ms^{-1}).

It is very important to determine the correct value of relative dielectric permittivity (ε_r) since it influences the thickness calculation of studied layers:

$$h = v\frac{\Delta t}{2}\,, \tag{3}$$

where h is the depth to an interface between layers, $\Delta t/2$ is a two-way travel time from surface of the medium to the interface depth.

3. Methodology

A small part of the Žilina Airport runway has been investigated in detail by the GPR system SIR-20 (GSSI) in a 3D alignment (grid 26 m × 14 m with spacing of 0.2 m) (Fig. 2) The test place (field) for the trial GPR survey has been chosen because of the presence of the drill hole (J02) with a documented drill core (*Záthurecký et al., 2007*). In this study antennas with central frequency of the 1 GHz and the 2 GHz were applied. The step of 0.01 m measurement has been used in both cases. The time record length differs, 20 ns were used for the 1GHz antenna and 30 ns for 2GHz antenna. Manufacturer's specified depth range for this type of antenna is about 0.9 m for 1 GHz and 0.75 m for 2 GHz antenna, which is sufficient for diagnosing the road condition and construction layers. Radargram has been treated by a special software package ReflexW.

The raw 2D data were first processed in the following manner:

Fig. 2. GPR investigation of the Žilina Airport runway, measuring procedure.

1. 1D filtration – subtract mean (dewow);
2. Correction of max 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; 100/300/1700/1900 – 1 GHz);
6. background removal;
7. spectral whitening (1500-2500 – 2 GHz; 500-1500 – 1 GHz).

Raw data, which were processed in such a manner, were consequently interpreted. Since the dielectric constant decrease, positive peaks were considered as boundaries between layers. These positive peaks were detected semi-automatically in the ReflexW software package. Two boundaries were found in both cases of investigation and more or less also interpreted on 2D profile in x and y direction if boundary was obvious. In the end, all of processed data were stacked together and give the 3D result. The definitive results of this investigation are the comparison between the results obtained from 1 GHz and 2 GHz antenna.

4. Results

The investigation in applied geophysics is carried out directly from the investigated surface, invasive techniques or methods in general are not needed. These techniques are usually expensive and time consuming therefore cannot be used on a large scale. On the other hand, geophysical methods of survey are usually less expensive, less time consuming therefore larger area can be investigated effectively. The accuracy and quality of the survey increase when more than one geophysical method is carried out. At the Žilina Airport, the GPR survey using two horn antennas (1 GHz and 2 GHz) has been elaborated. Here, the results obtained by the interpretation of data from different antennas are compared. As it has been mentioned, already two layers were identified in both interpretations; therefore the layer 1 and the layer 2 were compared in both investigated directions (x and y).

4.1. Layer 1X

The first example (Fig. 3) is the resulting comparison of the layer 1 in the x-direction between the data interpretation measured by 1 and 2 GHz antennas. In common antennas with higher frequencies have much better resolution in shallow depth but small depth range on the other hand antennas with lower frequencies having a deeper ranger of investigation. Also here, the 2 GHz antenna gives a better result in a very shallow layer It was possible to follow positive picks practically in every single line in x-direction with small discontinuities. On the other hand, it was hard to follow positive picks using 1 GHz antenna. If there were no possibility to distinguish any sharp boundary between the layers, the radargram stays un-interpreted. This happens mainly in 1 GHz antenna interpretation case in higher footage x-direction. The high quality interpretation has been difficult hence in the area where no data are available, and the comparison is missing. The final comparison shows that the difference between the 1 GHz and 2 GHz data

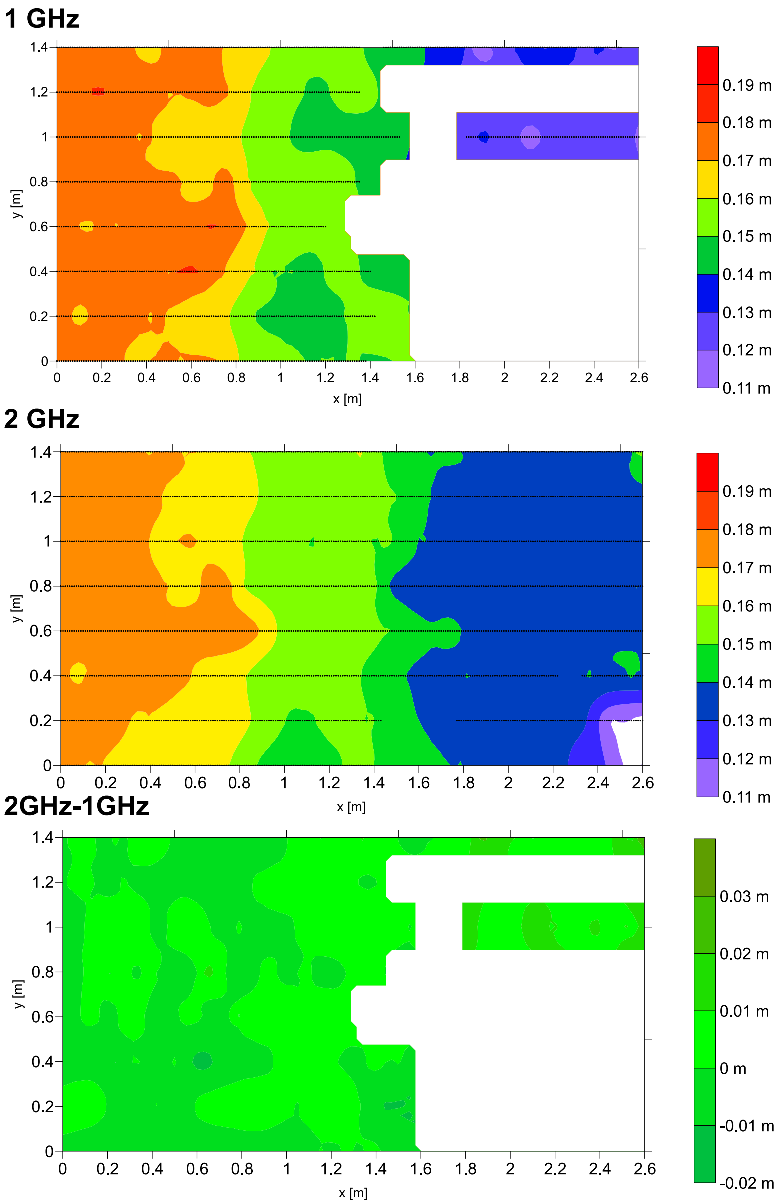

Fig. 3. Layer 1 in x-direction (Lay1X); a) result obtained by 1 GHz antenna; b) result obtained by 2 GHz antenna; c) result obtained by subtraction of 1 GHz antenna from 2 GHz antenna. White fields on maps show areas where no data are available.

interpretation is mostly very small – ± 1 cm, which is within usual error (5%−10%) (*Maser and Scullion, 1991; Morey, 1998; Matula, 2013*).

4.2. Layer 1Y

The second comparison of the layer 1 in the y-direction shows quantitatively un-satisfying results. However 2 GHz antenna gives a better result (Fig. 4), the positive picks were quite reliably detected only in the first half of the investigated area. The data based on the 1 GHz measurements interpretation are even worse. It was hard to detect significant positive picks. And as the Fig. 4 shows, interpreted data are quite disturbing The feature about the $x = 1.4$ m can be only seen on this profile when using 1 GHz. On the other hand, the profile lies exactly on the linear crack which could be impregnated by water. This fact can significantly influence the measurements The 2 GHz profiles in y-direction are very similar to the previous profiles in x-direction. Also here, the good quality interpretation was difficult the comparison is missing where there are no interpreted data available. The final comparison shows that the difference between the 1 GHz and 2 GHz data is excessively higher than it can be reasonable mainly on the $x = 1.4$ m profile.

4.3. Layer 2X

The third comparison is comparison of the second layer (Layer 2, Fig. 5) and results in the x-direction. It shows quantitatively good results. Both antennas have good resolution at the Layer 2 depth, therefore the boundary can be followed truly. However it was quite easy to detect the boundary, both results slightly differ mainly about $1-12$ m on the y-axis. This difference is not significant and is still smaller than 10%.

4.4. Layer 2Y

The fourth result (Fig. 6) shows a comparison of the Layer 2 in the y-direction. As it was in the previous Layer 1 (y-direction) case, figure shows bigger differences comparing results of both antennas (mainly about $x = 1.4$ m, which is similar to the Layer 1 1 GHz case and $x = 0.4$ m; $x = 2.0$ m).

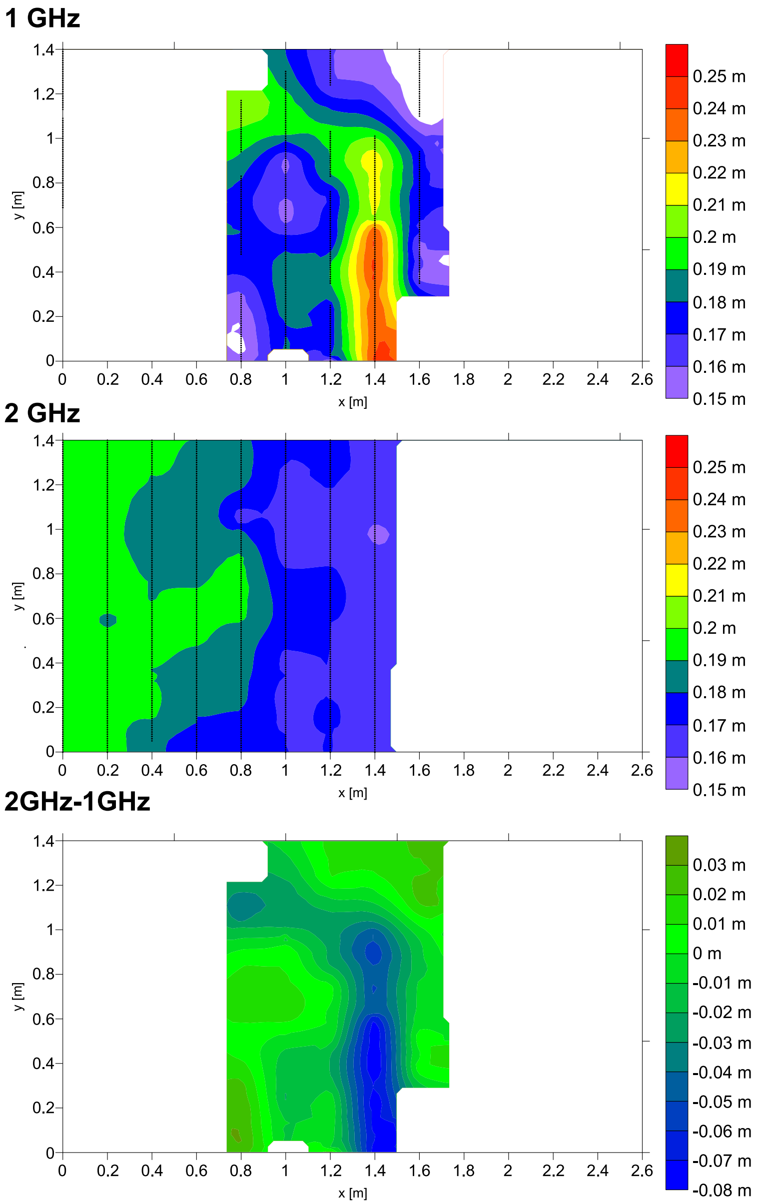

Fig. 4. Layer 1 in y-direction (Lay1Y); a) result obtained by 1 GHz antenna; b) result obtained by 2 GHz antenna; c) result obtained by subtraction of 1 GHz antenna from 2 GHz antenna. White fields on maps show areas where no data are available.

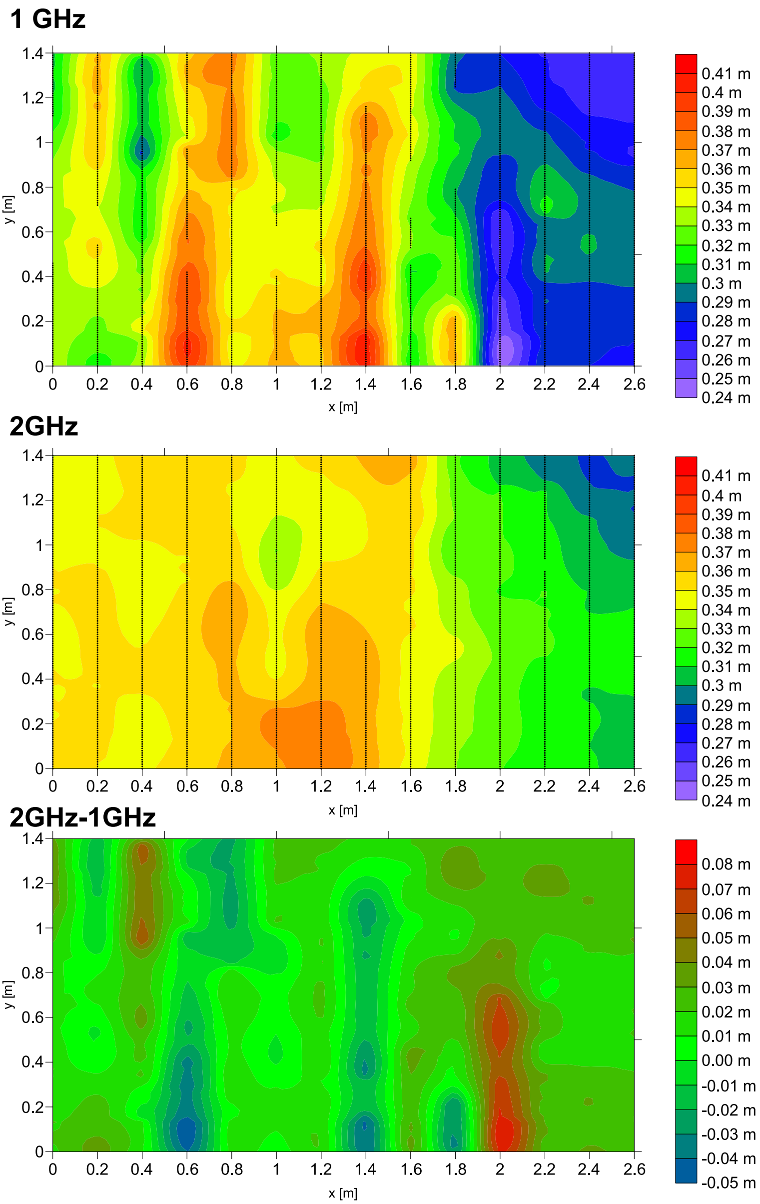

Fig. 5. Layer 2 in x-direction (Lay2X); a) result obtained by 1 GHz antenna; b) result obtained by 2 GHz antenna; c) result obtained by subtraction of 1 GHz antenna from 2 GHz antenna.

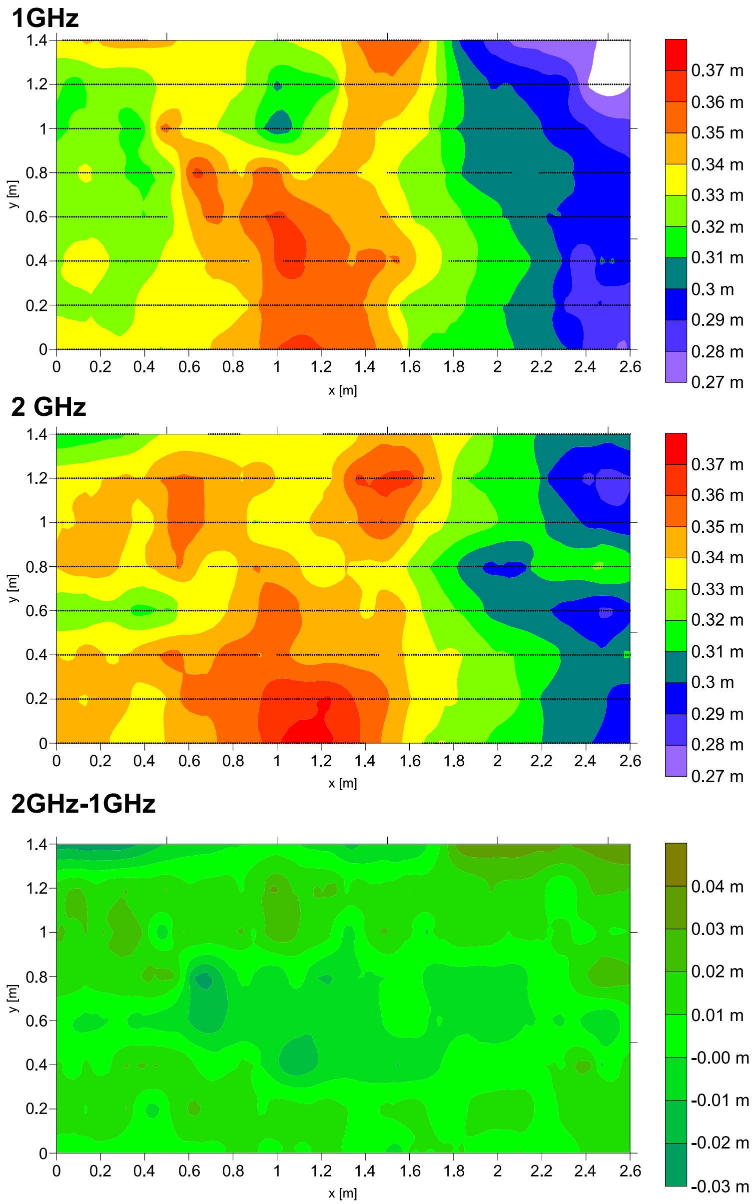

Fig. 6. Layer 2 in y-direction (Lay2Y); a) result obtained by 1 GHz antenna; b) result obtained by 2 GHz antenna; c) result obtained by subtraction of 1 GHz antenna from 2 GHz antenna.

Also here, there are areas with good fit and with fit that does not satisfy. Areas where the difference is bigger than ±0.04 m, the error exceeding the 10% boundary.

5. Conclusion

Progressive methods for the assessment of road surface quality are meant to facilitate the fulfilment of one of the central objectives of the research activity 3.1 – "research and development in the field of monitoring and assessment of transport infrastructure" in the framework of the Research Centre founded under the auspices of the University of Žilina.

One of the main subjects of this activity is the development and verification of the new conditions diagnostic and monitoring methods of the transport infrastructure. The comprehensive output of the research project will be a development of infrastructure diagnostic systems and methodologies for automated data collection. Consequently, it will therefore be possible to objectively evaluate variables and in-variable parameters of a road.

Here, comparison of the results based on the geophysical measurements with the device SIR 20 (GSSI) between two horn antennas with central frequencies of 1 and 2 GHz are presented. In common results in x-directions seem to give better results in terms of tighter fit. On the other hand, in y-direction the results are quantitatively less satisfying. The fact is also that the antenna of 1 GHz gives qualitatively worse resulting data than 2 GHz antenna data about Layer 1. This might be caused by a worse resolution of the 1 GHz antenna in very shallow depth or/and the presence of water in the pavement. It would be very advisable to use also other fast geophysical methods (e.g. Dipole electromagnetic profiling – DEMP) in order to do the interpretation more accurate. However the 3D GPR survey is more time consuming than classical 2D survey, and it gives a better idea about the distributions of anomalies in the investigated area.

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References

Ballard G., 1992: Under the Skin. World Highways/Routes du Monde. Jan/Feb 1992, 37–39.

Ballard G., 1993: Non Destructive Assesment of Pavement Design New Build Quality. Proceedings of Conference on Non-Destructive Testing in Civil Engineering, 1–16 April 1993, Liverpool, UK, 39–404.

Cantor T., Kneeter C., 1978: Radar and Acoustic Emission Applied to Study of Bridge Deck, Suspension Cables and Masonry Tunnel. Transportation Research Record 676, Washington D.C., 37–42.

Carlsten P., 1988: Peat, Geotechnical Properties and Up-to-Date Methods of Design and Construction. Varia 215. Statens geotekniska institut, Linköping, Sweden. 35 p.

Carter C R., Chung T., Masliwec T., Manning D G., 1992: Analysis of Radar Reflections from Asphalt Covered Bridge Deck Structures. In: J A. Pilon (ed) Ground Penetrating Radar, Geological Survey of Canada, Paper no. 90-4, 3–40.

Daniels J. D., 2004: Ground penetrating radar, 2nd edition. Published by the Institution of Electrical Engineers, London, United Kingdom, p. 734.

Hobbs C. P., Temple J A. G., Hillier M. J., 1993: Radar Inspection of Civil Engineering Structures. In: J. Bungey (ed) Proceedings of Conference on Non-Destructive Testing in Civil Engineering, 1–16 April, Liverpool, UK, 7–96.

Hopman V., Beuving E., 2002: Repeatability, Reproducibility and Accuracy of GPR Measurements. In: Proceedings of the 6th International Conference on the Bearing Capacity of Roads, Railways and Airfields, Lisbon, Portugal, 24–26 June, 2002, 637–645.

Jol H. M., 2009: Ground Penetrating Radar: Theory and Applications. Elsevier Science Amsterdam, First edition 2009, p. 509.

Manning D. G., Holt F B., 1983: Detecting Deterioration in Asphalt Covered Bridge Decks. Transportation Research Record, 899, 10–19.

Matula R., 2013: Nondestructive diagnostic of road pavement structures by ground penetrating radar (Nedestruktivní diagnostika konstrukcí vozovek pozemních komunikací georadarem). Thesis, Univerzita Pardubice, Pardubice, p. 148 (in Czech).

Maser K. R, Scullion T., 1991: Automated detection of pavement layer thicknesses and subsurface moisture using Ground Penetrating Radar. Transportation Research Board Paper 1991, p. 12.

More J R., Erhard J D., 1978: Radar Detection of Voids Under Concrete Highways. Georgia Institute of Technology, Atlanta, p. 68.

Morey R. M., Kovacs A., 1977: Detection of Moisture in Construction Materials. CRREL (Cold Region Research and Engineering Laboratory). Report 77–25. Hannover, New Hampshire, 9 p.

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.

Pälli A., Aho S., Pesonen E., 2005: Ground Penetrating Radar as a Quality Assurance Method for Paved and Gravel Roads in Finland, Proceedings of the 3rd International Workshop on Advanced Ground Penetrating Radar, S. Lambot and A. G. Gorriti (eds), May –3, 2005, Delft, The Netherlands.

Pašteka R., Wunderlich T., Wilken D., Stümpel H., Rabbel W., Erkul E., Herceg P., Kvetánová I., Pánisová J., Papčo J., Putiška R., Kušnirák D., Krajňák M., 2013: Results of the archaeogeophysical research of the site Katarínka realized during the years 2011 – 2012, 10th Slovak Geophysical Conference, Smolenice, 19.–21. 8. 2013. Bratislava: Geophysical Institute, Slovak Academy of Sciences, 2013. ISBN 978-80-85754-27-8, 55–56 CD-ROM.

Putiška R., Kušnirák D., Dostál I., 2013: Waterborne GPR survey for riverbed-sediment mapping, 10th Slovak Geophysical Conference, Smolenice, 19.-21.8.2013. Bratislava: Geophysical Institute, Slovak Academy of Sciences, 2013. ISBN 978-80-85754-27-8, 58–59, CD-ROM.

Saarenketo T., 1992: Ground Penetrating Radar Applications in Road Design and Construction in Finnish Lapland. Geological Survey of Finland, Special Paper 15, 161–167.

Saarenketo T., Roimela P., 1998: Ground Penetrating Radar Technique in Asphalt Pavement Density Quality Control. Proceedings of the Seventh International Conference on Ground Penetrating Radar, May 27–30, 1998, Lawrence Kansas, Vol. 2, 461–466.

Saarenketo T., Silvast M., Noukka J., 2003: Using GPR on Railways to Identify Frost Susceptible Areas. Proceedings of 6th International Conference on Railway Engineering, April 3–May 1 2003, London, UK, 11 p.

Saarenketo T., 2006: Electrical properties of road materials and subgrade soils and the use of Ground Penetrating Radar in traffic infrastructure surveys. Faculty of Science, Department of Geosciences, University of Oulu, PhD. Thesis, p. 121

Scullion T., Saarenketo T., 1998: Applications of Ground Penetrating Radar Technology for Network and Project Level Pavement Management Survey Systems. Proceedings of the 4th International Conference on Managing Pavements, Durban, South Africa, 17th–21st May 1998.

Ulriksen C. P. F., 1982: Application of Impulse Radar to Civil Engineering. Doctoral Thesis. Lund University of Technology. Department of Engineering Geology, 179 p.

Wikipedia, the free encyclopedia online, 2015: Žilina Airport (Letisko Žilina) `http://sk.wikipedia.org/wiki/Letisko_%C5%BDilina` (accessed February 15, 2015) (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, Ltd., Žilina November 2007 p. 78 (in Slovak).