CETRA2022 11-13 May 2022, Pula, Croatia
7th International Conferenceon Road and Rail Infrastructure

INFLUENCE OF DATA ACQUISITION SPEED ON PAVEMENT LAYER THICKNESS DETERMINED BY GPR

Šime Bezina, Ivica Stančerić, Tatjana Rukavina, Josipa Domitrović
University of Zagreb, Faculty of Civil Engineering, Department of Transportation Engineering

Abstract

Information on pavement layer thickness is crucial for estimating bearing capacity, assessing remaining service life, and strengthening planning. Traditionally, the pavement layer thickness is determined by extracting cores and digging test pits. These methods are destructive, require temporary road closures and subsequent repairs, and at the same time provide incomplete information as the data relates to a specific location. For this reason, ground-penetrating radar has become one of the most widely used methods for determining pavement layer thickness in recent decades. GPR is a non-destructive testing method based on the emission of low-power electromagnetic waves to obtain images of subsurface layers. The reflection and scattering of the broadband electromagnetic waves emitted by the radar occur due to discontinuities in the electrical and magnetic properties of the structure under investigation. The echoes detected in the structures or subsurface layers under investigation are then converted into images using signal processing and imaging techniques. The main advantage of the GPR application is continuous data acquisition at a steady driving speed without interrupting traffic, resulting in reduced cost and inconvenience to users. This study aimed to investigate the effect of data acquisition speed on the accuracy and repeatability of the GPR method for determining pavement layer thickness. Data acquisition was performed using a survey vehicle equipped with an air-coupled GPR system. The speed of the survey vehicle varied between 30 and 100 km/h (in steps of 10 km/h). After interpreting the GPR data, the pavement layers thickness was compared with the cores.

Keywords: ground-penetrating radar (GPR), asphalt layer thickness, non-destructive testing (NDT), repeatability, statistical analysis

1 Introduction

Pavement is a crucial element of the road network that must ensure safe and uninterrupted traffic flow throughout its service life. This is achieved by applying appropriate maintenance procedures and measures, which should be based on data on the actual condition of the pavement and its physical properties. In recent decades, data on pavement conditions are usually obtained by non-destructive testing (NDT) methods, as they are fast, reliable, and cost-effective. One such method is ground-penetrating radar (GPR). The GPR method is based on the emission of low power electromagnetic waves to obtain images of the subsurface layers [1]. The reflection and scattering of wide-band electromagnetic waves transmitted by radar occur because of discontinuities in the electrical and magnetic properties of the studied structure. The echoes detected in the examined structures or subsurface layers are then converted into images using signal processing and imaging techniques.

GPR is used efficiently for subsurface inspection, such as: determining the location of reinforcements [2], appraising the condition of pipes [3], evaluating the degree of compaction of the asphalt layer [4], and delamination between asphalt layers [5], as well as to detect moisture damage in the asphalt pavement [6]. However, GPR has been the most widely used method for determining the pavement layer thickness, which was its primary function [7]. Information on pavement layer thickness is crucial for estimating bearing capacity, assessing remaining service life, and strengthening planning. In the 2000s, the accuracy of determining the pavement layer thickness by GPR was systematically researched in the USA [8], [9], [10]. According to a test [8], a hot mix asphalt (HMA) layer thickness error of about 3 % was found when the individual layers were resolved in the reflected GPR signal. The error increased to 12 % when the entire HMA layer was considered without resolving the thin layers. By test [9], conducted on heavily trafficked highways, the error in determining asphalt layer thickness ranged from 3.7 % to 8.4 %, with a mean of 5.7 %. The GPR error in determining asphalt layer thickness ranged from 3.7 % to 11.8 %, with a mean of 8.0 %, as reported by [10]. In Europe, studies have been conducted on motorways, regional and county roads as well as on airport runways and aprons [11-13]. The error for motorways' new pavements was mainly less than 10 % and varied from 0.16 % to 12.32 % [11]. For regional and county roads that have been in service for years, the error ranges from 6.70 % to 14.83 % [11]. The thickness of asphalt overlay on runways was found to have a relative error ranging from 2.0 % to 12.9 % [12] and less than 5.6 % on an apron [13].
The main advantage of the GPR application is continuous data acquisition at a steady driving speed without interrupting traffic, resulting in reduced cost and inconvenience to users. As stated in [14], GPR can acquire data at speeds up to 100 km/h. The aim of this study was to investigate the effect of data acquisition speed on the accuracy and repeatability of the GPR method for determining pavement layer thickness.

2 Methodology of research

The test was conducted on the B8 expressway in Croatia on the section between Lupoglav and Cerovlje, which was opened for traffic at the end of 1988. Visual inspection revealed significant pavement deterioration, primarily with crocodile cracking and rutting in the wheel path. According to the project design, the pavement should consist of AC surf layer (thickness of 40 mm), AC base layer (thickness of 80 mm) and a layer of compacted crushed stone aggregate (thickness of 300 mm). Due to the extracted cores, it was determined that the thicknesses of both asphalt layers (AC surf and AC base) ranged between 105 mm and 170 mm. The thickness of the unbound granular base course layer, located just below the asphalt layers, varied between 195 mm and 370 mm. The influence of data acquisition speed on pavement layer thickness determined by GPR was checked on 100 m subsection of the expressway (Fig. 1a).

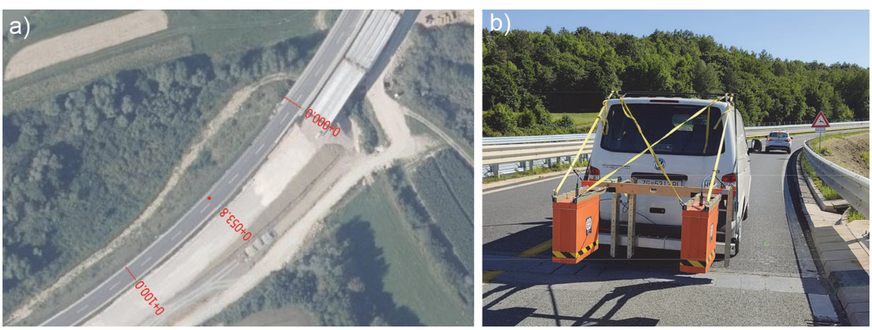

Figure 1 GPR data acquisition a) display of the road subsection [15]; b) survey vehicle

2.1 GPR data acquisition

The survey vehicle (Fig. 1b) was equipped with GPR system and was used to acquire the data on the total asphalt layer thickness of the pavement. The system included a 1.0 GHz air-coupled antenna, a central unit for connecting the system components (SIR 20), a computer for processing and storing the data and a distance measuring instrument (DMI).

Table 1 Parameters and filters

Parameters and filters	Variable	Value
Position/Range	Range (ns)	20
	Position (ns)	96
Range gain	Point	1
	Number of points	1
	Value	13
FIR filter	Low pass [MHz]	5000
	High pass [MHz]	300
	Filter type	boxcar

Before starting data acquisition, specific parameters and filters need to be set (Table 1). Position correction is the parameter that controls the length of the time that the system will acquire data. Range gain, controls the time-variable gain. Gain is signal amplification used to compensate for the natural effects of signal attenuation. As the transmitted signal passes through a material, it will attenuate as the material absorbs some signal. Gain amplifies that signal, after it is received, to compensate for signal losses and make weaker reflectors easier to see. A finite impulse response filter help reduce high and low-frequency noise in the data. For the examination purpose, the influence of data collection speed on the accuracy of layer thickness and repeatability, data acquisition was made on a 100 m subsection. Data collection speed varied between 30 km/h and 100 km/h, in 10 km/h increments. For individual speed, data were collected three times. Data were collected every 10 cm along the lines. The dilatation on the viaduct was chosen as the start position for the measurement line (Figs. 1, 2). Since the reflection of electromagnetic (EM) waves from the steel dilatation is complete in radargram, the exact position of the start point can be clearly seen when interpreting the data. The endpoint of the measuring line was determined based on the DMI value. Approximately at half-length of the measuring line, core was extracted to determine the thickness of the asphalt layers.

2.2 Processing and interpretation of the GPR data

The values for the total thickness of the asphalt layers were obtained by interpreting the acquired data (Fig. 2). The GPR data was processed before interpretation by combining the raw GPR data with the calibration data acquired over the metal plate. The principle of using GPR to calculate the layer thickness was, in detail, explained in [16]. The processing and interpretation of the acquired GPR data was, according to [17] performed in RADAN 6.6 software. At the different layer boundaries within the pavement, the EM wave reflections were visually identified in the B scan (Fig. 2a). As can be seen in Figure 2a, a continuous strong reflection defines an obvious interface between the air and asphalt layers and between the asphalt layer and the unbound base layer. The layer depth was determined by interpretation based on finding the nearest peak. Layer thickness for different data acquisition speed are presented on Figure 3.

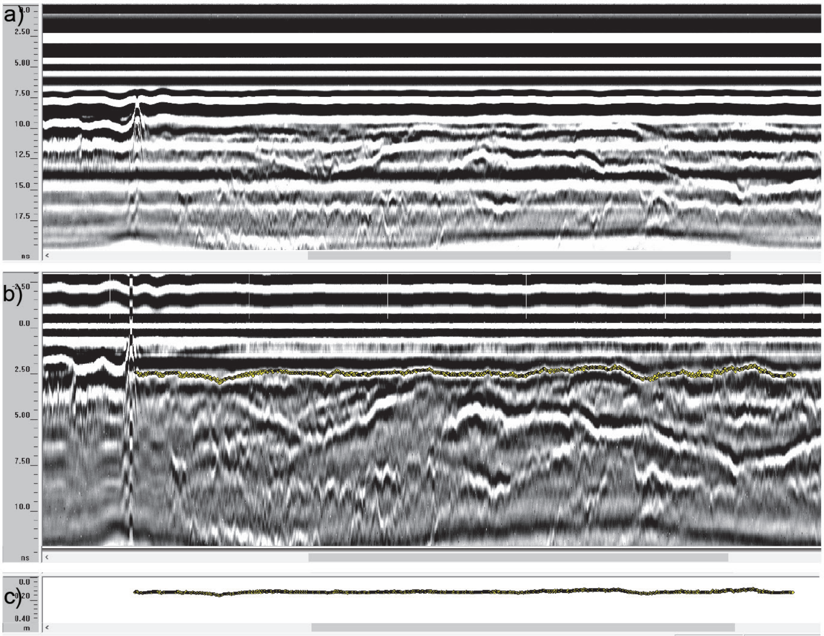

Figure 2 Example of the layer thickness determination procedure a) raw GPR data; b) processed and interpretated GPR data; c) total asphalt layer thickness

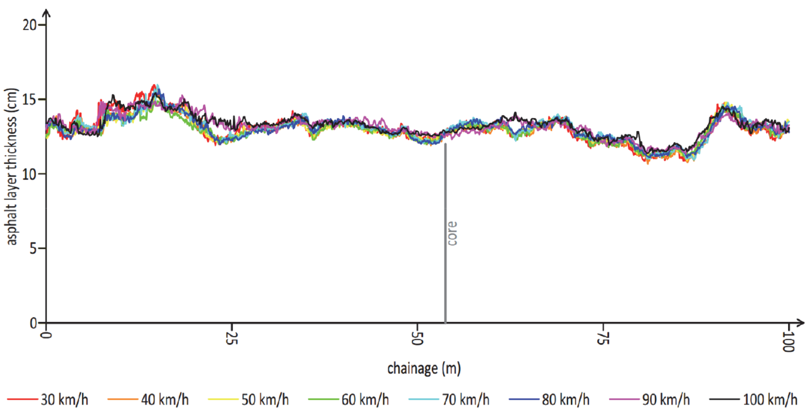

Figure 3 Asphalt layer thickness at different data acquisition speed

3 Results

In order to determine the repeatability of GPR measurements, statistical processing of test results (asphalt layers thickness) was performed. Statistical data based on average values from three measurements are presented in Table 2. Data show the following:

- The minimum thickness of asphalt layers was recorded at a speed of 40 km/h and is 104 mm, the largest difference in measured thicknesses, depending on the speed, is 4 mm,
- The maximum thickness of asphalt layers was recorded at speeds of 30 and 90 km/h and is 160 mm, the largest difference between the measured thicknesses, depending on the speed, is 10 mm
- The average thickness of asphalt layers is the highest for the speed of 100 km/h, and the lowest for the speed of 40 and 60 km/h, the largest difference between the average values of the measured thickness depending on the speed is 4 mm,
- Standard deviation is the largest for speed of 30 km/h, and the smallest for speed of 50, 60 and 100 km/h, the largest difference in standard deviation, depending on speed, is 0.002,
- The coefficient of variation is the highest for the speed of 30 km/h and the lowest for the speed of 60 km/h, the largest difference in the coefficient of variation, depending on the speed, is 1.186.

In order to determine the influence of the survey vehicle/test speed on the thickness of asphalt layers, core was extracted from the pavement at a distance of 53.8 m from the beginning of the subsection. The determined thickness of the core asphalt layers was 120 mm (AC surf 35 mm and AC base 85 mm): The thickness was compared with those acquired by the GPR for each speed (Tables 2, 3). The values (average of three measurements/data collection) of the thickness of the asphalt layers ranges from 126 mm to 129 mm and the relative error of GPR measurement ranges from 5.0 % to 7.5 % (Table 3). The relative error of the thickness values acquired by the GPR was calculated as the absolute error (the difference between the GPR thickness data and core thickness) and the core thickness ratio.

Table 2 Statistical data as a result of measuring the thickness of asphalt layers by GPR (average values of three measurements)

Speed [km/h]	30	40	50	60	70	80	90	100
Min. thickness [mm]	106	104	105	107	105	107	110	110
Max. thickness [mm]	160	158	156	150	158	154	160	153
Avg. thickness [mm]	130	129	130	129	131	130	132	133
SD	0.010	0.009	0.008	0.008	0.009	0.009	0.009	0.008
CV (%)	7.433	6.835	6.474	6.247	6.636	6.615	6.653	6.282

Table 3 GPR thickness of asphalt layer on core location

Speed [km/h]	30	40	50	60	70	80	90	100
Avg. thickness [mm]	127	127	127	128	129	128	126	128
Relative error [%]	5.8	5.8	5.8	6.7	7.5	6.7	5.0	6.7

4 Conclusions

To assess the road's remaining life and bearing capacity, information on the thickness of the pavement layer is crucial. Nowadays, GPR and coring are the most widely used methods for determining pavement layer thickness. GPR is the NDT method whose application allows continuous data acquisition at a steady driving speed without interrupting traffic.

In this study, the effect of data acquisition speed on the accuracy and repeatability of the GPR method for determining pavement layer thickness is investigated. The study was conducted using a 1 GHz air-coupled antenna on a 100 m subsection of the expressway. The thickness of the asphalt layers was determined using the surface reflection method.

Statistical analysis of the GPR data acquired at different speeds between 30 km/h and 100 km/h showed excellent repeatability. The standard deviation of asphalt layer thickness ranged from 0.008 to 0.010. The coefficient of variation ranged from 6.247 % to 7.433 %.

The asphalt layer thickness values collected by coring and the GPR method, were compared to determine the effect of acquisition speed, on GPR method thickness data accuracy. The relative error ranges from 5.0 % to 7.5 %, consistent with previous research.

The statistical analysis suggests that the speed of data acquisition does not significantly affect the accuracy and repeatability of the asphalt layer thickness determined by the GPR method. However, data acquisition speed must not exceed the maximum allowable speed, which is determined based on the system settings: the number of individual data scans acquired by the system per second and the number of scans per distance along the measurement line.

References

[1] Pajewski, L., Fontul, S., Solla, M.: Ground-penetrating radar for the evaluation and monitoring of transport infrastructures (Chepter), Innovation in Near-Surface Geophysics: Instrumentation, Application, and Data Processing Methods, pp. 341–398, 2018, DOI: 10.1016/B978-0-12-812429-1.00010-6

[2] Agred, K., Klysz, G., Balayssac, J.-P.: Location of reinforcement and moisture assessment in reinforced concrete with a double receiver GPR antenna, Construction and Building Materials, 188 (2018), pp. 1119–1127, DOI: 10.1016/j.conbuildmat.2018.08.190

[3] Zhao, S., Al-Qadi, I.: Pavement drainage pipe condition assessment by GPR image reconstruction using FDTD modelling, Construction and Building Materials, 154 (2017), pp. 1283–1293, DOI: 10.1016/j.conbuildmat.2017.06.103

[4] Wang, S., Al-Qadi, I.L., Cao, Q.: Factors Impacting Monitoring Asphalt Pavement Density by Ground Penetrating Radar, NDT & E International, 115 (2020) 102296, DOI: 10.1016/j.ndteint.2020.102296

[5] Liu, H., Deng, Z., Han, F., Xia, Y., Liu, Q.H., Sato, M.: Time-frequency analysis of air-coupled GPR data for identification of delamination between pavement layers, Construction and Building Materials, 154 (2017), pp. 1207–1215, DOI: 10.1016/j.conbuildmat.2017.06.132

[6] Zhang, J., Zhang, C., Lu, Y., Zheng, T., Dong, Z., Tian, Y., Jia, Y.: In-situ recognition of moisture damage in bridge deck asphalt pavement with time-frequency features of GPR signal, Construction and Building Materials, 118295 (2020) 244, DOI: 10.1016/j.conbuildmat.2020.118295

[7] Solla, M., Pérez-Gracia, V., Fontul, S.: A Review of GPR Application on Transport Infrastructures: Troubleshooting and Best Practices, Remote Sensing, 13 (2021) 4, DOI: 10.3390/rs13040672

[8] Al-Qadi, I.L., Lahouar, S., Loulizi, A.: Ground-Penetrating Radar Calibration at the Virginia Smart Road and Signal Analysis to Improve Prediction of Flexible Pavement Layer Thicknesses, Technical Report No. FHWA/VTRC 05-CR7, Virginia Tech Transportation Institute: Charlottesville, Virginia, 2005.

[9] Flintsch, G.W., Al-Qadi, I.L., Loulizi, A., Lahouar, S., McGhee, K., Clark, T.: Field Investigation of High Performance Pavements in Virginia, Technical Report, Report No. VTRC 05-CR9, Virginia Tech Transportation Institute: Charlottesville, Virginia, 2005.

[10] Holzschuher, C., Lee, H.S., Greene, J.: Accuracy and Repeatability of Ground Penetrating Radar for Surface Layer Thickness Estimation of Florida Roadways, Technical Report No. FL/DOT/SMO/07-505, Florida Department of Transportation, State Material Office: Gainesville, FL, USA, 2007.

[11] Ožbolt, M., Rukavina, T., Domitrović, J.: Comparison of the Pavement Layers Thickness Measured by Georadar and Conventional Methods—Examples from Croatia, The Baltic Journal of Road And Bridge Engineering, 7 (2012) 1, pp. 30–35, DOI: 10.3846/bjrbe.2012.04

[12] Domitrović, J., Bezina, Š., Stančerić, I., Rukavina, T.: 3D modelling of asphalt concrete overlay based on GPR data, International Journal of Pavement Engineering, pp. 1-10, 2021, DOI:10.1080/10298436.2021.2004413

[13] Bezina, Š., Stančerić, I., Domitrović, J., Rukavina, T.: Spatial Representation of GPR Data—Accuracy of Asphalt Layers Thickness Mapping, Remote Sensing, 13 (2021) 864, pp. 1-22, DOI:10.3390/rs13050864

[14] Plati, C., Loizos, A., Gkyrtis, K.: Integration of non-destructive testing methods to assess asphalt pavement thickness, NDT & E International, 115 (2020) 102292, DOI: 10.1016/j.ndteint.2020.102292

[15] Geoportal, https://geoportal.dgu.hr/, 07.03.2022.

[16] Maser, K.R., Scullion, T.: Automated Detection of Pavement Layer Thicknesses and Subsurface Moisture Using Ground Penetrating Radar, Transport Research Record, 1344 (1991), pp. 22–30

[17] GSSI RADAN 6.6 Manual, https://www.geophysical.com/wp-content/uploads/2017/11/GSSI-RADAN-6_6-Manual.pdf, 07.03.2022.