CETRA[2018]

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

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CETRA[2018]
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
"Tiskara Zelina", May 2018

COPIES
500

Zagreb, May 2018.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
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CETRA2018 17–19 May 2018, Zadar, Croatia
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INVESTIGATING THE USE OF GPR FOR PAVEMENT CONDITION ASSESSMENT

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Abstract

Over the last two decades, Ground Penetrating Radar (GPR) has become more and more present as a tool for the evaluation of asphalt pavements. Although it is mainly used for non-destructive determination of layers thickness, significant effort is invested in exploring its possible application in determining pavement distresses. The aim of research presented in this paper was to investigate possible application of GPR for pavement condition assessment. A visual inspection of pavement surface was carried out on heavily distressed, sporadically repaired local road. Map indicating type and extent of surface distresses was created. Upon visual inspections measurements were taken by two GSSI air-coupled antennas with central frequency of 1.0 GHz and 2.0 GHz. Simultaneously to GPR measurement, high resolution digital camera was used to record pavement surface distresses. GPR measurements were repeated on the same measurement line with different system parameters settings. Additionally positon of antennas was changed to collect data on both antennas in the same measurement line. Collected data was analysed in RADAN 6.6 software. Conducted surveys have partially enabled the determination of pavement surface as well as subsurface condition.

Keywords: Ground Penetrating Radar, pavement surface distress, pavement condition, dielectric permittivity, wave speed

1 Introduction

Pavements are crucial elements of road network that, during its service life, needs to sustain adequate level of performance. In order to fulfil this task they are subjected to timely maintenance and preservation measures. For economical and effective maintenance it is necessary to collect data on pavement condition. Data collection could be performed by destructive or non-destructive techniques (NDT). Today preferable are NDT which do not impair the structural integrity of the pavement, are faster and often could be conducted under traffic.
One such technique is Ground Penetrating Radar (GPR) that is primarily used for determination of pavement layers thickness. Beside determination of layers thickness, due to accelerated development of software [1], electronic equipment and antennas [2], application of GPR is extended to detect different types of pavement distresses such as: segregation, delamination, stripping and crack detection. More recently investigations are made towards utilization of GPR for pavement condition assessment [3, 4].
In this paper air-coupled GPR system was used to investigate its possibility for pavement surface and subsurface condition assessment. Pavement surface conditions were determinate by means of pattern recognition and analysis of pavement surface reflection amplitude and amplitude of antenna movements with respect to ground surface. For assessment of pavement subsurface condition analyses of pavement layers wave propagation speed and dielectric permittivity determinate by ″reflection method″ was conducted.

2 Description of investigation site

The measurements were taken on heavily distressed, sporadically repaired local road in the length of 250 m. On this relatively short section four major pavement surface distresses were recorded and mapped. Due to sporadic repairs of the section there was a large number of patches, both expendient (Fig. 1 a) and reconstruction (Fig. 1 b) often with defects within the patch. There were also numerus potholes, single and group (Fig. 1 c) and most common distresses were delamination and alligator cracks (Fig. 1 d). Upon mapping of the distresses GPR measurements and video logging by high definition camera were conducted.

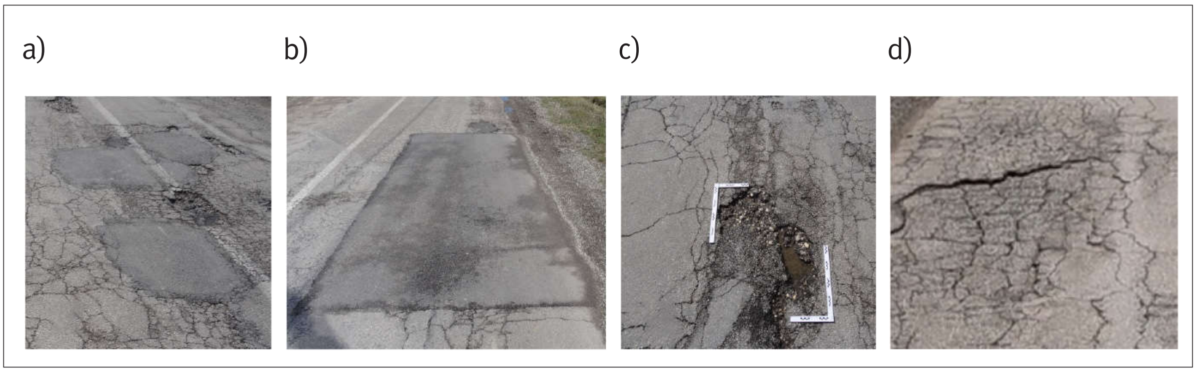

Figure 1 Example of pavement surface distresses on investigation site

3 GPR measurements

GPR system components (Figure 2), configuration and parameter settings used in this research are described in chapters 3.1 and 3.2.

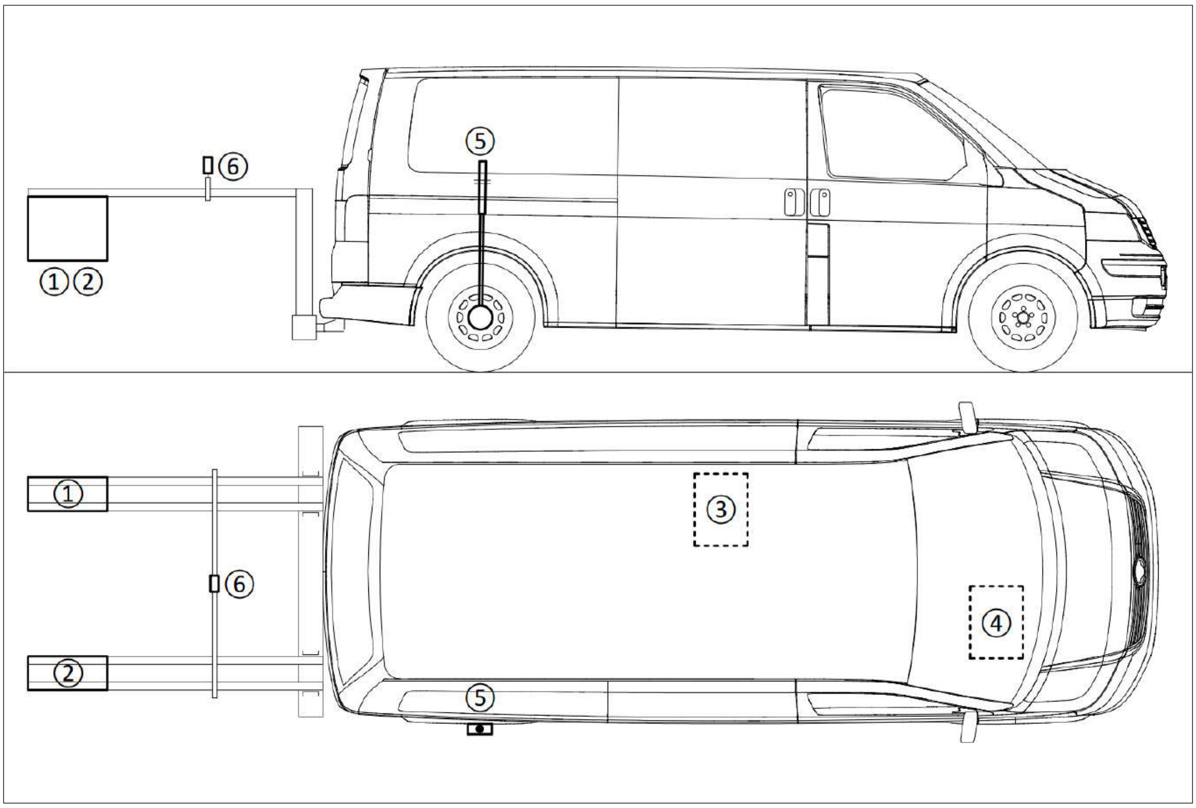

Figure 2 Schematic display of measuring equipment

3.1 Measuring equipment

For the purpose of this research two GSSI air-coupled antennas with central frequency of 1.0 and 2.0 GHz were used. Combination of these two central frequency antennas is a good compromise between the possible depth and resolution of recording. A higher frequency gives a higher resolution, but a smaller penetration depth (approx. 0.5 m), while at lower frequency, waves penetrate deeper (approx. 0.8 m) and the resolution is lower [5].
GPR system components and physical set up is shown in Fig.2. Antennas (1) (2) were set at 0.48 cm above pavement surface, more than 1.0 m from the vertical metal rods and with 1.04 m spacing between antennas. In addition to the antennas, the system consists of a SIR-20 electromagnetic wave pulse generator (3) and a portable computer (4) for data storage and processing. Distance is measured by DMI mounted on the vehicle rear wheel (5). The GPR system is complemented by a high definition digital camera (6).

3.2 GPR system configuration and parameters setup

GPR configuration and system parameters used in this research are shown in Table 1. At this stage of the research only step distance (scan/m) was changed during the measurement. Usually step distance of 10 scan/m is used for basic investigation, and 20 scan/m in a case of detailed investigation. Taking in consideration length and number of surface distresses measurements were also taken with step distance of 50 and 100 scan/m. In order to cover both lines of measurement with same central frequency, antennas position was changed after first set of measurements.

Table 1 GPR system configuration and parameters

	GPR system setup	2 GHz	1 GHz
Configuration	sample/scan	512	512
	scan/sec	200	200
	scan/m	10/20/50/100	10/20/50/100
Parameters	Range (ns)	15	20
	Position (ns)	96.5	97.5
	FIR filters low pass (MHz)	4000	3000
	FIR filters high pass (MHz)	250	250

4 GPR data interpretation

Before data interpretation choice was made on optimum number of scan/m. As it can be seen on Fig. 3 at low scan density (10 scan/m) surface distresses such as potholes could be missed during the interpretation. At scan densities of 20 and 50 scan/m pothole is noticeable, whereas density of 100 scan/m gives us real insight into extent of distress.
To cover up all surface distresses described in Section 2, further research has been conducted on GPR data recorded with scan density of 100 scan/m. Data from 2.0 GHz antenna was used to detect surface distresses while the data from 1.0 GHz antenna served for assessment of pavement subsurface condition.

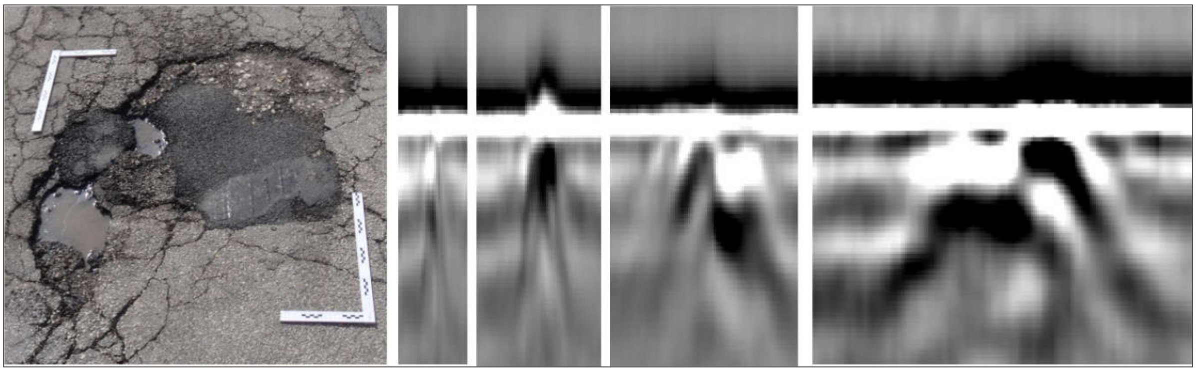

Figure 3 Linescan of pothole recorded with 10, 20, 50 and 100 scan/m (from left to right)

4.1 Pavement surface conditions

Evaluation of pavement surface condition was done by combining visual observations, on-site and video, with visual inspection of GPR profile. To determine homogenous zones of pavement surface analysis of surface reflection amplitude and amplitude of antenna movements with respect to ground surface was done. Fig. 4 shows Linescale of first 25 m on investigation site and diagram of surface reflection amplitude with distinctive homogenous zones. On the basis of inspected elements five distinctive zones were determinate and connected to specific pavement surface condition. For the purpose of distinguishing between five major surface distresses on radargram the way they are seen in Linescan and O-Scope was explored and is described below.

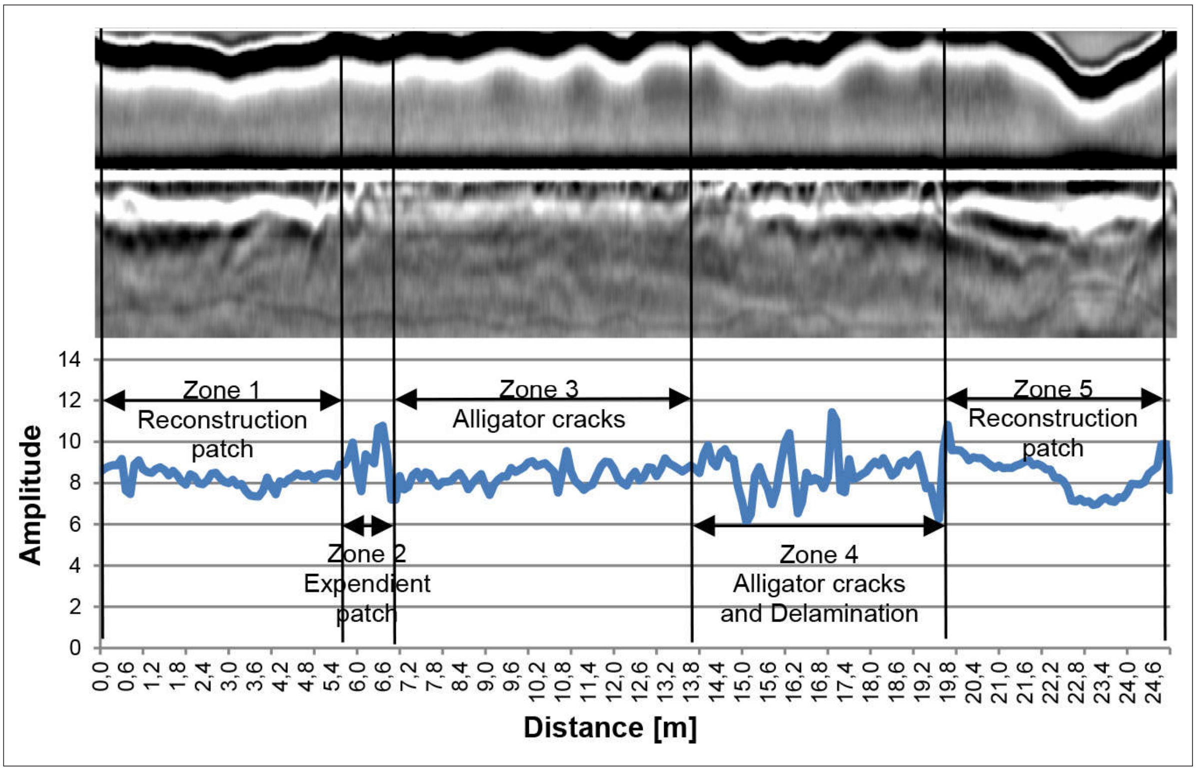

Figure 4 Example of radargram and diagram of surface reflection with homogenous zones

Reconstruction and expedient patch

Bottom of reconstruction patches was easy to spot in Linescane as white stripe with clearly defined edges and uniform thickness, whereas on O-Scope it is seen as strong positive reflection (Fig. 5 a).

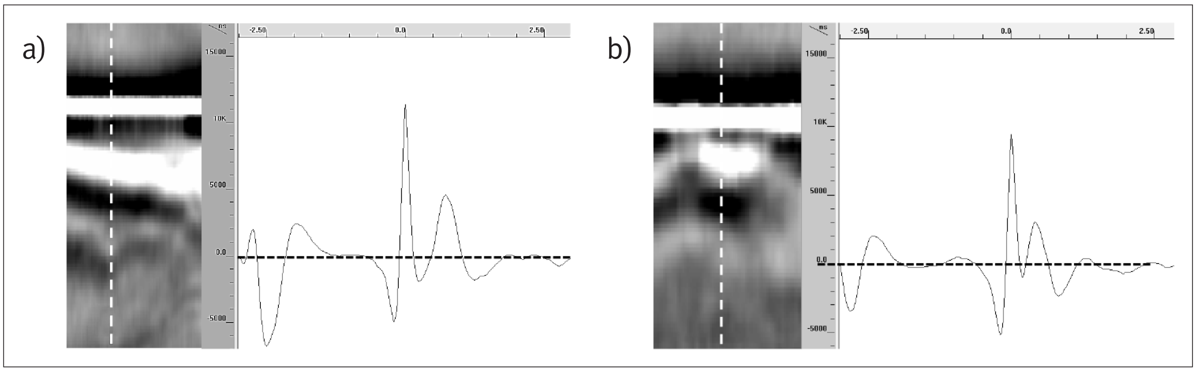

Figure 5 Linescan and O-Scope of reconstruction (a) and expedient patch (b)

The way we can see bottom of expedient patch depends on its depth and length. Typically it is seen as near surface, relatively shallow, white section with smeared edges in Linescane and as near surface positive reflection of smaller amplitude on O-Scope (Fig. 5 b).

Pothole

Due to presence of water in potholes they are seen on Linescan as near surface, relatively shallow, black section and on O-Scopes as near surface negative reflection with higher surface amplitude (Fig. 6 a).

Alligator cracks and delamination

Because alligator cracks and delamination on investigation site almost always appeared together the attempt was made to find a pattern in appearance in GPR data for both distress types. In Linescan and O-Scope these distresses can be recognized as areas without distinct continuous positive or negative reflection. The appearance of O-Scope changes from scan to scan and their only common parameter is small reflection amplitude (Fig. 6 b)

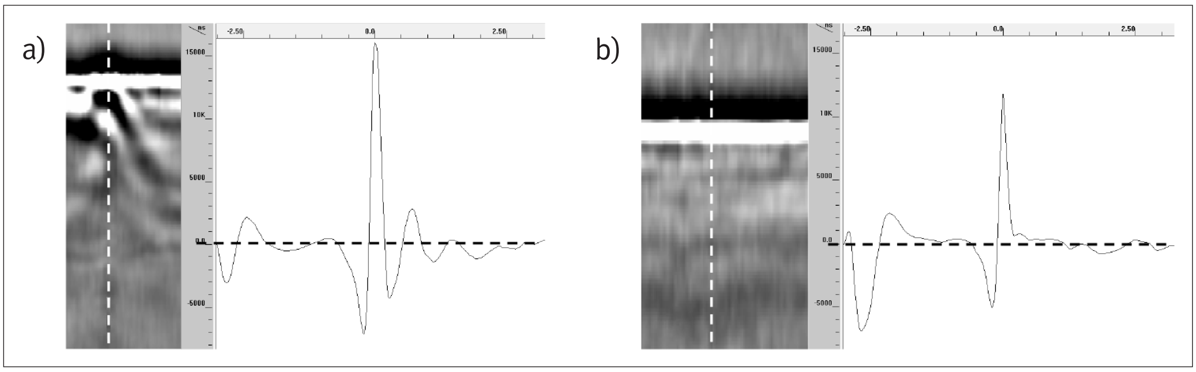

Figure 6 Linescan and O-Scope of pothole (a) and alligator cracks and delamination (b)

Conducted analyses show that it is possible to distinguish homogeneous zones on the bases of surface reflection amplitude and antenna movements and connect them to visual observed surface distressed. Distinguishing between various surface distresses on the bases of Linescale and O-Scope pattern recognition is time consuming and there is great possibility of replacement between different distresses, for example between aggregate polishing and alligator cracks.

4.2 Subsurface pavement condition

Procedure for evaluation of pavement subsurface condition is presented in the paper on first 25 m of investigation site. This section was divided in three zones for estimation of asphalt wearing course and six zones for estimation of asphalt base and unbound base condition

(Fig. 7). On the radargram three distinctive positive reflections representing three layer interfaces were noticed. For defined zones an analysis of layers average depth, wave speed and dielectric value determinate by ″reflection method″ [6] was conducted (Table 2).
Interface between asphalt wearing and asphalt base layer was defined as first distinctive positive refection underneath pavement surface. Interface between asphalt base and unbound base was defined as first continuous reflection underneath asphalt wearing layer. Asphalt base in reality consisted of number of asphalt layers (differing in thickness and length) that were built over the years as remediation measures. Due to similar electric properties of these layers in GPR interpretation they were treated as one layer. Interface between unbound base and subbase was defined as second continuous reflection underneath asphalt wearing layer.

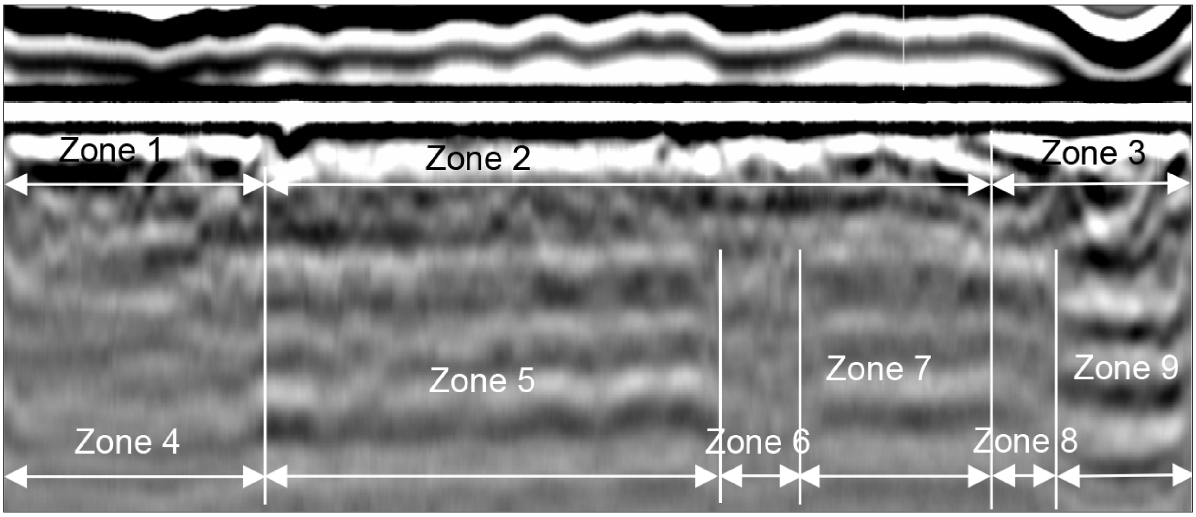

Figure 7 Example of radargram with defined homogeneous zones

Condition of previously defined layers was estimated on the basis of characteristic values of wave speed and dielectric permittivity for various road construction materials find in the literature [5, 4, 7].

Table 2 Characteristics of pavement layers

Homogeneous zone		**Zone 1**	**Zone 2**			**Zone 3**	
Asphalt wearing layer	**z (cm)**	7.6	7.8			6.4	
	v (cm/ns)	16.5	14.9			13.8	
	ε'_r	3.3	4.0			5.3	
Homogeneous zone		**Zone 4**	**Zone 5**	**Zone 6**	**Zone 7**	**Zone 8**	**Zone 9**
Asphalt base	**z (cm)**	23.3	23.2	21.2	20.1	18.4	14.6
	v (cm/ns)	9.0	11.7	10.3	10.9	8.0	4.9
	ε'_r	11.1	6.6	8.5	7.6	14.1	37.5
Unbound base	**z (cm)**	35.8	39.9	38.2	36.9	30.7	25.1
	v (cm/ns)	8.4	10.3	9.5	9.9	7.4	3.9
	ε'_r	12.7	8.5	9.9	9.2	16.4	59.2

Values of dielectric permittivity for dry asphalt vary between 2 and 5, and between 6 and 12 for moist asphalt [5]. As it can be seen in Table 2 asphalt wearing layer can be classified as dry, while asphalt base course in zones 4 to 7 is considered as moist. In zones 8 and 9 values of dielectric permittivity are 14.1 and 37.5 respectively. Such high values of dielectric permittivity are not characteristic for asphalt, dry or moist. So, it can be assumed that there is high amount of water infiltrating asphalt base layer making it unstable.

According to quality criteria for unstabilized base material [7] unbound base condition for zones 5 to 7 can be classified as good aggregate base at or below optimum moisture content with good bearing capacity. Unbound base in zone 4 is moist susceptible indicating reduced but adequate bearing capacity. Whereas zones 8 and 9 are highly water susceptible with low bearing capacity prone to plastic deformations under traffic load.

5 Conclusions

In the case study presented in this paper, GPR measurements with two air-coupled antennas were conducted on heavily distressed local road. Pavement condition on investigation site was assessed by analysing surface reflection amplitude, amplitudes of antenna movements, distress pattern recognition, determination of subsurface layers and analysing layers wave speed and dielectric permittivity calculated by ″reflection method″. Pavement surface condition can be evaluated by combining on site observations and video record with GPR data on surface reflection amplitude and amplitude of antenna movements with respect to ground surface. Detecting surface distresses on the basis of pattern recognition requires significant amount of manual data analysis and there is a possibility of misinterpreted. Subsurface pavement condition can be evaluated by analysing variations in layers depth, dielectric permittivity and wave speed. Obtained results can be used to identify possible causes of pavement degradation, primarily if the cause is moisture related. If there are a large number of surface distresses on a short pavement section it is not possible to connect subsurface pavement condition to certain surface distress. Obtained results indicate that there is a possibility of applying GPR in combination with video record for pavement condition assessment, but only as a means of identifying potential problems in pavement layers. In order to obtain real insight into pavement condition GPR should be combined with other NDT methods.

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