A comparison of dielectric constants of various asphalts calculated from time intervals and amplitudes

Andrea Porubiaková*, Jozef Komačka

University of Žilina, Faculty of Civil Engineering, Department of Highway Engineering, Univerzitná 8215/1, 01026 Žilina, Slovak Republic

Abstract

When measurements by a Ground Penetrating Radar are evaluated, a dielectric constant is very important electrical property of pavement materials. The numerical value of the dielectric constant is different for various materials used in road construction and it affects the signal velocity in pavement layers. The main subject of research outputs introduced in the article is comparison of dielectric constants of the various asphalts calculated from time intervals and amplitudes. The series of laboratory and in situ measurements were made on three different asphalts (Asphalt Concrete (AC), Porous Asphalt (PA) and Stone Mastic Asphalt SMA). The Ground Penetrating Radar (GPR) with 2 GHz air-coupled antenna was used. The antenna was moved over three sections: floor, a steel plate and an asphalt slab. The dielectric constant of asphalt was determined using time interval between positive amplitudes peaks representing the asphalt slab thickness and also using the amplitudes values. It was found the dielectric constants of the AC, PA and SMA differed regardless the calculation method. Differences in dielectric constant values were also found between two calculation methods.

Keywords: GPR; Amplitude; Frequency; Air-coupled antenna; Dielectric constant; Asphalt; Time.

* Corresponding author. Tel.: +421-41-513-5947.
E-mail address: andrea.porubiakova@fstav.uniza.sk
1. Introduction

To keep quality of transport infrastructure at the level that provides comfortable, safe and economic drive for road users require also regular diagnosis of road pavements. Ground Penetrating Radar (GPR) is one of diagnostic devices developed for identification not only pavement structure layers but also defects in pavement structure.

GPR systems use discrete pulses of electromagnetic energy with a central frequency from 10 MHz up to 2,5 GHz to detect locations and dimensions of electrically distinctive layers and objects in materials [3]. Pulse radar systems transmit short electromagnetic pulses into a medium and when the pulse reaches an electric interface in the medium, some of energy will be reflected back while the rest will proceed forwards. The reflected energy is collected and displayed as a waveform showing amplitudes and time elapsed between transmission and reflection. The basic principle of GPR is shown in Figure 1.

![Figure 1](image)

Fig. 1. Typical GPR reflections from a pavement system [2]

Velocity of GPR signal propagation is influenced by the properties of material. A dielectric constant is the most important material characteristic from this point of view. As it is stated in [4] it is not constant for road construction materials and due to possible variability in material composition can be found in a range (Table 1). The range of dielectric constants for asphalts is wide and it is necessary to specify correct value when thickness of asphalt layers has to be determined. Therefore, cores are obviously taken from pavement to calculate the dielectric constant value. When this destructive method could not be applied knowledge of the dielectric constant values of various asphalts is useful information. There is not a lot of information on this topic and therefore the laboratory investigations were carried out on three kinds of asphalts used in Slovakia for wearing courses.

Table 1. Range of dielectric constants [4]

| Material        | Dielectric constant | Velocity [mm.ns⁻¹] |
|-----------------|---------------------|-------------------|
| Air             | 1                   | 299               |
| Asphalt mixtures| 4-10                | 90-160            |
| Concrete        | 5-9                 | 100-130           |
| Aggregate       | 6-18                | 70-120            |
| Water           | 81                  | 33                |
2. Dielectric constant calculation

According [1] the use of GPR to assess pavement properties relies on the effect that different materials, and material properties, have influence on the passage of electromagnetic waves from GPR. A number of factors can affect the propagation of GPR signals and the electromagnetic properties of a material are particularly important: namely the dielectric permittivity ($\varepsilon$), magnetic permeability ($\mu$) and electrical conductivity ($\sigma$). The dielectric properties are the most important for GPR investigations on typical pavement materials (asphalt, concrete, granular materials, etc). The dielectric constant is a critical parameter in the practical application of GPR, as it affects the velocity of signals, the reflection coefficient (governing how much energy is reflected from material interfaces) and the resolution of GPR data obtained.

The overall bulk dielectric constant of asphalt will be a product of the contribution of the properties of each of the various materials within the asphalt mix. Most asphalt materials have dielectric constant values in the range approximately 4-10, depending on material type and condition.

2.1. Calculation from time intervals

The dielectric constant can be determined by calculating the GPR signal velocity within a material. The velocity is related to the dielectric constant by the relationship according [1] that is:

$$ s = v \times \left( \frac{t}{2} \right) $$

where:

- $s$ - thickness [mm]
- $v$ - velocity of electromagnetic wave [mm.ns$^{-1}$]
- $t$ - two-ways travel time of reflected signal [ns]

The speed of the pulse through a layer depends on the dielectric constant:

$$ v = \frac{299}{\sqrt{K^*}} $$

where:

- $K^*$ - dielectric constant

2.2. Calculation from amplitudes

The calculation of the dielectric constant from amplitudes is based on comparing amplitudes of reflection from asphalt slab surface and metal plate surface, where the latter is taken as 100% reflection. The dielectric constant of asphalt slab is then calculated from equation:

$$ \varepsilon_a = \left[ \frac{1 + A_1}{A_m} \right]^2 $$

where:

- $\varepsilon_a$ - the dielectric constant of asphalt slab
- $A_1$ - the amplitude of the reflection from the asphalt slab surface
- $A_m$ - the amplitude of the reflection from the metal plate surface
3. Experimental measurements by GPR

Experimental measurements were performed with GPR system consisting of the air-coupled antenna with the central frequency of 2 GHz, the control unit SIR 20 and the computer ToughBook Panasonic (Fig. 2A). The antenna was hung on a support structure and connected with the control unit by the cable. The antenna was moved over three sections: floor, a steel plate and asphalt slab (Figure 3) and signal was recorded. The asphalt slabs with dimensions of 30 x 40 cm (Fig. 2B) were prepared from asphalt concrete (AC), stone mastic asphalt (SMA) and porous asphalt (PA) using roller compactor. The dielectric constant of laboratory prepared asphalt slabs positioned below the antenna path was calculated based on known thickness of asphalt slabs, time intervals and amplitudes.

The measured values were processed in the software RADAN that gives the possibility to carry out operations necessary to increase the readability of the record (gain, contrast). The GPR records (Fig.3) were converted to an ASCII file and this one was imported into the GRAPHHER software where the amplitudes of positive and negative reflections and time courses were subtracted from the radargram (Figure 4).

Fig. 2. (A) the computer ToughBook Panasonic, (B) asphalt slab

Fig. 3. (A) Measurement with GPR, (B) A example of GPR data output

Fig. 4. (A) Radargram of AC slab, (B) Radargram of PA slab, (C) Radargram of SMA slab
4. Results of measurements

All calculated dielectric constants of three asphalt slabs are in the Table 3.
The dielectric constant of 6.90 for AC slab was determined from the time interval between positive amplitudes (Table 2). Next, the dielectric constant of 7.10 for AC slab was calculated from comparison of reflection amplitudes from metal plate and asphalt slab surface (Table 2). This value was substituted into the Equations (1) and (2) and calculated AC slab thickness was 39.43 mm. It means there is difference between real and calculated slab thickness.
The same calculations were made for the SMA slab. The dielectric constant calculated from time intervals was 8.08. The value of dielectric constant of the SMA slab calculated from amplitudes was 6.24 and calculated thickness of SMA slab was 35.04 mm. As for the PA slab, the dielectric constant from time intervals was determined as 4.79 and dielectric constant calculated from amplitudes was 3.46. Consequently, the calculated PA slab thickness was 47.04 mm.

Table 2. Amplitudes and times of asphalt slabs

| Asphalt slabs | AC slab | SMA slab | PA slab |
|---------------|---------|----------|---------|
|               | Amplitude | Time [ns] | Amplitude | Time [ns] | Amplitude | Time [ns] |
| Amp1-         | -9915    | 3,984    | -8898    | 3,984    | -5707    | 3,984    |
| Amp1+         | 10459    | 4,16     | 10321    | 4,219    | 7801     | 4,277    |
| Amp2-         | -16405   | 4,57     | -17321   | 4,688    | -21124   | 4,629    |
| Amp2+         | 17757    | 4,863    | 18970    | 4,98     | 18826    | 4,863    |

The differences among the values of dielectric constant obtained from time intervals and amplitudes are shown in Table 3. Percentage difference in the thickness between real thickness and calculated thickness from amplitudes was 1.42 % for AC slab. It was only 12.4 % for SMA slab and 17 % for PA slab.

Table 3. Dielectric constant of asphalt slabs

| Asphalt slabs | From time intervals | From amplitudes | Real thickness [mm] | Calculated thickness from amplitudes [mm] | Percentage difference [%] |
|---------------|---------------------|-----------------|--------------------|------------------------------------------|--------------------------|
| AC            | 6.90                | 7.10            | 40                 | 39.43                                    | 1.42                     |
| SMA           | 8.08                | 6.24            | 40                 | 35.04                                    | 12.4                     |
| PA            | 4.79                | 3.46            | 40                 | 47.04                                    | 17.6                     |

5. Conclusion

The measurements were made to determine the dielectric constant of the asphalt slabs produced from three different asphalts. Two calculation methods (time intervals and amplitudes) were used.

It was found the dielectric constants of the AC, SMA and SPA are in the known range for asphalts but they differ each other regardless the calculation method. The differences in dielectric constant values were also found between two calculation methods. That means asphalt composition and material characteristics (e.g. aggregate bulk density, bitumen content, air voids content) are the source of differences in the dielectric constants of asphalts. It is important for exact determination of pavement layer thickness when a core is not available.
Acknowledgements

The paper is a result of research supported by European Union and the state budget of Slovak Republic via the project “Výskumné centrum Žilinskej univerzity”, ITMS 26220220183.

References

[1] EVANS, R.D., FROST, M. F. 2011. The effect of moisture on ground penetrating radar (GPR) data from asphalt road pavements, 5th International conference bituminous mixtures and pavements, Thessaloniki, Greece, 1-3 June 2011
[2] Non-destructive survey of pavement layer thicknesses with Ground Penetrating Radar. Available at: <http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6718938>
[3] SAARENKETO, T. 2006. Electrical properties of road materials and subgrade soils and the use of ground penetrating radar in traffic infrastructure surveys, 2006. Oulu
[4] TP 3/2012 Využitie georadaru (GPR) pri návrhu rehabilitácie/rekonštrukcie vozoviek. Technické podmienky, MDPT SR, október 2012. Available at: <http://www.ssc.sk/files/documents/technicke-predpisy/tp2012/tp_03_2012.pdf>