



## COMPARISON OF PAVEMENT LAYERS THICKNESS MEASURED BY GROUND PENETRATING RADAR AND CONVENTIONAL METHODS

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### Abstract

The thickness of the pavement layers represents an important data for implementation into the database of roads already constructed, during designing of the pavement strengthening, particularly if the estimation of the bearing capacity of the pavement is done by means of the Falling Weight Deflectometer, during reconstruction of pavements or during control of the newly-constructed roads. If reconstruction is carried out by procedures of recycling of the existing pavement, the data about the thickness of asphalt layers are important not only during determining the depth of the intervention, but also during designing of the asphalt mixture. During quality control of newly-constructed road sections, GPR can be used as the means for fast and efficient determining of the thickness of layers. Measuring is done at speeds which approximately correspond to speeds of the traffic flow, so that disturbance of traffic is minimum, whereby the safety of participants in traffic and measuring personnel is increased. The paper presents several examples of determining the thickness of layers of road pavement by the non-destructive GPR method. The obtained results were compared to conventional methods of determining thicknesses which are used in Croatia, which are coring or data obtained by surveying methods during constructing of the pavement layers. Measurements were done on completely new and existing roads of different age with the asphalt final layer.

*Keywords: GPR, radar, nondestructive, pavement, layer, thickness*

### 1 Introduction

Knowing the composition and thickness of layers of flexible and rigid pavements are important data in making decisions about the pavement management activities. Thus, for example, the layer thickness is a very important detail in determining the bearing capacity and estimation of the remaining life of the pavement, designing the strengthening of the existing pavement or construction quality control. The layers thickness is usually determined by coring, by which the exact, but “point” data are obtained on selected locations, due to which many deviations in thicknesses, damages or some other specific features in the pavement may remain unnoticed. Besides, the method of coring is a destructive, it requires traffic closure, and it is relatively dangerous for the operating personnel and other participants in traffic. The paper gives a short description of the GPR (Ground Penetrating Radar) system, with the description of thickness determination on examples recorded on sections of roads in Croatia. The purposefulness of using the GPR system in relation to some other methods that are in common use in Croatia, is explained. The GPR system is a non-destructive method of testing, it is mounted on the measuring vehicle which, during testing, moves at the speed of 50 – 80km/h along the section. In that way, it is not necessary to close the tested section, and disturbing of the traffic flow is almost negligible. The main part of processing the data collected in the field is

done in an office, with the use of the recorded data, video material, notes from the field and data obtained from the employer [1]. Such a radar system is an excellent supplement or basis for some other methods of studying the pavement structures, such as determining the bearing capacity by the Falling Weight Deflectometer method (FWD).

## 2 Description of GPR Device

In the continuation, components and the operating basics of the GPR system are described, and also the basics of calculating layer thicknesses.

### 2.1 Measuring Device

The GPR device is based on the radar principle, in which the antenna sends and receives electromagnetic (EM) waves directed towards the pavement. The system is controlled by means of a software by which the recording parameters are set, and by which the operation of the central unit, the generator of EM waves which are transmitted to the antenna, is controlled.

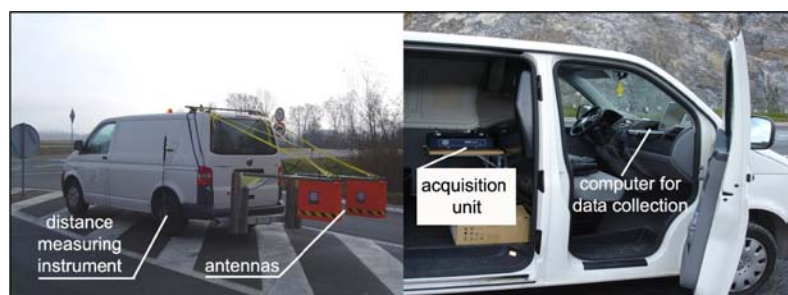


Figure 1 Department of Transportation's GPR equipment mounted on vehicle

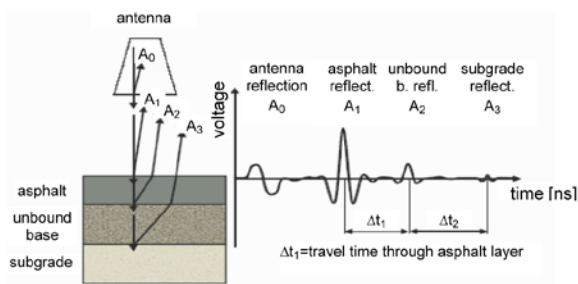
The Department of Transportation of the Faculty of Civil Engineering, University of Zagreb own two air-horn antennas, with frequencies of 2.2 and 1.0 GHz, manufactured by GSSI (Figure 1). This frequency range is very good compromise between the possible depth and resolution of recording. With a lower frequency, it is possible to record layers at a greater depth (approx. to the subgrade level), but with a lower resolution, while in case of a higher frequency antennas, layers are seen in greater detail, but the recording depth is smaller.

### 2.2 Operating Basics of GPR System

The system emits pulses of electromagnetic (EM) waves, which partly reflects, and partly pass through the layers of materials with different EM characteristics which they come across. A part of energy which reflects from particular layers returns to the antenna, during which its energy is registered, i.e. the amplitude and the time necessary for it to return to the antenna. The speed of passing of an EM wave through a particular media (a layer of air or a pavement layer) is influenced by the relative dielectric constant ( $\epsilon_r$ ) of the specific media. To determine the thickness of a particular layer ( $h$ ), eq. (1) is used,

$$h_i = \frac{c \cdot \Delta t_i}{\sqrt{\epsilon_r}} \quad (1)$$

where  $c$  – is the speed of the EM wave through the vacuum ( $3 \times 10^8$  m/s),  $\Delta t_i$  – the time between the amplitudes  $A_i$  and  $A_{i+1}$ , and  $\epsilon_r$  – the relative dielectric constant of the medium, [2].



**Figure 2** The schematic presentation of EM wave emitted in pavement

Figure 2 gives schematic presentation of one emitted and reflected ray of the EM wave directed into the pavement. EM wave has a greater amplitude on layer interfaces. In Figure 2,  $A_1$  marks the reflection amplitude from the pavement surface,  $A_2$  the reflection amplitude from the unbound base surface and  $A_3$  the reflection amplitude from the subgrade surface. The amplitude between two media depends on relative dielectric constants, which is the usual term for the ratio of dielectric permeability of a particular material in relation to the dielectric permeability of the vacuum. The range of its value varies from 1 for air (vacuum) to 81 for water. Dielectric constants of the materials that are used in the pavements are from 4 to 8 for asphalt layers, 8 to 10 for concrete layers, 4 to 7 for crushed stone material, and 25 to 40 for clay materials [3].

### 2.3 Interpretation of Data

The signal, schematically presented in Figure 2, can also be sent up to several hundred times in a second. If the test vehicle is moving along the road, a continued presentation is obtained as in the top part of Figure 3, which presents the GPR profile recorded on the hot-mix asphalt pavement. The processing and interpretation of the data can be carried out by various specialized computer software packages, such as e.g. RADAN (Radar Data Analyzer). The top part of the Figure shows the GPR data with the time of reflection from a specific layer and the chainage. “Brighter” horizontal lines represent layer interfaces. By subsequent processing of the recorded data, layers marked with “dots” are, at the bottom part of the Figure 3, calculated into the thicknesses by a software, using calculations described in Section 2.2. The right side of the Figure is intentionally left unprocessed, without “dots”, so that layer interfaces could be observed.

In specific situations, the layers of the pavement structure cannot be clearly determined on the obtained image because of various disturbances that influence the quality and the depth of penetration of the EM wave into the pavement, so sometimes it is not possible to use the possibilities of the device completely [1].

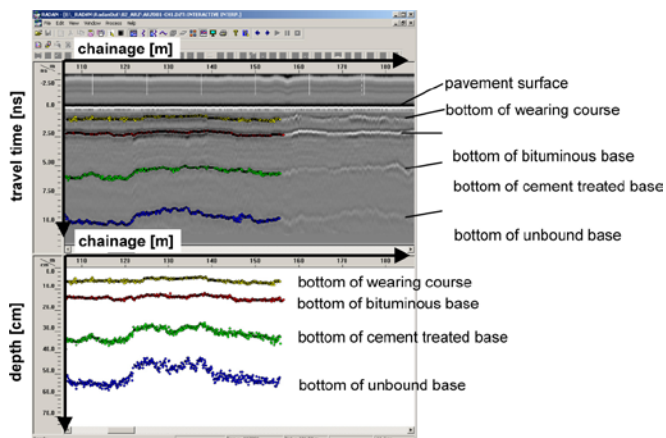


Figure 3 GPR presentation for marking layers of pavement structure.

### 3 Examples of determining thicknesses of pavement layers

In the continuation, the comparison of the thicknesses of the layers from several sections of motorways in Croatia will be given.

#### 3.1 A6 Motorway, Rijeka-Zagreb

Measuring by a GPR device was carried out in October 2006, on one kilometer long section of the right-hand carriageway (chainage from km 75+425 to 76+425 according to project documentation), situated after the Veliki Gložac tunnel in the direction of Zagreb. The section was not opened to traffic at the moment of measurement. The results in the overtaking lane were presented. According to the design documentation, the following layers were executed on the subject section at the moment of measurement:

- binding course (vs) with the thickness of 5cm,
- bitumen stabilized base course (BNS) with the thickness of 7.5cm,
- cement stabilized base course (CNS) with the thickness of 20cm, and
- mechanically compacted base course (MNS) with the thickness of 20cm.

The final wearing course of splitmastiks asphalt with the thickness of 3.5cm had also been anticipated, but was not executed at the moment of measurement.

After measurement, the survey data were available, which were carried out for the purpose of the construction quality control (CQC) by the investor. From those data, the thicknesses of constructed layers in the overtaking lane at the chainages km 75+500, km 75+825 and km 76+050 were calculated and marked as “position 1”, “position 2” and “position 3” respectively. Those thicknesses were compared to the thicknesses obtained by the GPR device recorded by the 2 GHz antenna at the same locations. The error obtained as the ratio of the thickness from GPR and the survey data expressed in the percentage is presented in Figure 4 (Section 3.4) for asphalt layers, in Figure 5 for the cement treated base and in Figure 6 for the unbound base.

#### 3.2 A11 Motorway, Zagreb-Sisak

Measurement was carried out in September 2009, on the section Jakuševac-Velika Gorica, which was not opened to traffic at the moment. A part of that section from chainage km 3+050 to km 3+840 was measured. Results presented here below refer to the driving lane of the right-hand carriageway in the direction towards Velika Gorica. According to the project

documentation, following layers were constructed on the subject section at the moment of measurement:

- splitmastiks asphalt (SMA 16) with the thickness of 4.5cm,
- binding course (vs 16) with the thickness of 5cm,
- bitumen stabilized base course (BNS 32) with the thickness of 8cm,
- cement stabilized base course (CNS) with the thickness of 20cm
- mechanically compacted base course (MNS) with the thickness of 20cm.

After measurement, the survey data (carried out for the purpose of CQC by the investor) were available, from which layer thicknesses on the specific locations were calculated, so that thicknesses obtained by processing the 1 GHz GPR data could be compared to them. The results of the thicknesses comparison of the layers selected at the chainages 3+500, 3+720 and 3+800 marked as “position 1”, “position 2” and “position 3” respectively are presented for the specific layers in Figures 4, 5 and 6 in Section 3.4.

At the chainage km 3+800, marked as “position 2” in this example, the core was taken out, from which only asphalt layers data were obtained. The thicknesses of layers obtained by different methods are given in Table 1. The reason of deviation of the values can be due to the different position in the cross section (e.g. the core was taken out in the right-hand rut, and the survey data is from the middle of the lane), partially incorrect determining of the chainage during the surveying or coring or due to the human factor.

**Table 1** Layer thickness data at chainage km 3+800

	core [cm]		survey [cm]		GPR [cm]
splitmastiks asphalt	4.15	17.09	4.40	16.40	16.64
binding asphalt layer	4.90		4.70		
bituminous base	8.04		7.30		
cement treated base	n/a		18.80		22.96
unbound base	n/a		27.90		34.38

### 3.3 A3 Motorway, Bregana-Lipovac

Measurement was carried out in March 2009 on section Slavonski Brod – Spačva from the chainage km 228+000 to km 285+500 on both the southern and the northern carriageway in the driving lane. The motorway is about 20 years old, and it was recently reconstructed by the recycling method, whereby the existing wearing course and a part of the base course were milled and replaced by new layers, so that, according to the project documentation, the pavement should have the following composition:

- asphalt concrete 6cm,
- bituminous base 12cm,
- cement treated base 20cm and
- unbound base 40cm.

For the subject section, the coring data, performed by IGH d.d. were available. On the basis of those data, a comparison to the data obtained by GPR was made. The coring was done on the driving lane in the right-hand rut, and the GPR data were obtained at the same locations by processing the data from the 2 GHz antenna. The coring data contains only the asphalt layers thicknesses, so that a comparison to the thicknesses of the cement treated and the unbound base obtained by the GPR device could not have been calculated. The results of the comparison at the locations km 264+000 and km 268+200 on the southern carriageway, and km 279+000 from the northern, marked “position 1”, “position 2” and “position 3”, respectively, are presented in Figures 4, 5 and 6.

### 3.4 Comparison of Data

The previous Sections describe road sections on which the layer thickness data were obtained. In the continuation, the presentation of the comparison to the layer thickness obtained by the GPR device and the data from the surveying data or from the data about the extracted cores (ratio GPR thickness/core thickness or GPR/survey) on the observed sections of roads is given. The comparison for asphalt layers is presented in Figure 4, for the cement treated base layer in Figure 5 and for the unbound base layer in Figure 6.

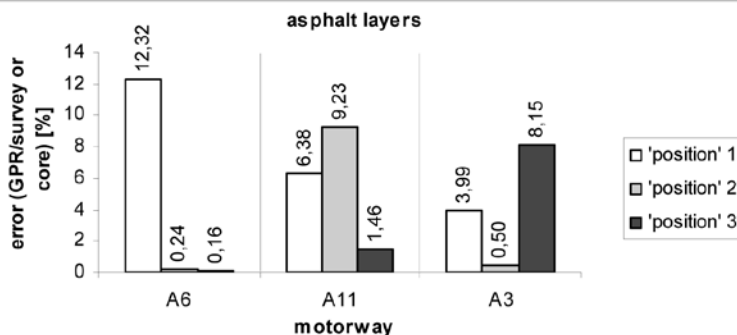


Figure 4 Comparison to thickness of asphalt layers

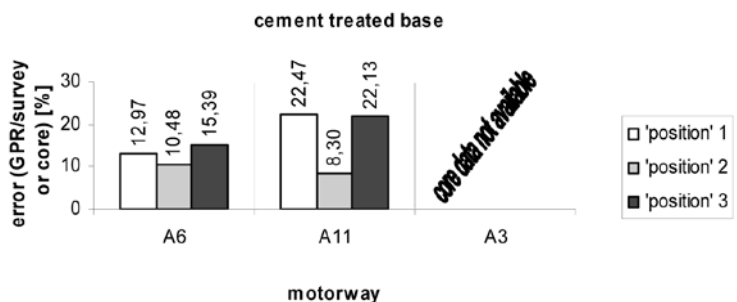


Figure 5 Comparison to thickness of cement treated base

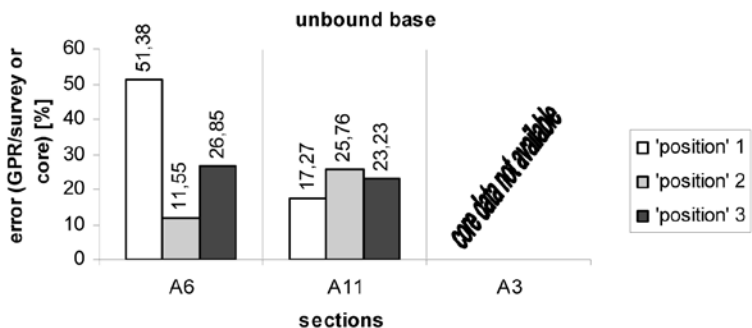


Figure 6 Comparison to thickness of unbound base

## 4 Conclusion

The comparison of the pavement layer thicknesses from the GPR and the survey or the coring data was made on three sections selected on motorways in Croatia, two of which have not yet been opened to traffic, and third was in use. The asphalt layers thicknesses determined by the GPR in the examples show the accuracy that is within the tolerance limits even for the procedures of the construction quality control, not to mention the accuracies that would satisfy the needs of the overlay design or reconstruction. The error is mostly less than 10%, and it is even smaller for new pavements, which corresponds to the data from literature [4], [5]. Such accuracy is achieved on the whole length of sections, and examples described in this paper are used for comparing different methods. The comparison of the thicknesses of the cement treated and the unbound base, give a somewhat greater error, which appears due to the algorithm of calculation of thicknesses (depths) of layers by the processing software, because the error is cumulatively increased with the greater depth of the layer. Taking in consideration the thickness of the layer and the percentage of the error, the difference in thicknesses of the layers is only several centimeters, which can be acceptable, since base layers are in question. In general, the non-destructive GPR method gives very useful data, in case of which determining layer thicknesses is done with great accuracy, mostly all pavement layers are comprised and what is very important, the data are continuous. Coring gives “point data”, which very often comprise only asphalt layers, which is not enough, for example, for reconstruction of the pavement, where the bearing capacity of the existing pavement is an important detail. From the GPR data once recorded, beside the layer thickness, many other specific features of the layers can also be determined, such as inhomogeneity and damages of the layers, moisture zones, air voids under concrete pavement slabs or even installations under the pavement. An increase in the accuracy of the GPR device was enabled by supplementing the equipment of the Department of Transportation with the GPS device that has a much greater accuracy in distance determination than the existing DMI device.

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