COMPARISON OF THE PAVEMENT LAYERS THICKNESS MEASURED BY GEORADAR AND CONVENTIONAL METHODS – EXAMPLES FROM CROATIA

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Abstract. Thickness of the pavement structure layers represents an important data for the implementation into the database of roads already constructed, during the pavement strengthening design, particularly if the appraisal of the bearing capacity of the pavement structure 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 details about the thickness of asphalt layers are important not only when determining the depth of the intervention but also when designing asphalt mixture. During quality control of the newly constructed road sections the Ground Penetrating Radar (GPR, georadar) can be used as the instrument for fast and efficient determination of the thickness of layers. Measuring is done at speeds that approx correspond to the speeds of 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 structures by the non-destructive GPR method. The obtained results were compared to conventional methods of determining thicknesses that are used in Croatia, i.e. coring or data obtained by surveying methods during construction of the pavement structural layers. Measurements were done on completely new and existing roads of different age having the asphalt pavement.

Keywords: pavement, thickness, strengthening, georadar, GPR, ground penetrating radar.

1. Introduction

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 (Maser 1994). 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 (Angi *et al.* 2003).

The paper gives a short description of the georadar system (GPR or Ground Penetrating Radar) with the description of thickness determination (Fontul 2004; Harris 2006; Saarenketo 2006) 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 50–80 km/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 (Ožbolt *et al.* 2009). Such a radar system is an excellent supplement or basis for some other methods of studying the pavement structures, such as determining bearing capacity by the Falling Weight Deflectometer (FWD) method where the thickness of the layer is an important parameter. GPR is fast and efficient method for the determination of layer thickness which is used in FWD data analysis (Chen *et al.* 2011; Yi *et al.* 2010) or can substitute other methods of layer thickness determination mentioned in other researches (Čygas *et al.* 2008).

2. Description of GPR device

In the continuation, components and the operating basics of the GPR system are described, 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 software by which the recording parameters are set and by which the operation of the central unit, the generator of EM waves that are transmitted to the antenna, are controlled.

The Dept of Transportation of the Faculty of Civil Engineering, University of Zagreb own two air-horn antennas with frequencies of 2 GHz and 1 GHz, manufactured by GSSI (Fig. 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, the layers are seen in greater detail but the recording depth is smaller.

2.2. Operating basics of the GPR system

The system emits pulses of EM waves which partly reflects and partly pass through the layers of materials with different EM characteristics that they come across (Leng 2011). A part of energy that 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 (ε_r) of the specific media. To determine the thickness of a particular layer (h) the Eq (1) is used:

$$h_i = \frac{c\Delta t_i}{\sqrt{\varepsilon_r}}, \tag{1}$$

where c – the speed of the EM wave through the vacuum (3×10^8 m/s); Δt_i – the time between the amplitudes A_i and A_{i+1}; ε_r – the relative dielectric constant of the medium (Cao *et al.* 2011; Fontul 2004).

Fig. 2 gives a schematic presentation of one emitted and reflected ray of the EM wave directed into the pavement. EM wave has greater amplitude on layer interfaces. In Fig. 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 that are 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
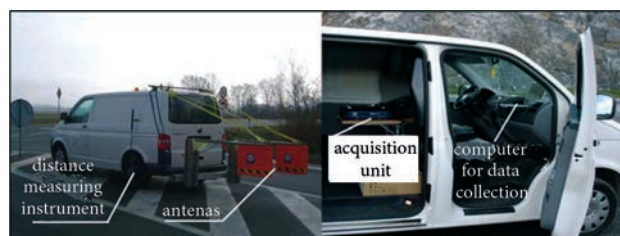

Fig. 1. Department of transportation's GPR equipment mounted on vehicle
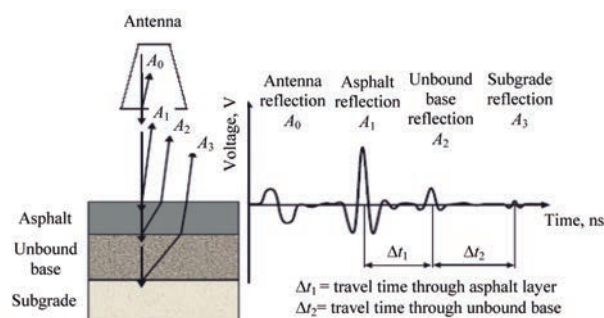

Fig. 2. Electromagnetic wave transmitted to the pavement structure

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 (Saarenketo 2006).

For calculating relative dielectric constant of pavement layers with air-horn antennas (Fig. 1) the Eq (2) is used. For that purpose proportion of amplitudes of reflected signal and relative dielectric constant of adjacent layer are used. For calculation of dielectric constant of the first layer, proportion of amplitude reflection from metal plate set on the pavement surface and amplitude from pavement surface without metal plate. Metal plate is used because it completly reflects the EM wave and amplitude reflection is max. Value of relative dielectric constant of air is 1, thus, relative dielectric constant of the first layer could be calculated using Eq (2):

$$\sqrt{\varepsilon_{r1}} = \frac{A_m + A_1}{A_m - A_1}, \tag{2}$$

where ε_{r1} – relative dielectric constant of the first layer; A_m and A_1 – amplitudes reflection from metal plate and from pavement surface without metal plate, respectively.

Acordingly, relative dielectric constant of the next layer could be calculated using Eq (3):

$$\sqrt{\varepsilon_2} = \sqrt{\varepsilon_1} \left[\frac{1 - \left(\frac{A_1}{A_m}\right)^2 + \left(\frac{A_2}{A_m}\right)}{1 - \left(\frac{A_1}{A_m}\right)^2 - \left(\frac{A_2}{A_m}\right)} \right], \tag{3}$$

where ε_2 – relative dielectric constant; A_2 – amplitude reflection from the second layer. Relative dielectric constants of multi layer pavement could be calculated acordingly.

2.3. Interpretation of data

The signal, schematically presented in Fig. 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 Fig. 3 that 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 Fig. 3 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 the layers marked with "dots" are, at the bottom part of the Fig. 3, calculated into the thicknesses by software using calculations described in Section 2.2. The right side of the Fig. 3 is intentionally left unprocessed, without "dots" in order the 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, thus, sometimes it is not possible to use the possibilities of the device completely (Ožbolt *et al.* 2009).

3. Examples of determining thickness of pavement layers

In the continuation, the comparison of the thicknesses of the layers from several sections of motorways, regional and county roads in Croatia will be given. Thicknesses obtained by the GPR device were calculated by processing the recorded data from sections of roads described in the continuation. Data was processed by the RADAN software which uses the algorithm described in Sections 2.2 and 2.3.

3.1. Motorway A6 Rijeka–Zagreb

Measuring by a GPR device was carried out in October 2006 on 1 km long section of the right-hand carriageway
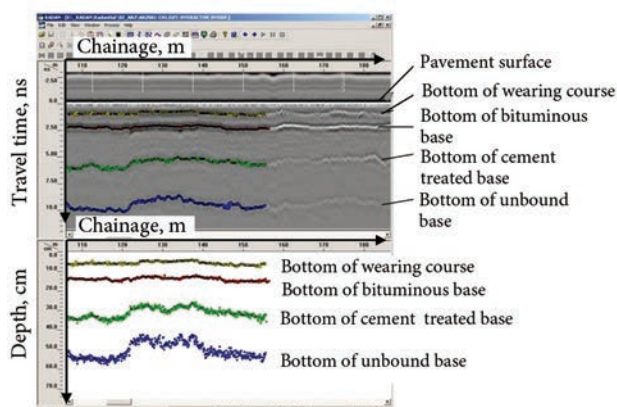

Fig. 3. Marking pavement layers on the recorded GPR data

(chainage from 75.425 km to 76.425 km according to project documentation) situated after the Veliki Gložac tunnel in the direction of Zagreb. The section was not open 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:

- binder course with the thickness of 5 cm;
- bitumen stabilized base course with the thickness of 7.5 cm;
- cement stabilized base course with the thickness of 20 cm; and
- mechanically compacted base course with the thickness of 20 cm.

The final wearing course of stone mastic asphalt (SMA) with the thickness of 3.5 cm had also been anticipated but was not executed at the moment of measurement.

After measurement the survey data was available 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 75.500 km, 75.825 km and 76.050 km 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 Fig. 4 (Section 3.6) for asphalt layers, in Fig. 5 for the cement treated base and in Fig. 6 for the unbound base.

3.2. Motorway A11 Zagreb-Sisak

Measurement was carried out in September 2009 on the section Jakuševec–Velika Gorica which was not yet opened to traffic. A part of that section from chainage 3.050 km to 3.840 km was measured. The 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 the following layers were constructed on the subject section at the moment of measurement:

- SMA with the thickness of 4.5 cm;
- binder course with the thickness of 5 cm;
- bitumen stabilized base course with the thickness of 8 cm;
- cement stabilized base course with the thickness of 20 cm and
- mechanically compacted base course with the thickness of 20 cm.

After measurement the survey data (carried out for the purpose of CQC by the investor) was available from which the layer thicknesses on the specific locations were calculated in a way that the 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 Figs 4, 5 and 6 in Section 3.6.

At the chainage 3.800 km, marked as "position 2" in this example, the core was taken out from which only the asphalt layers data was 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.

3.3. Motorway A3 Bregana–Lipovac

Measurement was carried out in March 2009 on section Slavonski Brod–Spačva from the chainage 228.000 km to 285.500 km 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 6 cm,
- bituminous base 12 cm,
- cement treated base 20 cm and
- unbound base 40 cm.

For the subject section the coring data, performed by IGH Inc., was available. Based on 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 264.000 km and 268.200 km on the southern carriageway, and 279.000 km from the northern, marked "position 1", "position 2" and "position 3", respectively, are presented in Figs 4, 5 and 6 in Section 3.6.

3.4. State road D2 Ludbreg–Koprivnica

Measurement was carried out in November 2006 on section of state road from Ludbreg to Koprivnica, in length of 15 km. It is a two-way road with one traveled way in each direction. Pavement structure is about 30 to 40 years old, during this period only the necessary maintenance works were performed, like patching and laying thin overlays. Existing pavement structure is in poor condition and the reconstruction was started. Measurement was done before the reconstruction.

Existing pavement structure consists of one or more hot mix asphalt layers, bituminous base layer and unbound granular base layer sporadically mixed with earth material. For analysis, data from coring report was obtained. Coring was performed on the total depth of the structure including part of the subgrade. GPR measurement was performed with 2 GHz antenna on the same transversal location
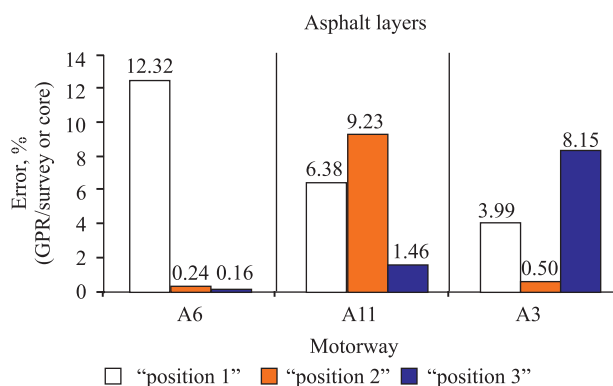

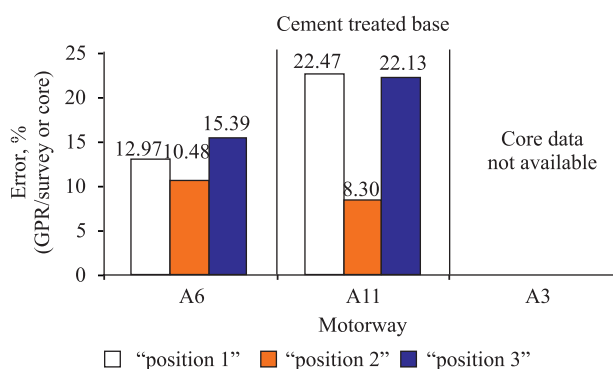**Fig. 4.** Comparison to the thickness of asphalt layers on motorways

Fig. 5. Comparison to the thickness of cement treated base layers on motorways
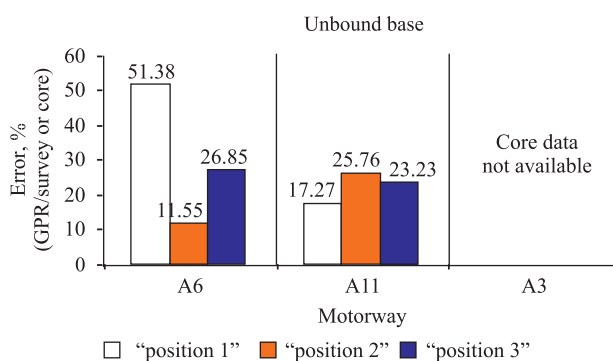

Fig. 6. Comparison to the thickness of unbound base layers on motorways

Table 1. Layer thickness data at chainage 3.800 km

Layer	Core, cm	Survey, cm	GPR, cm
Stone mastic asphalt	4.15	4.40	
Binder course	4.90	4.70	
Bituminous base	8.04	7.30	
Total	17.09	16.40	16.64
Cement treated base	not available	18.80	22.96
Unbound base	not available	27.90	34.38

as the location of cores. In continuation comparison of thicknesses from cores and GPR data on three locations is given on chainages 0.228 km, 1.036 km and 5.829 km marked as "position 1", "position 2" and "position 3" respectively. In Fig. 7 of Section 3.6 comparison of asphalt layers is shown, while in Fig. 8 comparison of unbound base layers is given.

3.5. County road ŽC 2196 Zaprešić–Gubaševo

Measurement was carried out in May 2005 on section of the county road ŽC 2196, between intersections Zaprešić and Gubaševo, in length of 19 km. It is a two-way road with one traveled way in each direction. For the measured section data from coring was available, however only from asphalt layers. For both traveled ways for the whole section only six cores were extracted from which comparison with GPR data for only two of them was possible because of insufficient data. According to coring report the pavement structure consisted of base layers on layer of unbound granular material (gravel) of unknown thickness.

Pavement structure is about 30 years old, during this period the patching and several overlays were performed in places where needed. Maintenance works were caused by rutting, depressions on the right side of the traveled
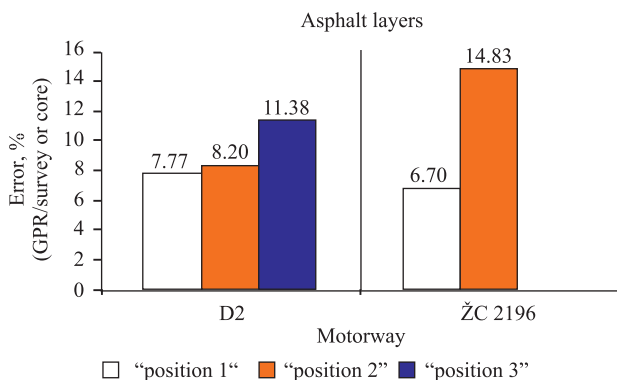

Fig. 7. Comparison to the thickness of asphalt layers on regional and county road
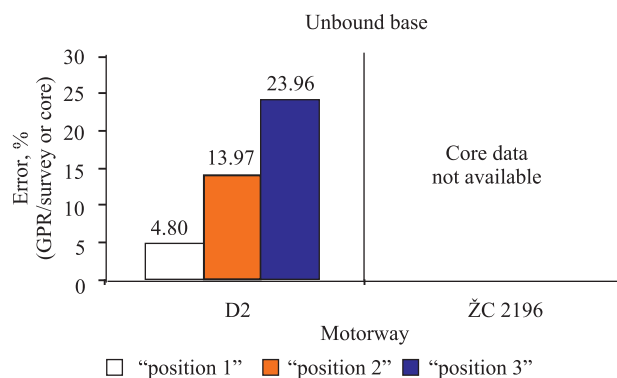

Fig. 8. Comparison to the thickness of unbound base layers on regional and county road

way probably because of insufficient bearing capacity of the subgrade. Pavement surface is very rough and, generally, the whole pavement structure is in poor condition. The section is located between the motorway A3 Zagreb–Macelj and the river Krapina and is laid on embankment in the whole length.

Comparison of thicknesses was performed with GPR data from 2 GHz antenna and data from cores on two locations on the same transversal position of traveled way. Location of the cores was on chainage 1.200 km and 5.400 km marked in comparison as "position 1" and "position 2" respectively and are shown in Figs 7 and 8 in Section 3.6. The coring data contain only the asphalt layers thicknesses because of the limitations of coring technology used, so that a comparison to the thicknesses of the unbound base obtained by the GPR device could not have been calculated. This example and the example from the motorway A3 manifests advantage of GPR which, almost always, gives thicknesses of all layers in continuation.

3.6. Comparison of the data

The previous sections describe road sections on which the layer thickness data was 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 data) on the observed sections of roads is given. The comparison for asphalt layers is presented in Fig. 4, for the cement treated base layer in Fig. 5 and for the unbound base layer in Fig. 6 for the examples from motorways. The comparison of thickness from regional and county road is presented in Fig. 7 for asphalt layers and in Fig. 8 for unbound base layers.

4. Conclusion

The comparison of the pavement layer thicknesses from the GPR and the survey or the coring data was made on three selected sections of the motorways in Croatia, on one section of regional road and one section of county road. Two sections of motorways have not yet been opened to traffic and the third was in use. The sections of regional and county roads were in use for a long period of time during which many repairs were performed. On the section of regional road the reconstruction was started.

1. 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. Such accuracy is achieved in the whole length of sections and examples described in this paper are used for comparing different methods. Thickness comparison for regional and county road gives less accuracy than for examples from motorways. This level of accuracy is considered acceptable due to greater possibility of error

in determining identical location in coring and in processed GPR data and due to many repairs performed on pavements.

2. The comparison of the thicknesses of cement treated and unbound base gives a somewhat greater error which appears due to the algorithm of calculation of thicknesses (depths) of layers by the processing software since 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 what can be acceptable since the base layers are in question.

3. 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 is continuous. Coring and experience from that kind of data in Croatia is that it gives "point data" which very often comprise only asphalt layers what is not enough, for example, for reconstruction of the pavement where the bearing capacity of the existing pavement is an important detail.

4. From the GPR data once recorded, beside the layer thickness, many other specific features of the layers can also be determined, such as homogeneity and damages of the layers, moisture zones, air voids under concrete pavement slabs (where analysis of dielectric constant e_r is used) or even installations under the pavement.

The 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 a distance determination than the existing DMI device.

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