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Road Diagnostics - Ground Penetrating Radar Possibilities

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Abstract:

GPR (Ground Penetrating Radar) is non-destructive equipment coming to be accepted in diagnostics of road structures. The paper describes state-of-the-art of a GPR usage in several European countries in this field. Beside basic GPR applications in the field of road diagnostics like a determination of pavement layer depths and a location of joint dowel bars in concrete pavements the more complicated application possibilities are mentioned such as detection of voids under the concrete slabs of rigid pavements, detection of excessive amount of water in structural layers of pavements, determination of crack depth in the bituminous layers etc.

The situation in the Czech Republic is described in the paper and some projects concerning GPR testing, the author participated on, are mentioned.

KEYWORDS: NDT, Non-destructive testing, GPR, Ground Penetrating (Probing) Radar, Pavement diagnostics, PMS, Pavement Management System

1 GPR INTRODUCTION

Ground Penetrating Radar (GPR) is equipment, which uses high frequency electromagnetic waves. In combination with a suitable software it provides evaluation of electrical and magnetic features of studied environment. GPR has the highest resolution from all geophysical methods used in non-destructive diagnostics.

Boom in GPR usage started with commercial selling of this equipment by American company GSSI in 1972. GPR started to be used in a lot of different areas. One of these areas is diagnostics of roads and bridges.

A use of GPR in the field of road diagnostics is common today [1], while GPR usage in the field of bridge diagnostics is ordinarily limited to a pavement and a bridge deck control [2].

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2 DIFFERENT INPUTS TO PMS

One of the main inputs to Pavement Management System are results of road condition measurements.

Road diagnostics is realized both on project level (mostly local) and network level (continuous). The diagnostics on project level is commonly realized on selected places where some problems occurred or on chosen sections with connection to planning of maintenance, repair or reconstruction. The diagnostics on network level is normally carried out at a primary road network (motorways, high speed roads, etc.).

Typical areas which are realized as a part of diagnostics on network level are:

a) visual inspection (basic diagnostic method),

b) unevenness and macrotexture (riding comfort and safety),

c) skid resistance (safety).

In addition there are other diagnostics methods which are carried out locally:

d) bearing capacity (durability; LCA: life cycle analyse),

e) diagnostic of pavement structure (layer composition, localization of structural defects, etc.),

f) noise - wheel/surface interaction (environmental friendliness),

g) analyze of cores (real structure of the pavement), etc.

It is evident that a preference is given to nondestructive diagnostics methods, mostly to the methods that do not disturb the traffic on roads. For area a, b, and c the measurements are normally realized under the traffic speed. For area e and f there are already some systems allowing traffic speed measurements (up to 80 km/hour). We still cannot exclude some destructive methods from road survey, the basic one is taking of cores.

The common equipment used in the Czech Republic for individual areas mentioned above are as follows:

- area a, b: ARAN: Automatic Road Analyzer, ARGUS: Automatic Road Condition Graduating Unit System (traffic speed measuring cars),
- area c: TRT: Czech measuring car, SCRIM: Sideway-force coefficient routine investigation machine (traffic speed measuring cars),
- area d: FWD: Falling weight deflectometer or deflectograph (local and slow speed measuring equipment),
- area e: e.g. GPR system with dipole or horn antennas (local or traffic speed measuring equipment),

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- area f: SPB: statical pass-by method (measuring system situated near a road) or CPX: close proximity method (traffic speed measuring trailer or car),
- area g: local analyse by drilling rig.

There are some innovations in this field currently realized abroad. Two basic ones are mentioned below.

In the field of bearing capacity measurements two prototypes of high speed deflectograph exist which allow a traffic speed measurement. The owners of them are DRI (Danish Road Institute) and TRL (Transport Research Laboratory - UK). This method is based on contactless measurement with the help of new lasers. This measuring car is currently in the stage of testing and calibrating.

Fig. 1 - GSSI integrated system: measurement of bearing capacity by FWD and diagnostics by GPR

In the field of GPR usage there are developed multichannel systems with an autocalibration function in TRL. In some cases there are produced combinations of more measurements within one measuring car. Figure 1 shows the combination of GPR and FWD - producer: American company GSSI: Geophysical Survey Systems, Inc.

3 ROAD DIAGNOSTICS BY GPR

In Europe and USA there is popular using of horn antennas, which are placed 300 - 500 mm above the pavement surface (for continual measurements). In United Kingdom there are much popular dipole antennas. Better results are obtained in case that a dipole antenna is placed directly on the pavement surface (for continual measurements it is placed approximately 30 mm above the pavement surface). Figure 2 and 3 shows examples of horn and dipole antennas which are used in German institute BASt: Bundesanstalt für Straßenwesen.

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Fig. 2 - 2 GHz GSSI horn antenna: attachment to the measuring car

Fig. 3 - 1,5 GHz GSSI dipole antenna: measuring in test pit

It is possible to measure locally or continually. In case of continual survey the GPR system is fixed to an auxiliary equipment or to a measuring car. Survey is carried out in a slow speed (from walking to 25 km/h - mostly dipole antennas) or in a high speed (80 km/h and more - mostly horn antennas). The main advantage of the high speed survey is fact that you do not need to close a measured road.

One of the first application of GPR in the field of road diagnostics was location of joint dowel bars in rigid roads [3] and determination of pavement layer depths [4]. Currently a GPR application in those areas is used ordinarily. The interpretation of measured data is mostly sufficient (frequency range of antennas in GHz, a controller capable to operate more channels simultaneously, 3D software, etc.) [5].

Figure 4 and 5 shows radargram example with indication of layer depths and GPR data interpretation in MS Excel sheet.

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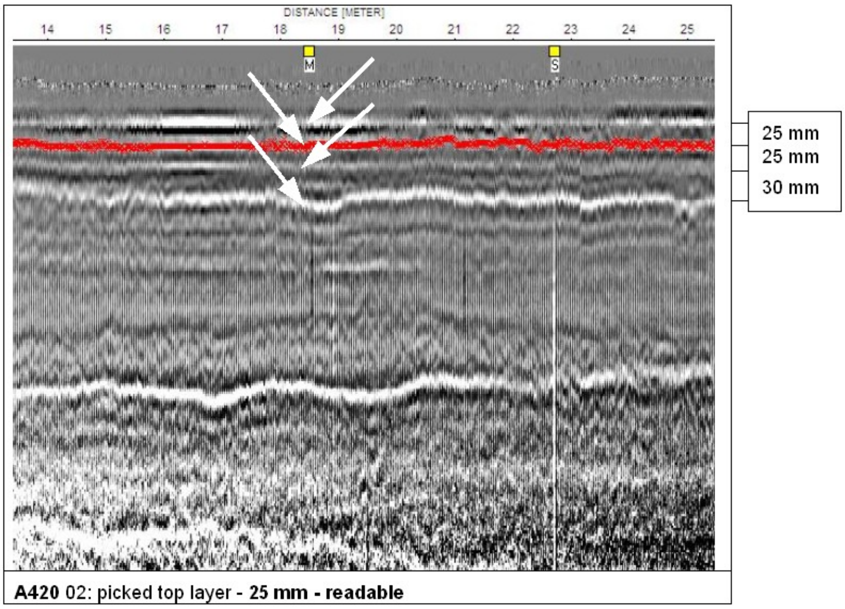

Fig. 4 - Radargram example: measurement of layer depths by 4 GHz antenna

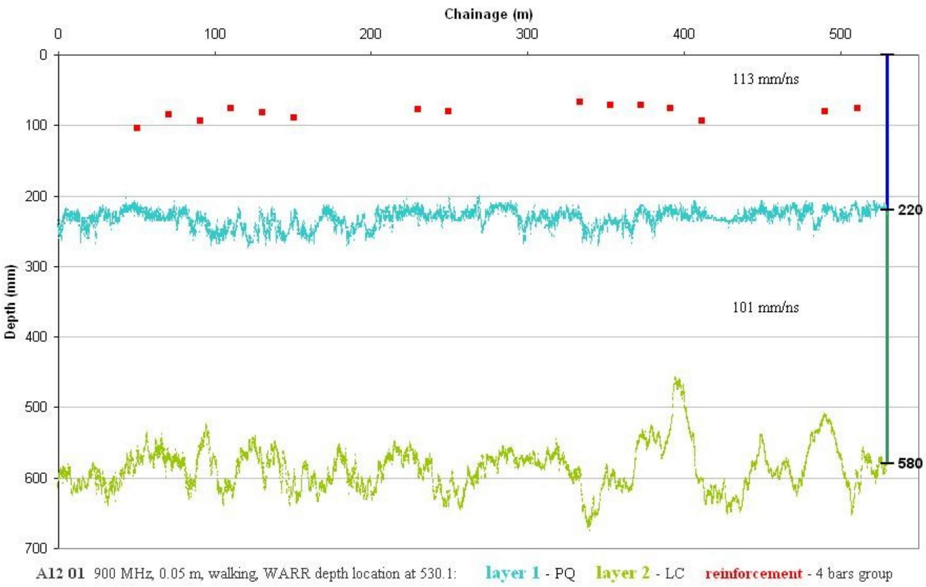

Fig. 5 - GPR data interpretation in MS Excel: location of rebar in rigid pavement, determination of pavement quality concrete depth and lean concrete depth, calibration by core

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The other contribution to the development of GPR systems was usage of antennas' array, see figure 6. On the base of its usage it is possible to carry out autocalibration of layer depth measurements. The main advantage is minimization of needed cores along investigated area [6].

The current experience indicate that the accuracy of determination of roadbase depth is approximately 5 %, in case of slow speed measurements and up to 10 % in case of high speed measurements. For the lower layers the accuracy is between 10 and 30 % in dependence on used velocity of measurement [1].

During the high speed measurement it is possible to locate bigger defects. The smaller defects can be detected but you have to use smaller measurement speed. The main disadvantage of slow speed measurements is a limitation of traffic and a need of road closures.

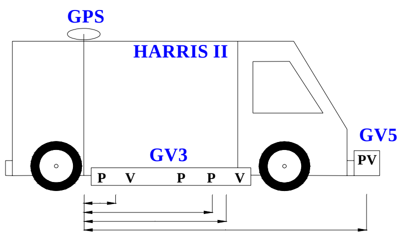

Fig. 6 - Four-channel system used in TRL: attachment to measuring car Harris (photo TRL)

Currently, researchers are dealing with application of GPR in further areas on several places all around the world. These areas are:

- detection of voids under roadbase of rigid pavements,
- detection of excessive amount of water in structural layers of pavements,
- determination of crack depth in the bituminous layers, etc.

3.1 Detection of voids under roadbase

The formation of voids under roadbase of jointed unreinforced concrete pavements is caused by movement of concrete slabs, high loading or poor subgrade/ subbase. The project dealing with detection of such voids was solved in TRL in 1993-1994. The applied system was capable to detect air voids of 30 mm thick. In case of voids filled with water it was possible to detect voids of 10 mm thick. With the use of current more sophisticated technique these numbers should be even lower.

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3.2 Detection of excessive amount of water

Problem of detection of excessive amount of water in structural layers of pavements is directly connected with underdrain problems. In TRL in 1993 there was carried out project focused on detection of water table, which was based on evaluation of changes in EM wave velocity. A disadvantage of this research is a need for more comparative measurements (in the period with minimal rainfall and in period with maximal rainfall). A project dealing with determination of road subgrade moisture was realized in 2001 in TRL. The comparison of signals reflected from interface between the granular foundation layer and the overlaying layers were carried out. This method has the following limitations: there is need for more comparative measurements (dry and wet season), there are difference in absorption of the GPR signal by overlaying bituminous layers on different sites. Currently there is third project in progress. The change in the frequency content of the radar signal reflected from the foundation layer is investigated. The research is realized also at other places [7].

3.3 Determination of crack depth

For a long time a visual control was the only possibility for a road crack monitoring. Subsequently a software for a processing of video records during continuous survey was used. It was able to detect cracks but it was not able to determine their depth. Company Utsi Electronics Ltd. in cooperation with TRL researches started to develop GPR system for determination of crack depths in 1999. At present it is capable to detect cracks depth higher than 25 mm, better results are obtained with 50 mm and deeper cracks [8]. The research is still in progress. Picture of equipment is shown at figure 7. An example for comparison of results with a core taken from the measured place is shown at figure 8.

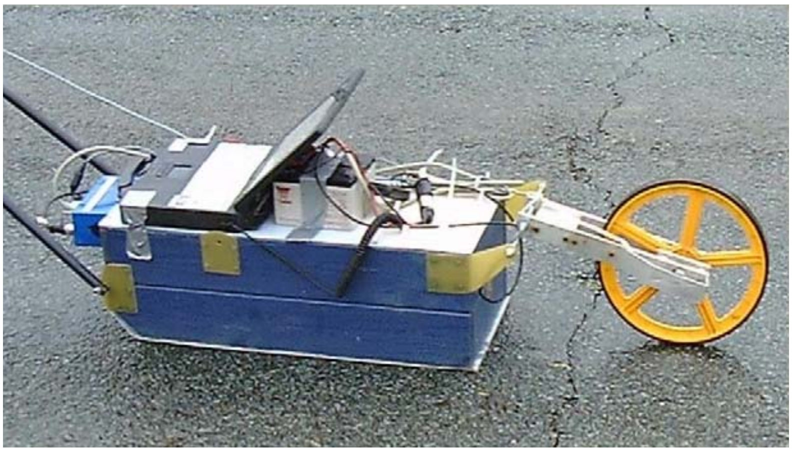

Fig. 7 - GPR crack depth detector (photo TRL, Utsi Electronics)

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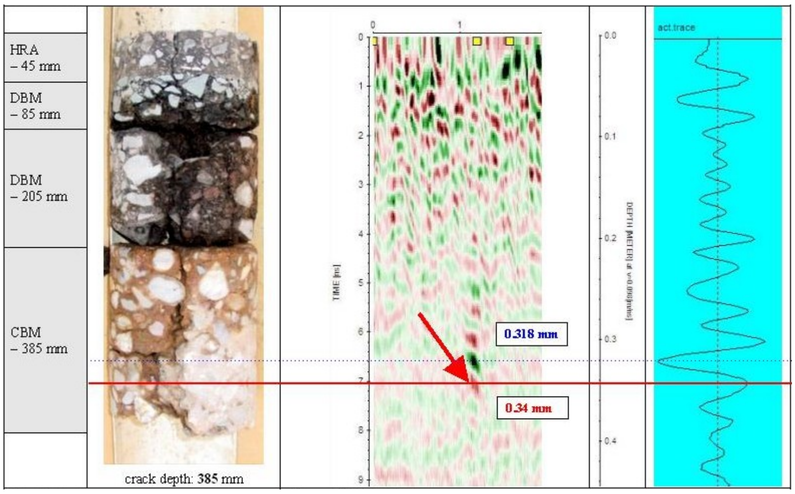

Fig. 8 - Result of crack depth survey: core, radargram, signal from one shot (location of the signal in the radargram is marked by the arrow)

4 OTHER GPR TOPICS

There are specific topics in the field of GPR road diagnostics which should be improved and further developed. The basic ones are mentioned below:

- influence of measurement speed on quality of GPR data (different sampling frequency),
- localization of measured data during high speed measurements (usage of measuring wheel, GPS and other systems),
- data interpretation and automation of this process (filtering, gain, etc.),
- autocalibration of layer and defect depths (using of multichannel systems, and different methods - WARR method: Wide Angled Reflection Refraction Analysis, CMP method: Common Mid-Point method, etc.),

Important area is also selection of correct antennas for specific measurements. This choice will affect the reach of measurement and its accuracy. The basic types of currently used dipole antennas with their basic parameters (wavelength, resolution, penetration) are mentioned in table 1. In the table there are mentioned also parameters of new 4 GHz horn antenna produced by company Utsi Electronics Ltd.

Tab. 1 - GPR antenna types with basic parameters

Frequency	900 MHz	1 GHz	1.5 GHz	4 GHz
Wavelength /mm	136	122	81	31
Resolution /mm	68	61	41	15
Penetration to /mm	1000	800	500	100

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5 SITUATION IN THE CZECH REPUBLIC

In the Czech Republic there are some companies which offer GPR road diagnostics. They are commercial companies which are concentrated mainly on determination of pavement layer depths and location of major defects.

In the Czech Republic there are no standard for GPR usage in the field of roads, but there is one standard for diagnostics of railway formation [9]. Figure 9 shows a railway radargram and its interpretation.

In USA they have two standards in the field of road diagnostics [10, 11], in the United Kingdom there are two specifications in Design Manual for Roads and Bridges [12, 13] (parallel with Czech technical specifications of Ministry of transport).

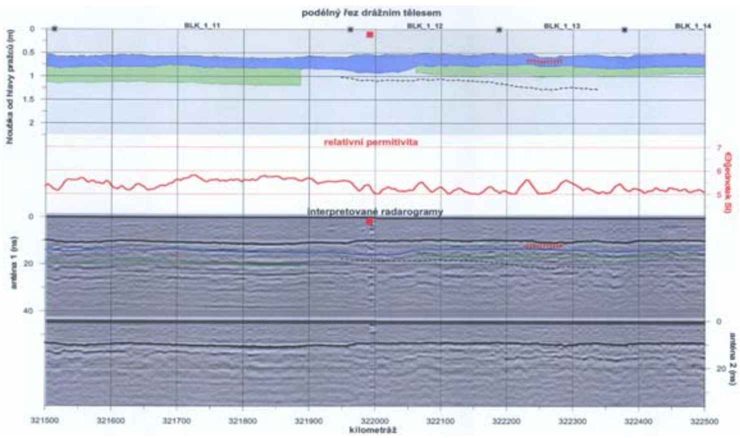

Fig. 9 - Czech Railways: GPR - longitudinal section of railway formation (radargram and its interpretation)

6 CONCLUSION

Usage of GPR in road diagnostics has a big advantage in obtaining of continual information about the structure and defects of measured road sections. Results of measurements are supplemented by information from control cores whose number is minimal. Traffic speed GPR measurements (more than 80 km/h) have positive impact on traffic flow.

Limitation of closures is important factor today. The traffic intensity is increasing every year and therefore the maintenance works and measurements which need a closure even of one lane have very negative impact on it.

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