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## GROUND PENETRATING RADAR APPLICATIONS FOR ROADS AND AIRPORT PAVEMENTS INVESTIGATIONS

A. Mocnik<sup>1,2</sup>, M. Dossi<sup>1</sup>, E. Forte<sup>1,2</sup>, R. Zambrini<sup>2</sup>, A. Zamariolo<sup>2</sup>, M. Pipan<sup>1,2</sup>

<sup>1</sup> Department of Mathematics and Geosciences, University of Trieste, Italy

<sup>2</sup> Esplora srl, academic spin-off of the University of Trieste, Italy

**Introduction.** In this work we present three examples of application of Ground Penetrating Radar (GPR) method for pavement thickness evaluation and stratigraphic analysis using R.Ex. (Road Explorer), a new system developed by Esplora srl, an academic spin-off of the University of Trieste, in collaboration with the geophysical group of the Department of Mathematics and Geosciences of the same University.

The implementation of this GPR system aims to obtain information that are crucial for the good management and planning of road maintenance, which is fundamental to prevent and minimize the risks to which light and heavy vehicles may be exposed during transit, and ensure the maximum safety for passengers. Nowadays, for testing of pavement of new road infrastructures, direct measurements such as drill cores are performed. Usually drillings reach a depth of about one meter from the road surface and its lateral spacing is variable, basing on the importance of the road and its constructive characteristics, but typically it exceeds some hundreds of meters.

These surveys are primarily aimed at:

- evaluating the thicknesses and local thickness variations;
- collecting all the elements for the definition of the mechanical properties of the road pavement;
- identifying voids, fractures or local defects;
- evaluating the correspondence between the design specifications and the actual work.

Similar surveys are also carried out even after the realization of significant works of maintenance of existing infrastructures or where particular problems have been reported on specific segments of a road infrastructure.

In recent years, such direct investigations, which are necessarily destructive and require the partial or total road block, have been joined with other surveys globally defined as “indirect” that let to obtain information about the subsurface without coring, being not-invasive and not-destructive methods. These methods are used for the extraction of elastic properties of the substrate and aggregates layers as Falling Weight Deflectometer - FWD (Briggs *et al.*, 1991),

and for the water content estimation by means of Time Domain Reflectometry-TDR techniques (Topp *et al.*, 1980). These approaches, while being generally very precise and accurate, provide just punctual information and are also very time consuming and quite expensive.

GPR can provide a continuous survey of a road segment: this is a very important factor since both the moisture content and thickness may have strong lateral variations. Moreover, the GPR is a fast and quite cheap technique.

Applications of GPR on road surfaces can be divided into four main categories: 1- surveys for planning of new roads; 2- investigations for the renovation of existing roads; 3- quality control or security investigations during road projects; 4- targeted surveys to the management of the road surface (Saarenketo, 2009).

In recent years, various applications have been tested for different purposes, ranging from thickness mapping to quality controls, with the development of techniques to achieve an accuracy of 2.5 mm (Maser *et al.*, 2003) and absolute errors of 2.9% by comparing direct data and radar profiles (Al Qadi *et al.*, 2003). Moreover, examples of detection of discontinuities, defects and studies of infiltration are reported (Saarenketo and Scullion, 2000, Grote *et al.*, 2005), as well as measurements aimed to the moisture content and the density estimation and to the quantitative characterization of the materials forming the pavements (Benedetto and Pensa, 2007; Benedetto, 2010; Plati and Loizos, 2013; Shangguan *et al.*, 2014).

In surveys performed on infrastructures with high traffic, the major advantages of GPR surveys are the continuous profiling, as well as the speed and accuracy. Such technique continues to be the only one that can provide meaningful subsurface information at an acquisition speed close to the highway velocity limits. The development of GPR application in infrastructures open to the traffic started in the seventies of last century with systems mounted or dragged by a van; from 1980s in Finland the method become the most popular and used as a routine surveys tool in various road applications (Saarenketo, 1992). Then, it soon developed especially in north Europe and nord America and actually it is a worldwide used technique for different purposes of the roads monitoring.

The GPR hardware is generally mounted on a survey van and made up of a control unit, cables, a positioning System (GPS); air or ground coupled antennas may be mounted on the van or dragged. The instrument is triggered by both constant time intervals or electro-mechanic odometers.

The system can also record simultaneously data using different frequencies. This aspect is very important because the higher frequencies allow to reach higher resolution levels but within limited depths, while antennas transmitting at lower frequencies penetrate deeper even if the degree of detail is reduced.

We describe the method for GPR data acquisition by using the R.Ex. system showing applications for: 1) the analysis of the thickness and the shallow stratigraphy in an airport transit area; 2) thickness evaluation in a newly constructed aircraft apron; 3) thickness lateral changes on recently re-paved roads.

**Method.** Esplora srl and the geophysical group of the Department of Mathematics and Geosciences of the University of Trieste developed a prototype of a GPR equipment support for roads investigation, that has been named R.Ex.-Road Explorer (Fig. 1).

It is composed by a tow entirely made in fiberglass in order to avoid electromagnetic (EM) noises caused by metal supports; it includes special anti-shock boxes to support two ground coupled GPR antennas with different frequencies. The wheels of the tow contain an encoder for the trace positioning, connected to the central unit. The latter is positioned inside the van that drag the R.Ex. system; depending on the conditions of wear and alteration of the surface, the van can reach speeds up to 50-60 km/h, without altering the GPR records.

A Malå ProEx GPR is used to transmit simultaneously two EM waves with different frequencies by connecting two antennas to the central unit. All the antennas are shielded in order to avoid or limit spurious signals. One of them is in the frequency range 800-500 MHz,



Fig. 1 – R.Ex. GPR system and its components connected to a van during a survey.

while the other in the 1.6-2.3 GHz one. In the tow R.Ex., the two antennas are aligned with the truck: at the head the medium frequency antenna is positioned, while on the back the higher frequency one, distant from each other 0.61 m. Depending on the objectives of the investigations and the depth of the targets, we tested that the 2.3 GHz with the 800 MHz couple is used for very high resolution investigations and shallow objectives (determination of the centimetric thickness of aggregate layers), reaching a maximum depth of about 30 cm for the 2.3 GHz and 1m for the 800 MHz. The combination of 1.6 GHz with 500 MHz antennas is generally used to detect structures reaching a depth up to 2 m, like the base and subgrade strata for the 500 MHz antenna, and about 50 cm for the antenna of 1.6 GHz. This is not a standard rule since, as for any practical GPR application, the performance must be tested in situ in order to verify the actual penetration depth and resolution.

One clear advantage of the ground coupled antennas system is the better signal penetration compared with that of the air-coupled ones; another advantage is the better focusing respect air-coupled antennas, that allows an improved pavement cracks or cables detection (Saarenketo, 2009). Laboratory analysis performed on asphalts cores during the R.Ex. system implementation, let us to determine the maximum elevation of the antennas from the ground to obtain the best tradeoff between GPR performances and logistic effectiveness.

The accurate positioning of the GPR data is the most important factor during the data collection phase. Data with incorrect spatial referencing are worthless to the customer and damaging for engineering applications. Positioning can be done using an encoder, that controls the trace interval, or/and using GPS devices; in addition markers at known reference points can be fixed during the data acquisition. The R.Ex. system allows a combination of the previous methods allowing a better control and location of the GPR traces. We install a RTK mode GPS with centimetric precision connected with the GPR control unit, so for each trace of both antennas, we have the coordinates(X, Y and Z). This procedure allows us to geographically locate some defects of the roads, locate specific points of relevant thickness variations, and to associate the position of a drill core to a specific trace, which is useful and necessary for an accurate calibration of the EM velocities.

**Processing and data production.** The processing sequence is aimed at enhance the signal to noise ratio by reducing ringing and low frequency components (DC), as well as the high frequency ones, after the determination of the actual time zero (drift removal).

In the following case histories we adopted a standard processing sequence encompassing: background removal, high-pass filtering, true amplitude recovery and depth conversion. A static correction has not been applied due to the sub-horizontal topographic surface and the sub parallel nature of the imaged horizons.

In relation to the evaluation of the reliability and accuracy of the obtained results, one of the most critical points is the degree of confidence of the thickness values of the different

pavement layers (wear, binder, base). Regarding this point the demand of end-users is a sub centimeter precision. In order to approach such precision is necessary: a) to increase the accuracy in determining the EM wave velocity in the subsurface that allows to convert in depth data originally acquired as a function of traveltime; b) increase the precision of picking the first sample relative to a actual reflection (first break).

The EM wave velocity can be estimated on the basis of the GPR data with different levels of precision (Jol, 2009), but an intrinsic error of the order of 5-10% (Forte *et al.*, 2014) is expected.

For the presented work we used a traditional method for determining the dielectric value of pavement by back-calculating the velocity values by using the drill core data.

*CASE-1: airport pavements.* We tested R.Ex. system on two different sites of an airport pavement in order to: 1) give information of the stratigraphic sequence up to about 2 m of depth from the surface and recognize possible failures or subsidences structures, and lateral variations of the geotechnical properties (Test Site1); 2) verify the thickness of new constructed FRC (Fiber Reinforced Concrete) plates (Test Site 2).

The Test Site 1 is an airport transit area where we used the combination of 500 MHz and 1.6 GHz antennas in order to achieve the better tradeoff between resolution and investigation. The depth conversion has been obtained by diffraction hyperbola analysis and by the available drill cores and continuous penetrometric surveys. In Fig. 2a an example of profile is shown. The lateral contrast between the concrete plates (left of profile) and the bituminous aggregate (right of profile) is clear: in yellow we marked the base of concrete and in green the base of the asphalt. The depth of each layer has been stored in a dedicated database implementing a GIS project, which allows to produce depth maps that can give a global overview of the stratigraphic variations of all the imaged layers. In particular, it was observed that the sedimentary contact between granular sub base and clay-silty levels (light blue) deeps below the concrete reaching a depth close to 2.5 m and it disappears in the central sector of longitudinal profiles (map in Fig. 2b).

The Test Site 2 is a new aircraft apron where we used the 1.6 GHz and 800 MHz antennas couple. We collected longitudinal transects to cross all the length of the aircraft apron for a maximum length of 160 m. The exact location of already drilled cores on some selected plates was available before geophysical data collection and so we designed the GPR survey crossing all the drill locations for a more constrain data calibration.

The GPR analysis evidenced a very strong EM attenuation. This let more difficult and delicate the horizon picking phase aimed at the recognition of the base of the concrete, evidenced by a weak reflector only on the 1.6 GHz data (Fig. 2c). The low reflectivity has been inferred to the high metallic mineral compound within the concrete mixture, as reported by the client.

For the depth conversion, we used a variable lateral velocity field, due to the variation of thickness measured by the cores (range from 32.9 to 37 cm) and because of the variability of reflected traveltimes of the horizons. Thus, maintaining the constraints in correspondence of the cores (generally 2/3 cores for each profile) we calculated the gradient of the resulted velocity value between them.

The intrinsic error of each picked measure is, from the statistical point of view, equal to the  $\pm$  the sampling interval. Considering the frequency of 1.6 GHz, the fixed time sampling interval equal to 0.096 ns and the measured velocity values close to 15 cm/ns, we have assumed that the picked horizon lies in a range of  $\pm 0.0072$  m from the inferred depth.

*CASE-2 highway survey.* 149 Km of recently paved roads were surveyed, recording multi-frequency (800 – 2300 MHz) GPR profiles. We recorded a total of 351 km of data, composed by the acquisition along each road lane in the two track directions.

The aim of these surveys was to measure the thickness of the aggregate layers and the depth of the subgrade, imaging and locating any possible lateral variation of thickness and evidencing the main stratigraphic features.

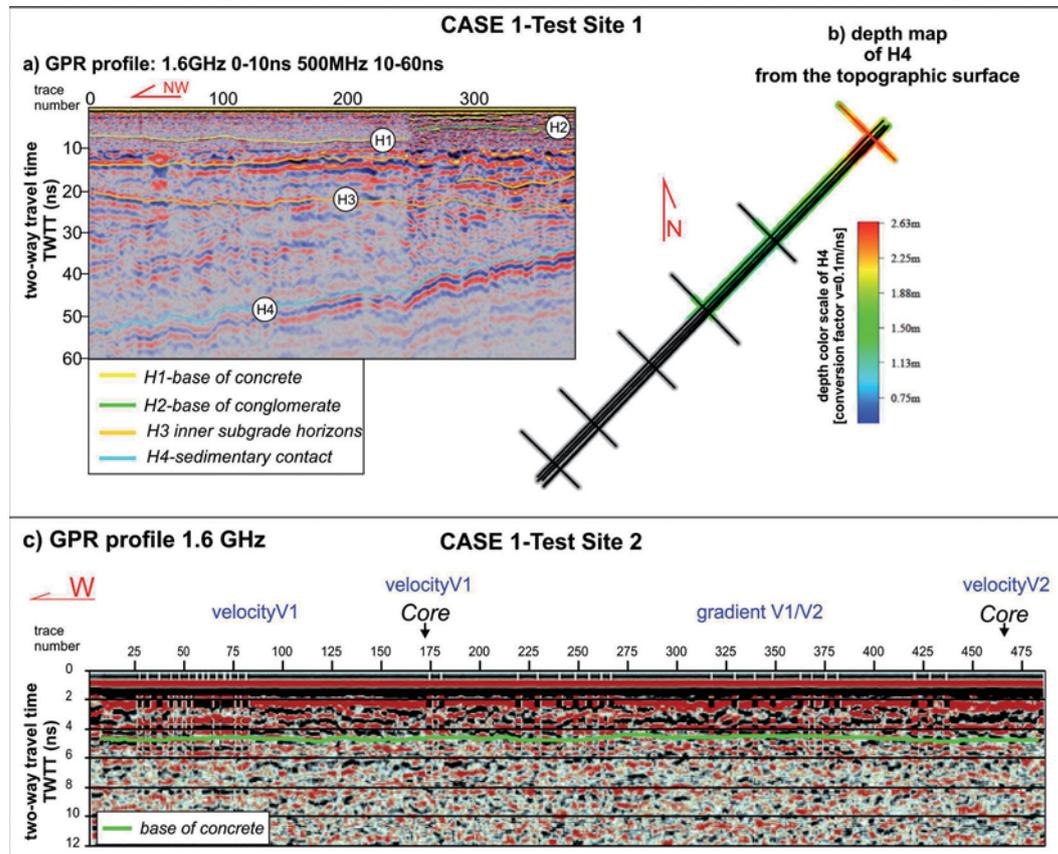


Fig. 2 – example of results from CASE 1 applications of R.Ex. system; a) example of GPR profile acquired in Test Site 1 with 1.6 GHz data till 10ns and 500 MHz data from 10 to 60 ns. b) depth map of sedimentary contact horizon H4 of Test Site 1 where the layer deeps toward north; c) example of GPR profile acquired in Test site 2 where in green color is depicted the weak reflection of the base of the concrete plates.

The GPR survey was joined by FWD performed on the same roads crossed by R.Ex.

Due to the objective of the survey, which was not dedicated to fractures or defects location, we used an horizontal trace spacing of 1m and we fixed a mean acquisition speed of 50 km/h.

In Fig. 3 we show an example; this profile is peculiar because it evidences strong lateral variations of thickness of the aggregates layers. This trend has been also confirmed by the sample cores executed by a geotechnical company, which have been used for velocity calibrations. Along the 2.3 GHz profiles we interpreted the trend of the conglomerate layers (binder and base interfaces, in green and yellow) while along the 800 MHz data we interpreted the horizons associated to the old pavement (in pink) and subgrade (in light blue). Till about trace 2000 from the south, the base of conglomerates lies at an almost constant depth; prosecuting toward the north, the thickness increases and is based on the old pavement not evident southward; the subgrade layer is also irregular. This different behavior from north to south has been observed even by the FWD data response, associated to strong inhomogeneities of the road embankment.

Generally, for this survey, GPR profiles depth conversion has been executed using a vertical variable velocity field: we used a constant velocity for the conglomerate layers derived by the available drill cores, and different velocity values for the subgrade. The latter have been calculated for each road lane based on the building project specifications.

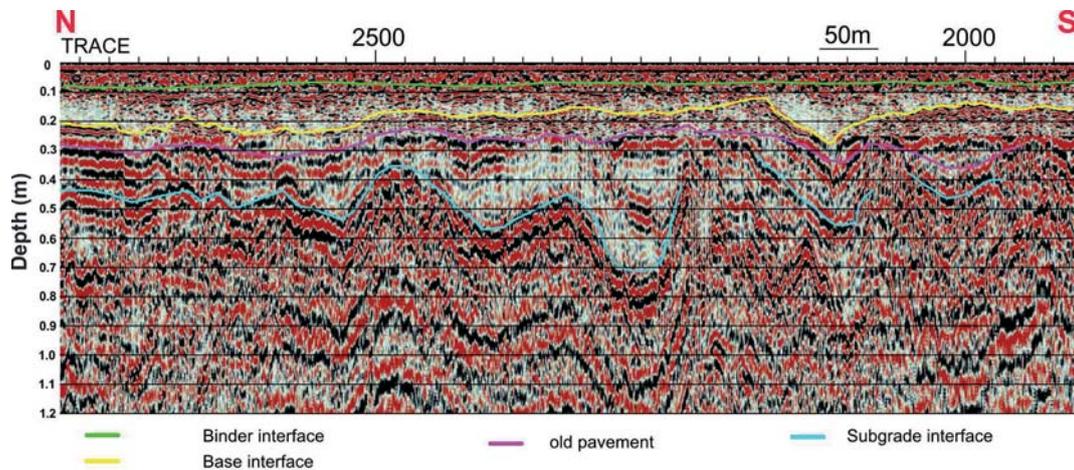


Fig. 3 – Portion of GPR profile of CASE-2 composed by 2.3 GHz till 25 cm from the surface and 800 MHz from 25 cm to 1.2 m of depth; the lateral variation of thickness of the aggregate layers and of subgrade is evident.

**Conclusions.** The R.Ex. system constitutes an acquisition device aimed at obtaining a huge amount of high quality GPR data in a relatively short time. Furthermore, the integration and joining of multi-frequency antennas is essential to obtain high resolution in the shallower portion of paved roads and detailed information down to 2-3 m below the topographic surface.

The methodology described in this work allows to achieve the information that are important for a traffic infrastructure company before maintenance operations planning and after new roads constructions. In Case-1-Test site-1 the interpretation of inhomogeneities of the subgrade let to locate the critical failure points and drive for future maintenance activities; Case-1-Test site 2 and Case 2 report the surveys after pavement and construction works, that has been used as a sort of verification of the layers thicknesses and its analyses between the cores.

Future developments have to be addressed to the improvement in the precision (and the speed) of picking horizons. In this regard, a picking method was recently implemented and tested in different fields of application (Forte *et al.*, 2013; Dossi *et al.*, 2015a) including pavements (Dossi *et al.*, 2015b, 2015c). The obtained results are encouraging allowing to achieve a faster and more accurate picking, diminishing at the same time the subjectivity level of the interpretation.

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## NON-INVASIVE PROSPECTING IN THE OLD TOWN CENTRE OF MESAGNE (BRINDISI, SOUTHERN ITALY)

G. Leucci, L. De Giorgi, L. Matera, R. Persico

*Institute for Archaeological and Monumental Heritage IBAM-CNR, Lecce, Italy*

**Introduction.** Geophysical methods play an important role within many important applications. In particular, it is an important noninvasive technique widely exploited in the contexts of discovery and/or preservation of cultural heritage (Giannotta *et al.*, 2015; Goodman and Piro, 2013; Leucci *et al.*, 2011; Negri *et al.*, 2008; Pieraccini *et al.*, 2006; Matera, 2015) and civil engineering (Cataldo *et al.*, 2014; Piscitelli *et al.*, 2007), that are the most relevant for this contribution. In some cases, the two kind applications can converge together, as e.g. in the case of the investigation of columns (Leucci *et al.*, 2007; Masini *et al.*, 2010). Also in this paper we present a case history where these two kind of interests are joined together. In particular, a multisensory measurement campaign will be presented, including earth resistivity tomography (ERT), spontaneous potential (SP) and ground penetrating radar (GPR) investigations carried out in the old town centre of the town of Mesagne, placed in the outskirts of Brindisi, southern Italy. In particular, after a strong storm a pipe of the aqueduct in Mesagne broke down causing serious subsidence events. Fortunately, no person has been injured during the event, but several buildings have been seriously damaged, and the local municipality has been compelled to vacate several houses that have become definitely dangerous after the event. Moreover, the municipality of Mesagne contacted the Institute for Archaeological and Monumental Heritage IBAM-CNR and committed to it a non-invasive geophysical measurement campaign in order