GPR profiling and electrical resistivity tomography for buried cavity detection: a test site at the Abbaye de l'Ouye (France)

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ABSTRACT
The abbaye de l'Ouye (France) presents an underground room situated under a flat graveled path perfect for testing the complementarity of two geophysical methods, ground-penetrating radar (GPR) and electrical resistivity tomography (ERT), for buried cavity detection. One GPR mono-offset profile was acquired along with a 2D ERT profile on the surface above the cavity of known dimensions. We use our field site to test 2D ERT data acquisition and inversion parameters and how to complete GPR data information with ERT and vice-versa. As expected the mono-offset GPR profile contains strong reflections on the ceiling and the floor of the room. Arrival times of those reflections are translated to depth using classical GPR data processing techniques. The measured electrical apparent resistivities were inverted using the Loke (2001) software with three different options: i) no a priori information, ii) a priori information included as high resistivity value in an area determined from the GPR reflections, iii) a priori information included as boundary positions derived from the GPR reflections.

INTRODUCTION

Our basement contains a dense network of underground cavities. These sub-surface voids make many buildings or infrastructures unstable or cause them to collapse. Therefore it is of major interest to be able to detect underground cavities in urban environment.
Different geophysical investigations have been carried out on this purpose with diverse methods such as gravity, seismic, electrical and electromagnetic measurements [1]-[5]. The main difficulties reside in the necessity for dense station spacing to reduce spatial aliasing, and high quality data to resolve small features. We decide to focus on two geophysical methods: ground penetrating radar (GPR) and electrical resistivity tomography (ERT).
The GPR is one of the most recommended non-destructive techniques used in near surface mapping studies [5]-[6]. It allows fast and dense data acquisition in urban environment. Its data sensitivity to dielectric permittivity variations makes it a common tool to detect the underground cavities (natural or man-made), with reflections due to the soil-air and air-soil interfaces easily identified.
The ERT is a common method to investigate shallow depth structures [7]-[8]. Two-dimensional resistivity imaging is used successfully for detection of underground cavities because of the electrical resistivity of the void is higher than the surrounding rocks and this difference may be the most outstanding physical feature of a cave.
In this paper we test the two method complementarity over an existing cave at the Abbaye de l'Ouye.

SITE OF INVESTIGATION

We have carried out our study in the garden of an abbey (Abbaye de l'Ouye) located beside the town of Dourdan (France). We have acquired GPR and ERT profiles above the underground room (yellow lines) along the green line as indicated in Figure 1.

INSTRUMENTATION

The GPR mono-offset profile was acquired using 250 MHz antennas with a RAMAC Mala system. Those 250 MHz antennas were selected as the most suitable for this work due to their optimum compromise between penetration and resolution. Traces were collected every centimeter. It consisted of 1024 samples for a time window of 80 ns. To help for velocity analysis we acquired also a multi-offset profile (not shown here). All GPR data were processed using the REFLEXW

Sandmeier software. We applied time zero correction, dewow filtering, and compensanted the amplitude attenuation due to geometrical divergence. To interpret our GPR data, we simulated radargrams using GprMax which solves Maxwell's equations using the finite-difference time-domain method [9].

For the ERT survey, we used the Wenner configuration [10]. The measuring device is constituted by a resistivimeter connected to an arrangement of 48 electrodes with an electrode spacing of 0.5 m. We derived resistivity model sections from the measured apparent resistivity pseudosection using the RES2DINV (ver.3.59.66) software package [10].

RESULTS AND DISCUSSION:

GPR and ERT data comparison:

In order to make a direct comparison, GPR and resistivity survey lines were acquired along a coincident profile (green line in Figure 1). In Figure 2, we present our results. Figure 2c shows the processed GPR mono-offset profile with reflections that could come from the soil-air interface and the air-soil one. From hyperbolas fitting and the multi-offset profile analysis, we determined a velocity of 0.08 m/ns for the electromagnetic wave propagating in the soil. Using this velocity, we migrated the GPR profile with the Stolt method (Figure 2d). To have an idea of the expected GPR signal over the cavity we simulated the radargram shown Figure 3. The time delay between the first and the second reflection on the simulated radargram (Figure 3b) matches the observed one on the measured radargram Figure 2c. An inversion of signal polarization between the two reflections is clearly visible on the simulated radargram (Fig. 3b) but not so easily on the measured radargram (Fig. 2c). The red arrows on Fig. 2 show the time delay taken for the depth estimate for the first layer. The time zero was set to the maximum amplitude of the soil direct wave. The transmitter and receiver being 31 cm, the thickness is estimated to 1 m. As a results, it is possible from GPR data to estimate the top layer thickness, to laterally position the middle of the underground cavity, and to evaluate its height. Even with the migrated data, it is difficult to status on the kind of permittivity variations creating the reflections. The inversion of polarization is not clear and the migrated profile is not awfully wrong about the second reflection on the interface air-soil.

Figures 2a and 2b are the inversed electrical resistivity sections obtained after 10 iterations using a least-square inversion routine offered in RES2DINV including no a-priori information. Fig. 2a is obtained with a unit electrode spacing of 1 m. To get a better resolution the profile was acquired a second time using a unit electrode spacing of 0.5 (Fig. 2b). The root mean square error between the simulated apparent resistivities and the 360 measured ones is around 0.9% for both electrode spacing. These first inversions of the ERT data alone confirms the interest of using electrical resistivity imaging in order to detect cavities in the soil structure; the coincidence of the region of high resistivity anomaly (400 – 1000 Ω m) with the reflections observed on the radargram (Figure 2c) correspond to the cavity zone. However the boundaries of the cavity are not very precise on the right side. Both geophysical signals seem to be annoyed by a higher resistivity zone encircled with a question mark on Fig. 2b.

Using GPR data as a priori information for ERT data inversion:

We used the radargram to define the limits of the cavity, using arrival time-picking of the top reflection after migration of the data (velocity of 0.08 m/ns) and assuming a flat floor for the cave. We introduce this information by two methods in the inversion of the electrical resistivity measurements with a unit electrode spacing of 0.5 m. First we imposed a high resisitivity of 10000 Ohm.m inside the limits determined by the GPR. Those limits were approximated using trapezoidal elements as shown as the black line in Fig. 4b. The result of the 10^{th} iteration of the inversion in Fig. 4a gives an image of the cavity that is closer to the measured dimensions of the cavity (Fig. 3a). It respects the information coming from the radargram and it fits as well the resistivity measurements as the model in Fig. 2a as the RMS errors are comparable on the two models.

As a second test, we introduced the GPR information as sharp boundaries (black line on Fig. 4b) allowing the model to take any electrical resistivity distribution. The method gives more freedom in the inversion procedure. The inversed

ERT after 10 iterations is shown Fig. 4b. The image of the cavity section is less precise than in Fig. 4a but it still fit what we know from the cavity size and the data fit is still as good as for the two other models (RMS error of 0.80 %). In Figure 5 we show the interpolated images of Figure 4.

CONCLUSIONS:

From our results, it is clear that from mono-offset GPR profiling alone it is difficult to determine precisely the cavity boundary even after data migration. The electrical resistivity measurements inversed on their own indicates a high resistivity area on the place of the cavity. The top soil-air interface seems to be partly resolved when using the smaller electrode spacing but the underground room floor position is not clearly defined even using the larger electrode spacing. Introducing GPR information such as depth of the ceiling and a shape for the cavity coming from the migrated image help to construct an electrical resistivity model that fits the reality.

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Figure 1: Location map of the study area. The limits of the underground room are represented in yellow. The geophysical profiles were acquired along the green line.

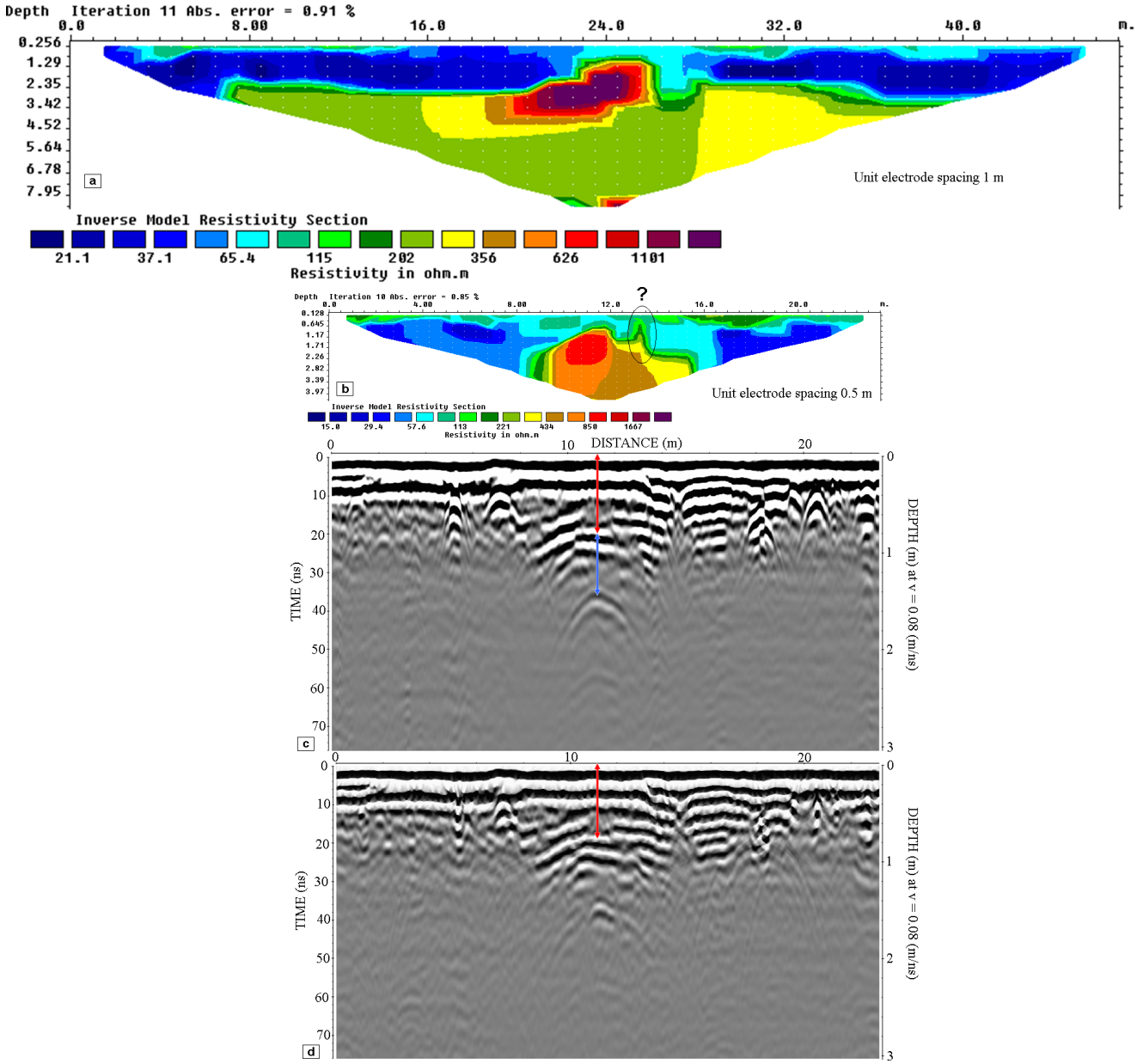


Figure 2: Geophysical results as inversed electrical resistivity variations with no a-priori information with **a)** unit electrode spacing of 1 m, **b)** unit electrode spacing of 0.5 m, and processed radargrams corrected for divergence attenuation compensation **c)** non migrated data, **d)** using Stolt migration routine with a velocity of 0.08 m/ns.

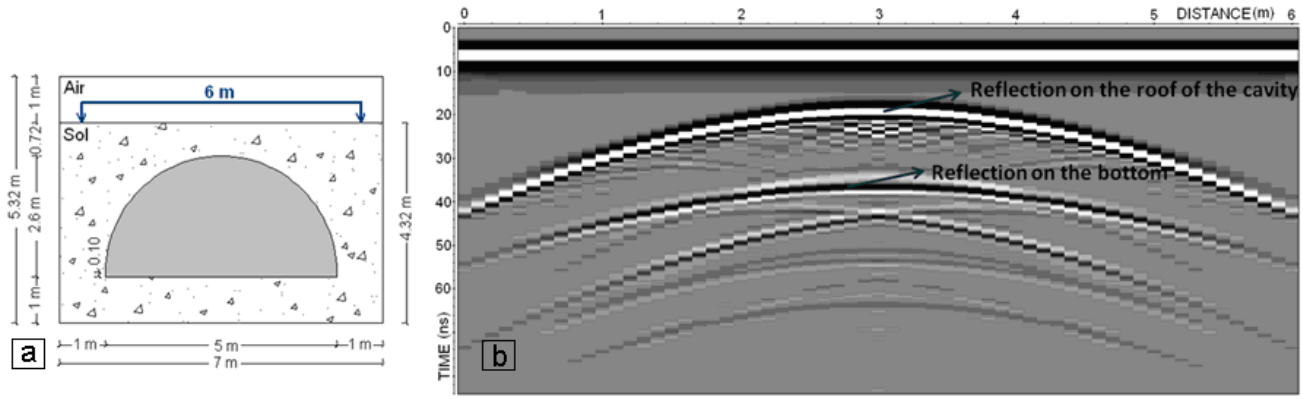


Figure 3: a) Geometry of the model and b) its simulated radargram (no gain applied). The soil properties are 9 for the dielectric permititivity and 0.01 S/m for the DC electrical conductivity

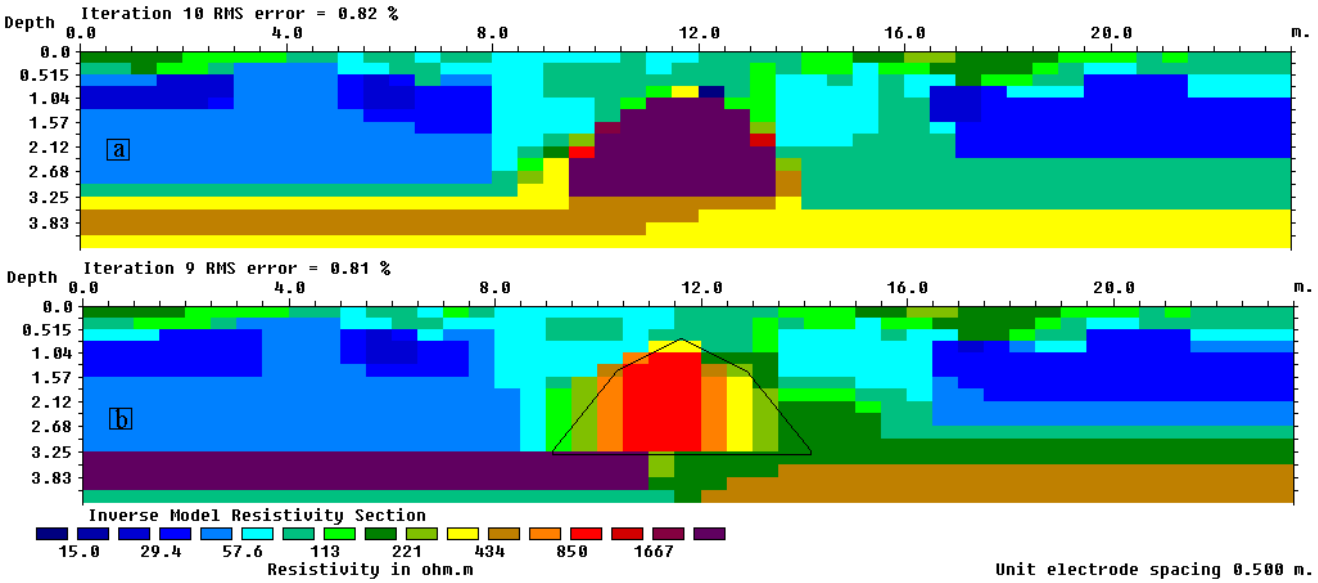


Figure 4: Inversed electrical resistivity section using a priori information as a) imposing a high resistivity value of 10000 ohm.m inside a zone derived from GPR data, b) imposing sharp boundaries located from the GPR data.

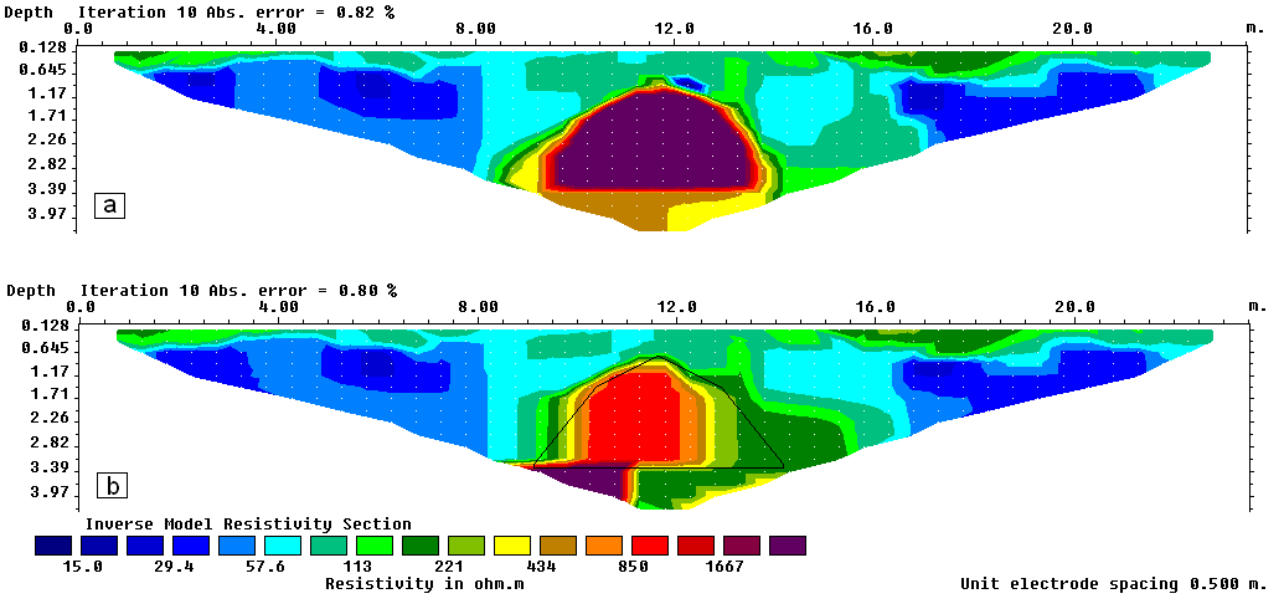


Figure 5: Interpolated images of Figure 4 results.