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Use of electric resistivity tomography (ERT) for detecting underground voids on highly anthropized urban construction sites

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Abstract

The current paper presents the use of ERT geophysical investigations performed on a construction site to investigate the presence of underground voids (old basements, embedded pipes etc.) that can cause safety and technological issues during future construction works. The data acquisition was based on 4 ERT profiles placed along the area were underground voids were expected. Some acquisition and processing challenges were encountered and the applied solutions are presented herein. The anomalies presented on profiles recorded with different electrode arrays (Wenner, Schlumberger, Dipole-Dipole) show the presence of underground voids, but the position and size cannot be determined exactly, so a reliability based approach is employed to characterize the result.

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Keywords: ERT; geophysics; underground voids

1. Introduction

Geophysical investigations are widely considered to be the best methods of finding underground cavities, with particular application in urban areas [1]. These cavities represent a major risk when heavy machines are deployed on a new construction site and should be detected prior to starting of construction works. The voids can be either air-filled, water-filled or partially water-filled, all cases yielding electrical resistivity contrast with respect to the surrounding soil. Therefore, ERT investigations have been generally employed to such applications, also providing a low-cost, fast and robust investigation tool.

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2. Site description

The Jewish Neighbourhood of Bucharest was a compact residential and commercial area built at the end of the 19th century, located on the left bank of the Dâmbovița River, close to what we know now as the Unirii Square. In the 1980's, under the communist regime, this neighbourhood was almost entirely demolished and in its place several large residential and administrative buildings were constructed according to the enforced urban planning. Therefore, the area had an intense anthropic activity (Fig. 1), and is currently undergoing a new stage of development, which carries some risks regarding the construction phase due to hidden underground voids.

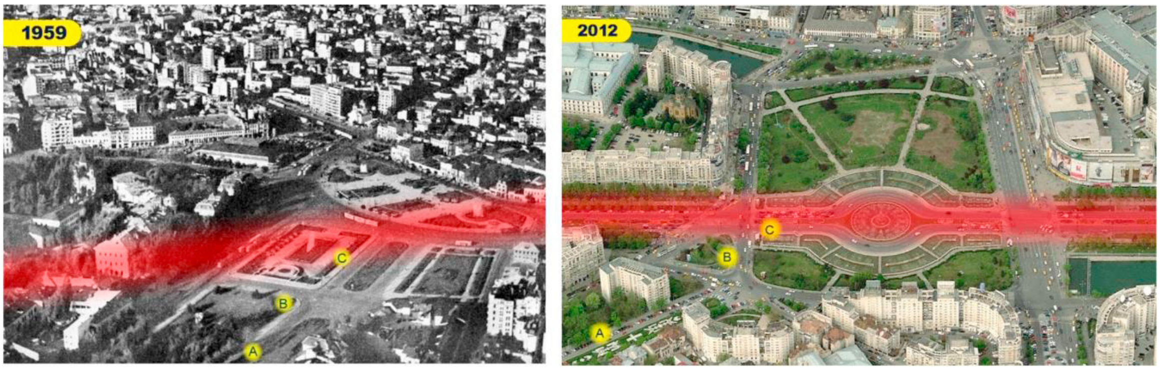

Fig. 1. Unirii square transformation in 50 years

3. Data acquisition and preliminary results

The data acquisition process was performed in two stages (Fig. 2) using an IRIS Electric Pro equipment with 1.0m electrode spacing. Inversion of ERT data was performed by using RES2INV software (M/s Geotomo Software, www.geoelectrical.com).

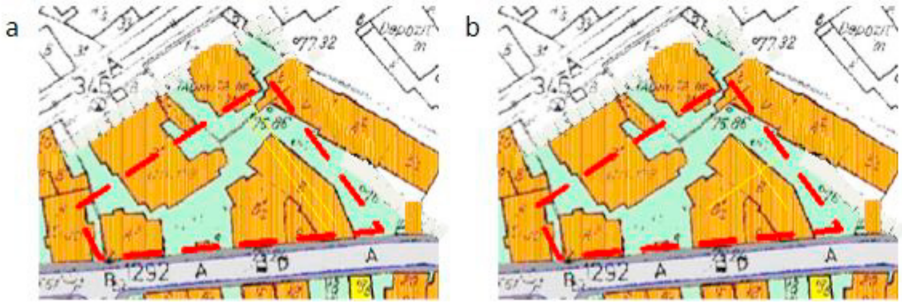

Fig. 2. Data acquisition stages (red line – site contour; yellow lines – ERT profiles): (a) stage 1; (b) stage 2.

The ground surface was composed mostly of construction debris from the former buildings so the electrodes had to be inserted into predrilled holes (Ø6mmx20cm) and the ground-electrode electric contact was enhanced by adding brine. The effect of the added brine was analysed for the first measurement stage, when an additional profile was recorded without any enhancements to the electric contact. Fig. 3 shows the contact resistance between adjacent electrode pairs in initial site conditions and with added brine. It can be noticed that the added brine improvement is significant, especially for electrodes that were placed in highly unconducive environment. The figure also shows that the top layer is highly heterogeneous, due to construction debris, which heavily effects the electric resistance variation along the profile. Adding the brine, not only improved the topsoil-electrode contacts, but also made the profile contact resistivity less disperse, thus reducing the acquisition noise.

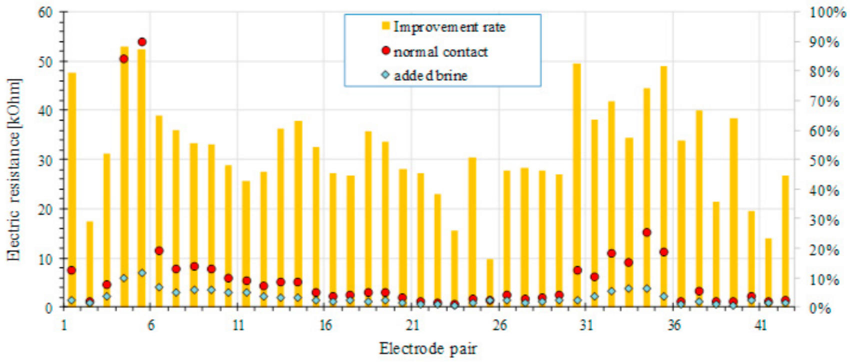

Fig. 3. Effect of contact resistivity improvement by added brine

The first stage of data acquisition was performed using Wenner [2] and Shlumberger [2] protocol, because of the heterogeneous nature of the top layer. Pazdîrek and Bláha [3] reported that these methods provide good horizontal and vertical subsurface resistivity resolution as well as high signal strength. Fig. 4 and Fig. 5 show the first two profile results (all resistivity sections in this paper are represented using the same resistivity color scale), which indicate some potential cavities, but precise characterisation of their size and position is difficult to assess as shown by lack of correlation between the results in profile 2 (Fig. 5). Furthermore, it can be noticed that the topsoil layer shows high resistivity and horizontal variation on both profiles. This may be a source of poor correlation between the resistivity profiles obtained by data acquisition using different electrode arrays.

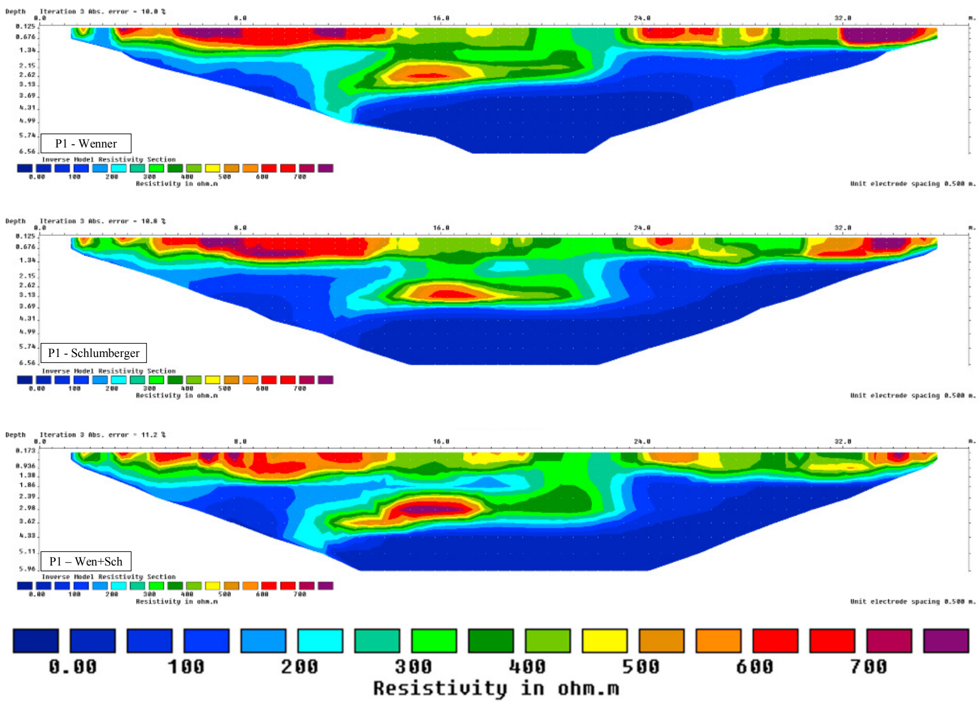

Fig. 4. Resistivity cross-sections obtained for profile 1

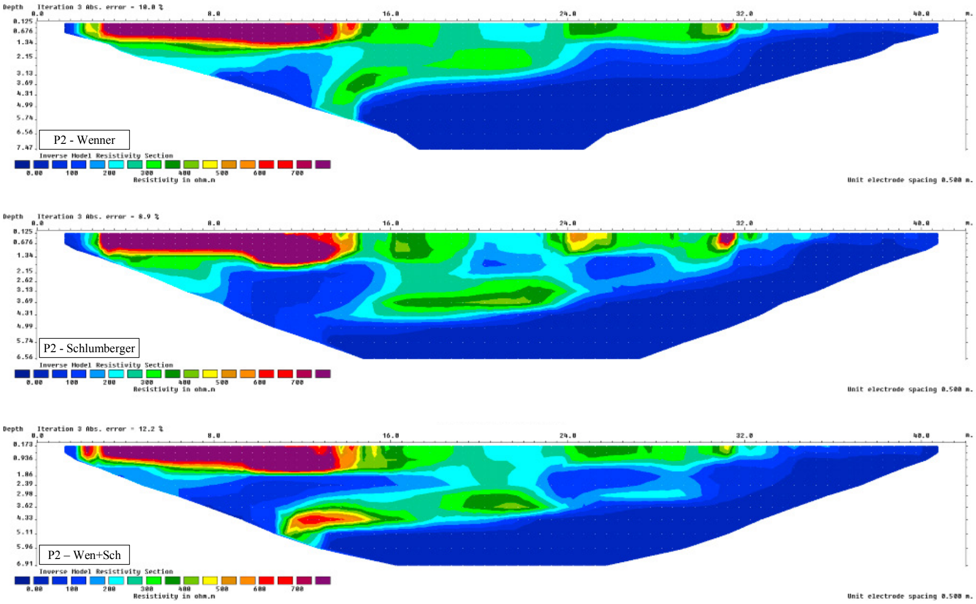

Fig. 5. Resistivity cross-sections obtained for profile 2

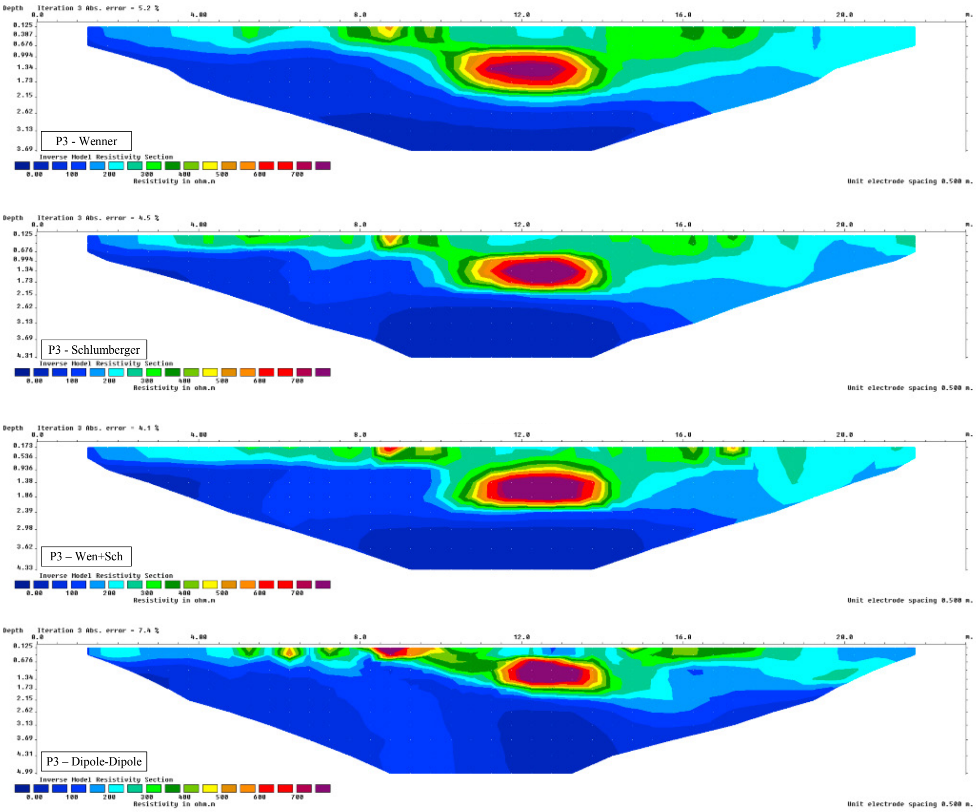

Fig. 6. Resistivity cross-sections obtained for profile 3

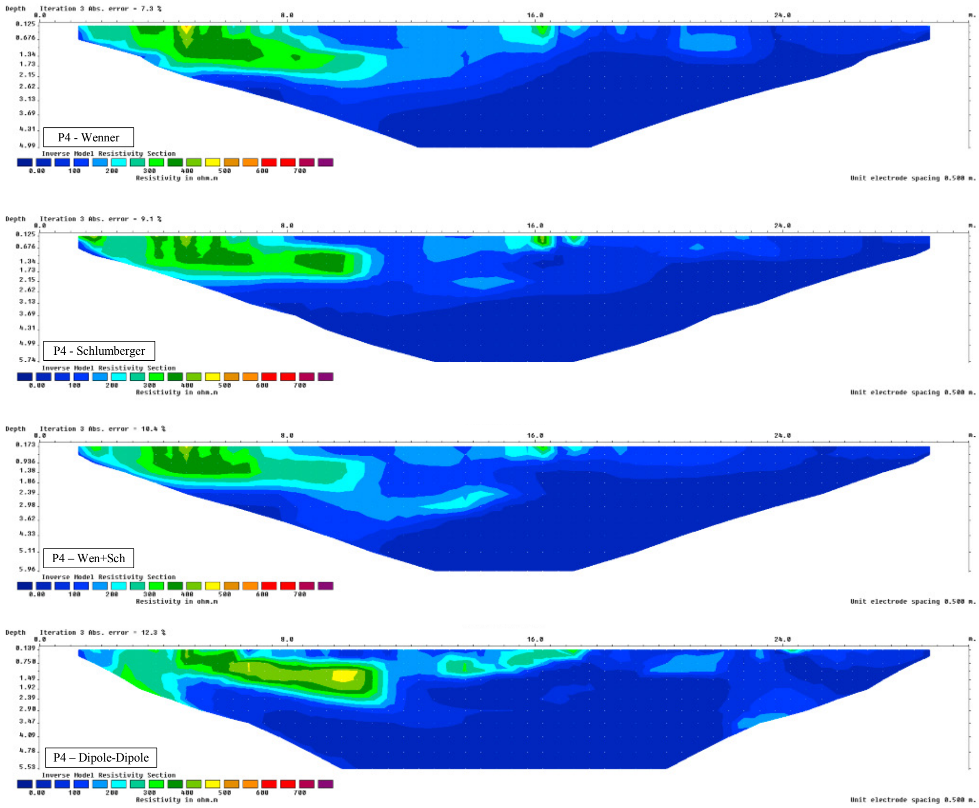

Fig. 7. Resistivity cross-sections obtained for profile 4

Due to the results obtained from interpretation of data acquired in stage 1, a second set of measurements (Fig. 2b) were conducted two weeks later, after an increase in moisture content of the topsoil due to snow thawing. In order to quantify the quality of acquisition between the two stages, profile 3 was performed on the same alignment as profile 2 (of stage 1). In order to improve the horizontal resolution of the resistivity profiles [4], Dipole-Dipole electrode array [2] was also employed for the second stage.

Fig. 6 and Fig. 7 show a very good correlation of the high resistivity anomalies between all the cross-sections obtained by acquisition with different electrode arrays. Also, it may be noticed that the increase in moisture content of the topsoil resulted in a decrease in resistivity values and lateral variation. The improvement in correlation of the second stage acquisition with respect to the initial stage shows that the change in environmental conditions had an important effect on the collected data, indicating that the high resistivity and heterogeneity of the topsoil in the first stage was creating considerable acquisition noise.

4. Data processing and interpretation

The inversion was performed with RES2INV software using refined mesh and robust inversion techniques on automatically filtered data (with PROSYS II) and the resulted inverted model is obtained based on nonlinear least-squares optimization [5, 6]. Disregarding the noisy profile 2 and employing only the results obtained from profiles 1, 3 and 4, a set of two surfaces were created, indicating the higher and lower probability of cavity in-plane distribution. For each profile, the position of the void was expressed based on the distribution of resistivity along the cross-sections.

The used approach is described in Fig. 8, which shows how minimum and maximum estimated size of the void was obtained from profile 3. The same was performed for all profiles, which resulted in a plane distribution of the void position, described in Fig. 9.

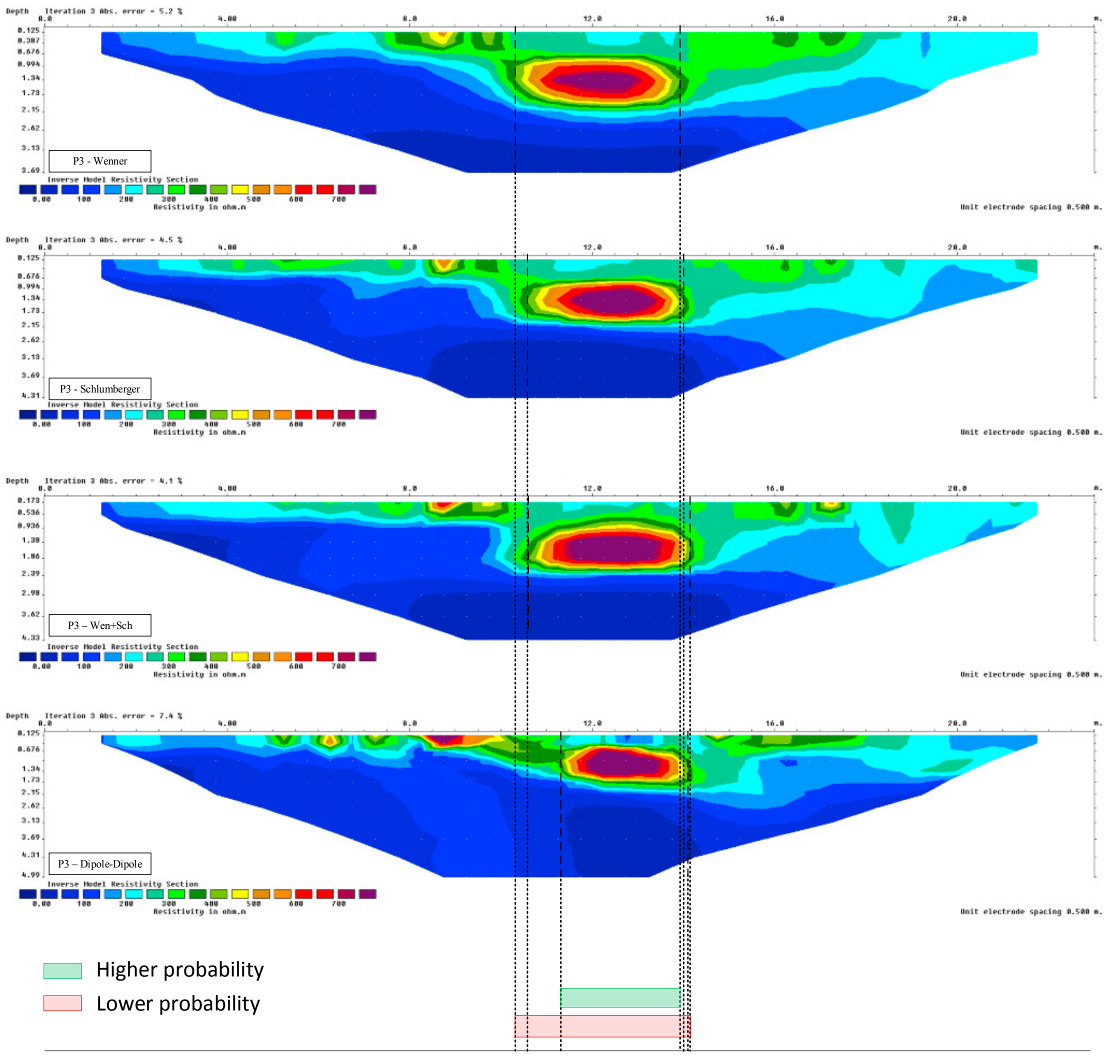

Fig. 8. Void position estimation based on different electrode arrays ERT sections

The obtained plane distributions of the void are expressed in comparison to the real confirmed void, and the results are in acceptable agreement. The estimated area of the void was 20% less in the case of the higher probability distribution, 30% more for the lower probability case, with an average of 5% with respect to the real cavity size. It can be noticed that an average estimation of the void size can be done with confidence, although the exact position lacks accuracy, due to errors which might be caused not only by data processing, but more likely by inexact electrode location during data acquisition. The position of the real void was determined with topographical precision, as opposed to the position of the electrodes installed in-situ, which was established by means of ruler and site benchmarks.

To further characterize the accuracy of single ERT profiles, the real void size was plotted against profile 3 (Fig. 10). The first stage acquisition does not show very accurate estimations of the cavity position, but still gives some insight of the voids presence. The second stage, however, gives consistent results regarding the presence and position of the void.

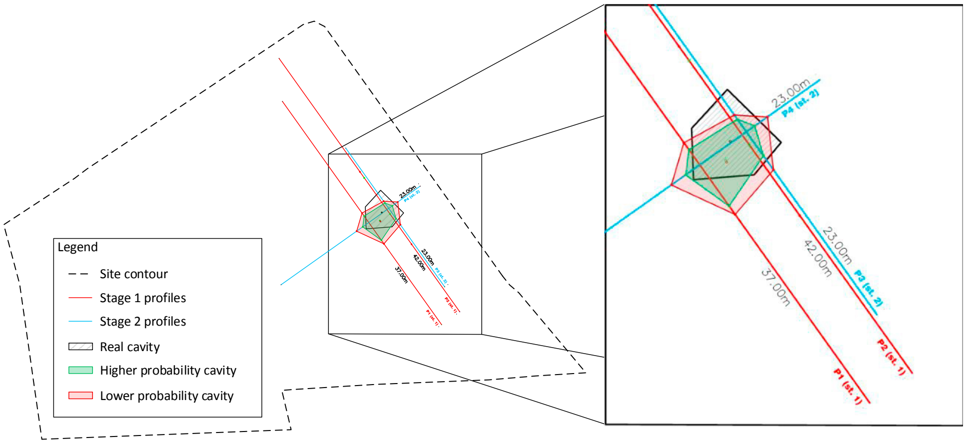

Fig. 9. Comparison between estimated cavity horizontal distribution and real cavity

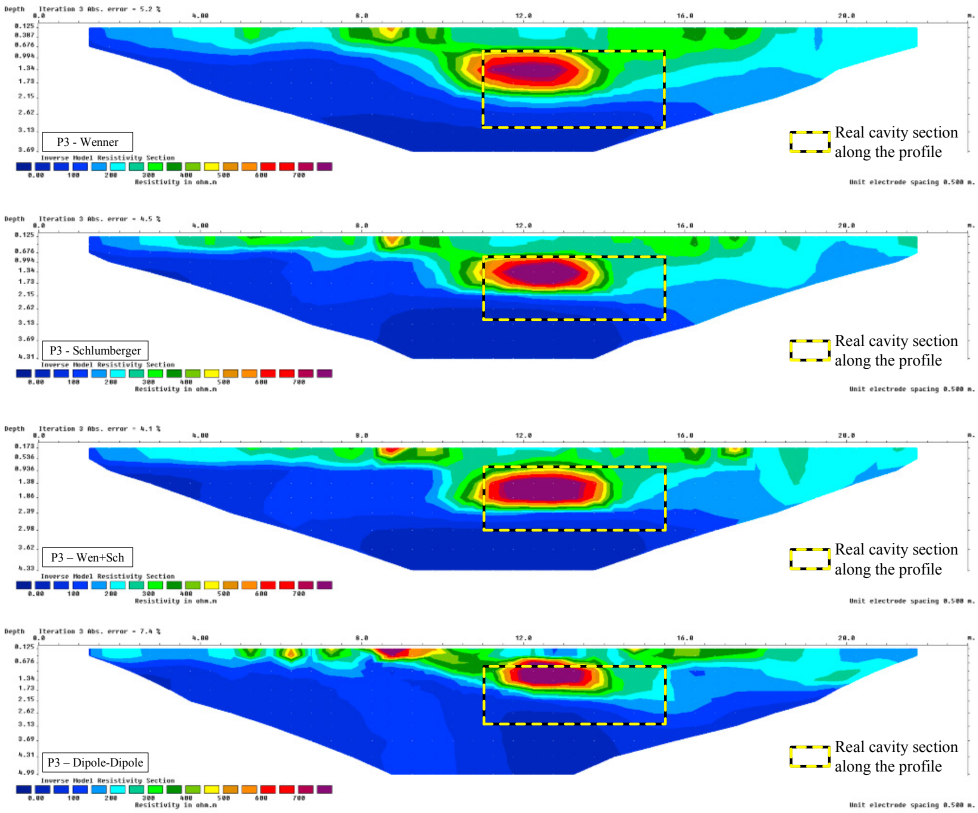

Fig. 10. Real cavity distributions on ERT profile 3

5. Conclusions

ERT investigations are widely considered to give good indications to the presence of underground cavities. However, the present paper shows that accurate results can only be obtained in favorable site conditions. Applying the method in highly anthropized areas is prone to data acquisition challenges, but using various acquisition methods is more likely to yield good results, as presented herein. The conducted measurements were sufficient not only to indicate the position of the void, but also a fair estimate of its size.

Using a 2D inversion software for mapping a 3D body inherently brings some considerable inconsistencies, especially for deeper investigation depths. This will provide less accurate information regarding the bottom depth of the target, thus yielding fair results in terms of cavity horizontal boundaries, however the depth is much more challenging to estimate.

Although the site conditions during the first stage of data acquisition were not optimal, the results clearly show an anomaly indicating a void, however it is difficult to estimate its shape or volume due to noisy readings towards the top of the profiles. The second stage measurements provide much better indication of the cavity due to the increase in overall soil moisture content and electric conductivity. As shown in profile 3, obtaining consistent resistivity cross-sections using different electrode arrays for the same profile, indicates a good signal to noise ratio of the measurements and a high level of confidence of the obtained results.

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