

Evaluation of ground-penetrating radar (GPR) survey for void detection

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Summary

A geotechnics related case study is presented in the paper. A 3-4 m depth sinkhole formed in an urban area during the dry summer. Since it occurred in the middle of a frequently used yard, the investigation of the area was crucial in order to maintain the safe usage of the ground. Thus, a detailed ground-penetrating radar (GPR) survey was carried out along a grid network. The aim was to map to map further possible voids in the vicinity of the hole and to investigate the compaction conditions of the subsoil. After measurement planning and data collection, the 2D radargrams were processed using MATGPR software. Based on the processed results, the critical parts of the area were marked out where further hollowing and breakdown are possible. Creating the simplified geophysical model was necessary to be able to handle and solve the geotechnical problem.

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Introduction

Ground-penetrating radar (GPR) is a non-destructive geophysical technique that uses electromagnetic (EM) waves to image the shallow subsurface. It is widely used for solving various near-surface problems in the field of civil engineering, hydrogeology, geology, archaeology, etc. The effectiveness of GPR is thanks to its speed, relatively low cost and reliability. However, GPR has some limitations as well. For example, it can be hardly applied in low resistivity environment. In the presence of clayey wet soils, the method cannot be used successfully because of the fast attenuation of EM waves. Resolution and penetration depth are also limited. That is why measurement design has to be the first step when starting dealing with any kind of GPR project. Forward modelling can be also useful before the on-field GPR survey, especially if there are available information about the area.

This study presents a case study about a GPR survey for delineating possible voids. A hole with a diameter of about 60-70 cm was created in the asphalt of the yard of a property in Miskolc, Hungary. Underneath this, the subsoil and fill collapsed, and a significant part disappeared in the widening cavern at a depth of 3-4 m. With the help of an 8 m bendable rod, the lateral continuation of the created cavity was proved mechanically. The purpose of the measurement is to investigate these possible cavities extending horizontally near the rupture, or looser, less compact zones.

Field survey

The measurements were made with the MALA GPR instrument of the University of Miskolc (Figure 1b), using a 500 MHz antenna, in a "cart" configuration with 18 cm antenna offset. The measurements were carried out by the authors in the summer during a drought period. During the data acquisition, the sampling interval was 0,1437 ns with 73,4 ns time window in one trace (512 samples per trace). The trace spacing was 4,7 cm. The hole can be seen on Figure 1a and Figure 1b as well.

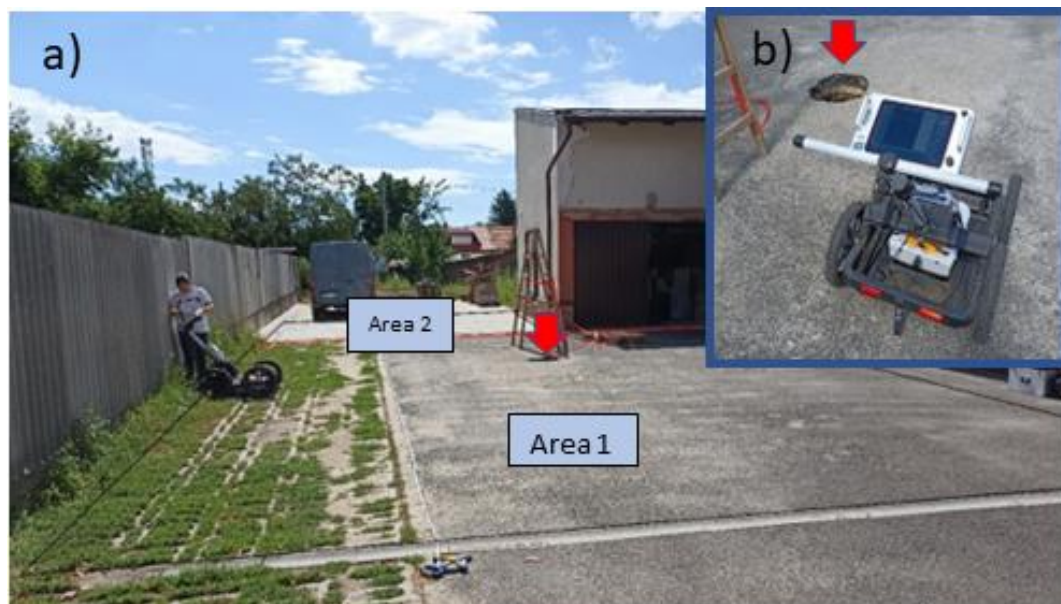


Figure 1 a) The survey site. The two areas and the occurred hole (red arrow) are indicated. b) Cart configuration of the MALA GPR system equipped with 500 MHz shielded antenna.

After getting familiar with the exploration aim and site, the survey design was the next important step, including the designation of the survey lines. The measurement area was divided into two parts (Figure

1a). The first one (Area 1) is approximately a 10*13 m area bounded by the fence, the building, and the drainage channels (mostly covered with asphalt, in the 2.5 m strip along the fence with a grass grid). The break-in (hole) is located here. The second one (Area2) is 6*7 m piece of the courtyard covered with paving stones bordering Area 1.

A total of 29 sections (22+7) were measured. The measurement sections were taken in two directions, perpendicular to each other longitudinally and transversely. The number, start and end points of each section are shown in the site plan (Figure 3). A red circle indicates the location of the break (hole) in the yard. In all cases, the section number indicates the end point. Due to the proximity of the broken part, Area 1 was measured more densely in a 1x1 m grid, while area 2 was measured in a 2x2 m grid. Sections 5 (5a and 5b) and 14 (14a and 14b) were recorded in two parts, as their track went through the broken part.

Data processing and results

Although in many cases the original (unprocessed) data also show the main characteristics, the application of some well-chosen processing steps can be beneficial. The aim was to increase the signal/noise ratio with the data processing and to improve the quality of the radargrams. The raw 2D radargrams were processed using the MATGPR software (Tzanis, 2016).

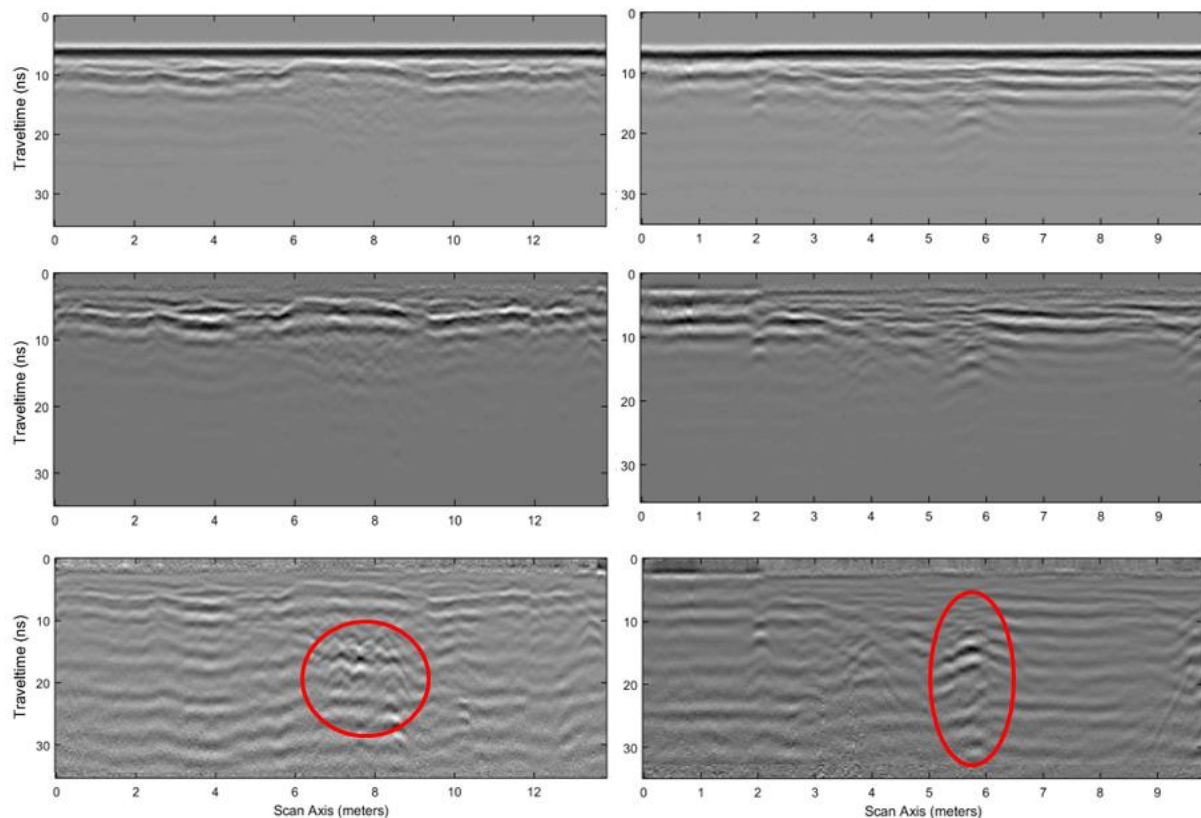


Figure 2 The raw and processed radargrams of Section 3 (left side) and Section 12 (right side). a) The registered raw sections. b) The processed sections after applying time-zero correction, DC component removal, dewow filter and background removal. c) The further processed radargrams after gaining based on inverse amplitude decay. The red ellipses indicate the anomalous zones.

The literature gives several recommendations for the processing of radar profiles (Annan, 1999; Conyers, 2004; Cassidy, 2009). Based on these recommendations and testing of the processing tools on the dataset, a five-step routine processing sequence was performed for the sections of Area 1 which seemed appropriate among the given conditions (medium, frequency, instrument settings).

The processing steps and settings for these operations were as follows: 1) "Moved Time Zero" by 3.5 ns; 2) Removed the DC component; 3) "Dewow" filter; 4) Noise reduction by dampening the effects appearing on all channels ("Removed Global Background"); 5) Gain (Inverse Amplitude Decay).

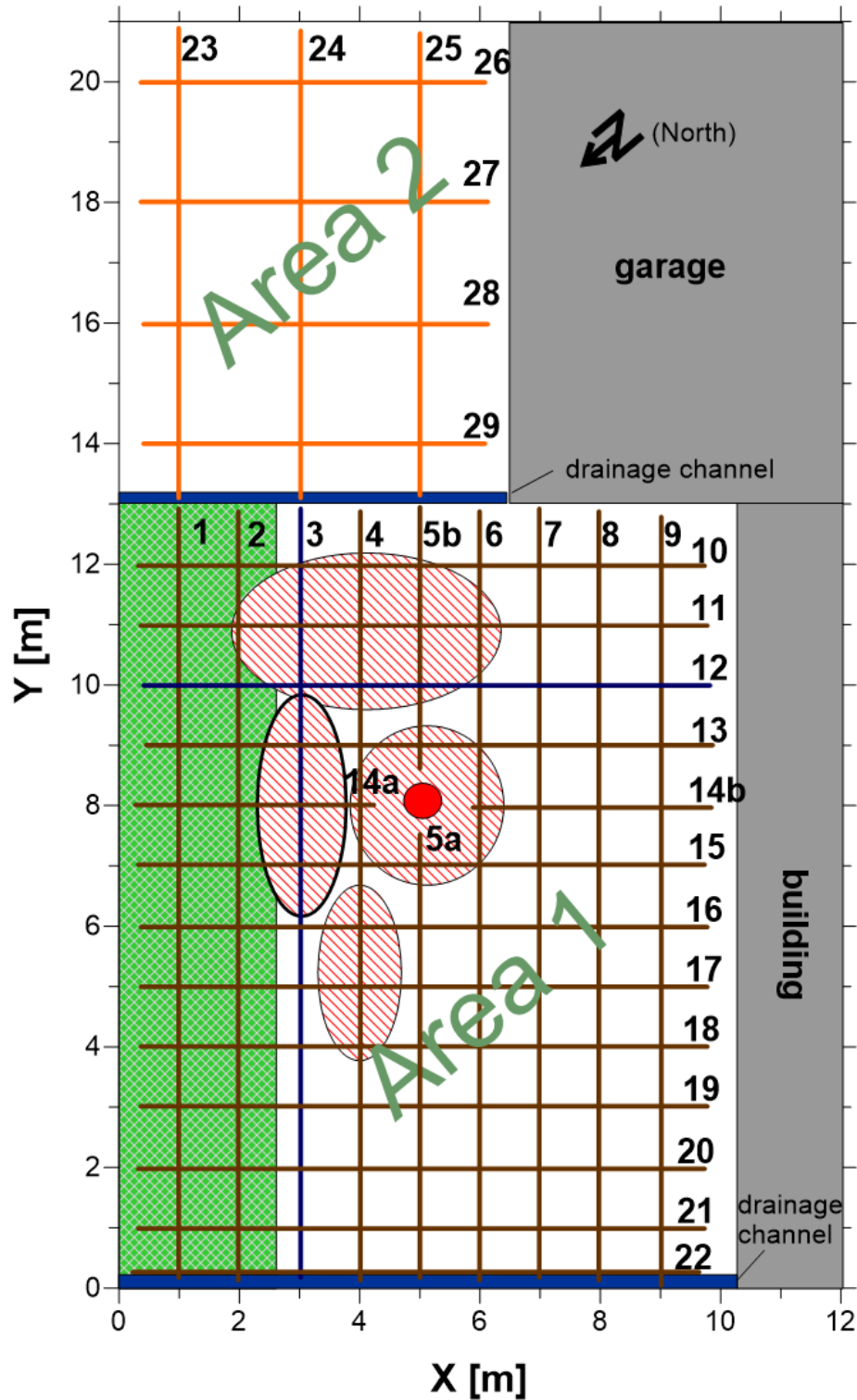


Figure 3 Site plan of the registered 2D GPR profiles. The red circle indicates the occurred hole in the middle of the court. Red hatched ellipses show the critical zones. The radargrams of the blue profiles (Profile 3, Profile 12) can be seen in Figure 2.

In Figure 2, two sections (one in-line and one cross-line) are presented from the survey which show the characteristic features of a disturbed zone. Both of them are close (1 and 2 m distance) to the hole. The identified features (relatively high amplitudes, hyperbolas) are indicated with red ellipses on the radargrams. These anomalous features can be detected on the raw sections as well but they are visible better on the processed ones. The originally sampled time interval is visualized only up to 35 ns. After this time no remarkable signals can be observed. Assuming 0.1 m/ns EM wave velocity, the estimated depth of the indicated anomalies is about 1.5 m.

During the measurements (and the post-processing also) it became obvious that there are not any large-size voids underneath except of the downward continuation of the already existing hole. A large-size cavity would cause a much wider hyperbolic anomaly. But, based on the analysis of the processed radargrams, several inhomogeneous zones have been explored and marked. Most of them can be connected through the ellipses and may indicate less compact subsoil.

Conclusions

Looking into the cavity in the yard of the property, it has been obvious that the examined near-surface space is an upfill. The soil is loose, less compact and mixed with different type waste products. At the time of the formation of the cavern, the weather was hot and dry, with no precipitation. There was no visible sign of leaking water or moisture. All these circumstances could have caused the area breakdown.

The goal of the study is to use ground penetrating radar measurements to determine possible lateral continuations of the demarcated rupture. In this environment, the 500 MHz frequency antenna is suitable for getting information down to a depth of 3-4 meters. In order to obtain sufficiently detailed information sideways, the area was measured in a 1x1 meter grid.

In order to improve the raw measurement data, the radargrams were processed by using MATGPR software. However, obvious indication of large cavities on the 2D sections were not detected, some critical zones (Figure 3) have been identified which have the risk of subsidence and possible further rupture. Looser, less dense (less compact) volumes may be found under these areas. Soil mechanical drilling can be useful at some points inside the critical zones. The solution of the problem is the gradual loading of compressible material in the hole. The intermittent uploading is recommended with continuous monitoring.

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