Detecting cavities and archaeological remains with GPR

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Abstract

Two examples were considered in this presentation; detection of cavities in limestone, delineation of boundaries of an archeological remain using Ground Penetrating Radar (GPR) method and affect of the trees on the GPR data. The GPR method has been successfully applied to detect and map underground cavities in Limestone in a reservoir area of a dam being built in southeast Turkey. The study area divided into nine segments each of which was 100m wide. Total study area was 696x100 m^2. Ground Penetrating Radar data were collected on parallel profiles of 2 m interval. Station interval set 0.5 m on each profile. Following the data processing, new amplitude-color range and opacity function were constructed for 3D visualization. Finally cavity locations on x-y coordinates and their depths determined on the 3D Ground Penetrating Radar data blocks and marked on the map. The result of the drilling of some locations showed that the ratio of success was % 95. In the second example, the GPR method was used to search the archeological remains in 20x10 m area northern part of the Turkey. After the data process steps similar to those given above, remains of the castle wall were found.

Introduction

The range of Ground Penetrating Radar (GPR) applications is very wide and diverse. GPR provides high resolution and has been used in environmental problems, geology, geotechnical engineering, archeology etc (Benson, 1995; Grasmueck, 1996; Aldas et al., 2003; Green et al., 2003; Cezar et al., 2001; Kadioglu and Daniels, 2002, 2004; Kadioglu et al, 2003; Cardelli, et al., 2002;).

GPR techniques are based on the principle that high-frequency electromagnetic waves may be reflected or diffracted at boundaries separating heterogeneous regions of the subsurface. They are best suited for high-resolution geophysical and geological engineering investigations of underground to depth less than 50m. GPR surveys are conducted with the transmitter and receiver antennas very close together, practically at zero offset.

The objective of the first work was to find cavities in Aktas Limestone near Köycegiz, Mugla, Turkey (Fig. 1.). The study area is reservoir area of Akköprü dam and hydroelectric power station (HEPS) on Dalaman Creek. The electricity production potential of Akköprü HEPS will be 115 MW (established power) and 343 GWh/Year (annual production). The watering area of dam is 14.192 ha. In addition, the dam will protect Dalaman, Ortaca town and their villages, airports and tourism foundations from floods. The construction of majority part of the dam has been completed already.

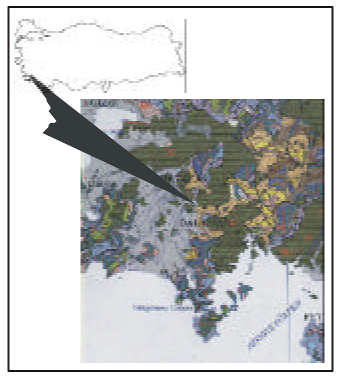

Figure 1. Location map

The objective of the second work was to investigate architectural remains in Akalan archeological site (Fig. 5). Akalan is a fortess-type settlement established on the steep slope of a plateau, situated in the vicinity of Samsun, Turkey. The research project was based on the use of the GPR and the Direct Current resisitivity (DCR) methods, the aim was to obtain accurate information on the depth, extension and position of the building remains expected to be found under the surface.

Exploring Cavities in limestone

Some part of the reservoir area was on Aktas Limestone overlaid by Fylish layer. During the excavation work on fylish and limestone some sinkholes were discovered. Some of them were very large and long like a cave. The existence of sinkhole is a common problem in Torid belt in southern Anatolia and some of them may reach to Mediterranean Sea. Even a single sinkhole may cause leakage of large amount (e.g >10 ton/sec) of water from reservoir and prevent the water level increase to necessary level to produce electric.

Knowing that Aktas Limestone has very low conductivity and has no water in the sinkhole, the aim of the GPR method is to delineate the boundary between limestone ($\varepsilon < 3\varepsilon_0$ and $V_{EM} \approx 0.18$ m/ns) and air filled cavities ($\varepsilon < 80\varepsilon_0$ and $V_{EM} \approx 0.3$ m/ns). Fig. 3 shows the plan of GPR data collection. The field was divided into nine segments widths of each of which is 100m. The profile interval on each segment is 2 m. All profiles start at the left boundary and finish at the right boundary of the each segment. The numbers of profiles for each segment were different because of the Fylish layer, which limits the EM wave penetration because of its high conductivity value.

Figure 2. The study area Akköprü reservoir area.

Pulse EKKO100A (Sensor and Software) GPR system and 25 MHz antenna were employed. The measurement point interval was 0.5m and recording time set 1024ns. The total survey area was 696x100 m^2 (Figure 2 and 3)

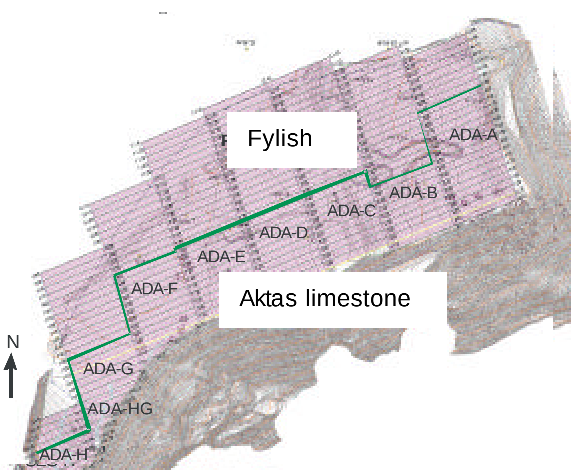

Figure 3. The plan of the GPR data collection. The green line shows the last profile on the each segment (ADA-A to H).

Determination of the cavities

The data processing was done by using GPHYZGPR program (IDL 5.0, Daniels 2002). Firstly, all collected data were rearranged according to the starting point of the profiles and end of the profiles, which must be the same for all profiles on each segment. Secondly, filtering and amplitude gain processing were applied. Thirdly, the profiles on each segment were divided into subpart in order to construct 3D visualization. Fourthly, amplitude-color and amplitude-opacity functions were arranged for 3D block displaying. Finally, velocity analysis was done to transform the processed data from time domain to depth domain. All cavities on the study area were defined on the 3D block, in which trace slices (x direction), profile slices (y direction) and time slices (z direction), can be displayed step by step individually or together to determine length, width and depth of any cavity.

Validations of findings

Cavity locations on x-y coordinates and their depths determined on the 3D GPR data blocks were placed on the level maps. Nine anomalies at different depths were selected and drilled to confirm the findings. The total success according to drilling results was %95. However, the success ratios according to the depth estimation can be given as 100 % in first 10m depth, 90% between 10m and 15 m and 80% for below 15m depth. Figure 4 shows a cavity location on ADA- D and drilling results.

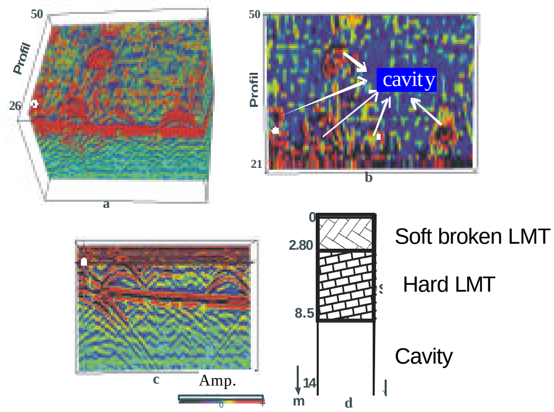

Figure 4. Drilling of defined cavity on ADA-D, a) 3D block displaying of ADA-D profiles between 26-50 starting at the surface of 8m depth, b) The depth slice of 11.14m of ADA-D profiles between 21-50, c) The cavity starting at 8.5m depth on the profile 28 (white spot), d) Drilling result of given white spot, on a and b, in the middle of defined cavity before.

Exploring the archeological remains

The GPR measurements were taken from within two areas in the Acropolis (Figure 5). The initial work was carried out on the western slope of the raised area in the western part of the Acropolis in an area measuring 200 m^2 and 20 x 10 m in dimension (Area 1) (Figure 5). The frequency used was 200 MHz antenna and the distance between antennas was set 0.50 m, while the interval between the measurements taken was 0.10 m.

In the first work area were investigated with parallel profiles approximately 21-23 m in length. The distance between the profiles was 0.50 m. The Second work area (Area 2) was surveyed with profiles approximately 12 m in length (result not presented here). All profiles extend north to south in both areas.

The time pillows of Area 1 of the Acropolis, obtained from the profiles are presented in Figure 6. The data given in the form of three time levels shows a specific depth for each image. The dark colored sections show strong reflection of EM waves and therefore indicate the existence of a sublevel. In all three maps, a continuous zone can be traced along the northern side. The circular section towards the centre of the line on the western side is related to a hole in the surface.

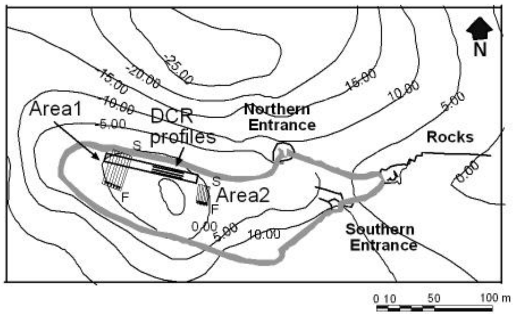

Figure 5 Location map of Akalan archaeological site

For the purpose of comparison, measurements were also taken in the same area in the east-west direction. The section intersects the lines of N-S at 7.5-10.0 m the purpose of this was to investigate the possible existence of any structure parallel to the previous lines. No linearity was observed in the time slices showing the depth levels. Therefore the result is not presented here.

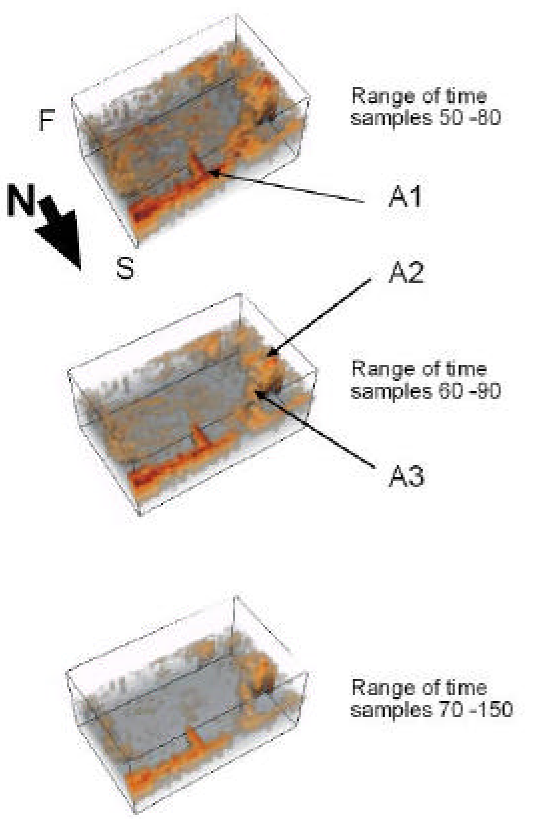

Figure 6. Time-pillows visualizations of the Area 1. S and F specify, respectively, the starting and final points of the profiles (see Figure 5). Time values were given as number of samples. A1 indicates a wall like structure while A2 is a pit and A3 is an affect of a channel

Conclusions

GPR method was successfully used to detect cavities and search ancient remains. In the first study, the dielectrical contrast between limestone and air filled cavities allowed to use of GPR to detect the cavities. 69400 m^2 areas were searched, 283 locations were detected. 10 anomalies at different depths were selected and drilled to confirm the findings. Only one of them did not encounter with a cavity since a equipment failure. The total success according to drilling results was %95. However, the success ratios according to the depth estimation can be given as 100 % in first 10m depth, 90% between 10m and 15 m and 80% for below 15m depth.

In second study area, a trace of a wall and channel were delineated. The result was confirmed with usage of DCR method. Unfortunately, no excavation has been performed yet.

Both results indicate that, data process techniques including application of amplitude-color and amplitude-opacity functions are as important as the data quality.

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