Sigma J Eng & Nat Sci 36 (4), 2018, 1297-1310

Sigma Journal of Engineering and Natural Sciences
Sigma Mühendislik ve Fen Bilimleri Dergisi

Research Article

DETECTION OF THE COMPLEX GROUND PROBLEMS BY GROUND PENETRATING RADAR: EXAMPLES FROM GÜMÜŞHANE UNIVERSITY

Mahmut SARI*[1], Serkan ÖZTÜRK[2]

[1]*Gümüşhane University, Department of Geophysics, GÜMÜŞHANE;* ORCID: 0000-0002-1006-6332
[2]*Gümüşhane University, Department of Geophysics, GÜMÜŞHANE;* ORCID: 0000-0003-1322-5164

Received: 11.10.2018 Revised: 22.11.2018 Accepted: 27.11.2018

ABSTRACT

In this study, Ground Penetrating Radar (GPR) technique was used for the detection of *i*) the reasons of deformations which occur in the field ground of Gümüşhane University Sport Complex (GUSC), and *ii*) the congestion in flow pipe of Gümüşhane University, Engineering and Natural Sciences Faculty (GUENSF). GPR data was collected by using the RAMAC CU II device and a shielded antenna with a 500 MHz center frequency. The wave fields for GUSC were examined by 2D and 3D processing. The large-scaled hyperbolic reflections are in corresponds to the areas where the field ground has deformations. It is considered that these anomaly areas may include a gap or a padding having a large gap and suggested that these damaged areas must be full with hard materials. The large-scaled hyperbolic reflections approximately starts in one-meter depth and reaches three-meters. For GUENSF, the measurements were conducted on the route where the main flow pipe crosses. In GPR sections, hyperbolas with high amplitudes were observed in the zones where flow pipe passes. Information on slope of flow pipe was provided by examining the association of these hyperbolas with the depth, and the clogged zones were detected. It is stated that unclogging the clogged zones of the flow pipe will not fully contribute to the resolution of the problem. Therefore, it is suggested to provide necessary slope to the flow pipe by completely removing and mounting back. These results show that GPR technique is an effective tool to provide a good image and solution for the complex ground problems.
Keywords: GPR, clogged zones, flow pipe, 2D-3D inversion, deformation.

1. INTRODUCTION

Ground Penetrating Radar (GPR) is a high frequency electromagnetic method and this technique has been used as one of the most promising geophysical applications in near surface investigations for surficial mapping studies. GPR method depends on the emission, transmission, reflection, and reception of an electromagnetic pulse. It can provide rapidly and efficiently continuous high resolution profiles of the subsurface [1]. One of the first successful practice was the measurement of ice thickness on the polar ice sheets in 1960s [2]. Since then, the rapid developments in hardware, measurement and analysis techniques have been introduced by different researchers. In the past, this method was used to investigate the densities and fractures of tunnel rocks [3], glaciers [4], [5], and salt domes [6], and to locate the buried piper and cables [7]. In recent years, this method has a wide range of application such as detecting of near surfaces [8]

* Corresponding Author: e-mail: msari@gumushane.edu.tr, tel: (456) 233 10 00 / 1701

and near surface geological units [9], definition of discontinues like fault and fracture [10], [11], [12], [13] searching of karstic gaps [14], [15], determining the groundwater level [16], [17] and exploring the liquid hydrocarbon near the surface [18]. GPR applications have also been used in the archeological studies in order to discover the temples, tombs, walls, basic structures and similar historical ruins [19], [20], [21], in order to detect the buried pipes, pipe lines in subsurface, water or fuel tanks and industrial waste areas [22], [23], [24], [25], [26] as well as the researching the routes of ground, tunnels, highways, railways and water tunnels. In fact, GPR is a measurement device and the advantages of this process are the controlled radiation and measurement of free electromagnetic waves. In this study, ground problems in Gümüşhane University Sport Complex (GUSC) and Gümüşhane University, Engineering and Natural Sciences Faculty (GUENSF) were reconnoitered, and the origin of deformations was tried to detect by using the GPR technique (Figure 1).

2. BRIEF DESCRIPTION OF GPR METHOD

GPR technique is an electromagnetic method which images the shallow depths of investigated surface in high resolution, and offers a new way of viewing shallow soil and rock conditions. This method processes by transmitting a very short electromagnetic pulse into the subsurface using a transmitting antenna. The center frequency of antenna is generally between 10 and 1000 MHz [27]. Some of the energy is reflected back to the radar antenna whereas some of the energy is transmitted downward to deeper material if the spreading energy encounters heterogeneities in electrical properties of the subsurface [1]. Electrical heterogeneities are determined primarily by water content, dissolved minerals and expansive clay and heavy mineral content in the subsurface material. The reflected signal is amplified, transformed to the audio-frequency range, recorded, processed and displayed. The records show the total travel times for signals to pass through the subsurface, reflect from heterogeneity and return to the surface. This two-way travel time is measured in nanoseconds (1 ns=10^{-9} seconds).

The application areas of GPR technique are diverse, and it has been used successfully to map ice thickness, water depth in lakes, bedrock depth, soil stratigraphy, and water table depth. It is also used to delineate rock fabric, detect voids and identify karst features. The effective application of the radar for the high-resolution definition of soil stratigraphy and fractures in bedrock is highlighted. In this method, the investigations are made by using high-frequency electromagnetic fields which varies in time, and these electromagnetic fields are sent to the investigated medium from a source (Figure 2a, from Knödel *et al*. [2]). The processing diagram of GPR data is also given in Figure 2b (from Annan [28]). Basic data processing requires several principle manipulations in order to make more acceptable outcomes for the first interpretation and data assessment. In many examples, these types of data processes are already applied in real time to generate the real time screen. There are two advantages of post survey processing: (*a*) the basic processing can be applied more systematically, and (*b*) non-causal operators to extract or enhance certain characteristics can be applied.

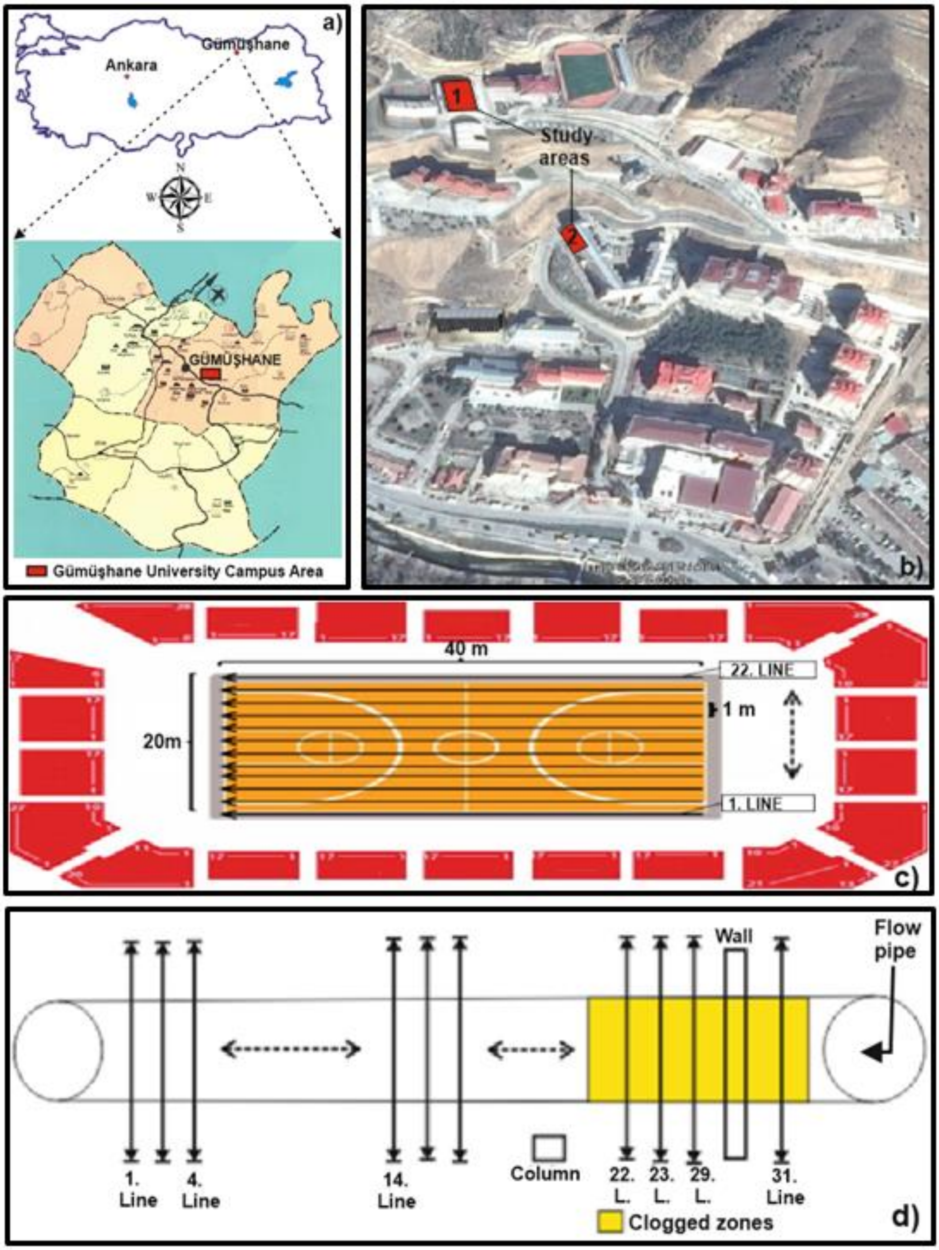

Figure 1. a) Location map of Gümüşhane, **b)** GUSC (st udy region 1) and GUENSF (study region 2), **c)** General sketch of sport complex and measurement profiles in study region 1, **d)** Measurement profiles for main flow pipe in study region 2.

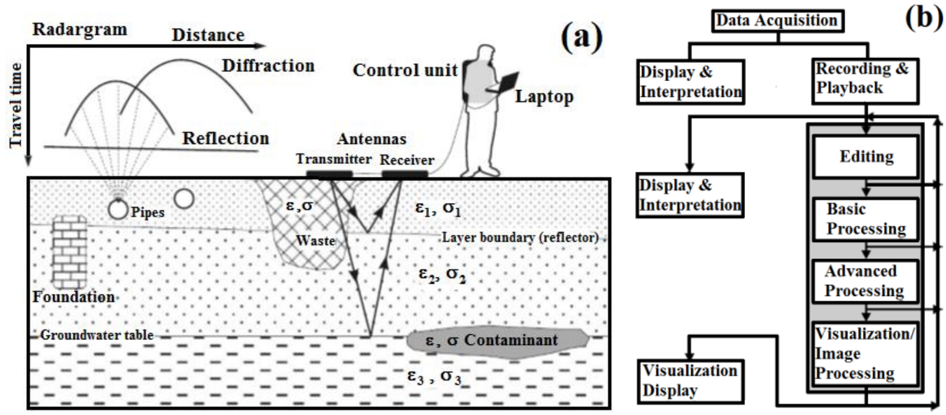

Figure 2. a) Representation of main components and principle of GPR system (modified from Knödel *et al*. [2]), **b)** Data processing stages of GPR method (modified from Annan [28]).

Electromagnetic fields with flexible time are formed from the components of electrical and magnetic fields. These two fields are changed under the effects of subsurface materials and allow to be observed the variations of electrical properties of underground structures [20], [28]. Some parts of high-frequency electromagnetic signals which are sent to the subsurface with a transmitter antenna are reflected from interfaces which have different dialectical features in subsurface, whereas the other parts can propagate to deeper medium. Standard scanning measurements of GPR change in a depth from a few to several tens of meter. However, this depth depends on the clay, water, iron and salt content, but also on the used frequencies. Thus, measurement scales of GPR applications changes between a few tens of meters up to several hundred meters. A receiver antenna takes the reflected signals and received signals are collected in control unit [1], [8], [29], [30]. Recorded traces are aligned side by side as a function of distance and this section is called as radargram. Amplitudes of the reflected and transmitted signals changes depending on the reflection coefficient and the size of the objects in reflection boundary. Consequently, the reflection surfaces in underground are different and may be given as soil-rock interfaces, man-made objects and the boundaries of material-space which are formed from the fractured-cracked systems in the medium.

3. DATA ANALYSES AND RESULTS

It was firstly investigated the reasons of the partial collapses and the fractures/cracks which is occurred in GUSC and which can be observed from the surface. GUSC indoor sport hall has 40 m length and 20 m width. This area is scanned with GPR by taking totally 22 lines measurements with one-meter intervals. By using necessary data processing steps as given in Figure 2b, received measurements are prepared as 2D and 3D images. According to the 2D radargram sections as shown in Figures 3b, c and d, it was concluded that there is a layer which is consisting of concrete and has a rubber flooring of 15 cm. This rubber flooring level is also shown with straight-dashed line in Figure 3a as lines 9, 10 and 11.

There is a layer which is considered as a landfill structure that has non-massive discontinues and this layer reaches deeper (between 0.3 and 2.0 m) than that of rubber flooring. It can be seen clearly that large-scaled hyperbolic reflections nearly which is starting from 1 m and reaching 3 m are observed in distances between 30 and 40 m. These anomaly regions are especially detected from the radargrams which belongs to the lines of 9, 10 and 11 (Figures 3b, c and d). As shown in these Figures, all the reflections are signalized by being getting circles with dashed lines. These reflections are observed approximately under the damaged areas. Hence, this situation revealed that the fractures/cracks which is occurred in surface of study area and the partial collapses are related to the large scaled hyperbolic reflections. 3D image of the sections is obtained by combining of 2D radargrams. In this 3D model, reflections are tried to be made more distinctive by intersection of *X* and *Y* sections (Figures 4a, b). As shown in Figures 3 and 4, important anomalies were observed intensely between one-meter and 3 m. Thus, it was interpreted that the reason of fractures/cracks and partial collapses in the floor is due to the regions which have hyperbolic reflections in high amplitude that is clearly observed in the radargrams of 9, 10 and 11. As an important result, it was concluded that these areas in GUSC may have a large gap or filling material having a large gap.

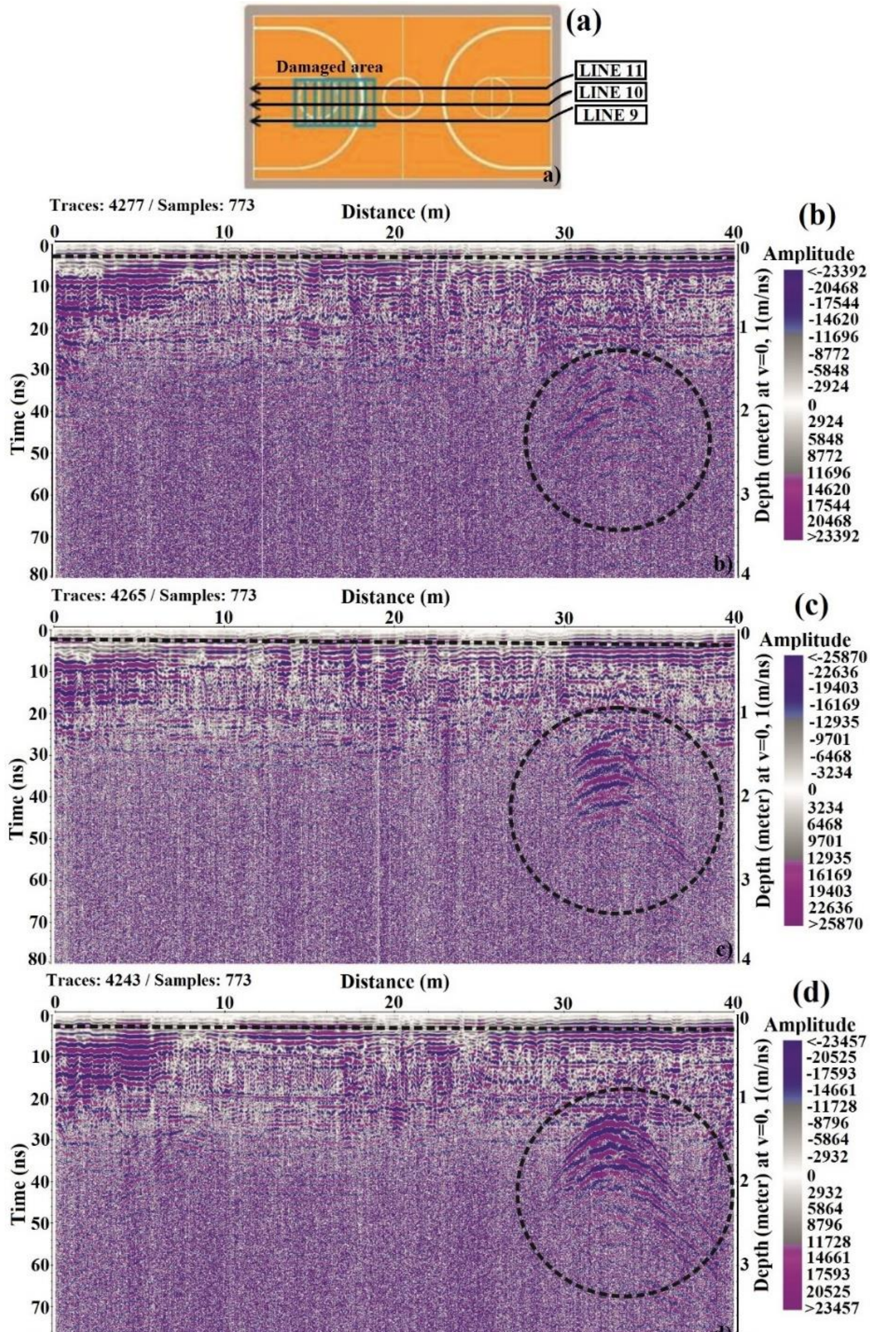

Figure 3. a) Field sketch and damaged area GUSC, **b)** Radargram section of line 9, **c)** Radargram section of line 10 and, **d)** Radargram section of line 11.

All pipe sections starting from the water utility areas to the manhole outside the building are called indoor wastewater installation. Considering the tasks of pipe sections for indoor wastewater installation, they are reviewed in five sections; main pipe, column pipe, floor pipe, connecting pipe and air pipe (Figure 4c). Main flow pipe is the section which is located 1.0-1.5 m outside the building and up to the manhole. Main pipes are the sections with the largest diameter which are used in the indoor installation. It transmits dirty and polluted waters from wastewaters columns to the manhole outside the building by gathering within the main boundaries of building. Wastewater load of building is transported by these pipes. There are several reasons for congestions; they have so much density, they are not suitable for use or there are some reasons from human use.

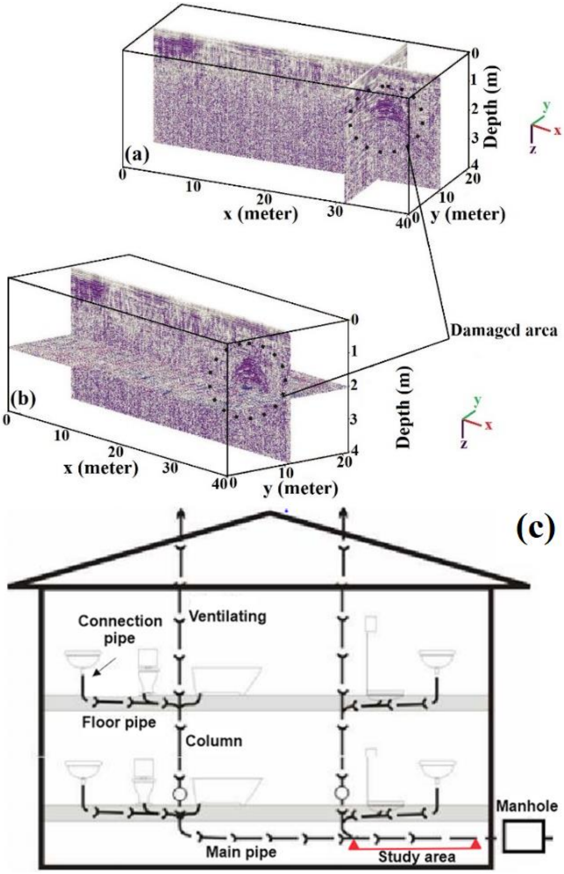

Figure 4. a) 3D image of damaged area by intersection of *X* and *Y* sections, **b)** Slice image of damaged area by intersection of *Y* section, **c)** Indoor wastewater installation pipe sections and representative study area (designed from URL-1, 2018).

In the large complex structures, the congestion of main flow pipes causes major problems in the identification of clogged zones. High-frequency electromagnetic waves can be used in these types of investigations because of main advantages of this method such as its low cost, rapid use and non-destructive operation. In this study, our second aim is to detect the congested area on the main pipe of the wastewater installation of GUENSF. All measurements were conducted on the route where the main flow pipe crosses. The RAMAC CU II device with 500 MHz frequency was used on 31 profiles with 3.5 m long lines having 40 cm distance between each other. In order to analyze data acquired from inversion method, 2D and 3D vertical sections were obtained by using the REFLEXW 7.2 software.

Figures 5a, b and c show the 2D vertical sections of GPR data for the second study region. The flooring which covers the main pipe and the route that main pipe passes were detected from these sections. Hyperboles with high amplitudes were obtained for the regions that the main pipe passes and does not fill with waste (the lines between 1st line and column in Figure 1d). The lines of 1st, 4th and 14th were selected as the examples, and the changes in amplitude with depth were demonstrated by taking the hyperbolic reflections into the circle (Figures 5a, b and c). Hyperbolic reflections with large amplitudes which taken into circles with green color in lines shows the route that main flow pipe passes. Also, depth information about the route that flow pipe passes was obtained from 2D GPR sections. It was determined the depth of line 1 to the main flow pipe as 32 cm, depth of line 4 to the main flow pipe as 28 cm and depth of line 14 to the main flow pipe as 24 cm.

Non-hyperbolic scattering with large amplitudes was observed in the parts, and the pipe was thought to be full of waste (the lines between 31st line and column in Figure 1d). By selecting the lines of 22nd, 23rd and 29th, the reflections with high amplitudes were shown by taking into rectangular with green color (Figures 6a, b and c). Because the inner part of the main flow pipe is full with the waste dirty material, non-hyperbolic scattering reflections were not observed. Hence, it was considered that where the main flow pipe is clogged is between the lines of 22nd and 31st. General sketch of clogged parts for study region is plotted in Figure 1 by taking into rectangular with yellow color.

In addition to these measurements and analyses, this comprehensive investigation was achieved since it was considered that this congestion is caused by insufficient slope. Because the slope to be given to horizontal pipes is very important, we obtained information about slope of the main flow pipe by examining the relation between hyperbola and high amplitude scattering with depth. The slope of horizontal wastewater pipes must be 2% (URL-1). Slope can be reduced as 0.5 depending on the size of the pipe diameter. In the light of this information, it was replaced the radargram section of the lines of 1st and 31st side by side and it was reached the slope information about the study region (Figure 7). The point where the main flow pipe in line 31st is located was accepted as zero point and, total depth and distance between lines are estimated as 18 cm and 1200 cm, respectively. The slope was calculated as 1.5% from Figure 7 and it was detected that the slope is close to ideal value. Also, 3D radargram section was obtained by transferring 2D radargram section to 3D (Figure 8) and the slope was not observed in 3D radargram section.

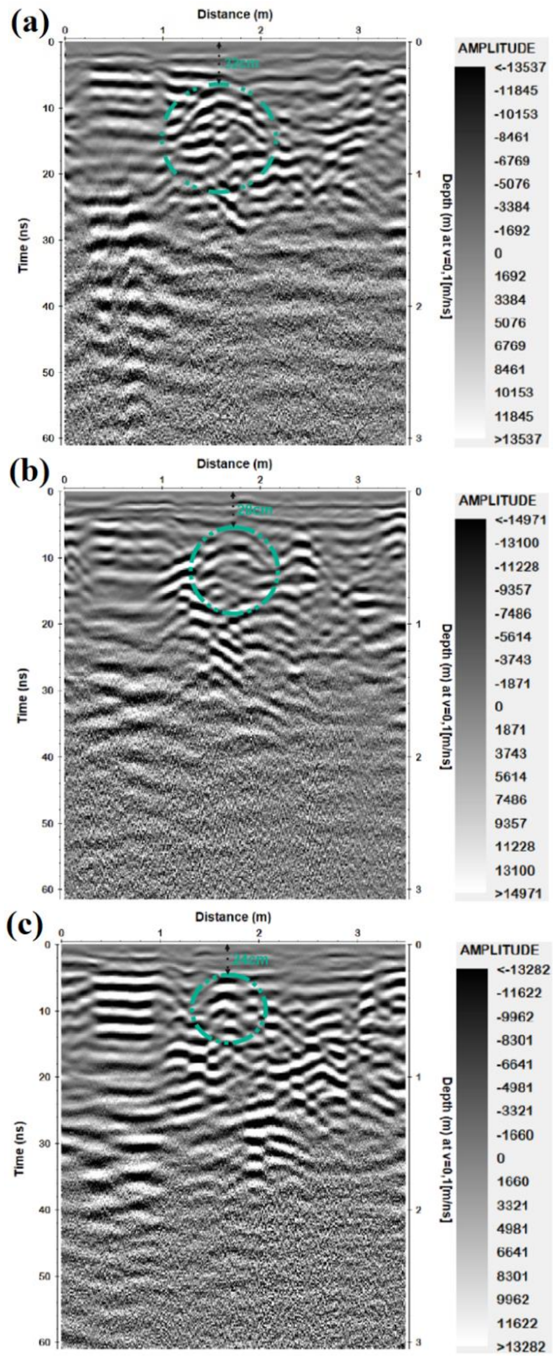

Figure 5. a) Radargram section of line 1 for study region 2, **b)** Radargram section of line 4 for study region 2 and **c)** Radargram section of line 14 for study region 2.

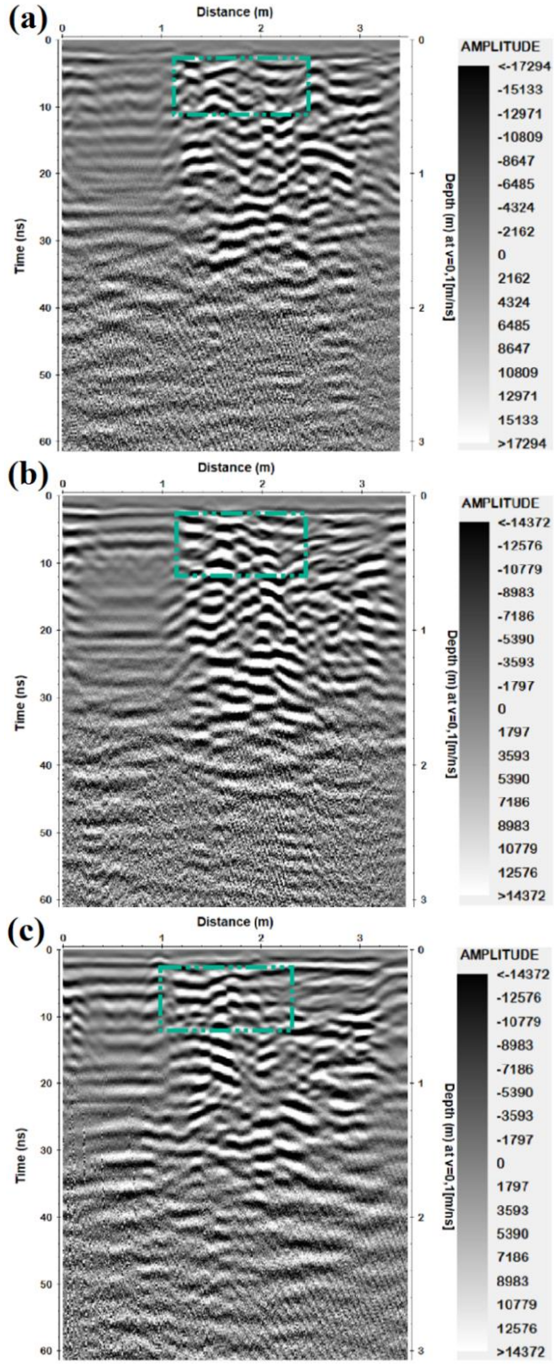

Figure 6. a) Radargram section of line 22 for study region 2, **b)** Radargram section of line 23 for study region 2 and **c)** Radargram section of line 29 for study region 2.

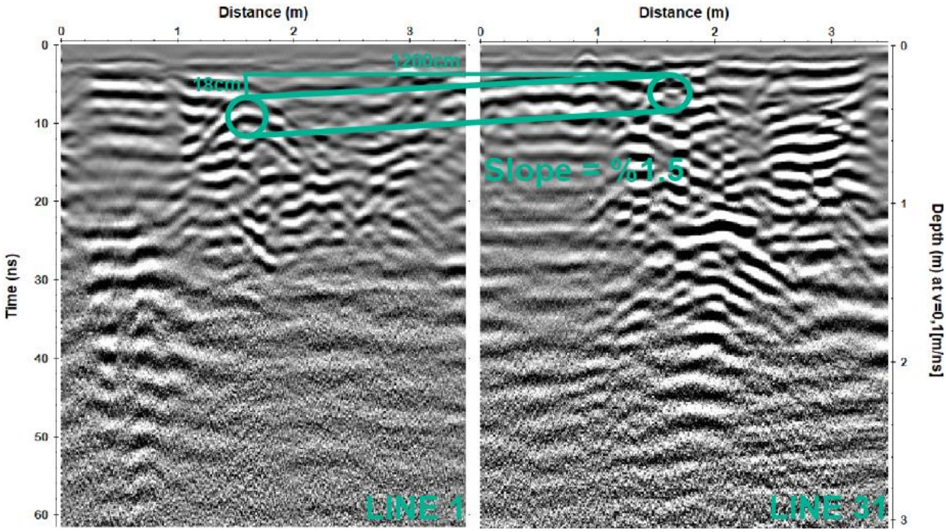

Figure 7. Slope image between line 1st and line 31st for study region 2.

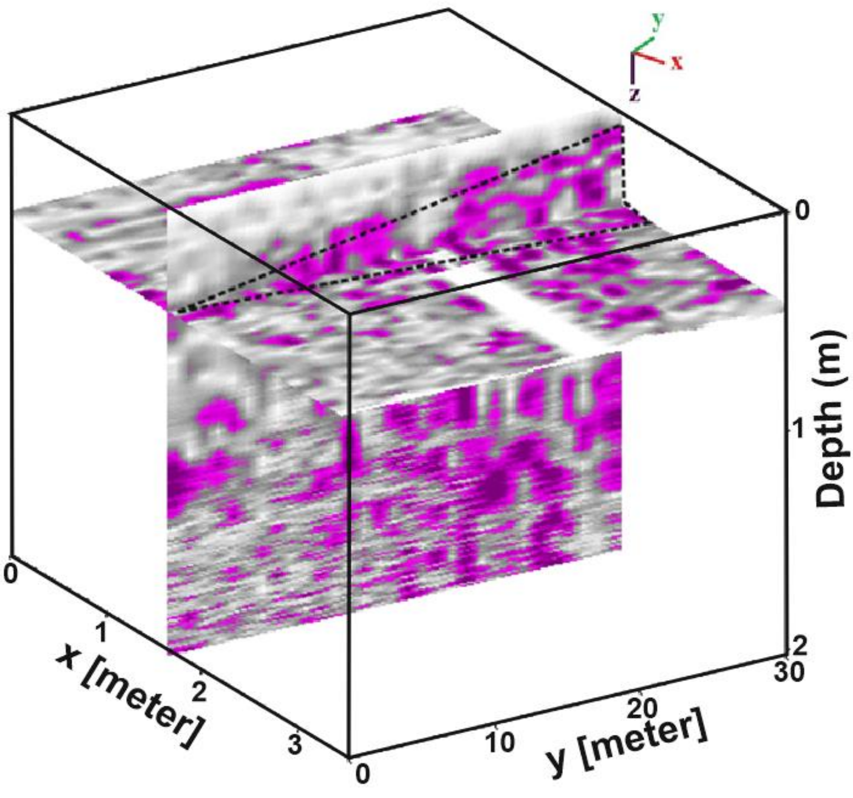

Figure 8. 3D image of slope by intersection of *X* and *Y* sections for study region 2.

4. CONCLUSIONS

Ground Penetrating Radar (GPR) technique has been successfully applied in a wide range of environmental studies. GPR is a geophysical technique with multidisciplinary applications and has become a valuable tool in different applications. This study focused on two main problems in the campus area of Gümüşhane University by using GPR technique: (*a*) detecting the reasons of fractures/cracks, deformations and partial collapses which occur in the ground of GUSC in Gümüşhane University, (*b*) congestion in flow pipe of GUENSF. Obtained results and suggestions can be given as follows:

- Large-scaled hyperbolic reflections in 2D and 3D images can be related to the deformations in the ground of GUSC.
- It was interpreted that these damaged areas in Gümüşhane University indoor sport hall may be due to a gap or a filling material having a great gap.
- It was suggested that these damaged areas must be full with hard materials. Another suggestion is that a suitable padding must be selected for the damaged areas and these areas can be full with a jet grouting method which is used to improve the soil strength parameters and at the same time to create an impervious layer.
- Hyperbolas with high amplitudes were observed in the zones where flow pipe passes in the GUENSF.
- The clogged zones in the washbasin flow for GUENSF were detected by examining the association of hyperbolas with the depth.
- It was concluded that unclogging the clogged zones of the flow pipe will not fully solve the problem. Thus, we proposed to give necessary slope to the flow pipe by completely removing and mounting back.

As a remarkable fact that, this article has provided good practice guidelines on the collection, processing and interpretation of GPR data. This paper also presents an overview of good practice material for non-specialist GPR users in which works the field of environmental investigations. The results from this study suggest that high quality, high resolution, continuous subsurface profiles obtained by GPR may be qualitatively used in ground survey with data processing.

REFERENCES

[1] Beres M. Jr., and Haeni F. P. (1991) Application of ground-penetrating-radar methods in hydrological studies, *Ground Water*, vol. 29, no. 3, pp. 375-386.

[2] Knödel K., Lange G., and Gerhard H. J. (2007) Environmental Geology: Handbook of field methods and case studies, *Bundesanstalt für Geowissenschaften*, Berlin: Springer, 2008, ISBN 978-3-540 74669-0.

[3] Cook J. C. (1975) Radar transparencies of mines and tunnel rocks, *Geophysics*, vol. 40, no. 5, pp. 865-885.

[4] Harrison C. H. (1970) Reconstruction of subglacial relief from echo sounding records, *Geophysics*, vol. 35, no. 6, pp. 1099-1115.

[5] Watts R. D., and England A. W. (1976) Radio-echo sounding of temperate glaciers: ice properties and sounder design criteria, *Journal of Glaciology*, vol. 17, no. 75, pp. 39-48.

[6] Holser W. T., Brown R. J. S., Roberts F. A., Fredriksson O. A., and Unterberger R. R. (1972) Radar logging of a salt dome, *Geophysics*, vol. 37, no. 5, pp. 889-906.

[7] Annan A. P., Davis J. L., and Vaughan C. J. (1984) Radar mapping of buried pipes and cables, *A-Cubed, Inc., Tech*., Note 1, 17 pp.

[8] Davis J. L., and Annan A. P. (1989) Ground penetrating radar for high resolution mapping of soil and rock stratigraphy, *Geophysical Prospecting*, vol. 37, no. 5, pp. 531-551.

[9] Koralay T., Kadıoğlu S., and Kadıoğlu Y. K. (2007) A new approximation in determination of zonation boundaries of ignimbrite by ground penetrating radar: Kayseri, Central Anatolia, Turkey, *Environmental Geology*, vol. 52, no. 7, pp. 1387-1397.

[10] Grandjean G., and Gourry J. C. (1996) GPR data processing for 3D fracture mapping in a marble quarry (Thasos, Greece), *Journal of Applied Geophysics*, vol. 36, no. 1, pp. 19-30.

[11] Green A., Gross R., Holliger K., Horstmeyer H., and Baldwin J. (2003) Results of 3-D georadar surveying and trenching the San Andreas fault near its northern landward limit, *Tectonophysics*, vol. 368, no. 1-4, pp. 7-23.

[12] Kadıoğlu S. (2008) Photographing layer thicknesses and discontinuities in a marble quarry with 3D GPR visualization, *Journal of Applied Geophysics*, vol. 64, no. 3, pp. 109-114.

[13] Sarı M., and Öztürk S. (2016) Detecting of damaged areas in the ground of BESYO Sport Complex in Gumushane, Turkey, with the Ground Penetrating Radar Method, *1st International Mediterranean Science and Engineering Congress* (IMSEC 2016), 633-639 pp., Paper ID:206, Adana, Turkey.

[14] Kadıoğlu S., Ulugergerli E. U., and Daniels J. J. (2006) 3D visualization to map cavities by GPR method: Dalaman Akkopru dam reservoir area, Muğla, Southwest Turkey. *Proceedings of the 11 th International Conference on Ground Penetrating Radar*, Columbus- Ohio, USA, CD paper No.156.

[15] Sarı M. (2012) Investigation of geophysical characteristics of gypsum (case of Sivas province), MSc Thesis, *Sivas Cumhuriyet University*, 65 pp (in Turkish with English abstract).

[16] Harrari Z. (1996) Ground penetrating radar (GPR) for imaging stratigraphic features and groundwater in sand dunes, *Journal of Applied Geophysics*, vol. 36, no. 1, pp. 43-52.

[17] Dannowski G., and Yaramancı U. (1999) Estimation of water content and porosity using combined radar and geoelectric measurements, *European Journal of Environmental and Engineering Geophysics*, vol. 4, no. 1, pp. 71-85.

[18] Changryol K., Daniels J. J., Guy E., Radzevicius S. J., and Holt J. (2000) Residual hydrocarbons in a water-saturated medium: A detection strategy using ground penetrating radar, *Environmental Geosciences*, vol. 7, no. 4, pp. 169-176.

[19] Sambuelli L., Socco L. V., and Brecciaroli L. (1999) Acquisition and processing of electric, magnetic and GPR data on a Roman site (Victimulae, Salussola, Biella), *Journal Applied Geophysics*, vol. 41, no. 2-3, pp. 189-204.

[20] Daniels J. J. (1989) Fundamentals of ground penetrating radar. Symposium on the Application of Geophysics to Environmental and Engineering Problems (SAGEEP'89)", *Proceedings of the Environmental and Engineering Geophysical Society, Englewood*, pp.62-142, Colorado.

[21] Kadıoğlu S., Kadıoğlu, Y. K., and Akyol A. A. (2008) Geo archaeological research of the mid-Age Ilyasbey Complex buildings with ground penetrating radar in Miletus, Aydın, Western Anotolia, Turkey, *Donald Harrington Symposium on the Geology of the Aegean*, 28–30 April 2008, University of Texas at Austin, Jackson School of Geosciences, USA, B C Burchfiel 2008 IOP Conference Series: Earth and Environmental Science, 2, published online.

[22] Kadıoğlu S. and Daniels J. J. (2008) 3D visualization of integrated ground penetrating radar data and EM-61 data to determine buried objects and their characteristics, *Journal of Geophysics and Engineering*, vol. 5, vol. 4, pp. 448-456.

[23] Kurt B., Kadıoğlu S., and Ekincioğlu E. E. (2009) Determination of the location, size and physical characteristics of buried pipes by ground penetrating radar method, *Bulletin for Earth Sciences*, vol. 30, no. 1, pp. 45-57.

[24] Holden J., Burt T. P., and Vilas M. (2002) Application of ground-penetrating radar to the identification of subsurface piping in blanket peat, *Earth Surface Processes and Landforms*, vol. 27, no. 3, pp. 235-249.

[25] Cheng N-F., Tang H-W. C., and Chan C-T. (2013) Identification and positioning of underground utilities using ground penetrating radar (GPR), *Sustainable Environment Research*, vol. 23, no. 2, pp. 141-152.

[26] Sarı M., Maden N., and Öztürk S. (2017) Detection of clogged flow pipe with Ground Penetrating Radar (GPR), *International Conference on Mathematics and Engineering*, 10-12 May, Istanbul, Turkey.

[27] Robinson M., Bristow C., McKinley J., and Ruffell A. (2013) Ground Penetrating Radar, *British Society for Geomorphology, Geomorphological Techniques*, Part 1, Sec. 5.5, ISSN 2047-0371, 2013.

[28] Annan A. P. (2003) Ground Penetrating Radar Principles, Procedures & Applications, *Sensors & Software Inc*., Canada.

[29] Zeng X., and McMechan G. A. (1997) GPR characterization of buried tanks and pipes, *Geophysics*, vol. 62, no. 3, pp. 797-806.

[30] Sandmeier K. J. (2012) Scientific Software, REFLEXW ver. 7.0. program for processing and interpretation of reflection and transmission data.

[31] URL-1. (2018) KLU-Öğr. Hör. Taner ERDOĞAN, Kırklareli University, Kırklareli, http://personel.klu.edu.tr/taner.erdogan.