Application of Ground Penetrating Radar to Detect Sinkholes and Ground Subsidence in Beryanak, Tehran

Authors: H. Gharahi, B. Yousefi and U. Aladin
Event name: Near Surface Geoscience 2016 - 22nd European Meeting of Environmental and Engineering Geophysics
Session: Engineering Geology and Geotechnical Investigations II
Publication date: 04 September 2016
DOI: 10.3997/2214-4609.201601980
Language: English
Info: Extended abstract, PDF (2.92Mb)
Price: € 20

Summary:
After occurring two dangerous subsidence in both Arab and Pahlavani Streets located at Beryanak in the 10 districts of the municipality of Tehran, the GPR Department of Geotechnical & Strength of material study centre of Tehran had decided to use ground penetrating radar method to detect possible sinkholes and aqueducts on the site. The GPR data acquisition had been performed by a 50 MHz GPR antenna made by MALA Company. GPR data gathered in 7 longitudinal profiles parallel to the street directions. In the processing of the GPR data, different filters such as background removal, Migration, Band pass filter, and horizontal and vertical smoothing are applied to the data. The final result shows that the most of detecting sinkholes which cause to the subsidence were created due to the scouring. GPR profiles from Arab Street indicate that those anomalies were detected at shallow depths (between 2/5 to 5 m) are due to the subsidence caused by excavation and placement of sewer pipeline. But at some areas were identified from depths 8 to 15 meters can be some sinkholes and may lead to a big subsidence. These areas are very important for both studying and reconstructions.

Application of Ground Penetrating Radar to detect Sinkholes and Ground Subsidence in Bryank, Tehran

HR. Gharahi, B. Yousefi, U. Aladin

Tehran Engineering & Technical Consulting Organization

bahram.yousefi82@gmail.com,

Introduction

Leaks not only waste precious natural resources and money, they create substantial damage to the transportation system and structure within urban and suburban environments. Leaks can be classified in two types: one leaking as a gradual drip and/or only as water passes through a pipe or an aqueduct and the second as a constant spray of water. Leaks that occur only when water is flowing can be more challenging to detect because the point of leakage may dry temporarily [J.L. Davis]. A large percentage of water usually is lost from the distribution systems in transit from the treatment plant to the consumer. The primary economic loss comes from the cost of raw water, its treatment, and transportation. Leakage inevitably also results in secondary economic loss in the form of damage to the distribution network itself (e.g. erosion of pipe bedding and major pipe breaks) and to the foundations of roads and other manmade structures. Leaky pipes also create a public health risk, as every leak is a potential entry point for contaminants if pressure should drop in the system.

Ground penetrating radar is a geophysical measurement technique that has been extensively used to map the relatively shallow subsurface features at scales from kilometers to centimeters. The GPR technique is similar in principle to seismic, one antenna, and the transmitter, radiates short pulses of high-frequency (MHz to GHz) electromagnetic waves, and the other antenna, the receiver measures the signal from the transmitter as a function of time. When the source antenna is placed on the surface, spherical waves are radiated both upward into the air and downward into the soil [S. Cardimona].

GPR could in principle identify leak areas by either detecting underground voids created by the leaking water as it circulates near the pipe or by detecting anomalies in the depth of the pipe or other passing tools as measured by radar [M. Nakhkash]. Saturation of soil by water leaking from a pipe slows down radar waves – thus making a leaking water pipe appear deeper than what it should be.

in their stability. b) Unconsolidated young deposits and semi-consolidated clastic sediments with high porosity which are located under alluvial deposits, lacustrine or shallow marine deposits. Typically such environments include confined or semi-confined sandy aquifer mid thin clay layers with low vertical permeability and high compressibility. Urban areas due to the density of population, buildings and vital arteries are particularly vulnerable. This phenomenon can cause major damages to roads, bridges and highways; and not only disrupts the water lines, sewer and gas pipelines but also caused cracks to the basement of buildings.

GPR is one of the near-surface geophysical methods that are applied in underground studies based on the transmission of high frequency electromagnetic waves into the ground and recording the reflected pulses. The quality of data acquired from underground objectives depends on some factors such as the type and gender of environments in terms of geology and depth. It is proved that the GPR method is a useful sensor in near-surface studies. Today, GPR has stabilized its role as a promising tool in the field of engineering and Geotechnical characterization of subsurface anomalies. In this method according to the relationship between the dielectric coefficient and electrical conductivity with some physical properties of material such as moisture content and soil salinity, the importance of outputs is doubled.

GPR Methodology

In recent decades, GPR has been used in the underground anomaly investigation. GPR signals are recorded in terms of amplitude, two-way time and the polarity of the wave. Electromagnetic wave propagates in the air with a speed of 0.3 m/NS. Generally, in another medium such as ground, velocity of EM waves is reduced due to *the relative dielectric permittivity (ε_r), magnetic permeability (μ_r), and electrical conductivity (σ). Velocity of electromagnetic wave in a host material is given by equation 1,*

$$v = \frac{c}{\sqrt{\varepsilon_r \mu_r \frac{1+\sqrt{1+(\sigma/\omega\varepsilon)^2}}{2}}} \qquad (1)$$

Where
c: EM wave velocity in vacuum (0.3m/ns)
$\varepsilon = \varepsilon r\ \varepsilon 0$, Dielectric permittivity and dielectric permittivity in free space
$\omega = 2\pi f$, angular frequency
σ = conductivity
$\varepsilon\omega/\sigma$ = loss factor
For non-magnetic ($\mu r = 1$) low-loss materials, such as clean sand and gravel, where $\sigma/\omega\varepsilon \approx 0$, the velocity of EM wave is reduced to the expression 2,

$$v = \frac{c}{\sqrt{\varepsilon_r}} \qquad (2)$$

Several processes lead to a reduction of electromagnetic signal strength. Among the important processes are attenuation, spherical spreading of energy, reflection/transmission losses at interfaces and scattering of energy [2]. The records of reflection describing the behavior of electromagnetic pulses are represented by means of two dimensional profiles called radargrams where the ordinate axis represents two-way travel time of signals [3].

GPR is the overwhelming geophysical method of choice for sinkhole investigations. GPR provides the opportunity for dense data coverage, high resolution, and very good penetration with quick turnaround and relatively low cost. Difficulties arise when a site has shallow clay or shallow, groundwater [5].

However, when the target of the investigation is to establish evidence of subsidence, the presence of clay is less of an issue than might be expected. If all we can image is the top of the clay and it can be shown that the clay is moving or is locally disrupted due to raveling, the GPR section still provides useful information [6]. A ravel zone can also be viewed directly on GPR sections as a near-vertical zone of discrete scatters and local increases in reflection amplitudes in the shallow section because of localized increases in soil porosity. Also, if fines (clay) are removed by the raveling process, such features are sometimes identified by a localized interval of increased GPR signal penetration due to the reduced electrical conductivity/ attenuation.

I. The Study Area

Regarding to some dangerous subsidence occurred in both Arab and Pahlavani streets in the Beryanak located in ten district in Tehran municipality, Geotechnical & Strength of material study center of Tehran had decided to detect possible cavities and aqueducts are listed on the site by GPR method. According to adjustment between Tehran's map with all of test pits which have been performed close to the area (Geotechnical & Strength of material study center of Tehran, 2011) and also base on the location of the study area on geological maps presented by JICA, the area is located in formation D (Fig. 1).

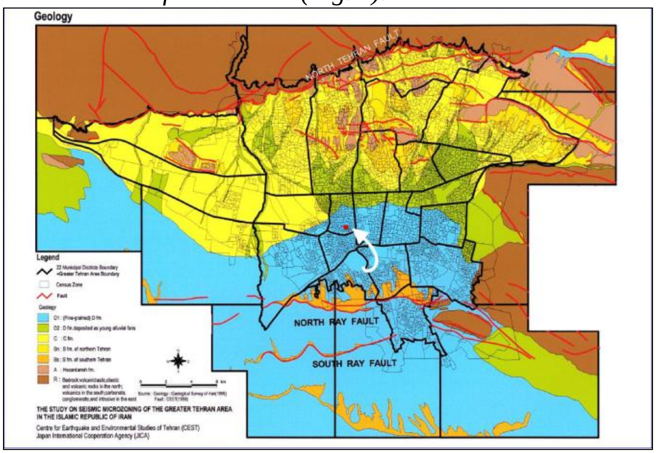

Fig. 1. Location of the study area (Beryanak) on Tehran geology map (JICA, 2000)

Recent alluvium or D alluvial formation is included of the youngest river sediments or floodplain and riverbed deposits; generally, D formation in north of Tehran contains the coarse sediment (sand and gravel without cementation) and in the South of Tehran is formed of the fine sediments (silt and clay). Current alluvial *deposits that most are in the form of discrete sediments are highly permeable and its mechanical strength is different compared to several locations. In the study area, the thickness of fill material is varied up to 6/6 meters. The clay layers (with variable thickness 1 to 5/6 meters) are observed with low adhesion between the layers of sand (Geotechnical & Strength of material study center of Tehran, 2011).*

GPR Data Acquisition

GPR GPR survey was performed in order to help evaluate the cause of the surface subsidence. 7 longitudinal profiles parallel to the street directions were scanned both Arab and Pahlavani streets using 50MHz antenna (Fig. 2).

GPR Data Processing and Interpretation

For the processing of the GPR profiles, the group's experts used GSSI RADAN 6.6 software. The processing flow used included a zero time correction, an infinite impulse response filter (band-pass filter for removing high and low frequencies), stacking, stretching, background removal and Kirchhoff migration for the geometry correction and the time-depth conversion. A topographic correction was not applied to any of the acquired profiles because the surveyed area was almost perfectly horizontal. According to Lehman and Green [1], topographic corrections should be considered in regions with surface gradients that are greater than 10% or the slope angle is higher than 60.

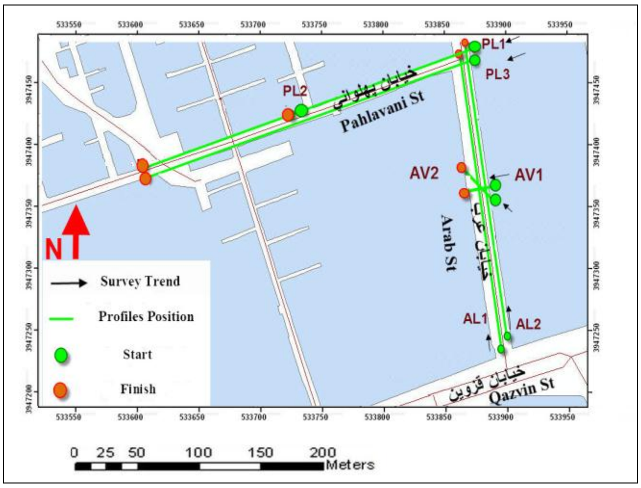

Fig. 2. Position of GPR Survey Profiles

Profile AL1:

The Length of the Profile is 258.6 m and its trend is South to North (Fig. 3). In this section, two major patterns of possible risk points have been detected; The first one in the shallow part is most probably related to be the result of drilling and placement of the sewer pipe have been created. The depths of this pattern are 3 to 5 meters. The air-filled void is identified due to its signal characteristic of strong reverberation and high amplitude reverberations produced by the voids. Furthermore, the FIROUZABADI Creek cuts the profile approximately at 180 to 190 meters in length as shown in the Fig. 3.

The second pattern of the detected anomalies seen in Fig 3, are located at the depth between 8 to 15 m (A, B, C, D, E and G); some reverberations (Kofman et al. 2006) inside the open space are visible.

Profile PL1:

Two profiles have been surveyed on the Pahlevani Street. The PL1 profile was taken in the northern part of Pahlevani Street that is approximately on top of the sewer pipeline. The profile's is length about 176.3 m and its trend is east – west. Some anomalies in 15, 25, 60, 80, 105, 115 and 140 m are observed (Fig. 4).

. *Profile PL2*

The PL2 profile was taken in the southern part of Pahlevani Street; the profile's is length about 173. A relatively large anomaly in the range of 35 to 55 meters and at a depth range of approximately 2 to 12 m is visible (Fig. 5). According to previous reports of subsidence in this area, a water leakage had been detected exactly at the anomaly location; so it is probably the major reason of the anomaly.

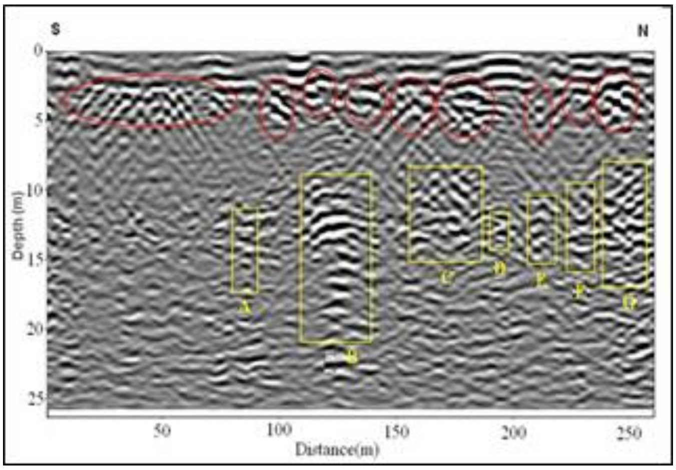

Fig. 3. GPR Section of Profile AL1

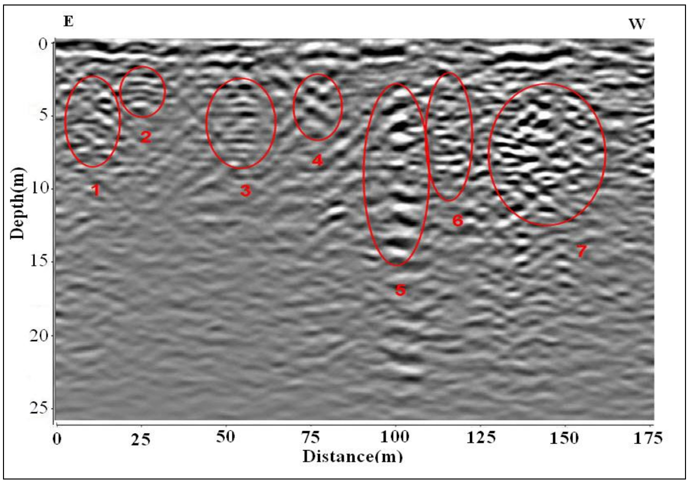

Fig. 4. GPR Section of Profile PL1

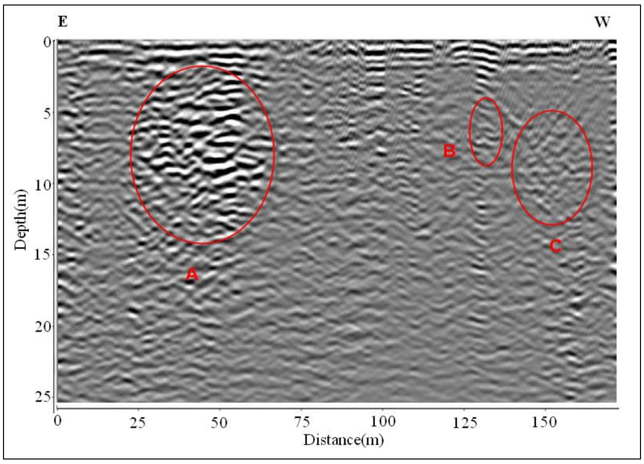

Fig. 5. GPR Section of Profile PL2

Conclusion

In this paper, the GPR data acquisition had been performed by a 50 MHz GPR antenna at Arab and Pahlvani streets located in Beryanak in the 10th district of Tehran municipality. The GPR data gathered in 7 longitudinal profiles parallel to the street directions. The data were processed and radargrams were made; then in data processing step, different filters such as background removal, Migration, Band pass filter, and horizontal and vertical smoothing were applied to the data. After analyzing and processing the GPR sections, according to main targets of this study, all the possible area which may have a high degree of risk to be a void or points with loose soils, had been determined (Fig. 6).

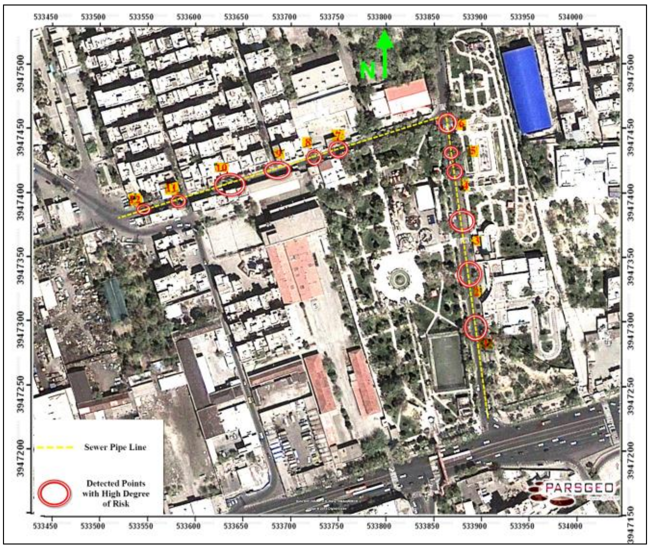

Fig. 6. Detected Anomalies with high degree of risk at both Arab and Pahlavani Streets

Generally, seems all the possible voids and a subsidence area may occur due to the water leakages and damages of the sewer pipe passing under these two streets. In the GPR sections, two major patterns of possible risk points have been detected; The first one in the shallow part is most probably related to be the result of drilling and placement of the sewer pipe have been created. The depths of this pattern are 3 to 5 meters. The second anomalies may create with the GPR data due to the air-filled void or loose soils at a deeper area up to 10 meters. These deeper anomalies are essential for study and also make a decision for reconstruction.

ACKNOWLEDGMENT

The authors wish to thank the Geotechnical & Strength of material study center of Tehran and Tehran Engineering & Technical Consulting Organization for funding.
The authors would like to thank Zamin Physics Pouya Company that collaborated in the execution of geophysical surveys.

References

F. Lehmann, A. G. Green, "Topographic migration of georadar data", Implications for acquisition and processing. Geophysics 2000, vol. 65(3), pp. 836–848.

I. Møller, F. Jørgensen, "Combined GPR and DC-resistivity imaging in hydrogeological mapping", In proceedings of 11th International Conference on Ground Penetrating Radar. 2006, pp. 1-5.

J. A. Avila-olivera. A GPR study of subsidence-creep-fault processes in Morelia Michoacán, Mexico", Engineering Geology, 2008, 100, pp. 69-81.

L. Kofman, A. Ronen, S. Frydman, "Detection of model voids by identifying reverberation phenomena in GPR records", J. of Applied Geophysics 2006, vol. 59, pp. 284–299.

N. Ismail, R. Saad, "A Case Study on Ground Subsidence Using Ground PenetratingRadar", 2012 International Conference on Environmental, Biomedical and Biotechnology, IPCBEE, IPCBEE, vol.41, 2012.

U. Matevz. U, Pavic and P. Blaz, "Detecting Karstic Zones during Highway Construction Using Ground Penetrating Radar", ACTA GEOTECHNICA SLOVENICA, 2011, vol 1, pp. 17-27.