2012 International Conference on Environmental, Biomedical and Biotechnology
IPCBEE vol.41 (2012) © (2012) IACSIT Press, Singapore

A Case Study on Ground Subsidence Using Ground Penetrating Radar

Nur Azwin Ismail+ and Rosli Saad

Geophysics Section, School of Physics, Universiti Sains Malaysia, 11800 USM, Penang, Malaysia

Abstract. Ground subsidence is a worldwide problem especially in urban areas and agricultural industry. Ground subsidence mainly associated with structural faults and compaction of overdraft aquifer system. This condition may lead to occurrence of subsurface voids which can pose hazards to engineers and general public. They can impede construction operations and undermine building foundation. Ground penetrating radar (GPR) have ability to reveal subsurface voids and localized area of potential ground subsidence. It is one of geophysical method that has been developed for shallow subsurface investigation. Its returns real-time signal above voids and subsided sediment have discrete signature that are used to interpret and identify these features. Total of 12 GPR survey lines were executed in Shah Alam, Selangor, Malaysia with the aim of identifying the ground subsidence area and detecting voids. This study implemented MALA 250MHz shielded antenna for data acquisition. GPR profiles successfully detected areas of subsidence and void, generally with depth <5m.

Keywords: Subsidence, Voids, GPR

1. Introduction

Ground subsidence is a worldwide problem especially in urban areas and agricultural industry. Subsidence is known as the process characterized by downward displacement of surface material cause by natural phenomena or manmade phenomena. Ground subsidence cause by compaction of overdraft aquifer system heavily dependent on groundwater supplies [1], while subsidence associated with structural faults will generate earth fissures and surface faults [2]. Ground subsidence may lead to many problems such as structural damage, roads and bridges. GPR is one of the near surface geophysical methods that involve the transmission of high frequency radar pulses from a surface antenna into the ground. It provides detailed information about the subsurface which is site-dependent and the quality of the results is dependent on the target, geologic environment, subsurface features and other factors that affect the contrast of the target to surrounding medium. It has been demonstrated that GPR is a useful sensor for shallow subsurface investigation [3]. Most complete information can be extracted from GPR data over an area of interest. It has proven to be a promising tool for subsurface characterization in the field of environmental and engineering since the dielectric properties and conductivity governing GPR wave propagation are strongly correlated to basic physical properties such as water content, and soil salinity [4]. GPR survey was performed in Shah Alam, Selangor, Malaysia using MALA 250MHz shielded antenna with total of 12 survey lines. There is subsidence (ground opening) occur with depth <7m and some cracks detected on the road along the survey lines.

2. Methodology

2.1. Basic principle

+ Corresponding author. Tel.: + (6017) 551 1013; fax: +(604) 657 9150.
E-mail address: nurazwinismail@yahoo.com.

Ground penetrating radar is a method that is commonly used for environmental, engineering, hydrogeological, and other shallow subsurface investigations [5]. It has been used for several years as a non-destructive method for locating subsurface anomalies. It uses the principle of scattering electromagnetic wave (EM) to locate target or interfaces buried within visually opaque substances or earth material [6]. An electromagnetic wave is transmitted into the ground and reflected based on different dielectric properties of subsurface materials (Fig.1). Reflected waves are received at the surface according to a general principle; the higher the frequency, the better the resolution and the shallower the depth of penetration [7].

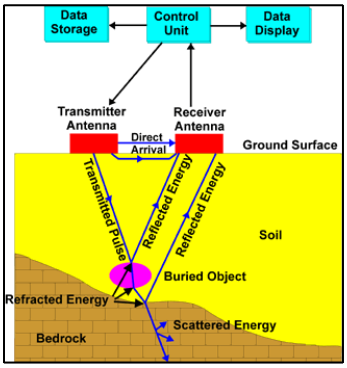

Fig. 1: EM wave propagation depends on dielectric and conductivity properties of material [8].

The recorded signal is registered as amplitude and polarity versus two way travel time. The electromagnetic wave propagates in air with the speed of light, 0.3 m/ns. Generally, in other medium such as ground, velocity of EM wave is reduced due to 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,

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

Where; c = EM wave velocity in vacuum (0.3m/ns)

$\varepsilon = \varepsilon_r \varepsilon_o$, dielectric permittivity and dielectric permittivity in free space

$\omega = 2\pi f$, angular frequency

σ = conductivity

$\sigma/\omega\varepsilon$ = loss factor

For non-magnetic (μ_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,

$$v = \frac{c}{\sqrt{\varepsilon_r}} \tag{2}$$

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 [9]. The records of reflection describing the behaviour of electromagnetic pulses are represented by means of two dimensional profiles called radargrams where the ordinate axis represents two-way travel time of signals [10].

2.2. Factors affecting GPR

Detectability of a subsurface feature depends on conductivity contrast, dielectric constant and geometric relationship between antennas, where electrical properties of geological materials are primarily controlled by water content and porosity. Conductivity is the ability of a material to conduct electrical current. For a solution of water, conductivity is highly dependent on salts concentration and ions, therefore the purer the water, the lower the conductivity. The dielectric constant is defined as the capacity of a material to store a charge when an electrical field is applied relative to the same capacity. Table 1 shows the dielectric constant, conductivity and velocity of common geological materials and medium.

Table 1: Typical dielectric constant, conductivity and velocity value of common materials and medium [11].

Medium	Dielectric, ε_r	Conductivity, σ (mS/m)	Velocity, v (m/ns)
Air	1	0	0.30
Fresh water	80	0.5	0.033
Salt water	80	$3\text{x}10^3$	0.01
Dry sand	3-5	0.01	0.15
Saturated sand	20-30	0.1-1	0.06
Limestone	4-8	0.5-2	0.12
Clay	5-40	2-1000	0.06
Granite	4-6	0.01-1	0.13
Ice	3-4	0.01	0.16

Variations in the dielectric constant of the ground caused the variations in electrical impedance. Reflection of electromagnetic occurs when there are impedance contrasts in the ground. The radar signal is attenuated more in wetter materials that have higher conductivity where depth of penetration is therefore reduced. The limited depth of penetrations are sometime not penetrate bedrock however soil disturbance by movement or arching at shallow depths may precede the development of soil subsidence which create anomalous radar reflections that are identifiable [12].

3. Study Area

Study takes place at Shah Alam, Malaysia. It is the state capital of Selangor, Malaysia situated within the Petaling district and a small portion of neighbouring Klang district. It is located about 25km west of the country's capital, Kuala Lumpur. GPR survey was conducted along the road of interest at main campus of public university in Shah Alam. There are total of 12 GPR survey lines were conducted with different length. Survey line L1 and L2 were executed along brick pedestrian with total length of 16m and 33m respectively. For survey line L3-L11, spacing between lines were 5m with average length of 7m for each lines. Orientations of these lines are across the road where cracks are obviously found. Line L12, with a length of 35m, executed opposite L1 and L2 (Fig.2). Site photos and sinkhole are shown in Fig.3.

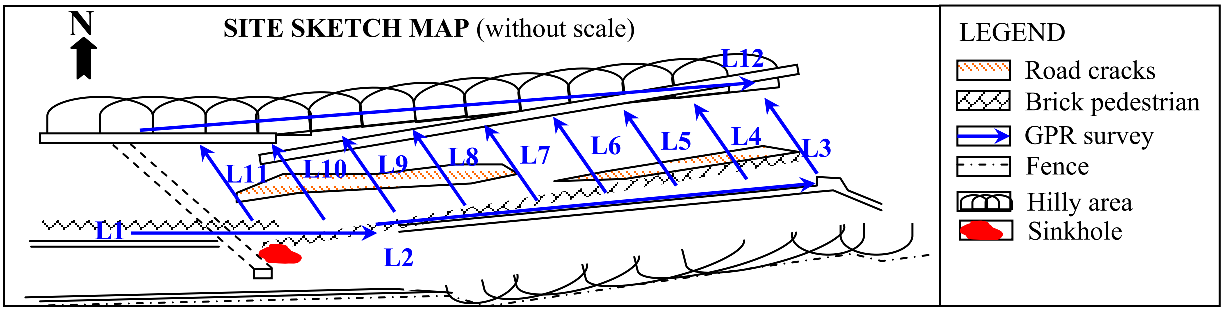

Fig. 2: Sketch map of 12 GPR survey lines.

Fig. 3: Site photos. a) cracks on the road, b) sinkhole with depth <7m and c) survey line L1 and L2.

4. Results and Discussions

From GPR profiles obtained, results show feature of soil subsidence observed at several depth. Major changes of soil in subsurface were identified with signal has been attenuate, resulting in weak reflection signal. Fig.4 shows GPR profile for L1 with broad area of subsidence zone at depth of >2.19m.

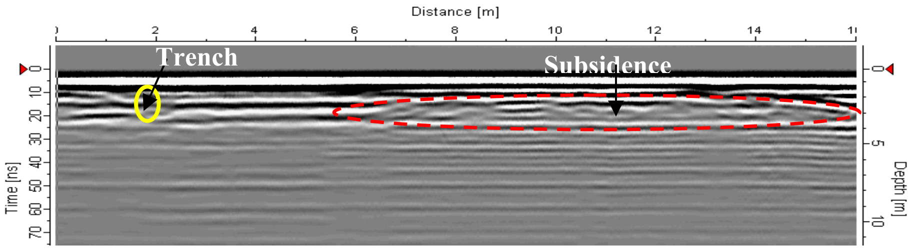

Fig. 4: GPR profile for L1 with subsidence zone.

For L2, ground subsidence detected along the line with one suspected air-filled void identified at distance 31.3m with depth of >2m (Fig.5). The air-filled void is identified due to its signal characteristic of strong reverberation and high amplitude reverberations produced by the void by the inner surface.

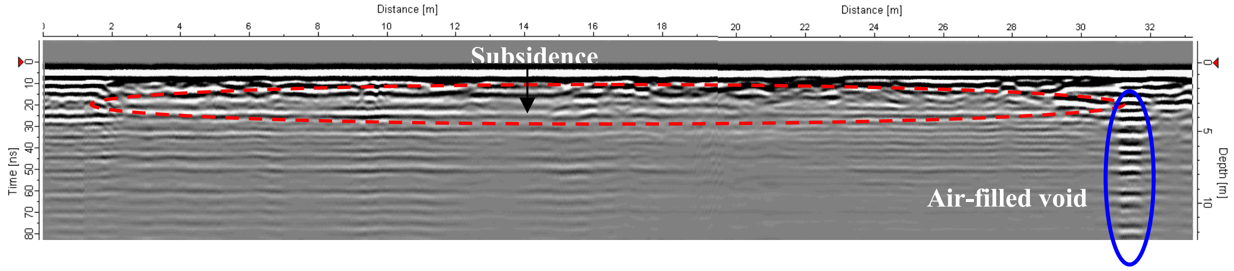

Fig. 5: GPR profile for L2 with subsidence zone and air-filled void.

For L3-L11 (Fig.6), ground subsidences are also detected, resulting in cracks that obviously found on asphalt road.

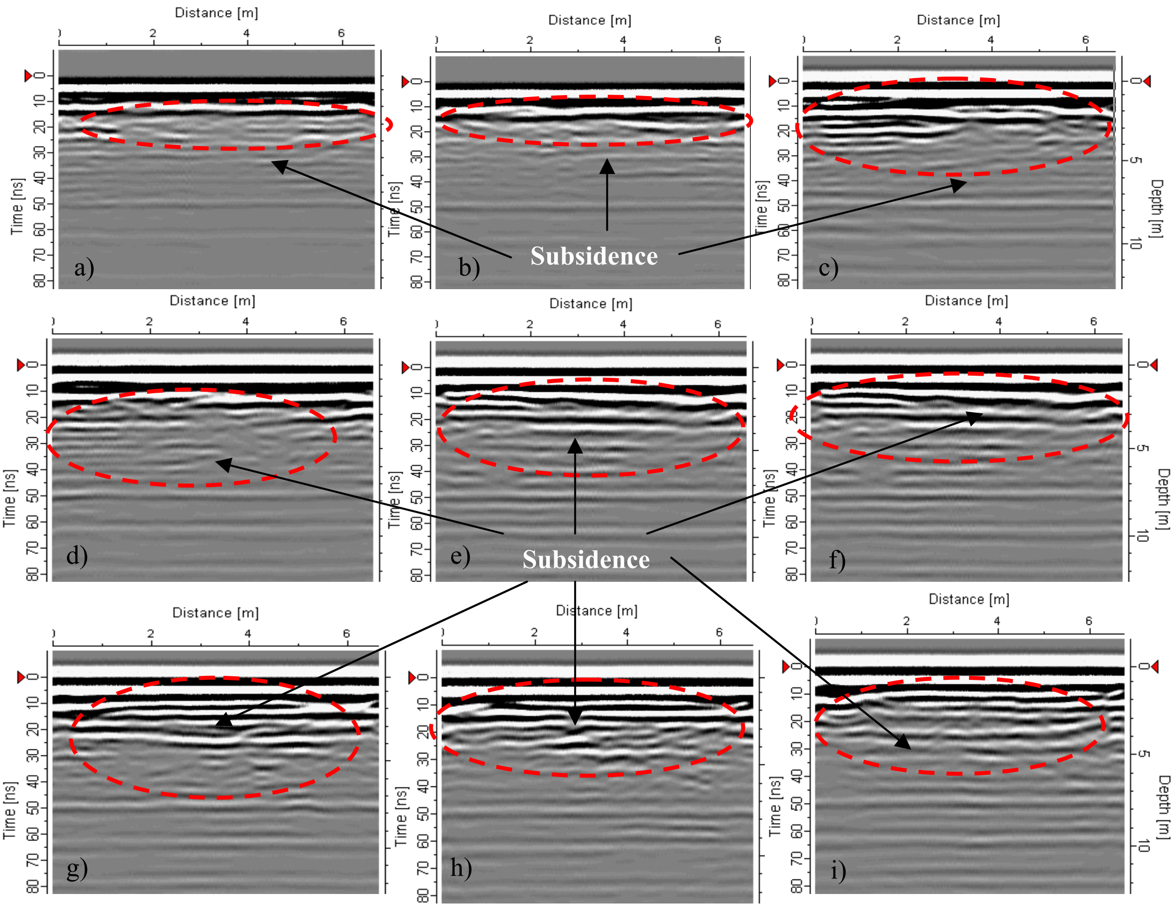

Fig. 6: GPR profiles for nine survey lines across road. a) L3, b) L4, c) L5, d) L6, e) L7, f) L8, g) L9, h) L10 and i) L11.

For survey line L12, ground subsidence detected at depth of >2m. There are two areas with relatively lost signal energy which are at distance 7.5-9.1m and 12.8-15.4m respectively (Fig.7). This is suggested as collapse zone may be due to erosion of underground soil or rock, cause by leaking human made sewer pipes or water mains.

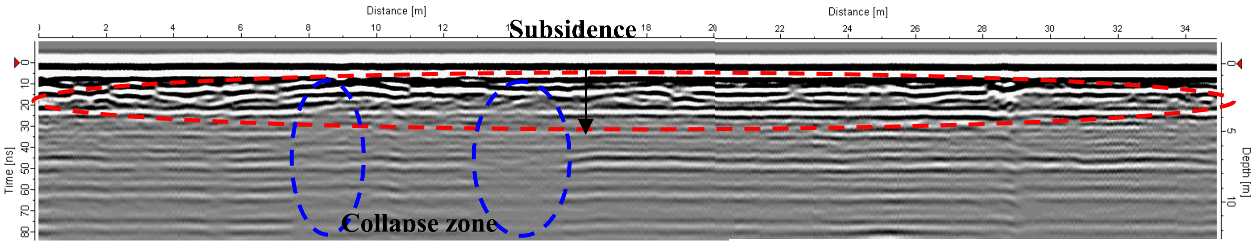

Fig. 7: GPR profile for L12.

5. Conclusion

GPR plays very important role for recognition of ground subsidence of the area as well as identify air-filled void. The results obtained from GPR method can be further used to analyze parameters such as water content, conductivity and porosity which related to ground subsidence by extracting data on amplitude and velocity. Based on this study, radar profiles obtained clearly displays subsidence zone at depth >2m with a suspected air-filled void detected at distance of 31.3m for survey line L2.

6. Acknowledgement

Our grateful thanks extend to Teroka Jaya for site suggestion. Thank you also dedicated to all geophysics staff and postgraduate students, Universiti Sains Malaysia for contribution during field data acquisitions.

7. References

[1] T. L. Holzer. Leveling data- Eglington faults scarp, Las Vegas Valley, Nevada: U.S. *Geological Survey-Open file report,* 1979, pp. 7.

[2] J. F. Poland. Guidebook to Studies Land Subsidence Due to Groundwater Withdrawal. International Hydrological Program, 1984, pp 305.

[3] E. Eide, P. A. Sandnes, , B. Nilssenand ,and S Tjora. Airfield runway inspection using 3 dimensional GPR. *Proceeding the 3rd International Workshop on Advance Ground Penetrating Radar (IWAGPR*), 2005, pp 87-91.

[4] E. C. Slob. GPR design and modeling for identifying the shallow subsurface dielectric properties. *Proceeding the 2nd International Workshop on Advance Ground Penetrating Radar (IWAGPR),* 2003, pp 130-135.R.E. Sheriff . *Encyclopaedic dictionary of applied geophysics, 4th edition Geophysical References Series*. 2011, Society of exploration geophysicists.

[5] R. E. Sheriff . *Encyclopaedic dictionary of applied geophysics, 4th edition Geophysical References Series*. 2011, Society of exploration geophysicists.

[6] J. D. Jeffrey. Ground penetrating radar fundamentals. Department of Geological Sciences, The Ohio State University. *Appendix to a report to the U.S.EPA, Region V,* 2000.

[7] H. M. Jol and C.S. Bristow. GPR in sediments: advice on data collection, basic processing and interpretation, a good practice guide. In Bristow CS, Jol HM (eds). *Geological society London special publication*. 2003, **211**: 9-27.

[8] J. Rittenhouse. *Environmental protection agency*. 2008.

[9] 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.

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

[11] M. Beres and F.P. Haeni. Application of ground penetrating radar methods in hydrogeologic studies, ground waves, 1991, **29** (3), pp. 177-193.

[12] T. Waltham, F.G. Bell and M.G. Culshaw. Sinkholes and subsidence: karst and cavernous rocks in engineering and construction, 2005, pp 185-194.