Jurnal
Teknologi

Full Paper

GEOPHYSICS APPLICATIONS IN ENGINEERING AND ENVIRONMENTAL ISSUES

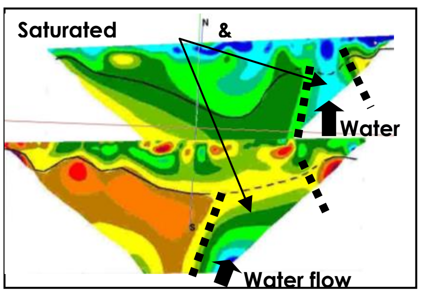
Rosli Saad[a]*, Edy Tonnizam Mohamad[b]

[a]School of Physics, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia
[b]Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

Article history
Received
18 January 2016
Received in revised form
8 March 2016
Accepted
18 March 2016

*Corresponding author
rosli@usm.my

Graphical abstract



Abstract

Geophysical investigation is non-invasive, time and cost effective. There is a relation between geophysics and geotechnical data. Unfortunately many engineers did not aware of this or have lost confidence in geophysics, as a result of insufficient communication of the capabilities, limitations and precision of the geophysical approach; poorly planned investigations; or lack of data integration. With good communications and planning, geophysics can be used together with borehole, excavation data or others to provide greater certainty of site characteristics. Three geophysical investigations case studies were discussed with different objective for assessment and design. The case studies illustrated how geophysical data can provide important geological interpretation that could not be achieved by interpretation from borehole results alone.

Keywords: Geophysical; mapping; borehole

Abstrak

Kajian geofizik bersifat tidak merosakan serta menjimatkan masa dan kos. Terdapat hubungan antara data geofizik dengan geoteknik. Malangnya kebanyakan jurutera tidak sedar dengan hubungan ini atau hilang keyakinan terhadap geofizik lanjutan dari maklumat yang kurang tentang kemampuan, kelemahan dan ketepatan kaedah geofizik; plan kajian yang lemah atau kekurangan data integrasi. Dengan komunikasi dan plan yang baik, geofizik dapat di gunakan bersama dengan data lubang gerudi atau data korekan atau lain-lain data bagi meningkatkan kepastian terhadap ciri-ciri kawasan kajian. Tiga kes kajian geofizik dibincangkan dengan objektif yang berbeza untuk penilaian dan rekabentuk. Kes kajian memperlihatkan bagaimana data geofizik boleh memberi tafsiran geologi yang penting, yang tidak dapat dicapai dari tafsiran melalui lubang gerudi secara bersendirian.

Kata kunci: Geofizik; pemetaan; lubang gerudi

1.0 INTRODUCTION

Geophysical method is non-invasive subsurface investigation characterization of geology, geological structure, groundwater, contamination, and human artifacts beneath the Earth's surface, based on lateral and vertical mapping of physical property variations that are remotely sensed using non-invasive technologies. Subsurface refer to the type of problem deals with shallow depths that are most significant in terms of the lives, work and activities of the earth's human population.

The geophysical data used to compliment with other data such as borehole for better result. Geophysical investigations assist the difficulties associated with mapping subsurface using borehole data alone, which provides geological interpretation and geotechnical design [1,2]. Engineer's requirements, such as mapping basement, identifying dynamic modulus, etc., to determine suitable geophysical method employed to assist with the engineering investigation is vital. Engineers, geologists and engineering geophysicist each interpret the use of geophysics in a different way [3-5]. Hence, it is importance to gather all to get very clear communication, investigation objectives, site conditions, access issues and geophysical method limitations. This paper presented few case studies to show the contribution and important of geophysical studies for engineers and environments.

2.0 METHODOLOGY

Three geophysical investigations case studies were carried out. Methods included within the case studies were 2-D Resistivity Imaging (2-DRI), Seismic Refraction Tomography (SRT) and Ground Penetrating Radar (GPR). The case studies illustrated the positive results that can be achieved with good communication, planning and interpretation between engineers and geophysicists.

3.0 RESULTS AND DISCUSSION

3.1 Case Study 1

Study was conducted with the objective to identify a potential groundwater source for industrial purposes. Generally 2-DRI survey carried out with a multi-electrode resistivity meter system using multi-electrodes laid out in a straight line. Figure 1 show a computer-controlled system used to automatically select the active electrodes for each measure [6].

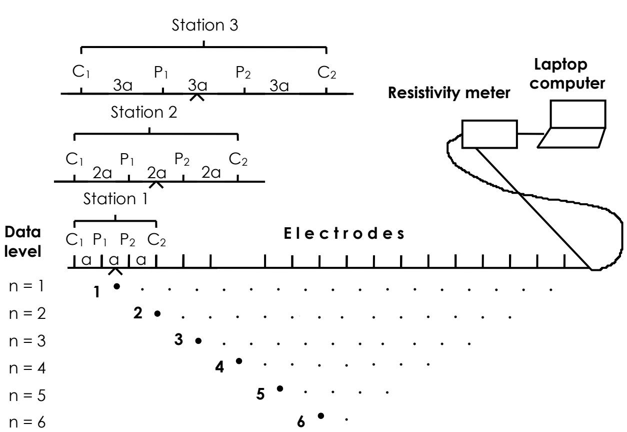


Figure 1 The arrangement of electrodes for 2-DRI survey and the sequence of measurement used to build up a pseudosection [7]

With information gathered from desk study of the area, two survey lines, L1 and L2 were design (Figure 2). Data were collected using ABEM multi-electrode resistivity meter system with 41 electrodes and Pole-dipole array. The collected data was processed and interpreted using Res2Dinv, Microsoft excel, Surfer, geology and geomorphology records.

Figure 2 The orientation of 2-D resistivity survey lines [8]

The resistivity method basically measures the resistivity distribution of the subsurface materials. Table 1 and Table 2 show the resistivity value of some of typical rocks, soil materials and water [9]. The resistivity of rocks is mainly dependent on the degree of fracturing.

Table 1 Resistivity values of common rocks and soil materials [9]

Material	Resistivity (ohm-m)
Alluvium	10 to 800
Sand	60 to1000
Clay	1 to 100
Groundwater (fresh)	10 to 100
Sandstone	8 - 4 x 10^3
Shale	20 - 2 x 10^3
Limestone	50 – 4 x 10^3
Granite	5000 to 1,000,000

Table 2 Resistivity values of some types of waters [9]

Type of water	Resistivity (ohm-m)
Precipitation	30 - 1000
Surface water, in areas of igneous rock	30 – 500
Surface water, in areas of sedimentary rock	10 - 100
Groundwater , in areas of igneous rock	30 - 150
Groundwater , in areas of sedimentary rock	> 1
Sea water	≈ 0.2
Drinking water (max. salt content 0.25%)	> 1.8
Water for irrigation and stock watering (Maximum salt content 0.25%)	> 0.65

Figure 3 shows 2-D resistivity interpreted section of all the survey lines after correlated with geology and geomorphology data. Generally the 2-D resistivity results show the study area was divided into two main zones. The first zone with resistivity value of less then 300 Ohm.m with depth of 5-80 m and interpreted as overburden. This zone consist of some saturated zones (<200 Ohm.m) and leachate area (<10 Ohm.m). The second zone with resistivity value of greater than 100 Ohm.m is interpreted as rock mass.

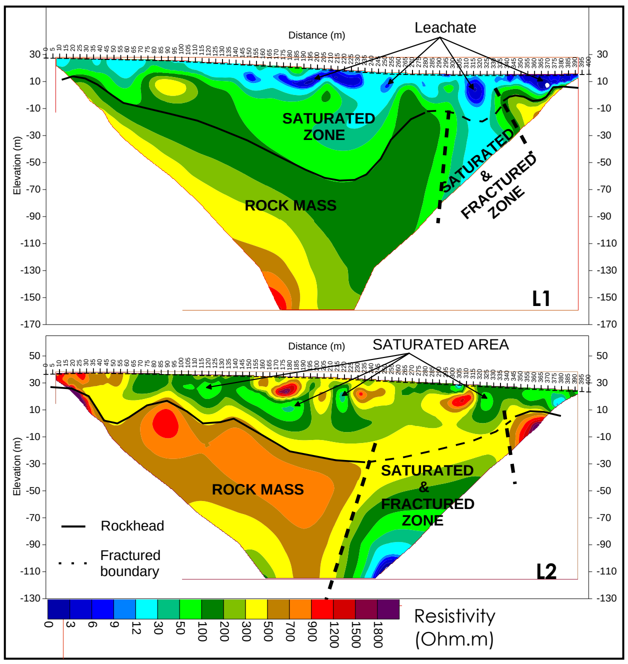


Figure 3 2-D resistivity cross section of line L1-L2 with interpretation

The study conclude that the area consists of interbedded sandstone, siltstone and shale with resistivity value of greater than 100 Ohm.m and depth of 5-80 m. A major fractured and saturated zones (could be water) was identified flowing from south to northeast with depth of about 100 m to 35 m respectively. Figure 4 shows a 2-D resistivity section in 3D view with groundwater flow.

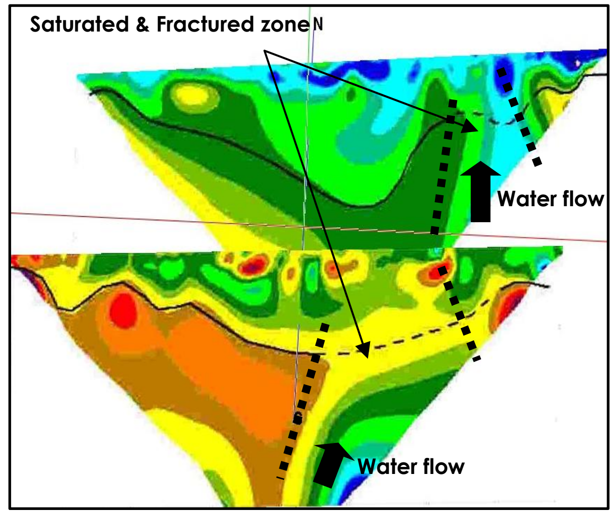


Figure 4 2-D resistivity sections in 3D view and groundwater flow

3.2 Case Study 2

The objective of the case study was to identify the depth of bedrock, volume of overburden and rock volume for commercial purposes. SRT apply sound wave (hammer, seisgun, dynamite) that was imposed to Earth's surface to produce reflection and refraction waves. This method also mirrors rock intrinsic characteristics such as porosity, density, particle size and shape, anisotropy, mineralogy, degree of cementation and moisture effect [10]. Refraction wave detected by ground detector (geophone) and recorded as function of time (Figure 5).

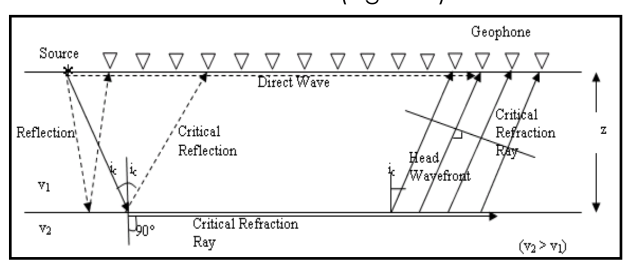
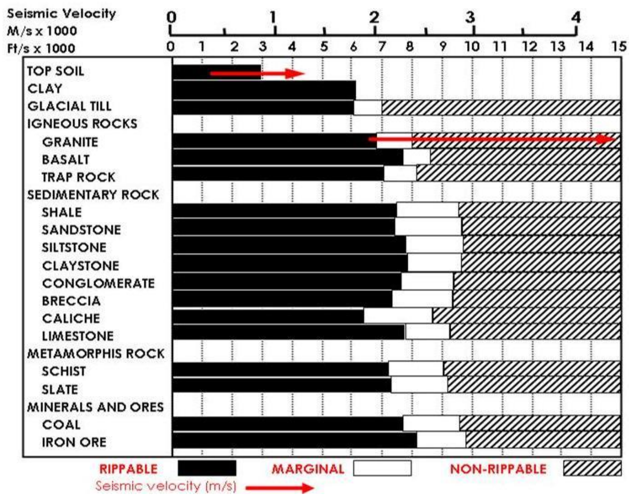


Figure 5 Direct wave, reflection and refraction ray [11]

Table 3 shows the relation between seismic velocity and rippability. Sixteen seismic survey lines (L1-L16) were design to fulfill the objectives (Figure 6). The study was carried out using 6.5 kg sledgehammer seismic source, 24 pieces of 24 Hz geophones laid in straight line with 5 m spacing and ABEM MK6 seismograph. The data was processed using Firstpix, Gremix15, Optim seismic software, Microsoft Excel and Surfer 8. The processed data were interpreted after correlated with geology, geomorphology and borehole data.

Table 3 Rippability assessment chart recommended by Caterpillar Tractor Co. (1988) for CAT D9 type dozer [12]



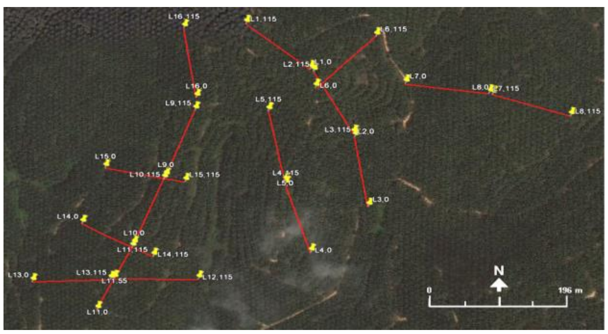


Figure 6 The orientation of sixteen seismic survey lines [8]

Figures 7 and 8 show interpreted seismic cross section of line L15 and L16. Generally all the seismic cross sections showed that the study area consisted of an overburden with velocity of <3600 m/s. Fresh bedrock (granite) with velocity of ≥3600 m/s was identified at depth of 12.9-64.7 m from ground surface. Figure 9 shows ground surface and bedrock topography map of the study area.

The study concludes that the study area was granitic bedrock with velocity of ≥3600 m/s and depth of 12.9-64.7 m from ground surface. Table 4 shows estimated volume of overburden and rock with interval of 5 m.

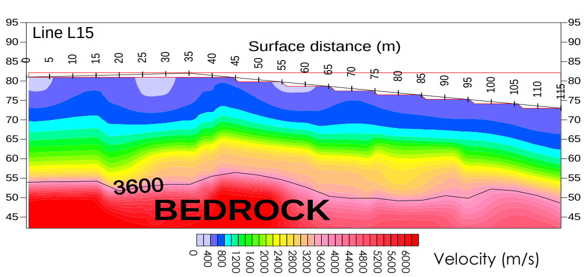


Figure 7 Interpreted seismic cross section of line L15

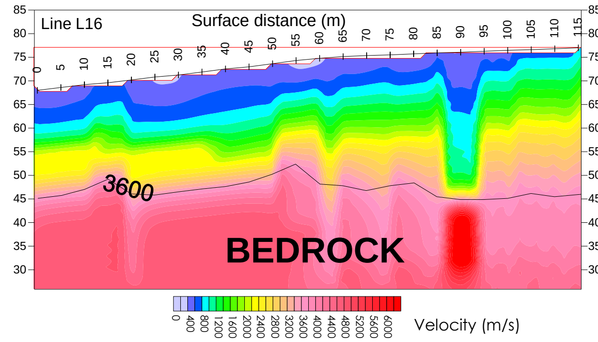


Figure 8 Interpreted seismic cross section of line L16

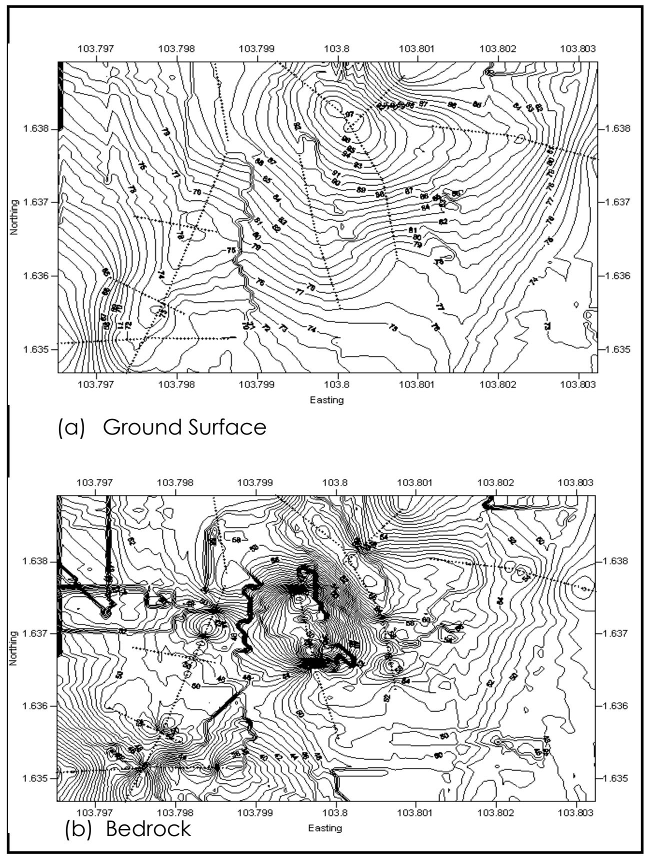


Figure 9 Topography map of the ground surface and bedrock at the study area

Table 4 Estimation of overburden and rock volume

No	MSL level (m)	Volume (m^3)	Remark
1	-	9756292.1	OVREBURDEN
2	68	102.0	Start of highest rock head
3	63	27452.6	
4	58	127906.7	
5	53	461641.7	
6	48	1270118.5	
7	43	2568239.2	
8	38	4069545.1	
9	33	5679526.6	
10	28	7336374.7	
11	23	9013997.1	
12	22	9350130.6	End of lowest rock head
13	18	10694778.6	

3.3 Case Study 3

Generally GPR is used to detect buried objects (metallic/non-metallic) that are not detectable by other methods. They include determining stripping zones in asphalt pavements, detecting subsurface voids, detecting subsurface anomalies (bedrock/peat), bridge deck delamination, underground utility locates, sub grade profiling, and pavement thickness. The effectiveness of GPR is a function of site conditions, the equipment used, and experience of personnel using the equipment and reading the results. Not all site conditions are appropriate for GPR applications. The system sends radar pulses through a transmitter (Tx) into the surface, and then received via a receiver (Rx) and processed the reflected energy (Figure 10).

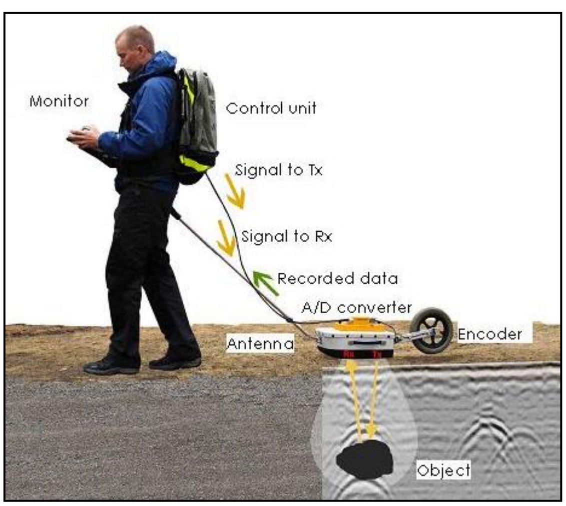


Figure 10 Principle of GPR survey [13]

GPR survey was proposed to detect underground structures including cavities at study area. The GPR lines were scanned using 800 MHz frequency for high resolution images and penetration depth of approximately 1 m. These scan mainly gave information on the concrete/asphalt platform and the structures within them. The transmitted GPR signals bounce of objects that have different dielectric constants (Table 5). The received signal is stored in a PC for processing. The stored data is retrieved and processed using MALA Groundvision and ReflexW software's. Three data processing techniques were applied:

i. DC Filter to remove DC noise.
ii. Time variable gain to enhance signals
iii. Band pass filter.

Table 5 Dielectric constants and propagation velocity of some common materials [14-17]

Material	Dielectric Constant	Propagation Velocity (m/ns)
Air	1	0.30
Ice (Frozen soil)	4	0.15
Granite	9	0.10
Limestone	6	0.12
Sandstone	4	0.15
Dry sand	4 to 6	0.12 to 0.15
Wet sand	30	0.055
Dry clay	8	0.11
Wet clay	33	0.052
Asphalt	3 to 6	0.12 to 0.17
Concrete	9 to 12	0.087 to 0.10
Water	81	0.033
Metal	∞	0

The radargrams were interpreted by observing the reflection patterns (Figure 11 and 12). The 800 MHz radargram shows information to approximately 1 m depth. The concrete platform is clearly visible. Below the concrete, the signals are rapidly attenuated due the possible presence of wet soil. On the right bank, strong hyperbolic signals are observed when the GPR sensor passes over the sewerage manhole. Few cavities identified along the L1 and L2.

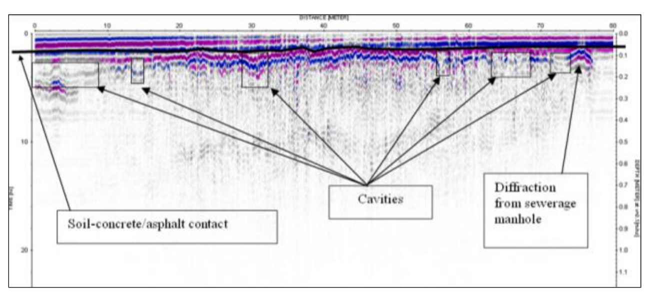


Figure 11 Radargram section showing GPR data along L1

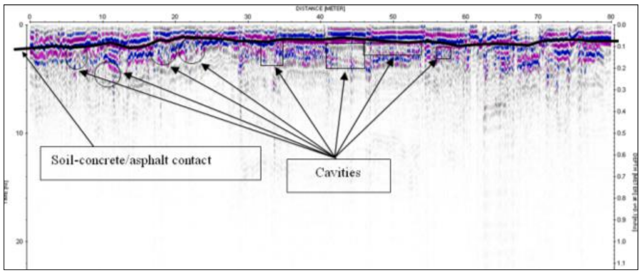


Figure 12 Radargram section showing GPR data along L2

4.0 CONCLUSION

The case studies presented in this paper proof that geophysics is a tool that can assist geotechnical engineers in dealing with the engineering and environmental problems. Case Study 1 assisted in providing groundwater detection and their flows instead of relies on geology and borehole alone. Case Study 2 illustrated the use of SRT in providing 3-D site view and estimated overburden and rock volume which is much better than relying on geology and borehole alone, while Case Study 3 showed GPR results that provided high resolution image for shallow investigation. Hence, geophysics is a tool that assists engineers, adds values to the final product, cost effective and filling in the blank between boreholes.

Acknowledgement

Thanks are due to Universiti Sains Malaysia (USM) and USM geophysics team.

References

[1] Fitzallen, A. 2010. An Improved Approach to Site Characterization Combining Geophysical and Geotechnical Data. *Australian Geomechanics Journal.* 45(1): 77-88.
[2] Gul, E. 2011. Geotechnical Mapping Using a Geophysical Method of Investigation, *Australian Geomechanics Journal.* 46(1): 51-66.
[3] Whiteley, R.J. 1988. Engineering Geophysics-A Geophysicist's View. *Australian Geomechanics Journal*. 15: 47-56.
[4] Stapledon, D. 1988. Engineering Geophysics-A Geologist's View. *Australian Geomechanics Journal*. 15: 57-62.
[5] Fell, R. 1988. Engineering Geophysics-An Engineer's Viewpoint. *Australian Geomechanics Journal*. 15: 63-68.
[6] Griffith, D.H., and Barker, R.D. 1993. Two Dimensional Resistivity Imaging And Modeling In Areas Of Complex Geology. *Journal of Applied Geophysics*. 29: 211-226.
[7] Loke, M.H., and Barker, R.D. 1996a. Rapid Least-Squares Inversion Of Apparent Resistivity Pseudosection Using A Quasi-Newton Method. *Geophysical Prospecting*. 44, 1
[8] Google Earth, 2015.
[9] Keller, G.V., and Frischknecht, F.C. 1996. Electrical Methods In Geophysical Prospecting. *Pergamon Press Inc.* Oxford.
[10] Bradybrooke, J.C. 1988. The State of Art of Rock Cuttability and Rippability Prediction. *Fifth Australia-New Zealand Conference on Geomechanics*. Sydney. 13-42.
[11] Telford, W.M., and Sheriff, R.F. 1984. Applied Geophysics. *Cambridge University Press*.
[12] Caterpillar Performance Handbook. 2001
[13] www.malags.com
[14] Geophysical Surveys Systems, Inc. 2002. User's Manual Subsurface Interface Radar SIRveryorSIR-20 System, North Salem, NH
[15] Daniels, D. J. 1996. Surface-Penetrating Radar. *The Institution of Electrical Engineers.* London, U.K.
[16] Sweeney, Marianne. 1986. Ground Penetrating Radar in the Detection of Subsurface Cavities Related to Sinkhole Activity in Florida. *M.S. Thesis*. University of Central Florida, Orlando, FL.
[17] Tannous, Bishar S. 1987. Investigation of Electrical Properties of Earth Materials by Ground Penetrating Radar. *M.S. Thesis*. University of Central Florida, Orlando, FL.