DEVELOPMENT OF AN ACOUSTICAL-BASED SYSTEM FOR SHALLOW SUBSURFACE OBJECT DETECTION IN A QUATERNARY AGE GEOLOGICAL AREA USING FINITE DIFFERENCE TIME DOMAIN (FDTD) AND SINGLE-CHANNEL REFLECTION WAVE (SRW) METHOD

MUHAMMAD NUR HIDAYAT BIN ZAHARI

A thesis submitted in
fulfillment of the requirement for the award of the
Doctor of Philosophy in Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

FEBRUARI 2023

This thesis is dedicated to my parents, my family, my friends, and my supervisors. For their endless love, support, and encouragement.

"Keep your dreams alive. Understand to achieve anything requires faith and belief in yourself, vision, hard work, determination, and dedication. Remember all things are possible for those who believe."

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful.

First and foremost, I would like to express my heartfelt thanks to my research Supervisor, Prof. Madya Dr. Samsul Haimi Bin Dahlan, and Co-Supervisor, Prof. Ts. Dr. Aziman Bin Madun from the Faculty of Civil and Built Environment (FKAAB), for their ideas, advice, encouragement, and direction in developing this thesis.

This research would not have been possible without the assistance of my family, including but not limited to my wife, my best buddy, Zahari' s, and Sam Hun's family members. Their innumerable efforts of encouragement and support have made my journey enjoyable. Not forgetting, I would also want to express my gratitude to all lecturers and personnel in UTHM, including the Centre of Excellence of the EMCenter and RECESS, who were directly or indirectly involved in this project by providing guidance and oversight.

I would like to express my gratitude to Malaysia's government and the Universiti Tun Hussein Onn Malaysia (UTHM) for their great support of my research by providing a Multidisciplinary Research Grant and Prototype Grant Scheme (PRGS) Vot G006 and special thanks to the Ministry of Higher Education for MyPhD scholarship as well.

Finally, I want to express my gratitude to each and every one of my friends for their contributions to this research, which has included countless helpful comments and ideas. Without the assistance and support listed above, the development of this research would be impossible.

ABSTRACT

The subsurface detection technique is one of the most frequent techniques used in Civil Engineering to improve the features of underground object identification. This study focused on accuracy, detectability, and reliability of the underground detection method. Ground Penetration Radar (GPR) is the best option in the determination of any buried objects which need to know the location installed and the depth of the object. However, GPR has an issue for detection due to the object subsurface detection especially in quaternary age area that poses high-water table which is the conflict of detection. Others geophysical method which is seismic reflection can be used for detection in high water table condition. Seismic reflection waves can be used to characterize anomaly properties at the homogeneous layer, specifically for sensitivity measurement quality control. The models were used, starting with a scaled-down shallow object detection model at 0.3 m depth. For measurements of soil conditions with the physical object model, the reflectivity profile showed a significantly higher amplitude at the top reflection than the measurements of soil conditions without an object that showed a decreased reflectivity amplitude. More intriguingly, the findings revealed that the reflectivity relationship varied depending on the diameter and depth of the object in the classification of irregular anomalies because reflection energy may generally propagate through anomalies, the object's dispersion, attenuation, and reflections may change the wave amplitude as it approaches the receiver. These findings reveal that sensor location in relation to the survey target does affect reflectivity profiles. This study shows that reflected waves can be used for object detection when employing the Single-channel reflection wave (SRW) approach, with an accuracy of 81.25 percent for the air-filled voids, 91.88 percent for water-filled voids, and 87.5 percent for buried pipes.

ABSTRAK

Teknik pengesanan bawah permukaan adalah salah satu teknik yang paling kerap digunakan dalam Kejuruteraan Awam untuk menambah baik ciri-ciri pengenalan objek bawah tanah. Kajian ini memberi tumpuan kepada ketepatan, kebolehkesanan dan kebolehpercayaan kaedah pengesanan bawah tanah. Radar Penusukan Tanah (GPR) adalah pilihan terbaik dalam penentuan mana-mana objek tertimbus yang perlu diketahui lokasi dipasang dan kedalaman objek. Walaubagaimanapun, GPR mempunyai isu untuk pengesanan bawah permukaan objek terutamanya di kawasan umur kuaternari yang mempunyai paras air tinggi. Kaedah geofizik lain iaitu pantulan seismik boleh digunakan untuk pengesanan dalam keadaan aras air yang tinggi. Gelombang pantulan seismik boleh digunakan untuk mencirikan sifat anomali pada lapisan homogen, khususnya untuk kawalan kualiti pengukuran sensitiviti. Model-model tersebut digunakan, bermula dengan model pengesanan objek cetek yang diperkecilkan pada kedalaman 0.3 m. Bagi pengukuran keadaan tanah dengan model objek fizikal, profil pemantulan menunjukkan amplitud yang lebih tinggi secara ketara pada pantulan atas berbanding pengukuran keadaan tanah tanpa objek yang menunjukkan amplitud pemantulan menurun. Lebih menarik, penemuan mendedahkan bahawa hubungan pemantulan berbeza-beza bergantung pada diameter dan kedalaman objek dalam klasifikasi anomali tidak teratur kerana tenaga pantulan secara amnya boleh merambat melalui anomali, penyebaran objek, pengecilan dan pantulan boleh mengubah amplitud gelombang kerana ia mendekati penerima. Penemuan ini mendedahkan bahawa lokasi penderia berhubung dengan sasaran tinjauan mempengaruhi profil pemantulan. Kajian ini menunjukkan bahawa gelombang pantulan boleh digunakan untuk pengesanan objek apabila menggunakan pendekatan gelombang pantulan saluran Tunggal (SRW), dengan ketepatan 81.25 peratus untuk lompang berisi udara, 91.88 peratus untuk lompang berisi air, dan 87.5 peratus untuk lompang berisi air. paip tertimbus.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

FDTD	–	Finite Difference Time Domain
GPR	–	Ground Penetration Radar
MRW	–	Multiple-channel Reflection Wave
SRW	–	Single-channel Reflection Wave
TDRD	–	Time Domain Reflection Profile
PVC	-	Polyvinyl chloride

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of research

Undetected underground objects or anomalies such as breakages of buried utilities, voids, and cavities can lead to natural disasters that consequently become national issues. In this study, an “anomaly” is defined as a buried object with different physical and chemical properties to those of the surrounding soil. Buried anomalies are either man-made or natural. Examples of anomalies commonly found underground are utilities such as water pipes, electric cables, fiber optics, and cavities. In civil engineering, unverified buried objects or anomalies can delay construction operations, weaken building foundations, and potentially cause destructive events. Problems arise when unknown objects remain undetected during construction operations, which can lead to serious hazards, delays, and cost increments (Glover & Wajzer, 2017). Therefore, hidden objects must be discovered at the earliest possible stage of any engineering project.

Hidden objects take many forms, such as voids, underground utilities, and even unknown basements or culverts, abandoned wells, mine shafts, and underground scouring. These can lead to problems like landslides (Kong, 2009), sinkholes (Ling, 2017), and soil erosion (Sri Praya, 2021), as illustrated in Figure 1.1.

The leakage pipe had caused the landslide tragedy at Ulu Kelang, Kuala Lumpur, Malaysia

A huge sinkhole caused by a burst water pipe is seen at Jalan Imbi in Kuala Lumpur

Erosion was due to a broken sewerage pipe

Figure 1.1: The example of disaster occurs by poorly maintained damaged drainage system

Despite years of research, the delineation and detection of subsurface objects remains a difficult and expensive task within modern geophysics (Butler, 2008). One focus of the current study is the specific term “underground detection”, which is used to describe findings related to approximate positions, depths, and sizes. Conventional geotechnical site characterization techniques are used to identify underground features such as penetration testing and soil trenching (Mayne, 2012). These methods involve the direct observation of underground materials but are extremely invasive. For example, when drilling is conducted over these objects, the sudden drop of an auger and the loss of drilling fluid are expected. Therefore, the conventional methods frequently fail to observe the objects and misrepresent the subsurface geology. A rapid, inexpensive, and reliable object detection technique could have major economic potential by enabling improved performance in environmental and engineering applications.

Underground detection involves a range of in situ tests using penetration and geophysical testing. Cost and time constraints are the main reasons behind the difficulty of investigating the subsurface completely using conventional methods (Madun *et al.*, 2016). Conventionally, field testing is involved only for limited areas, which may mean that objects’ positions remain undiscovered. To enhance the certainty of a site investigation, a dynamic approach must be implemented. Geophysical methods can provide better trace resolution and thus improve the definition of the subsurface geology, with better and thinner subsurface layer identification across a site (Song, 2015). The main advantages of these approaches are they are non-destructive and non-invasive, and they offer a quick assessment. Other geophysical techniques such as magnetism, ground-penetrating radar, and electrical resistivity are useful imaging tools, but they require significant skills, a good knowledge of the area’s geological model, and support from the surveyed data to interpret the results successfully, as demonstrated by Gambetta *et al.* (2011), Leech and Johnson (1992), and Long (1998).

Vadillo *et al.* (2012) implied that small, near-surface objects can be detected with geophysical methods, whilst deeper ones need to have a certain minimum height and width to be imaged. Choosing which geophysics tests to use depends on the parameters to be examined. The detection of objects is mainly performed using geophysical methods. Uncertainty over the selection of geophysical techniques may arise due to several factors, such as porosity, groundwater, locally complex geological contexts, and coordination. For example, Electrical Resistivity Tomography (ERT) may be appropriate in dolomitic rocks (Van Schoor, 2002), ground-penetrating radar gives optimal results for shallow detection in the absence of groundwater (Grandjean & Leparoux, 2004) or in glacial environments (Taurisano, *et al.*, 2006), and high-resolution seismic-reflection methods can be used to detect shallow objects (Driad & Piwakowski, 2002).

Different geophysical methods have been employed to identify underground anomalies, including seismic refraction (Engelsfeld *et al.*, 2008; Nolan *et al.*, 2011; Sloan *et al.*, 2013), surface wave (Grandjean & Leparoux, 2004; Nasseri-Moghaddam et al., 2005; Cascante, & Phillips, 2005b; Xia *et al.*, 2007; Xia *et al.*, 2006), gravimetry (Bitri *et al.*, 2014; McKenna *et al.*, 2016; Chromčák, *et al.*, 2016), resistivity (Bianchi *et al.*, 2013; Cardarelli *et al.*, 2010; Putiška *et al.*, 2012), and ground-penetrating radar (Tavakoli Taba e*t al.*, 2015; Karlovsek et *al.*, 2012; Cassidy *et al.*, 2011). Seismic reflection (Mohanty & Barala, 2016; di Fiore *et al.*, 2013; Buckley & Lane, 2012; Inazaki *et al.*, 2005; Inazaki *et al.*, 2004; Branham & Steeples, 1988; Hunter *et al.*, 1984; Miller & Steeples, 1994; Miller & Steeples, 1991) has also been utilized.

The extreme contrast between the elastic properties of objects and those of the surrounding geology provides an excellent reflecting interface. To evaluate the wave propagation, whereby a reflected wave is in a homogeneous medium, the Finite Difference Method (FDM) offers a promising means of visualization and could be implemented for field testing. For solving partial differential equations, the FDM has been developed and used for years in engineering applications. Finite difference solutions have since become extensive. Alterman and Karal (1968) were actively involved in using the FDM to solve the vector elastic wave equation for various initial and boundary conditions. The FDM used a velocity–stress formulation on a staggered grid. On the other hand, an advantage of the FDM is that its numerical implementation is considerably simpler than that of the finite element method (Frehner *et al.*, 2008).

The FDM has been used to study dispersion curves, amplitude-depth distributions, and the scattering of Love waves (Buchanan, 1986). Li *et al.*, (1995) analyzed the Frequency-dependent estimation of Love-type channel waves with a symmetrical, homogeneous, three-layered linear elastic model and developed a deterministic pure phase shift filter to extract the fundamental mode from multimode Love waves (Li, 1997). Gelis *et al.,* (2005) investigated the seismic responses of objects of different shapes and depths, as well as the existence of an altered zone, by means of synthetic modeling and frequency-domain studies. Modeling the propagation of elastic seismic waves, they computed time histories using a 2-D finite difference program. To avoid reflections from the boundaries of the numerical model and for the wavefield to propagate parallel to the edges, the code featured a perfectly matched layer absorbing boundary condition.

1.2 Research problem statement

Detecting subsurface anomalies is considered of great interest in many engineering projects. Numerous effective applications of detection methods for underground anomaly detection have been reported; nevertheless, additional experimental and analytical research is necessary to appreciate the nuances of the acquired data. At the quaternary ages, the sub profile was consisting of clayey material which is associated with high-conductivity materials where the water table is high (Riwayat *et al.*, 2022). Problems occur when surveying shallow subsurfaces, with objects remaining unseen because of a high-water table, especially when using ground-penetrating radar. Ground-penetrating radar (GPR) has problems locating objects at shallow depths when dealing with high-conductivity materials such as areas with a high-water table. Moreover, wetter materials (water, in this case) that produce higher conductivity can cause radar signals to attenuate and the depth of penetration is therefore reduced (Ismail & Saad, 2012). Waterlogged soils, such as silts and clays, will absorb radio waves and indirectly preventing them from traveling into the ground surface (Ling *et al*., 2020). In this circumstances, the electromagnetic waves pass into the wet ground, it is impossible to tell anything about the subsurface because it is heavily attenuated in wet clay materials. (Utsi, 2012)

This research utilized a seismic reflection system. The Single-channel Reflection Wave (SRW) and Multiple-channel Reflection Wave (MRW) methods using an optimum number of receivers were employed in this study. Furthermore, this approach used a consistent impact source, with a measurement optimization that allowed objects to be characterized and located. The design of Finite Difference Time Domain modeling by using parameter from the field study would be a successful idea, whereby an object detection method could be developed by synthetically programming. The proposed method employed a clearly defined data analysis algorithm by using time domain reflectivity profile covering the amplitude properties.

It is suitable as a detection technique, easy to perform, cost-effective, and can cover shallow subsurface objects. The objective of this research was to examine P-wave reflection techniques for the identification and characterization of objects at specific depths. The data processing method enabled an analysis of the subsurface velocity with alternating variations in density over short distances, resulting in success. In addition, simulation and physical field tests were calibrated for better understanding. A strategy for the rapid, low-cost, and accurate detection of objects could have huge economic potential, with enhanced detection techniques resulting in better engineering solutions.

1.3 Research aims and objectives

The aim of the study was to develop an acoustic-based system for obtaining and utilizing data to detect buried objects, thus enabling them to be characterized. To achieve this aim, the research objectives were as follows:

i. To develop an acoustic-based system, consisting of an acoustic impact source (hammer), accelerometer sensors, a data acquisition system (DAQ), and interpretation software to record the wave trace;
ii. To design modelling of seismic reflection based on a Finite Difference Time Domain (FDTD) model of a homogeneous for a preliminary study through preliminary field testing;
iii. To validate a significant methodological approach, with sensor positioning or array enables with hardware functions as intended upon shallow objects based on their time domain reflectivity profile.

REFERENCES

Al-Hunaidi, M. O. (1993). Insights on the SASW nondestructive testing method. *Canadian Journal of Civil Engineering*, *20*(6), 940–950.

Alam, M. (2003). Multi-channel spectrum analysis of surface waves. *Signals, Systems and Computers*, *3*, 771–775.

Alterman, Z., & Karal, F. (1968). Propagation of elastic waves in layered media by finite difference methods. *Bulletin of the Seismological Society of America*, *58*(1), 367–398.

Anno, P., Bleistein, N., & Cohen, J. K. (1992). Waves and rays in acoustic variable density media. *SEG Technical Program Expanded Abstracts 1992*, *1*, 1332–1336.

Anyanwu, T. (2021). Theory and Applications of Shallow Seismic Reflection Geophysical Method to Engineering and Groundwater Studies: An Overview Osita Okeke Theory and Applications of Shallow Seismic Reflection Geophysical Method to Engineering and Groundwater Studies: An Ov. *International Journal of Innovative Science and Research Technology*, *6*(2), 178–191.

Aziman, M., Hazreek, Z. A. M., Azhar, A. T. S., & Haimi, D. S. (2016). Compressive and Shear Wave Velocity Profiles using Seismic Refraction Technique. *Journal of Physics: Conference Series*, *710*, 012011.

Bekmambetova, F., Zhang, X., & Triverio, P. (2017). A Dissipative Systems Theory for FDTD with Application to Stability Analysis and Subgridding. *IEEE Transactions on Antennas and Propagation*, *65*(2), 751–762.

Benedetto, A., & Pajewski, L. (2015). Civil Engineering Applications of Ground Penetrating Radar. In *Springer*.

Benito, G., del Campo, P. P., Gutiérrez-Elorza, M., & Sancho, C. (1995). Natural and human-induced sinkholes in gypsum terrain and associated environmental problems in NE Spain. *Environmental Geology*, *25*(3), 156–164.

Berenger, J.-P. (1994). A perfectly matched layer for the absorption of electromagnetic waves. *Journal of Computational Physics*, *114*(2), 185–200.

Bianchi Fasani, G., Bozzano, F., Cardarelli, E., & Cercato, M. (2013). Underground cavity investigation within the city of Rome (Italy): A multi-disciplinary approach combining geological and geophysical data. *Engineering Geology*, *152*(1), 109–121.

Bitri, A., Samyn, K., & Jacob, T. (2014, September 8). Cavity Investigation by Surface Wave Tomography and Microgravity. *Near Surface Geoscience 2014 - 20th European Meeting of Environmental and Engineering Geophysics*.

Bording, R. P., & Lines, L. R. (1997). *Seismic modeling and imaging with the complete wave equation*. Society of Exploration Geophysicists.

Botteldooren, D. (1994). Acoustical finite-difference time-domain simulation in a quasi-Cartesian grid. *The Journal of the Acoustical Society of America*, *95*(5), 2313–2319.

Branham, K. L., & Steeples, D. W. (1988). Cavity detection using high-resolution seismic reflection methods. *Min. Eng.(Littleton, Colo.);(United States)*, *40*(2).

BS5930. (2015). Code of practice for ground investigations (BS 5930:2015). In *The British Standards Institution* (Vol. 576, Issue June).

Buchanan, D. J. (1986). The scattering of SH-channel waves by a fault in a coal seam. *Geophysical Prospecting*, *34*(3), 343–365.

Buckley, S. F., & Lane, J. W. (2012). Near-Surface Void Detection Using a Seismic Landstreamer and Horizontal Velocity and Attenuation Tomography. *Symposium on the Application of Geophysics to Engineering and Environmental Problems 2012*, 561–571.

Burger, H. R., Sheehan, A. F., & Jones., C. H. (2006). *Introduction to applied geophysics : exploring the shallow subsurface*. New York : W.W. Norton, c2006.

Butler, D. (2008). Detection and characterization of subsurface cavities, tunnels and abandoned mines. *Near-Surface Geophysics & Human Activity, Science*, *1*, 578–584.

Butler, D. K. (2002). Near-Surface Geophysics. In *Investigations in Geophysics* (Issue 13). Society of Exploration Geophysicists, Tulsa, Oklahoma, U.S.A.

Carcione, J. M., Herman, G. C., & ten Kroode, a. P. E. (2002). Y2K Review Article: Seismic modeling. *Review Literature And Arts Of The Americas*, *67*(4), 1304–1325.

Cardarelli, E., Cercato, M., Cerreto, A., & Di Filippo, G. (2010). Electrical resistivity and seismic refraction tomography to detect buried cavities. *Geophysical Prospecting*, *58*(4), 685–695.

Cascante, G., Najjaran, H., & Crespi, P. (2008). Novel Methodology for Nondestructive Evaluation of Brick Walls: Fuzzy Logic Analysis of MASW Tests. *Journal of Infrastructure Systems*, *14*(2), 117–128.

Cassidy, N. J., Eddies, R., & Dods, S. (2011). Void detection beneath reinforced concrete sections: The practical application of ground-penetrating radar and ultrasonic techniques. *Journal of Applied Geophysics*, *74*(4), 263–276.

Chalikakis, K., Plagnes, V., Guerin, R., Valois, R., & Bosch, F. P. (2011). Contribution of geophysical methods to karst-system exploration: An overview. *Hydrogeology Journal*, *19*(6), 1169–1180.

Chen, Z., Huang, Z., Jing, S., Tao, Z., & Zhao, Q. (2017). The fatigue behavior and fatigue reliability analysis of vibroseis baseplates based on fracture mechanics. *Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability*, *231*(6), 732–749.

Chromčák, J., Grinč, M., Pánisová, J., Vajda, P., & Kubová, A. (2016). Validation of sensitivity and reliability of GPR and microgravity detection of underground cavities in complex urban settings: Test case of a cellar. *Contributions to Geophysics and Geodesy*, *46*(1), 13–32.

Clayton, R., & Engquist, B. (1977). Absorbing boundary conditions for acoustic and elastic wave equations. *Bulletin of the Seismological Society of America*, *67*(6), 1529–1540.

Cole, J. B. (1994). A nearly exact second-order finite-difference time-domain wave propagation algorithm on a coarse grid. *Computers in Physics*, *8*(6), 730–734.

Collins, D., Gribble, P., Collins, H. D., & Gribble, R. P. (1972). Acoustic holographic scanning techniques for imaging flaws in thick metal sections. *Imaging Techniques for Testing and Inspection*, 67–82.

Collins, H. D. (1973). Acoustical holographic scanning techniques for imaging flaws in reactor pressure vessels. *Proc. 9th Symp on NDE*, 175–196.

Cooper, A. H. (2017). *Voids*.

Corradini, E., Groß, D., Wunderlich, T., Lübke, H., Wilken, D., Erkul, E., Schmölcke, U., & Rabbel, W. (2022). Finding Mesolithic Sites: A Multichannel Ground-Penetrating Radar (GPR) Investigation at the Ancient Lake Duvensee. *Remote Sensing*, *14*(3).

Cox, B. (2013). Acoustics for Ultrasound Imaging. *Lecture Notes, January*, 49–56.

Davis, J. L., & Annan, A. P. (1989). Ground-Penetrating Radar for High-Resolution Mapping of Soil and Rock Stratigraphy. *Geophysical Prospecting*, *37*(5), 531–551.

Di Bartolo, L., Dors, C., & Mansur, W. J. (2011). A new finite difference scheme for modeling acoustic wave propagation. *SEG Technical Program Expanded Abstracts 2011*, *7*, 3032–3036.

di Fiore, V., Angelino, A., Passaro, S., & Bonanno, A. (2013). High resolution seismic reflection methods to detect near surface tuff-cavities: A case study in the Neapolitan area, Italy. *Journal of Cave and Karst Studies*, *75*(1), 51–59.

Driad, L., & Piwakowski, B. (2002). Detection and characterization of underground cavities using high resolution seismic reflection (HRSR). *Meeting Environmental and Engineering Geophysics*, 31–34.

Dvorkin, J., Gutierrez, M. A., & Grana, D. (2014). *Seismic reflections of rock properties*. Cambridge University Press.

Edip, K., Garevski, M., Sesov, V., & Butenweg, C. (2011). Numerical simulation of wave propagation in soil media. *Proceedings of the 21st European Young Geotechnical Engineers' Conference Rotterdam*, 140–145.

Ehrlich, J. H. (2008). Time domain modeling of acoustic propagation with acoustic wave propagator and absorbing boundary conditions. *The Journal of the Acoustical Society of America*, *123*(5), 3530.

Engelsfeld, T., Šumanovac, F., & Pavin, N. (2008). Investigation of underground cavities in a two-layer model using the refraction seismic method. *Near Surface Geophysics*, *6*(4), 221–231.

Engquist, B., & Majda, a. (1977). Absorbing boundary conditions for numerical simulation of waves. *Mathematics of Computation*, *31*(139), 629–651.

Fomel, S., & Claerbout, J. F. (1997). *Exploring three-dimensional implicit wave eld extrapolation with the helix transform* (Vol. 60).

Foti, S. (2000). Multistation methods for geotechnical characterization using surface waves. In *Politecnico di Torino Ph D Dissertation* (Vol. 42).

Fox, D. M., Akers, S. A., Leiste, U. H., Fourney, W. L., Windham, J. E., Lee, J. S., Ehrgott, J. Q., & Taylor, L. C. (2014). The effects of air filled voids and water content on the momentum transferred from a shallow buried explosive to a rigid target. *International Journal of Impact Engineering*, *69*, 182–193.

Frehner, M., Schmalholz, S. M., Saenger, E. H., & Steeb, H. (2008). Comparison of finite difference and finite element methods for simulating two-dimensional scattering of elastic waves. *Physics of the Earth and Planetary Interiors*, *171*(1–4), 112–121.

Gambetta, M., Armadillo, E., Carmisciano, C., Stefanelli, P., Cocchi, L., & Tontini, F. C. (2011). Determining geophysical properties of a near-surface cave through integrated microgravity vertical gradient and electrical resistivity tomography measurements. *Journal of Cave and Karst Studies*, *73*(1), 11–15.

Geiger, H. D., & Daley, P. F. (2003). Finite difference modelling of the full acoustic wave equation in Matlab. In *CREWES Research Report* (Vol. 15, Issue 1997).

Gelis, C., Leparoux, D., Virieux, J., Bitri, a., Operto, S., & Grandjean, G. (2005). Numerical Modeling of Surface Waves Over Shallow Cavities. *Journal of Environmental & Engineering Geophysics*, *10*(2), 111–121.

Geraldine, A. (2016, November 8). Huge sinkhole opens up in Likas town. *New Straits Time*.

Glover, J. M., & Wajzer, M. R. (2017). *Void and cavity detection*.

Grandjean, G., & Leparoux, D. (2004). The potential of seismic methods for detecting cavities and buried objects: Experimentation at a test site. *Journal of Applied Geophysics*, *56*(2), 93–106.

Greenhalgh, S., & Manukyan, E. (2013). Seismic Reflection for Hardrock Mineral Exploration: Lessons from Numerical Modeling. *Journal of Environmental and Engineering Geophysics*, *18*(4), 281–296.

Gruber, W., & Rieger, R. (2003). High resolution seismic reflection: constraints and pitfalls in groundwater exploration. *RMZ - Materials and Geoenvironment*, *50*(1), 133–136.

Harlow, F. H., & Welch, J. E. (1965). Numerical Calculation of Time-Dependent Viscous Incompressible Flow of Fluid with Free Surface. *The Physics of Fluids*, *8*(12), 2182.

Henson Jr, H., & Sexton, J. L. (1991). Premine study of shallow coal seams using high-resolution seismic reflection methods. *Geophysics*, *56*(9), 1494–1503.

Hinze, W. ., Roberts, R. ., & Leap, D. . (1990). Combined analysis of gravity and magnetic anomaly data in landfill investigations. In *Geotechnical and environmental geophysics* (Vol. 02, pp. 267–272).

Hironaka, M. C., Hitchcock, R. D., Forrest, J. B., & Hueneme, P. (1976). *Detection Of Voids Underground And Under Pavements* (Issue August).

Hunter, J. A., Pullan, S. E., Burns, R. A., Gagne, R. M., & Good, R. L. (1984). Shallow seismic reflection mapping of the overburden-bedrock interface with the engineering seismograph—Some simple techniques. *Geophysics*, *49*(8), 1381–1385.

Hutchinson, D. J., Phillips, C., & Cascante, G. (2002). Risk considerations for crown pillar stability assessment for mine closure planning. *Geotechnical and Geological Engineering*, *20*(1), 41–63.

Inazaki, T., Kawamura, S., Tazawa, O., Yamanaka, Y., & Kano, N. (2005). Near-Surface Cavity Detection by High-Resolution Seismic Reflection Methods Using Short-Spacing Type Land Streamer. *Symposium on the Application of Geophysics to Engineering and Environmental Problems*, 959–970.

Inazaki, T., Yamanaka, Y., Kawamura, S., & Tazawa, O. (2004). High-resolution seismic reflection survey using Land Streamers for near-surface cavity detection. *Proceedings of 7th SEGJ International Symposium*, 475–480.

Isa, Y. M. (2014, July 2). Major access road to Bukit Bintang cut off by 10m-deep sinkhole. *Malay Mail*.

Ismail, N. A., & Saad, R. (2012). *A Case Study on Ground Subsidence Using Ground Penetrating Radar*. *41*, 157–161.

Jin, Q., Shiguo, W., & Ruofei, C. (2013). Accuracy of the staggered-grid fi nite-difference method of the acoustic wave equation for marine seismic reflection modeling*. *Chinese Journal of Oceanology and Limnology*, *31*(1), 169–177.

Jones, S. (2010). Ground vibration from underground railways: how simplifying assumptions limit prediction accuracy. In *Response* (Issue September).

Karlovsek, J., Scheuermann, A., & Willimas, D. J. (2012). Investigation of voids and cavities in bored tunnels using GPR. *2012 14th International Conference on Ground Penetrating Radar (GPR)*, 496–501.

Kawai, D., Kajikawa, Y., Nomura, Y., & Miyakura, T. (2011). Acoustic FDTD Analysis Considering Viscous and Advective Effects. *Forum Acusticum. Dnk.*

Kayal, J. R. (2006). Seismic waves and earthquake location. *Geological Survey of India*, *27*, 1–42.

Keller, G. V. (1986). An Introduction to Geophysical Exploration. In *Eos, Transactions American Geophysical Union* (Vol. 67, Issue 11). John Wiley & Sons.

Kistler. (2007). *Accelerometer Calibrator*. https://doi.org/8921_000-362a-03.07

Kong, L. (2009, December 7). Report: Pipe water leakage the cause of landslide. *The Star*.

Koulidis, A. (2018). *Modular Testing Facility for Downhole Sensor Evaluation*. *June 2017*.

Lankston, R. W. (1990). High-resolution refraction seismic data acquisition and interpretation. *Geotechnical and Environmental Geophysics*, *1*, 45–73.

Leech, C., & Johnson, R. M. (1992). Location Buried drums using a proton precession magnetometer and magnetic gradiometer. *Proceeding of the Second International Conference on Construction on Polluted and Marginal Land*, *30*, 37–49.

Li, X.-P. (1997). Elimination of higher modes in dispersive in-seam multimode Love waves. *Geophysical Prospecting*, *45*(6), 945–961.

Li, X.-P., Schott, W., & Rueter, H. (1995). Frequency-dependent Q-estimation of Love-type channel waves and the application of Q-correction to seismograms. *Geophysics*, *60*(6), 1773–1789.

Ling (Ed.), O. H. L., Saifuddin, K., Othman, A. N., Razali, M. H., & Khalid, N. (2020). Accuracy Assessment on Underground Utility Equipment. *Built Environment Journal*, *17*(3), 57.

Ling, W. W. (2017, April 4). Growing sinkhole forces road closure in Bandar Utama. *The Star*.

Loke, M. H., & Barker, R. D. (1996). Rapid least-squares inversion of apparent reistivity pseudosections by aquasi-Newton method. *Geophysical Prospecting*, *44*, 131–152.

Loke, M. H., Chambers, J. E., Rucker, D. F., Kuras, O., & Wilkinson, P. B. (2013). Recent developments in the direct-current geoelectrical imaging method. *Journal of Applied Geophysics*, *95*, 135–156.

Long, M. (1998). A trial of five geophysical techniques to identify small scale karst. In P. K. Robertson & P. W. Mayne (Eds.), *Geotechnical Site Characterization, Vols 1 and 2* (1st ed., pp. 569–574). A. A. Balkema.

Long, Michael, Donohue, S., L'Heureux, J.-S., Solberg, I.-L., Rønning, J. S., Limacher, R., O'Connor, P., Sauvin, G., Rømoen, M., & Lecomte, I. (2012). Relationship between electrical resistivity and basic geotechnical parameters for marine clays. *Canadian Geotechnical Journal*, *49*(10), 1158–1168.

Luna, R., & Jadi, H. (2000). Determination of Dynamic Soil Properties Using Geophysical Methods. *Proceedings of the First International Conference on the Application of Geophysical and NDT Methodologies to Transportation Facilities and Infrastructure*, *December*, 1–15.

M. Alotaibi, A., Nwokebuihe, S., Torgashov, E., Elkrry, A., & Anderson, N. (2019). Characterizing Lake Bottom Sediments Using Marine Geophysical Tools. *International Journal of Geosciences*, *10*(03), 328–350.

MacIntyre, N. (2013). *Review of MASW and Refraction Surveys*.

Madun, A., Tajuddin, S. A. A., Abdullah, M. E., Abidin, M. H. Z., Sani, S., Siang, A. J. L. M., & Yusof, M. F. (2016). Convertion Shear Wave Velocity to Standard Penetration Resistance. *IOP Conference Series: Materials Science and Engineering*, *136*(1).

Mayne, P. W. (2012). Geotechnical site exploration in the year 2012. *Proceedings of the 16th Nordic Geotechnical Meeting, Copenhagen*, *1–2*(May), 9–12.

McDowell, P. W., Barker, R. D., Butcher, A. P., Culshaw, M. G., Jackson, P. D., McCann, D. M., Skipp, B. O., Matthews, S. L., & Arthur, J. C. R. (2002). *Geophysics in engineering investigations*. Ciria London.

McKenna, J. R., Rim, H., & Li, Y. (2016). Feasibility and Limitations of Void Detection Using Gravity Gradiometry. *IEEE Transactions on Geoscience and Remote Sensing*, *54*(2), 881–891.

Meng, W., & Fu, L. Y. (2017). Seismic wavefield simulation by a modified finite element method with a perfectly matched layer absorbing boundary. *Journal of Geophysics and Engineering*, *14*(4), 852–864.

Mickens, R. E. (1994). *Nonstandard finite difference models of differential equations*. world scientific.

Miller, R.D., & Steeples, D. W. (1994). Applications of shallow, high-resolution seismic reflection to various mining operations. *Mining Engineering*, *47*(4), 65–72.

Miller, Richard D., & Steeples, D. W. (1991). Detecting voids in a 0.6 m coal seam, 7 m deep, using seismic reflection. *Geoexploration*, *28*(2), 109–119.

Milosavljevic, A. (2020). Identification of salt deposits on seismic images using deep learning method for semantic segmentation. *ISPRS International Journal of Geo-Information*, *9*(1).

Min, D.-J., & Kim, H.-S. (2006). Feasibility of the surface-wave method for the assessment of physical properties of a dam using numerical analysis. *Journal of Applied Geophysics*, *59*(3), 236–243.

Mochales, T., Casas, A. M., Pueyo, E. L., Pueyo, O., Rom??n, M. T., Pocov??, A., Soriano, M. A., & Ans??n, D. (2008). Detection of underground cavities by combining gravity, magnetic and ground penetrating radar surveys: A case study from the Zaragoza area, NE Spain. *Environmental Geology*, *53*(5), 1067–1077.

Mohanty*, P. R., & Barala, S. (2016). Seismic imaging to detect subsurface cavity associated with old abandoned coal workings. *SEG Technical Program Expanded Abstracts 2016*, *1*(x), 5684–5688.

Mohanty, P. R. (2011). Numerical Modeling of P-Waves for Shallow Subsurface Cavities Associated with Old Abandoned Coal Workings. *Journal of Environmental {&} Engineering Geophysics*, *16*(4), 165–175.

Moxhay, A., Tinsley, R., & Sutton, J. (2001). Monitoring of soil stiffness during ground improvement using seismic surface waves. *Ground Engineering*, *October*, 1–9.

Mur, G. (1981). Absorbing Boundary Conditions for the Finite-Difference Approximation of the Time-Domain Electromagnetic-Field Equations. *IEEE Transactions on Electromagnetic Compatibility*, *EMC-23*(4), 377–382.

Nabighian, M. N., Ander, M. E., Grauch, V. J. S., Hansen, R. O., LaFehr, T. R., Li, Y., Pearson, W. C., Peirce, J. W., Phillips, J. D., & Ruder, M. E. (2005). Historical development of the gravity method in exploration. *Geophysics*, *70*(6), 63ND.

Nanda, N. C. (2016). *Seismic Data Interpretation and Evaluation for Hydrocarbon Exploration and Production*.

Nasseri-Moghaddam, a., Cascante, G., Phillips, C., & Hutchinson, D. J. (2007). Effects of underground cavities on Rayleigh waves-Field and numerical experiments. *Soil Dynamics and Earthquake Engineering*, *27*(4), 300–313.

Nasseri-moghaddam, A. (2006). *Study of the effect of lateral inhomogeneities on the propagation of Rayleigh waves in an elastic medium by*.

Nasseri-Moghaddam, A., Cascante, G., & Phillips, C. (2005). Use of Numerical Simulations to Explain SASW Field Measurements. *Symposium on the Application of Geophysics to Engineering and Environmental Problems 2005*,

Nasseri-Moghaddam, Ali, Cascante, G., & Hutchinson, J. (2005). A new quantitative procedure to determine the location and embedment depth of a void using surface waves. *Journal of Environmental & Engineering Geophysics*, *10*(1), 51–64.

Nataf, F. (2013). *Absorbing boundary conditions and perfectly matched layers in wave propagation problems* (pp. 219–231). de Gruyter. https://doi.org/hal-00799759

Navarro, E. A., Segura, J., Sanchis, R., & Soriano, A. (2008). Solving 2D acoust ic duct s and m em branes by using FDTD m et hod. *Electronic Journal "Technical Acoustics," 18*, 1–13.

Nazarian, S. (2012). Shear Wave Velocity Profiling with Surface Wave Methods. *Geotechnical Engineering State of the Art and Practice*, 221–240.

Nesvijski, E. (2011). Model Based Design and Acoustic NDE of Surface Cracks. *Database of Nondestructive Testing (NDT) ISSN 1435-4934*, 1–15.

Nolan, J. J., Sloan, S. D., Broadfoot, S. W., McKenna, J. R., & Metheny, O. M. (2011). Near-surface void identification using MASW and refraction tomography techniques. *SEG Technical Program Expanded Abstracts 2011*, 1401–1405.

NRC. (2000). Noninvasive Characterization of the Shallow Subsurface for Environmental and Engineering Applications. In *National Academies Press Report: Vol. ISBN: 0*30*.

Orfanos, C., & Apostolopoulos, G. (2013). Multiparameter analysis of geophysical methods for target detection: The unified geophysical model approach. *Geophysics*, *78*(6), IM1–IM13.

Oskooi, A. F., Zhang, L., Avniel, Y., & Johnson, S. G. (2008). The failure of perfectly matched layers, and towards their redemption by adiabatic absorbers. *Optics Express*, *16*(15), 11376–11392.

Otieno, O. R., Manyonge, A., Maurice, O., & Daniel, O. (2015). *Finite Difference Analysis of 2-Dimensional Acoustic Wave with a Signal Function*. 1–14.

Park, C. B. (2022). *What Are Seismic Waves*. Park Seismic LLC, Shelton, Connecticut.

Park, C. B., Miller, R. D., Xia, J., & Ivanov, J. (2007). Multichannel analysis of surface waves (MASW)—active and passive methods. *The Leading Edge*, *26*(1), 60–64.

Park, C. S., Jeong, J. H., Park, H. W., & Kim, K. (2017). Experimental study on electrode method for electrical resistivity survey to detect cavities under road pavements. *Sustainability (Switzerland)*, *9*(12), 1–21.

Petersson, N., & Sjogreen, B. (2009). An energy absorbing far-field boundary condition for the elastic wave equation. *Communications in Computational Physics*.

Phillips, C. (2004). Evaluation of horizontal homogeneity of geomaterials with the distance analysis of surface waves. *Canadian Geotechnical …*, *226*, 212–226.

Piezotronics, P. (2018). *PCB Model 603C01*.

Putiška, R., Nikolaj, M., Dostál, I., & Kušnirák, D. (2012). Determination of cavities using electrical resistivity tomography. *Contributions to Geophysics and Geodesy*, *42*(2), 201–211.

Putnam, N.H., Peng, X., Cawlfield, J. D., Kovin, O. N., Torgashov, E. V., Modur, P., Stagner, C., Grant, S. L., Anderson, N. L., & Nasseri-Moghaddam, A. (2009). Attenuation analysis of Rayleigh waves used to locate shallow manmade tunnels. *43rd U.S. Rock Mechanics Symposium and 4th U.S.-Canada Rock Mechanics Symposium, November 2014*.

Putnam, Niklas H., Nasseri-moghaddam, A., Kovin, O., & Anderson, N. L. (2008). Preliminary analysis using surface wave methods to detect shallow manmade tunnels. In *SAGEEP proceedings*.

Rahman, A., Almallah, I., & Mousa, A. (2022). Subsurface Structures Delineation to Evaluate the Possibility of Groundwater Gathering Using Gravity Data Interpretation in Salman Basin, Iraqi Southern Desert. *Journal Of University Of Babylon for Pure and Applied Sciences*, *30*(2), 131–152.

Redpath, B. B. (1973). Seismic refraction exploration for engineering site investigations: US Army Engineer Waterway Experiment Station Explosive Excavation Research Laboratory, Livermore. *Livermore, California*, *Technical Report E*, *73*(4), 51.

Rehman, F. (2021). *Gravity Method*. University of Sargodha, Earth Sciences.

Remmani, S. A., Madun, A., Hidayah, N., & Mohd, B. (2020). *Asphalt Pavement Thickness Measurement Using the Seismic Reflection Technique*. *June*.

Reynolds, J. M. (1998). *An Introduction To Applied And Environmental Geophysics.*

Reynolds, J M. (1997). An Introduction to Applied and Environmental Geophysics. In *Geophysics* (Vol. 1).

Reynolds, John M. (2011). An introduction to applied and environmental geophysics. In *Igarss 2014* (Issue 1).

Richart, F. E., Woods, R. E., & Hall Jr, J. R. (1970). *Vibration Of Soils And Foundations*. Prentice-Hall.

Rivera-Recillas, D., Lozada-Zumaeta, M. M., Ronquillo-Jarillo, G., & Campos-Enríquez, J. O. (2005). Multiresolution analysis applied to interpretation of seismic reflection data. *Geofísica Internacional*, *44*, 355–368.

Riwayat, A. I., Nazri, M. A. A., & Ahmad, N. A. (2022). Mapping of Potential Groundwater Using Electrical Resistivity Imaging (ERI) at Low Land Area of Parit Raja Johor. *International Journal of Integrated Engineering*, *14*(9), 15–23.

Roberts, R. L., Hinze, W. J., & Leap, D. I. (1990). Data enhancement procedure on magnetic data from landfill investigations. *Geotechnical and Environmental Geophysics*, *2*, 261–266.

Robertsson, J. O. A., Blanch, J. O., Nihei, K., & Tromp, J. (2012). *Numerical Modeling of Seismic Wave Propagation* (Issue 28). Society of Exploration Geophysicists.

Salmasi, M., Potter, M. E., & Okoniewski, M. (2017). Coupling yee grid to lebedev grid in two dimensions. *IEEE Antennas and Wireless Propagation Letters*, *16*, 1755–1758.

Schneider, J. (2010). Understanding the finite-difference time-domain method. *Scholl of Electrical Engineering and Computer Science.*

Sheriff, R., & Geldart. (1995). *Exploration Seismology* (2 edition). Cambridge University Press.

Shokouhi, P., & Gucunski, N. (2003). Application of Wavelet Transform in Detection of Shallow Cavities by Surface Waves. *Symposium on the Application of Geophysics to Engineering and Environmental Problems 2003*, 813–831.

Sloan, S., Cudney, H., Miller, R., Ivanov, J., & Moran, M. (2016a). Depth estimation of voids using backscattered surface waves. In *SEG Technical Program Expanded Abstracts 2016* (pp. 2362–2366).

Sloan, S., Cudney, H., Miller, R., Ivanov, J., & Moran, M. (2016b). Depth estimation of voids using backscattered surface waves. *SEG Technical Program Expanded Abstracts 2016*, 2362–2366.

Sloan, S. D., Nolan, J. J., Broadfoot, S. W., McKenna, J. R., & Metheny, O. M. (2013). Using near-surface seismic refraction tomography and multichannel analysis of surface waves to detect shallow tunnels: A feasibility study. *Journal of Applied Geophysics*, *99*, 60–65.

Sloan, S. D., Peterie, S. L., Ivanov, J., Miller, R. D., & McKenna, J. R. (2010). Void Detection Using Near-Surface Seismic Methods. In *Advances in Near-surface Seismology and Ground-penetrating Radar* (Vol. 15, pp. 201–218).

Sloan, S. D., Peterie, S. L., Miller, R. D., Ivanov, J., McKenna, J. R., Broadfoot, S. W., & Metheny, O. M. (2012). Tunnel detection using near-surface seismic methods. *SEG Las Vegas 2012 Annual Meeting, November*, 13–16.

Sloan, S. D., Tyler Schwenk, J., & Stevens, R. H. (2016). An example of extreme near-surface variability in shallow seismic reflection data. *Interpretation*, *4*(3), SH1–SH9.

Smith, S. W. (1963). Generation of seismic waves by underground explosions and the collapse of cavities. *Journal of Geophysical Research*, *68*(5), 1477–1483.

Song, W. (2015). *Locating Petroleum Sources Using Dsp Techniques* (Vol. 1, Issue May).

Song, Z.-Y., Zhang, Y.-L., Wang, C., Xu, W.-W., & Ding, W. (2016). Experimental measurement of acoustically induced surface vibration with different soil conditions. *Advances in Manufacturing*, *4*(3), 278–285.

Sri Praya, S. (2021, September 17). 10 families evacuated as erosion threatens block of flats. *The Star*.

Stam, J. C. (1962). Modern Developments In Shallow Seismic Refraction Techniques. *Geophysics*, *27*(2), 198–212.

Steeds, M. W., Broschat, S. L., & Schneider, J. B. (1996). A comparison of two conformal methods for FDTD modeling. *IEEE Transactions on Electromagnetic Compatibility*, *38*(2), 181–187.

Steeples, D. O. N. W. (2005). Shallow Seismic Methods Don W. Steeples. In *Foundations* (Issue 1991, pp. 215–251).

Steeples, D W, & Miller, R. D. (1987). Direct detection of shallow subsurface voids using high-resolution seismic-reflection techniques. *Multidisciplinary Conference on Sinkholes and the Environmental Impacts of Karst. 2*, 179–183.

Steeples, Don W, & Editor, G. (1998). *Special Issue Shallow seismic reflection section — Introduction*. *63*(4), 20–22.

Steeples, Don W, & Miller, R. D. (1988). Seismic reflection methods applied to engineering, environmental, and ground-water problems. *Symposium on the Application of Geophysics to Engineering and Environmental Problems 1988*, 409–461.

Stokoe, K. H., Wright, S. G., Bay, J. A., Roesset, J. M., & others. (1994). Characterization of geotechnical sites by SASW method. *Geophysical Characterization of Sites*, 15–25.

Sufiyanussuari, S. A., Azhar, S., Tajudin, A., Azmi, I. S., Nur, M., Zahari, H., & Mohd, N. (2021). Groundwater Pathway Mapping Using Electrical Resistivity Tomography (ERT) Method. *Journal of Sustainable Underground Exploration*, *1*(1), 32–37.

Sumithra, P., & Thiripurasundari, D. (2017). Review on Computational Electromagnetics. *Advanced Electromagnetics*, *6*(1), 42.

Sundaram, R. (2019). *Geophysical Characterization of Metro Station Sites*. *July*.

T. Tanada, Y.Kajikawa, M. T. (2014). Study on Acoustic FDTD Analysis for Compact Acoustic Systems. *European Acoustics Association*.

Taflove, A., & Hagness, S. C. (2005a). Computational Electrodynamics. In *Artech House, Norwood, MA* (Third).

Taflove, A., & Hagness, S. C. (2005b). Computational Electrodynamics. In *Artech House, Norwood, MA* (Third).

Taipodia, J., & Dey, A. (2012). A Review of Active and Passive MASW Techniques. *Egceg*, *October 2016*.

Taurisano, A., Tronstad, S., Brandt, O., & Kohler, J. (2006). On the use of ground penetrating radar for detecting and reducing crevasse-hazard in Dronning Maud Land, Antarctica. *Cold Regions Science and Technology*, *45*(3), 166–177.

Tavakoli Taba, S., Rahnamayie Zekavat, P., Alipour Esgandani, G., Wang, X., & Bernold, L. (2015). A Multidimensional Analytical Approach for Identifying and Locating Large Utility Pipes in Underground Infrastructure. *International Journal of Distributed Sensor Networks*, *11*(6), 601859.

Telford, W. M., Geldart, L. P., & Sheriff, R. E. (1990). *Applied Geophysics*. Cambridge University Press.

Teramoto, K., & Tsuruta, K. (2003). Subsurface crack detection by spation-temporal gradient method. *SICE 2003 Annual Conference*, *1*(5), 782–787.

Thitimakorn, T., Anderson, N. L., Stephenson, R., & Liu, W. (2005). *2-D Shear-Wave Velocity Profile Along Test Segment of Interstate I-70, St. Louis, Missouri*. *40785*(April), 1–9.

Tinker, M. H. (2003). Teaching mathematics to physicists in the UK-FLAP and PPLATO. *Europhysics News*, *34*(5), 186–189.

Utsi, E. (2012). The Importance of Utility Detection. *11th International Symphosium & Exhibition on Geoinformation ISG 2012*, 1–10.

Vadillo, I., Benavente, J., Neukum, C., Gr?tzner, C., Carrasco, F., Azzam, R., Li??n, C., & Reicherter, K. (2012). Surface geophysics and borehole inspection as an aid to characterizing karst voids and vadose ventilation patterns (Nerja research site, S. Spain). *Journal of Applied Geophysics*, *82*, 153–162.

Van Schoor, M. (2002). Detection of sinkholes using 2D electrical resistivity imaging. *Journal of Applied Geophysics*, *50*(4), 393–399.

Ward, S. H. (1990). *Geotechnical and Environmental Geophysics: Volume I: Review and Tutorial: Vol. I* (S. H. Ward (ed.)). SEG.

Wells, B. A. W. and K. L. (2022). *Exploring Seismic Waves*. American Oil & Gas Historical Society.

Welvaert, M., & Rosseel, Y. (2013). On the definition of signal-to-noise ratio and contrast-to-noise ratio for fMRI data. *Plos One*, *8*(11).

Widess, M. B. (1973). How Thin Is A Thin Bed? *Geophysics*, *38*(6), 1176–1180.

William H. K. Lee, Hiroo Kanamori, Jennings, P. C., & Kisslinger, and C. (2002). International Handbook of Earthquake and Engineering Seismology (Part A). In *International Geophysics 81, Part A* (Issue 1st). Academic Press.

Xi, J., & Cui, D. (2021). Technology of detecting deep underground metal pipeline by magnetic gradient method. *IOP Conference Series: Earth and Environmental Science*, *660*(1).

Xia, J., Nyquist, J. E., Xu, Y., Roth, M. J. S., & Miller, R. D. (2007). Feasibility of detecting near-surface feature with Rayleigh-wave diffraction. *Journal of Applied Geophysics*, *62*(3), 244–253.

Xia, J., Xu, Y., Miller, R. D., & Nyquist, J. E. (2006). Rayleigh-wave diffractions due to a void in the layered half space. *SEG Technical Program Expanded Abstracts 2006*, 1406–1410.

Yee, K. S. (1966). Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media. *IEEE Transactions on Antennas and Propagation*, *14*(3), 302–307.

Yule, D. E., Sharp, M. K., & Butler, D. K. (1998). Microgravity investigations of foundation conditions. *Geophysics*, *63*(1), 95–103.

Zahari, M. N. H., Dahlan, S. H., & Madun, A. (2015). A review of acoustic fdtd simulation technique and its application to underground cavity detection. *ARPN Journal of Engineering and Applied Sciences*, *10*(19), 8878–8884.

Zahari, M. N. H., Madun, A., Dahlan, S. H., Joret, A., Hazreek, Z. A. M., Mohammad, A. H., & Izzaty, R. A. (2018). Shallow Reflection Method for Water-Filled Void Detection and Characterization. *Journal of Physics: Conference Series*, *995*, 012118.

Zahari, M. N. H. N. H., Madun, A., Dahlan, S. H. H., Joret, A., Zainal Abidin, M. H. H., Mohammad, A. H. H., & Omar, A. H. H. (2018). Experimental Detection and Characterization of Void using Time-Domain Reflection Wave. *Journal of Physics: Conference Series*, *995*(1), 012102.

Zhao, Y., & Rector, J. W. (2010). Using seismic surface waves generated by motor vehicles to find voids: field results. *SEG Technical Program Expanded Abstracts 2010*, *2002*, 2029–2033.

Zhou, W., Beck, B. F., & Adams, A. L. (2002). Effective electrode array in mapping karst hazards in electrical resistivity tomography. *Environmental Geology*, *42*(8), 922–928.

Zhou, Z., Liu, X., & Xiong, X. (2007). Finite-Difference Modelling of Rayleigh Surface Wave in Elastic MEDIA. *Chinese Journal of Geophysics*, *50*(2), 496–504.

APPENDIX A

LIST OF PUBLICATIONS

1) Zahari, M. N. H., Dahlan, S. H., & Madun, A. (2015). A review of acoustic fdtd simulation technique and its application to underground cavity detection. ARPN Journal of Engineering and Applied Sciences, 10(19), 8878–8884.
2) Zahari, M. N. H., Madun, A., Dahlan, S. H., Joret, A., Hazreek, Z. A. M., Mohammad, A. H., & Izzaty, R. A. (2018). Shallow Reflection Method for Water-Filled Void Detection and Characterization. Journal of Physics: Conference Series, 995, 012118.
3) Zahari, M. N. H. N. H., Madun, A., Dahlan, S. H. H., Joret, A., Zainal Abidin, M. H. H., Mohammad, A. H. H., & Omar, A. H. H. (2018). Experimental Detection and Characterization of Void using Time-Domain Reflection Wave. Journal of Physics: Conference Series, 995(1), 012102.
4) Zahari *et al.*, "Detection and Characterization of Buried Objects Using Seismic Reflection Technique Detection and Characterization of Pipe Using Time-Domain Reflection Wave (9481)," no. 9481, [Online].
5) Zahari, M. N. H., A. Madun, S. Azhar, A. Tajudin, and M. Zainizan, "Assessment of ground subsidence potential at problematic culvert on expressway: Case study using Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR)," vol. 1, no. 1, pp. 1–4, 2019.

APPENDIX B

VITA

The author was born on April 8, 1988, in Pahang. He received his early education at Sekolah Menengah Kebangsaan Agama Pahang in Pahang. He graduated with Bachelor Degree (B.Eng) form Universiti Tun Hussein Onn Malaysia, and earned a Bachelor Degree in honors in electrical and electronics engineering on 2012. After graduating, he was employed at a BQE Engineering Sdn. Bhd. in Selangor as an assistant engineer before continuing studied in Master. In 2014, he graduated his studies in Master level at Universiti Tun Hussein Onn Malaysia, and was awarded Master (M.Eng) of Electrical Engineering. Currently hold a position as Manager at Preston GeoCEM Sdn Bhd a spin-off company of Universitiy Tun Husssein Onn Malaysia. He has been involved with geophysical work since 2013. His experience includes Ground Penetration Radar (GPR) for cavity and utilities detection, geological mapping for slope and road construction works, subsurface mapping using seismic method including Multiple Analysis Surface Wave (MASW) and Seismic Refraction, Electrical Resistivity Tomography (ERT) for groundwater exploration, Transient Electromagnetic (TEM) and magnetic method for mineral exploration, and but not least geophysical software application using 2D seisImager, ZonD, Res2DInv and ReflexW.