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

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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."

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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. Modelmodel 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.



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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

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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 object 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 highresolution 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 *et 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 groundpenetrating 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 Pwave 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;
- 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.

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APPENDIX A

LIST OF PUBLICATIONS

- 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.
- 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.
- 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.

