Shallow Reflection Method for Water-Filled Void Detection and Characterization

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Abstract. Shallow investigation is crucial in enhancing the characteristics of subsurface void commonly encountered in civil engineering, and one such technique commonly used is seismic reflection technique. An assessment of the effectiveness of such an approach is critical to determine whether the quality of the works meets the prescribed requirements. Conventional quality testing suffers limitations including: limited coverage (both area and depth) and problems with resolution quality. Traditionally quality assurance measurements use laboratory and in-situ invasive and destructive tests. However geophysical approaches, which are typically non-invasive and non-destructive, offer a method by which improvement of detection can be measured in a cost-effective way. Of this seismic reflection have proved useful to assess void characteristic, this paper evaluates the application of shallow seismic-reflection method in characterizing the water-filled void properties at 0.34 m depth, specifically for detection and characterization of void measurement using 2-dimensional tomography.

1. Introduction
Shallow investigation is crucial in enhancing the characteristics of subsurface void commonly encountered in Civil Engineering, and one such technique commonly used is seismic reflection technique. Conventional testing suffers limitations including: limited coverage (both area and depth) and problems with resolution quality. Traditionally, the measurements are use laboratory and in-situ invasive and destructive tests. However geophysical approaches, which are typically non-invasive and non-destructive, offer a method by which improvement of detection can be measured in a cost-effective way. Mayne (2012) has published the use of geotechnical techniques that are commonly used to identify underground features such as penetration testing and soil trenching [1]. These methods involve direct observation of underground materials. However, the conventional methods are frequently failed to observe the void, provide insufficient data and can and misrepresent the subsurface geology [2]. This may lead to undiscovered of the void position. Cost and time constraint factors are the main reasons to explain the difficulty in investigating the subsurface using conventional methods [3].

For the past few years, a range of geophysical techniques have previously been utilized successfully in the detection of voids in various geologies: microgravity [4], magnetic [5][6], resistivity [7][8][9], a variety of seismic techniques (refraction [10][11]), (reflection [12][13][14][15] and recently
multidisciplinary techniques [16][17]. Compounding this, geophysics for void detection has an uncertain reputation in some areas of the engineering industry [5].

Void characterization by using seismic reflection technique has been proved useful, however, based on the previous work, the testing was conducted has focused on simulation-based observations making detailed evaluation of this approach difficult. Previously, the applicability of P-waves reflection techniques have been successfully detected subsurface voids [15][18][19][20][21][22]. The main advantages of these approaches are they are non-destructive, non-invasive, and require quick assessment. Such a method provides information with greater resolution in the lateral dimension with better traces resolution and thus, can define the geology of subsurface better with better thinner subsurface layers identification across a site. Therefore, to achieve better certainty of the site investigation, a dynamic approach is needed to be implemented

2. Working principle
This approach uses a piezoelectric sensor as receiver and trigger source, seismic hammer as a seismic source and data logger for data acquisition as illustrated in Figure 1. The water-filled ball at diameter of 0.16 m was buried at 0.3 m depth as shown in Figure 2. Therefore, this study has proposed straightforward method based on time domain sequence of data collection that can be generated by reflection method to simplify the problem of void size estimation and obviously lateral distances. Later, the two-dimensional contour of amplitude was aligned using first arrival as a reference. Thus, the voids dimensions at lateral distances was directly determined by scheming the 2D tomography of amplitude. This approach will provide the estimation of depth and dimension of water-filled void as well as P-wave velocity regarding the direct wave method that have been implemented into this approach as a reference point.

![Figure 1](image)

**Figure 1.** A hammer with consistent energy of 50 N force and located close to the trigger sensor namely (R0). Receiver (R1) was placed on the surface of soil. The computer was connected to the Data Acquisition System (DAQ).
Figure 2. The centre of ball position was at R4. The spacing between R0 and R1 was 0.1 m. Each movement of source receiver (R0) was set at 0.1 m to control the constraint such as useful distance between source and the receivers. There were 10 shot points which gave 0.9 m length of testing spread line. The impact source was moved based on the sequence of data collection to detect the anomaly or void subsurface.

3. Results
The amplitude of reflection wave for water-filled void pattern change with distance. Figure 3 illustrated the 2D pattern of amplitude tomography along the horizontal shot position, R1 till R10. In this study, reflection technique which has 10 steps of gathering shot was proposed.

Figure 3. From the figure, the centre of bright area at depth 0.34 m indicates high amplitude of energy when the wave propagated and reflected to the surface. Meanwhile, the centre of dark area at depth 0.56
m indicates negative amplitude where the energy is concentrated in the void before reflected to the surface. The direct wave also indicates in the dark area at 0.15 m depth because of small energy were reflected to the ground before reflection occurs. The 2D pattern of amplitude contour was aligned using first arrival as a reference.

4. Conclusions
This approach has come to conclusion whereas this study gives a significant value to overcome the uncertainty of void characterization. The estimation of depth and dimension of water-filled void as well as P-wave velocity has successfully determined using shallow reflection method.

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References

[1] P. W. Mayne, “Geotechnical site exploration in the year 2012,” in Proceedings of the 16th Nordic Geotechnical Meeting, Copenhagen, 2012, vol. 1–2, no. May, pp. 9–12.

[2] M. Farooq, S. Park, Y. S. Song, J. H. Kim, M. Tariq, and A. A. Abraham, “Subsurface cavity detection in a karst environment using electrical resistivity (er): A case study from yongweol-ri, South Korea,” Earth Sci. Res. J., vol. 16, no. 1, pp. 75–82, 2012.

[3] A. Madun, I. Jefferson, D. N. Chapman, M. G. Culshaw, K. Y. Foo, and P. R. Atkins, “Evaluation of the multi-channel surface wave analysis approach for the monitoring of multiple soil-stiffening columns,” Near Surf. Geophys., pp. 611–621, Dec. 2010.

[4] S. Fais, P. V. Radogna, E. Romoli, P. Matta, and E. E. Klingele, “Microgravity for detecting cavities in an archaeological site in Sardinia (Italy),” Near Surf. Geophys., vol. 13, no. 2096, pp. 495–502, Oct. 2015.

[5] P. James and P. Ferreira, “Geophysical Modeling of Typical Cavity Shapes to Calculate Detection Probability and Inform Survey Design,” J. Environ. Eng. Geophys., vol. 18, no. 4, pp. 297–316, 2013.

[6] C. Leech and R. M. Johnson, “Location Buried drums using a proton precession magnetometer and magnetic gradiometer,” in Proceeding of the Second International Conference on Construction on Polluted and Marginal Land, 1992, vol. 30, pp. 37–49.

[7] T. L. Dobecki and S. B. Upchurch, “Geophysical applications to detect sinkholes and ground subsidence,” Lead. Edge., vol. 25, no. 3, pp. 336–341, 2006.

[8] M. Gambetta, E. Armadillo, C. Carmisciano, P. Stefanelli, L. Cocchi, and F. C. Tontini, “Determining geophysical properties of a near-surface cave through integrated microgravity vertical gradient and electrical resistivity tomography measurements,” J. Cave Karst Stud., vol. 73, no. 1, pp. 11–15, 2011.

[9] J. Martinez-López, J. Rey, J. Dueñas, C. Hidalgo, and J. Benavente, “Electrical tomography applied to the detection of subsurface cavities,” J. Cave Karst Stud., vol. 75, no. 1, pp. 28–37, 2013.

[10] S. D. Sloan, J. J. Nolan, S. W. Broadfoot, J. R. McKenna, and O. M. Metheny, “Using near-surface seismic refraction tomography and multichannel analysis of surface waves to detect shallow tunnels: A feasibility study,” J. Appl. Geophys., vol. 99, pp. 60–65, 2013.

[11] J. J. Nolan, S. D. Sloan, S. W. Broadfoot, J. R. McKenna, and O. M. Metheny, “Near- surface
void identification using MASW and refraction tomography techniques,” *SEG Tech. Progr. Expand. Abstr.* 2011, pp. 1401–1405, 2011.

[12] J. Carvalho, R. Ghose, C. Pinto, and J. Borges, “Characterization of a Concealed Fault Zone Using P and S-wave Seismic Reflection Data,” in *Near Surface 2009 – 15th European Meeting of Environmental and Engineering Geophysics*, 2009, vol. A14, no. September 2009, p. 5.

[13] V. di Fiore, A. Angelino, S. Passaro, and A. Bonanno, “High resolution seismic reflection methods to detect near surface tuff-cavities: A case study in the Neapolitan area, Italy,” *J. Cave Karst Stud.*, vol. 75, no. 1, pp. 51–59, 2013.

[14] B. Piwakowski, J. C. Tricot, and B. Delannoy, “Underground tunnels detection and location by high resolution seismic reflection,” in *56th EAGE Meeting*, 1994, pp. 91–94.

[15] K. L. Branham and D. W. Steeples, “Cavity detection using high-resolution seismic reflection methods,” *Min. Eng.(Littleton, Colo.);(United States)*, vol. 40, no. 2, 1988.

[16] G. Bianchi Fasani, F. Bozzano, E. Cardarelli, and M. Cercato, “Underground cavity investigation within the city of Rome (Italy): A multi-disciplinary approach combining geological and geophysical data,” *Eng. Geol.*, vol. 152, no. 1, pp. 109–121, 2013.

[17] L. De Giorgi and G. Leucci, “Detection of Hazardous Cavities Below a Road Using Combined Geophysical Methods,” *Surv. Geophys.*, vol. 35, no. 4, pp. 1003–1021, 2014.

[18] S. F. Buckley and J. W. Lane, “Near-Surface Void Detection Using a Seismic Landstreamer and Horizontal Velocity and Attenuation Tomography,” *Symp. Appl. Geophys. to Eng. Environ. Probl.* 2012, pp. 561–571, 2012.

[19] T. Inazaki, Y. Yamanaka, S. Kawamura, and O. Tazawa, “High-resolution seismic reflection survey using Land Streamers for near-surface cavity detection,” in *Proceedings of 7th SEGJ International Symposium*, 2004, pp. 475–480.

[20] P. R. Mohanty, “Numerical Modeling of P-Waves for Shallow Subsurface Cavities Associated with Old Abandoned Coal Workings,” *J. Environ. & Eng. Geophys.*, vol. 16, no. 4, pp. 165–175, 2011.

[21] D. W. Steeples and R. D. Miller, “Direct detection of shallow subsurface voids using high-resolution seismic-reflection techniques,” in *Multidisciplinary conference on sinkholes and the environmental impacts of karst*, 2, 1987, pp. 179–183.

[22] D. W. Steeples and R. D. Miller, “Seismic reflection methods applied to engineering, environmental, and ground-water problems,” in *Symposium on the Application of Geophysics to Engineering and Environmental Problems 1988*, 1988, pp. 409–461.