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Extended Abstract **DOI: Not Included** **Open Access**

A Study Based on Large-Scale Model Test in a Field for Subsurface Cavity Detection

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Abstract: Ground sinkholes caused by subsurface cavities from tunneling poses a significant risk to urban areas. The 2020 Chofu accident highlighted that even deep cavities are dangerous. As surface detection is difficult, in-tunnel exploration is necessary. Seismic surveys might be an effective method to detect cavities, but its propagation mechanisms near tunnels are poorly understood. This study evaluates the applicability of in-tunnel SH-wave exploration for early cavity detection using large-scale model experiments. A large-scale model experiment was conducted. A tunnel structure was constructed on the surface, and two Styrofoam blocks simulating cavities were embedded in the loam. The survey was performed from the concrete surface. A predominantly SH-wave source was generated by horizontally striking embedded rebar. Waveforms were recorded with horizontal geophones. The results showed multiple hyperbolic curves interpreted as reflected and diffracted waves from the cavity edges were successfully captured from both simulated cavities at different depths. Furthermore, reflections from the top surface were also identified from the larger-sized cavity. These findings suggest that in-tunnel exploration using SH-wave sources is an effective technique for the early detection of cavities existing in the vicinity of a tunnel.

Keywords: ***Cavity detection; Seismic survey; Model test.***

Introduction

Ground sinkholes are a phenomenon where subsurface cavities, often caused by tunnel construction or aging sewer systems, propagate upwards and cause sudden surface collapses, posing a significant risk to urban life. The 2020 ground subsidence accident in Chofu, Tokyo, associated with shield tunnel excavation, highlighted a critical risk: even deep-seated cavities or loose zones at depths of approximately 40 meters can trigger catastrophic failures. Detecting such deep cavities from the surface is difficult in complex urban areas with congested underground infrastructure, necessitating exploration methods deployed from within the tunnel.

Ground Penetrating Radar (GPR) is a conventional method for detecting voids, identifying anomalies by analyzing reflected electromagnetic waves. However, GPR has two significant limitations: its shallow detection depth (typically 1.5 meters) and difficulty in application below the groundwater level. Seismic surveys represent a promising alternative method. Karasaki (2022) demonstrated the effectiveness of utilizing reflected waves from cavities generated by surface sources through DEM simulations. However, the propagation mechanisms of elastic waves associated with deep cavities, particularly their relationship with the tunnel structure itself, remain to be fully clarified. Therefore, this study aims to establish an early detection method for cavities near tunnels using in-tunnel surveys. To achieve this objective, model experiments using a structure simulating a tunnel were conducted to evaluate the applicability of elastic wave exploration using SH waves.

Methodology

Figure 1 shows overviews of the model test field, which simulates a tunnel structure in an inverted (upside-down) configuration. The overall dimensions of the field are 6 m (L) 14.5 m (W) 2.5 m (D). The ground in the field consists of sandy silt mixed with gravel. Two Styrofoam blocks (density: 0.011 g/cm3), simulating cavities, were installed in the ground. These were placed by excavating the respective sections. Both cavities are rectangular prisms, with dimensions and locations shown in Figure 1. On the surface of the ground, a 0.3 m thick concrete layer and a 0.2 m thick backfill grout layer were constructed to simulate the tunnel structure. These layers were cured for over 30 days to ensure sufficient strength.

The seismic survey was conducted using geophones placed on the concrete surface. The survey line (red solid line, Figure 1) was used for both signal generation (sourcing) and reception. Rebar embedded within the concrete served both to anchor the geophones and to transmit vibrations. The source signal was generated by striking this rebar with a hammer, to produce predominantly SH-waves. Sourcing was performed at 8 points, spaced 1.2 m apart, starting from the right end of the survey line. A total of 66 horizontal geophones, with a natural frequency of 40 Hz and a sensitivity of 28.8 V/m/s, were used for reception, installed at 0.15 m intervals along the line. The received waveform data was transmitted via takeout cables to a data logger, recording for 0.4 seconds at a sampling frequency of 20 kHz.

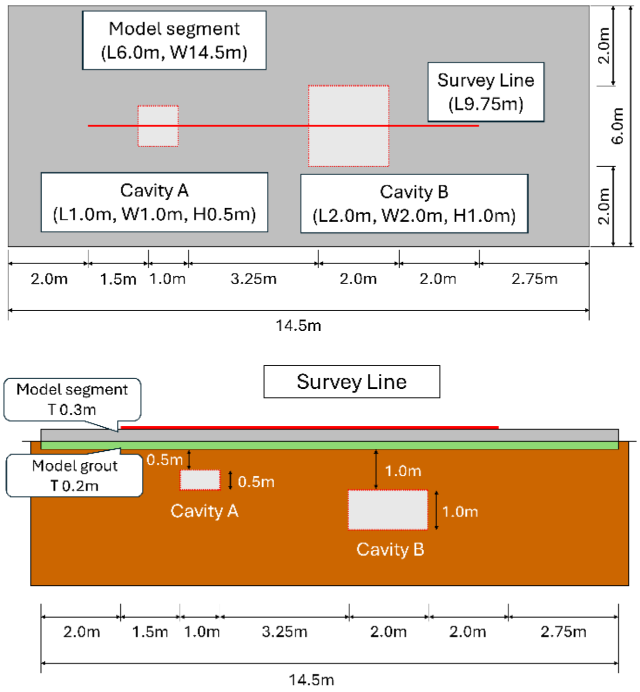

Figure 1, Outlines of the test site.
Upper; overhead view, Lower; cross section view.

Results

Figure 2 shows the received seismic records when the source point was located 4.5 m from the left end of the survey line. These waveforms are the result of stacking data acquired from multiple shots at the same source point. As data processing, a bandpass filter (40 Hz high-pass and 350Hz low-pass) was applied. Figure 2 presents the waveform records from each geophone as an amplitude-based color map.

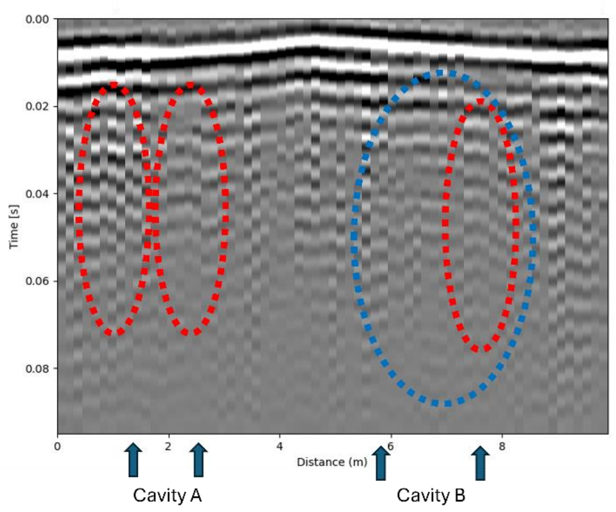

Figure 2, Seismic shots record with multiple geophones.

From the figure, multiple direct waves propagating along the concrete surface in both directions from the source point are observed. It is considered that reflections from the concrete-ground interface are superimposed on these direct waves. In addition to these direct waves, hyperbolic curves centered near both wall positions were clearly observed for Cavity A. Similarly, for Cavity B, hyperbolic curves originating from its edge were also identified (indicated by red-doted lines). These can be interpreted as waveforms that were diffracted by the edges of the cavities. Furthermore, multiple waveforms, presumed to be reflections from the top surface of the cavity, were also observed from Cavity B (indicated blue-dotted line). It is noted that the clear top-surface reflections observed only from Cavity B are likely due to its larger size compared to Cavity A. Additionally, the reason multiple (rather than single) direct and reflected waves were observed is likely due to the low damping of the rebar used for sourcing—which resulted in multiple source waves being transmitted from a single hammer strike—as well as the possibility of multiple reflections occurring between interfaces, such as the bottom of the grout layer and the top surface of the cavity.

Conclusion

This study investigated the applicability of in-tunnel elastic wave exploration using SH-waves, conducted through large-scale model experiments simulating a tunnel structure. From seismic records, diffracted waves originating from the edges of two simulated cavities at different depths were observed. Furthermore, reflections from the top surface were also identified from the larger-sized cavity. These findings imply that seismic surveys using SH-wave sources (horizontal striking) from within the tunnel structure is an effective technique for the early detection of cavities existing in the vicinity of a tunnel.

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References

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