A performance evaluation of geophysical methods for detecting underground cavity around sewer

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ABSTRACT

In recent years, the phenomenon of ground subsidence in major cities has caused social problems such as damage to roads and structures, inhibition of people's safety, and property damage. A survey released by the City of Seoul has showed that more than 80% of the phenomenon of ground subsidence occurred mainly around sewer pipes. Since sewer pipes tend to rapidly deteriorate, a technical standard is needed in order to effectively carry out replacements and repair reinforcement by evaluating the soundness of the existing sewer pipe and identifying any common occurrences of danger. In this study, the effective seismic survey technology for detecting a cavity near to sewer pipe was chosen as GPR, density logging, and impulse response method for the deteriorated sewer pipe. The pilot plant test was carried out so as to verify the performance of the cavity detection of the corresponding technique. Each method could detect the cavity proximity to the sewage pipe, but there was a difference in the applicable limit and detection performance according to each method.

Keywords : subsidence, sewage pipe, impulse response, ground penetrating radar (GPR), density logging

1 INTRODUCTION

The survey methods of sewer pipes mostly rely on CCTV investigations. The evaluation of a crack in the sewage pipes, breakage, or abnormal functioning is mainly being conducted through CCTV image analysis. This auditing system can evaluate the soundness of the sewage pipe itself, but it cannot present a criterion of judgment to check cavities, which may have developed in the outside of the pipe due to the abnormality of the sewage pipe and to expect the risk of the ground subsidence.

Along with recent occurrences of ground subsidence in urban area accompanied with disastrous urban problems which have been attributed mostly to underground cavities induced by soil loss around sewer pipes, the interest and demand in technologies enabling the management of underground sewer lines and detection of cavities have been increasing. Among such technologies, the GPR investigation mainly conducted on ground surface is frequently reviewed as a way to detect underground cavities.

A variety of approach methods such as complex analysis with CPT (Bullock and Dillman, 2002), seismic reflection and refraction method (Cook 1965, 1974), electric resistivity tomography method (Zhou et al., 2002) have been studied in order to overcome the uncertainty of GPR survey. The research results shows these composite investigation and analysis could increase the reliability of the cavity exploration (McGrath et al., 2002; Thierry et al., 2005). However, there is a limit in the depth of exploration due to the fact that it is being conducted on the ground surface. In the process of analyzing the collected data, there is a possibility that the result could be interpreted differently at the discretion of the engineer. In the case of complex analysis, it is difficult to secure reliability because there has been no connecting system of the standardized and proven investigation and analysis procedure up to date.

Since a method to detect the outside cavity and ground relaxation zone through geophysical exploration, the inside of sewer pipe has a shorter distance of exploration compared to the investigation method conducted on the ground surface. It has an advantage in that it can more accurately explore the cavity around sewage pipe. It is noted that the higher reliability of the cavity exploration can be obtained because an investigation is conducted for the corresponding section after selecting the risk zone by

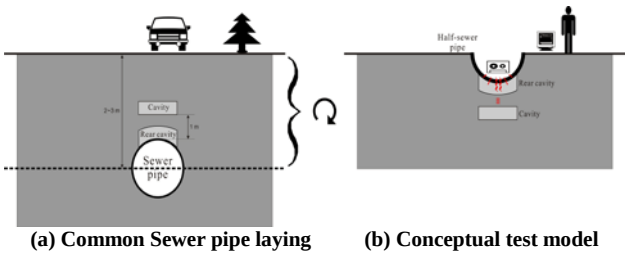
checking whether to have the soundness and abnormal functioning of sewer pipe.

It is considered that a GPR survey, impulse response survey, and radioactive density logging are appropriate as the cavity survey technologies that can be utilized i n the sewer pipe.

2 PILOT PLANT FOR THE VERIFICATION OF CAVITY DETECTION METHODS

To conduct an empirical experiment to detect underground cavities around sewer pipe lines, an equipment of geophysical exploration moving along the inside of such pipelines is needed. However, most of such geophysical exploration equipment are inapplicable thereto. Thus an experimental site prepared by taking the environment of underground sewer pipe lines into account is needed. Sewer pipe lines are typically buried in depth ranged from 2 to 3 m from ground surface and the underground cavities created by sewer pipe lines are mostly residing around these pipe lines and would result in an occurrence of cave-ins causing direct damages. Thus the spots of the most potential risks of the occurrence of cave-ins need to be explored and thereby, the extent between sewer pipe line and ground surface was determined as an interval of investigation.

Figure 1(a) represents the sewer pipe buried 2m~3m in depth in the ground. Figure 1(b), which is the corresponding illustration rotated by 180˚, represents the aspect of the detection of underground cavities around sewer pipe using existing exploration equipment. In here, the detection of underground cavity residing around the sewer pipe line is then turned into the detection of the cavity situated between sewer pipe and ground surface.



(a) Common Sewer pipe laying **(b) Conceptual test model**

Fig. 1. Sewer pipeline and pilot plant schematic diagram.

2.1 Cavity model

To produce a realistic underground cavity, the methods of burying ice blocks or light materials like polystyrene foam are generally used. And for the preparation of the pilot plant site of empirical experiment conducted in this study, the EPS (expandable polystyrene) block was used. The EPS foam is a comparatively light and compression resistant material and, owing to its low unit weight, the original shape buried in underground would be preserved and exhibit characteristics of pseudo-cavity with its small volumetric weight.

The size and scale of underground cavity models should be sufficient enough to be easily detected by methods of the exploration of underground cavities situated beneath sewer pipe together with varied depth and volume. In the experiment conducted in this study, the underground cavity models to be situated within 1 m sewer pipe were assumed. And due to the shallow depth of investigation of the prepared underground cavity models, the underground cavities situated less than 1 m in depth were assumed that they could be easily detected by the exploration. Accordingly, the varied sizes and scales of cavity models were employed for the preparation of underground cavity models to be situated below the sewer pipe as shown in table 1.

Table 1. Cavity models beneath buried sewer pipeline.

Model Names	Specifications (H×W×D, cm)	Model Names	Specifications (H×W×D, cm)
Cavity Model 1	45×45×20	Cavity Model 2	45×45×40
Cavity Model 3	20×20×20	Cavity Model 4	20×90×20
Cavity Model 5	45×90×20	Cavity Model 6	20×20×70

The underground cavity models to be situated below the sewer pipe line were prepared according to (1) each depth and (2) each size of cavity models. The material used for the preparation of the sewer pipe was concrete from which the 3 Hume concrete pipes of 450mm, 600mm, and 1,000mm in each diameter were prepared for the experiment.

The depth of underground cavity models was determined as 0cm (for the case of backside cavity), 30cm, 60cm, and 90cm. In the depth of 0cm and 30cm, Cavity Model 1 was used while Cavity Model 2 was applied to each depth of 60cm and 90cm.

The underground cavity models prepared according to each depth were then installed beneath the prepared Hume concrete pipe which is typically used for practical installation of sewer. The length of one unit Hume concrete pipe was 2.5m and the 4 units of Hume concrete pipes in equal diameter were connected to the length of 10m in which the underground cavity models were installed along with equal spacing at points of 1.25m, 3.75m, 6.25m, and 8.75m and the prepared cavity models were buried at each depth of 0cm (for the case of backside cavity), 30cm, 60cm, and 90cm below each point. In addition, beyond the installation of 4 cavity models with equal spacing under 10m of Hume concrete pipe, the identical cavity models were then installed beneath the Hume concrete pipes of 450mm, 600mm, and 1,000mm of each diameter

To identify the detection of cavity models of each volume, the cavity models numbered from 3 to 6 were installed 20cm beneath the bottom of sewer pipe. The preparation of the cavity models of each size was

determined to be placed below 20cm from the sewer pipe of 1,000mm in diameter. And in the center of the Hume concrete pipes, the polystyrene foam blocks of each size were determined to be placed 20cm below each Hume concrete pipe and, each cavity model was installed with equal spacing of 2.5m along the Hume concrete pipe.

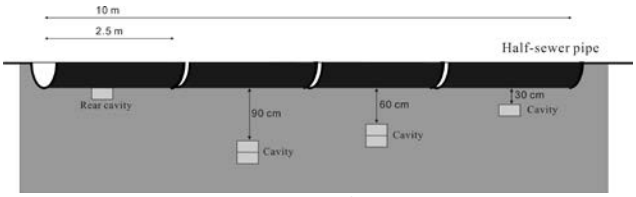
3 VERIFICATION OF THE CAVITY DETECTION SURVEY METHODS

3.1 IR(Impulse Response) method

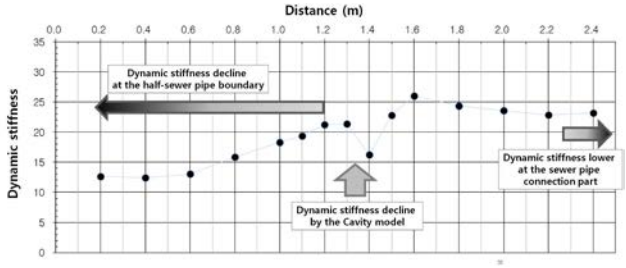
The cavity models of the sewer pipe lines of each diameter at each depth were detected by using the impulse response technique. In the impulse response exploration, the ratio of the spectra of force and velocity will be calculated from the bending movement speed measured with an accelerometer and from the impact force of the load cell mounted on the hammer used as a source of signal which are then represented as a mobility. The mobility is a reciprocal of dynamic stiffness which is varying according to the changing state and thickness of medium and the stress state of the bearing layer beneath the medium.

Figure 2 shows the results of impact response exploration of cavity models at each depth detected from Hume concrete pipe of 1,000mm in diameter. The underground cavity model beneath sewer pipe installed in the site is represented in Figure 2(a) and, the illustrations of Figure 2(b) ~ Figure 2(e) show the results of impact response exploration of cavity models resided in each depth of 0cm, 90cm, 60cm and 30cm, respectively. In contrast to the values of dynamic stiffness of the medium appeared approximately 25~30 (106 N/m) measured from Hume concrete pipe, the values thereof at both ends of the sewer pipe were approximately 10~15 (106 N/m) of low dynamic stiffness.

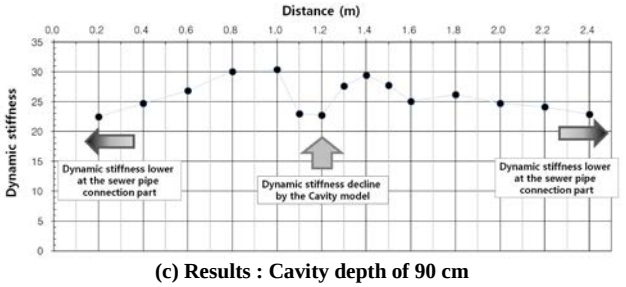
The dynamic stiffness of the segment of single continuous Hume concrete pipe tended to decrease at it goes towards the parts of concrete joints thereof contrasting to the increasing trend going toward the center of concrete. By the presence of cavity model placed in the center of concrete, the dynamic stiffness in the center of concrete appeared to be decreasing. The sensitivity of dynamic stiffness influenced by the cavity beneath sewer pipe did not show significant correlation with the depth of cavity model and, it was identified that it reflected overall dynamic stiffness around the point of measurement. Therefore, the cavity detection around sewer pipe through impact response exploration appears effective especially for cases of detecting comparatively large cavities.



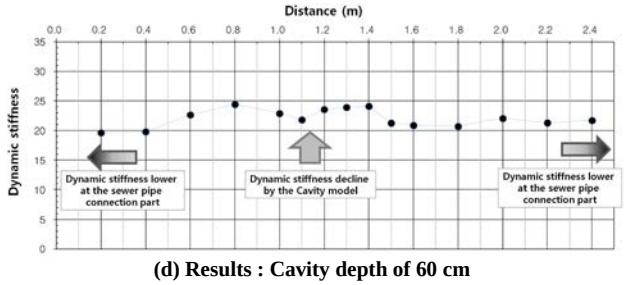
(a) Cavity models at each of hume concrete pipe



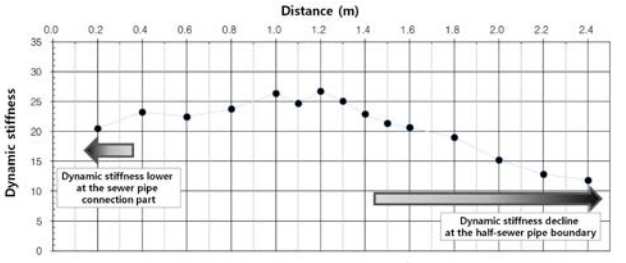
(b) Results : Cavity depth of 0 cm (backside)



(c) Results : Cavity depth of 90 cm



(d) Results : Cavity depth of 60 cm



(e) Results : Cavity depth of 30 cm

Fig. 2. Results of impulse response pilot plant test.

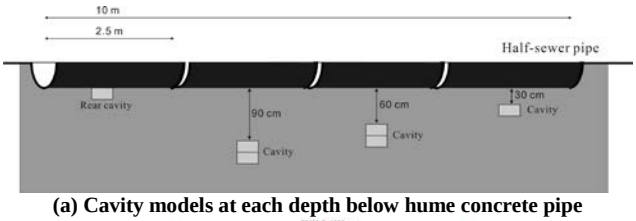
3.2 GPR method

The PulseEKKO PRO was used for the acquisition of the data of GPR exploration from the site for which the frequencies of 250MHz, 500MHz, and 1GHz of the antenna were used. The high frequencies antenna employed in GPR exploration is effective in detecting small scaled anomalies and thus it is typically used in the exploration of superficial layers rendering images of high resolution. The low frequencies antenna cannot detect small anomalies comparing to high frequencies antenna however it can be effectively applied to exploration of deep ground layers to identify bed

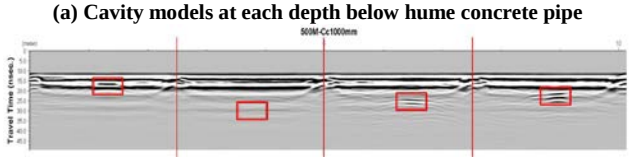
boundaries or depth of bedrocks, etc.

The GPR exploration with 1GHz antenna rendered favorable detection of cavity models resided in each depth of 0 cm, 60 cm, and 30 cm however it could not detect the cavity model situated in the depth of 90cm. This was attributable to the depth of investigation of 1GHz GPR exploration limited within the depth of 1m for the transference of electronic waves.

Figure 3 represents the results obtained from the GPR exploration employed 500MHz antenna to detect cavity models resided beneath Hume concrete pipes of each diameter. In Figure 3(a), the cavity models installed beneath the Hume concrete pipe at the site are represented. Figure 3(b) illustrates the results of GPR exploration obtained from the Hume concrete pipe of 1,000mm in diameter.



(a) Cavity models at each depth below hume concrete pipe

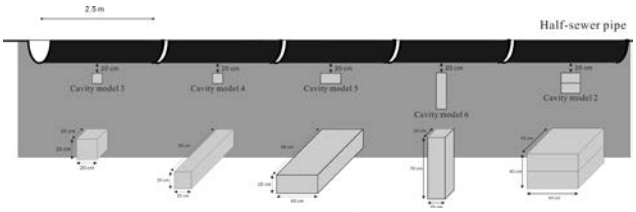


(b) GPR survey result at each depth (1,000mm pipe)

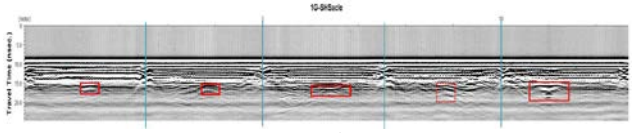
Fig. 3. Results of 500MHz GPR survey at each depth.

The GPR exploration employed 500MHZ antenna gave favorable detection of cavity models situated at each depth of 0cm, 90cm, 60cm, and 30cm. This suggests the 500MHz antenna can be effectively applicable to detection of cavities residing within the depth from 2m to 3m. In the case of Hume concrete pipe of 40mm in thickness and 450mm in its length, the cavity models resided at each depth of 60cm and 90cm were detected more distinctly than cavity models situated at each depth of 0cm and 30cm. And in accordance with the increased thickness of Hume concrete pipe, the cavity models situated at each depth of 0cm and 30cm were detected apparently.

The GPR exploration employed 250MHZ antenna rendered favorable detection of cavity models situated at each depth of 0cm, 90cm, 60cm, and 30cm however the detection of backside cavity appeared difficult. This suggests the 250MHz antenna can be effectively applicable to detection of deeply situated cavities contrary to the difficult detection of cavities residing in shallow ground layers. Thus the GPR exploration employed 250MHZ antenna appeared that it would be comparatively effective in the detection of cavity models situated at each depth of 60cm and 90cm comparing to cavity models resided at each depth of 0cm and 30cm.



(a) Cavity models of varied sizes



(b) GPR survey result of varied size cavities

Fig. 4. Results of 500MHz GPR survey of varied size cavities.

The cavity models of varied size were prepared for the experiment of the detection of corresponding cavity models through GPR exploration. The cavity models employed for the experiment of the detection of cavities through GPR exploration were Cavity Model 2 ~ Cavity Model 6 for which the Hume concrete pipe of 1,000mm in diameter was used. The depth and size of cavity models below the bottom of sewer pipe are as illustrated in Figure 4(a) and, Figure 4(b) shows the result of GPR exploration employed 1GHz antenna in the Hume concrete pipe of 1,000mm in diameter.

The 1GHz antenna ensuring high level of resolution can detect anomalies unavailable from 500MHz or 250MHz antennas in the GPR exploration. Due to the ground noises generated by the preparation of buried cavities, a rather complex events were observed. However, the GPR exploration with 1GHz antenna rendered respective detection of cavity models buried in depth of 20cm below. Contrasting to results of this exploration, the GPR exploration carried out with respective antennas of 500MHz and 250MHz returned degraded resolutions from the detection of the cavity model of 20cm in its length along its side line direction.

The reason of this result was concluded that it would be attributable to the size of cavity model reduced below the proximity spacing of antenna that deteriorated the spatial resolution. The resolution of GPR exploration in longitudinal direction explains the degraded resolution of detection in the case the transceiver antenna deviated outward beyond the distance of separation.

Therefore, the GPR exploration to be employed for the detection of cavities around sewer pipes should aims at cavities of the sizes bigger than the distance of separation of antennas and, in the case of GPR exploration intended to detect smaller cavities, the high frequency wave antennas should be used.

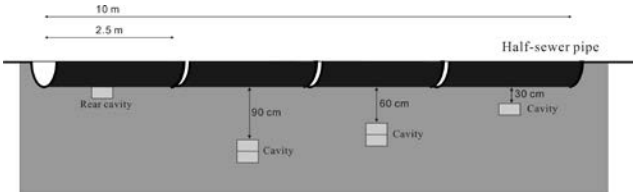
3.3 Density logging method

For the acquisition of the data from the site density logging, the Sidewall Density Probe of Robertson Geologging was used. And the Cs137 isotope of 10 millicurie (mCi) was used as a source of gamma-ray.

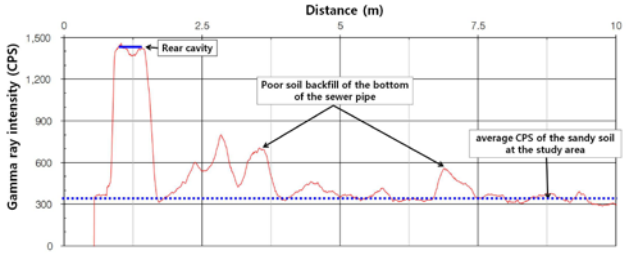
The method of density logging was then used for the

detection of cavity models situated at each depth according to each type and diameter of sewer pipes. The density logging enables the assessment of the ground in the range within 30cm of the radius of detector and it can also identify the state of ground compaction in the range within 20cm of ground layer by taking the thickness of sewer pipe into account.

Figure 5 shows the depth of the detection of gamma-rays at each cavity model in the Hume concrete pipe. Figure 5(a) shows the underground cavity models prepared beneath the sewer pipe installed at the site and in Figure 5(b), the results of the density logging conducted in the Hume concrete pipe of 1,000mm in diameter are illustrated.



(a) Cavity models at each depth below hume concrete pipe



(b) Density logging survey result at each depth (1,000mm pipe)

Fig. 5. Results of density logging survey at each depth.

In the case of the Hume concrete pipe of 1,000mm in diameter, the contact between the shield unit of density logging equipment and concrete floor surface was comparatively favorable. The value of 1400 cps of detected gamma-ray appeared from the backside cavity with the reference values ranged approximately from 300 cps to 400 cps.

In the density logging, the cavity situated behind the pipe was accompanied with the value of thousands of cps however the cavity models situated at each depth of 30cm, 60cm, and 90cn were not detected. The values of the reaction to each cavity model also varied along with changed thickness of concrete.

The cavity detection through density logging is limited to the extent of approximately 30cm of ground layer including the thickness of sewer pipe, thus it appeared effective in the detection of cavities situated right behind sewer pipes but then, it became ineffective in the detection of cavities resided in the extent beyond thereof. Besides, the density logging was found effective in the detection of relaxed formation of ground compaction evolved by the development of cavities.

4 CONCLUSION

The survey on diverse technologies currently employed for geophysical exploration was carried out in this study to construct a system to explore underground cavities directly from inside of buried sewer pipe. And the results obtained thereof are summarized as in the following:

1. The technologies of GPR, impulse response and density logging were concluded as feasible ones available for intra-ductal underground cavity exploration.
2. The impulse response technique was found that it would exhibit lower level of dynamic stiffness at the zone of formed relaxation of continuous Hume concrete pipe and that of buried cavity.
3. The GPR exploration was found that it could reach maximum 1m in depth of sandy ground with 1GHz antenna, approximately 2m~3m with the 500MHz one, and maximum 4m~5m with the 250MHz one.
4. The GPR exploration employed the 1GHz antenna was found effective in detecting cavities residing in the range within 1m behind underground sewer pipe.
5. The density logging enables the identification of the formed relaxation in ground by reflecting volumetric density in the range within 30cm of homogenous medium, and thus, this method would show excellent reflection of ground layer in thinner underground sewer pipes with shallow depth of cavities. However, the narrow range of the exploration limited within 30cm in depth would be a disadvantage of this technology.

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