EMPIRICAL VERIFICATION EXPERIMENT FOR SUBSURFACE EXPLORATION BY GROUND PENETRATING RADAR

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ABSTRACT: Ground penetrating radar (GPR) is one of the underground non-destructive monitoring methods based on the electromagnetic geophysics. GPR utilizes properties of electromagnetic waves consist of penetration, reflection and diffraction. A typical GPR system consists of pairing of a transmitter and a receiver antenna. The transmitter antenna radiates electromagnetic waves into the ground. The radiated wave penetrates into soil and is reflected at a boundary of two materials which have different dielectric constants. The receiver antenna receives the reflected wave. By analyzing the amplitude, waveform and arrival time of the reflected wave we can characterize the underground environment. The exploration of underground environments has become increasingly important in subsurface urban areas especially in Japan. In urban areas there are so many buried important utility infrastructures such as water pipes and gas pipes resulting. However utility infrastructures are not the only below-ground challenge. Recent years, underground cavities have become significant urban issues to be solved and can lead to serious accidents. Since the application of GPR has increased and many GPR products now exist, users have to consider appropriate GPR instruments and consider whether GPR can be applied to their field or not. This paper describes the idea of an evaluation method aiming to evaluate GPR instruments and applicability to various fields for GPR objectively as an empirical GPR verification. This evaluation method was demonstrated by using a real GPR dataset. And as a result, we concluded the method is reasonable and valuable to the evaluation of GPR instruments and the investigation of GPR applications.

1. INTRODUCTION

1.1 Background

Japan's economic had grown highly in the period from 1955 to 1973. In this period, many of important public facilities for our daily life such as road networks and life lines had been constructed by national and local governments. In the present day, the replacement time for most of them with end of 50 years life cycle has come. However both national and local government have not enough financial resources for their replacements. Furthermore Ministry of Land, infrastructure, transport and tourism as one of Japanese national agencies present a life cycle improvement policy and notify all of public facilities administrator to investigate actual conditions scientifically for decrepit public facilities in order to extend its life time. For this scientific investigation, geophysical exploration approach for understanding underground environment is expecting to be one of useful and effective monitoring methods for decrepit important public facilities. This geophysical exploration is based on the physical phenomena by applying physical property such as propagations or interferences of electromagnetic wave, electric current, magnetism and gravity. The geophysical exploration is known as a technique for visualizing underground environment. At the same time, it is also effective for monitoring for inside layer of paved surface, banks of port facilities and floorboard of bridges.

In high dense populated cities such as Japan biggest cities, Tokyo, Osaka and Nagoya, land surface had been fully utilized. And it has been extending to underground. Especially subsurface utilization is advanced and its layer is used as business facilities, subways and so many public and private facilities. This high dense subsurface utilization has become to be a social issue in urban area facilities management because of its complexity. In this subsurface high dense area, various public life lines such as water, gas pipes and electric lines are intricately buried. For our safety life, these facilities have to be well monitored and managed by evaluating their inner structures and physical property. For this facilities monitoring and management, geophysical exploration is effective and deals with important functions in order to assure the security of local communities.

1.2 Purposes

Therefore the authors focus on GPR (Ground Penetrating Radar) as an effective investigation method without any destruction for subsurface with few meters depth and carried out GPR exploration at the experimental field which we designed in order to understand the exploration capability of GPR. At this experimental field, we deployed various anomalies which consist of simulated cavity and pipes at different depths. As a consequence of experiments, we confirmed empirically how many meters depth GPR can detect anomalies and how subsurface anomalies can be visualized.

2. UNDERGROUND UTILIZATION AND SUBSURFACE EXPLORATION

2.1 Underground Complexity and Anomalies

Nearly 70% of the land in Japan is mountains and forests. The proportion of the land area compared to the whole area of land is small. So as to utilize a limited land effectively, multi-layered underground utilization has proceeded. In order to improve life functions, water supply and sewerage systems, traffic facilities, life lines which provide electricity and gas, urban facilities such as malls and parking have constructed in the high dense urban areas especially subsurface. Generally, the depth of excavating for them into the underground becomes deeper. An advantage of underground environmental utilization is to be able to utilize underground space with three dimensionally. An advantage of underground environmental utilization is to be able to utilize underground space with three dimensionally. Particularly in high dense urban area, land use is extending to underground space from land surface. The underground in Japanese urban area is enough sophisticatedly utilized in comparison with other advanced economies. The subsurface with few meters depth is utilized as various purposes such as life lines of water and electricity, walkways and subways in high dense urban area.

Not only manmade objects but also natural objects are buried in underground. Here, all buried objects are defined as underground anomalies. Figure 1 shows objects which are buried as underground anomalies. According to this classification procedure, we classify underground anomalies into two groups: manmade objects and natural objects.

Manmade objects divide into three subgroups: structures, buried objects and lost property. Structures are mainly civil engineering structures such as building foundation, deck of bridge, road structure and ancient structure buried in underground. Buried objects are infrastructures such as buried pipes, cables and tanks. Lost property consists of not in use objects such as artifact, landmine and disposed garbage in underground. On the other hand, natural features exist in underground naturally such as rock, mineral resource, stratum and heterogeneous soil. Structures and buried objects as manmade objects are mainly buried in subsurface.

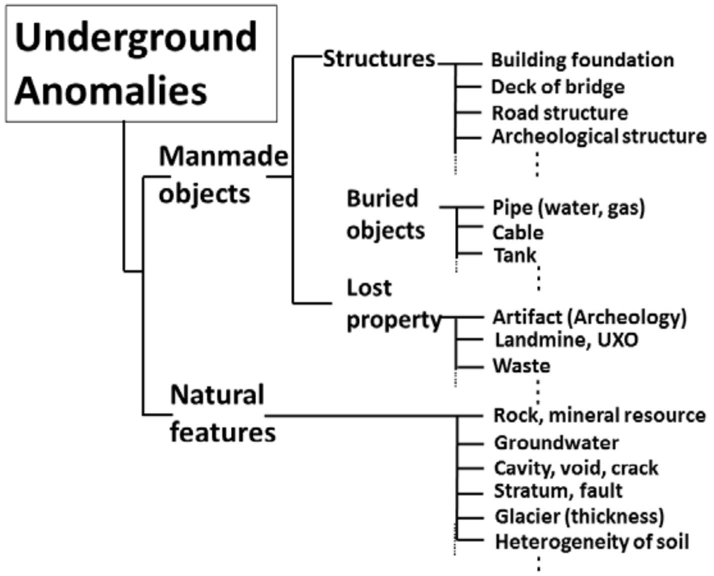

Figure 1 Underground Anomalies Classification

2.2 Principle of GPR Measurement

GPR is a non-destructive geophysical method and it produces a continuous cross-sectional profile or record of subsurface features without drilling, probing, or digging. The GPR cross-section shows the ground surface at the top of profile, and reflections of subsurface geologic units and objects to a certain depth at the bottom. Its profiles are used for evaluating the location and depth of buried objects and to investigate the presence and continuity of natural features in subsurface. Typical GPR system is configured by pair of a transmitter antenna and a receiver antenna. The transmitter antenna radiates electromagnetic wave down into ground. This transmitted wave is reflected at the boundary between different materials with different dielectric constants. The receiver antenna receives reflected waves. Received signal can be visualized through the appropriate signal processing.

The capability of GPR is defined by maximum exploration depth and radar resolution which means to be distinguished two independent bodies on radar image. Propagating Electromagnetic wave into ground is strongly attenuated by medium of soil. This attenuation is not even depending on the frequency. As a general rule, its attenuation is increased in according with frequency becomes high. Even in the same medium, maximum exploration depth which decreased in the case higher frequency is radiated. On the other hand, radar resolution is related to the wavelength.

The important parameters which define the radar capability summarizes as follows;

Frequency	Low ------- High
Wavelength	Long ------- Short
Attenuation	Low ------- High
Radar resolution	Low ------- High
Maximum exploration depth	Deep ------- Shallow

3. EXPERIMENTAL FIELD FOR EMPIRICAL VERIFICATION

In order to know GPR exploration performance, the authors simulated and designed subsurface in high dense urban area. And we constructed our own GPR experimental field where various shape, size, materials and depth anomalies were buried. This field is mainly consist of the same soil with 2.0m depth and is covered with 5cm thickness of asphalt pavement. Figure 2 shows anomalies deployment in ground plan. We simulated cavities and pipes infrastructures as the subsurface of urban environment.

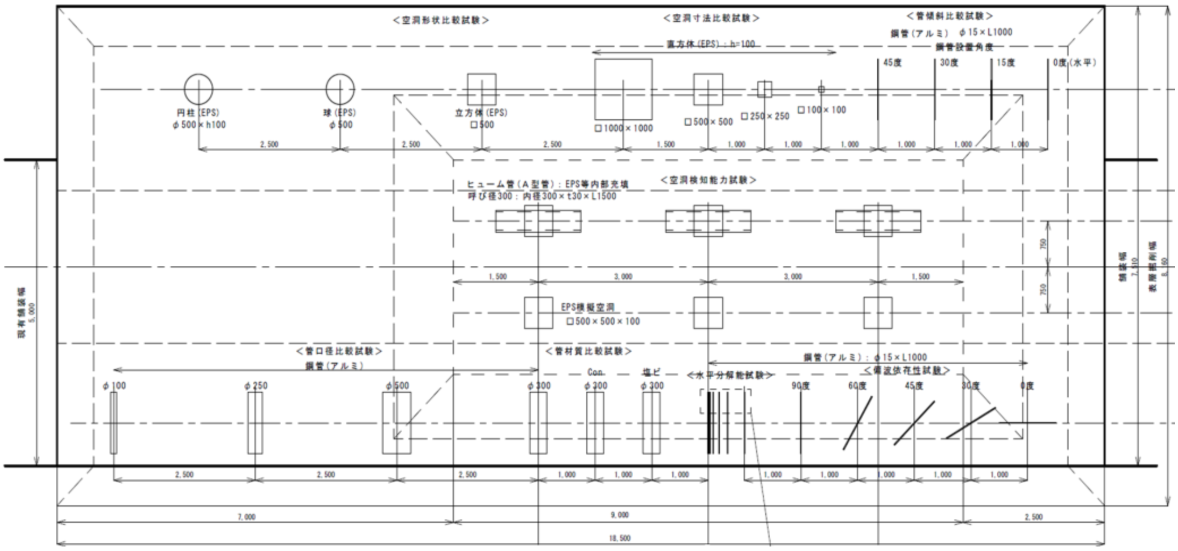

Figure 2 Anomalies Deployment at Experimental Field

The square objects in this figure are volume anomalies which composed of polystyrene foam with 50cm x 50cm x 10cm were buries at depths of 20, 50, 150 and 200cm. The line objects in this figure are aluminum pipes as liner anomalies having a diameter of 1.5cm with orientation of 0, 30, 45, 60 and 90 degrees at a depth of 50cm

4. GPR MEASUREMENT AT EXPERIMENTAL FIELD

4.1 Used GPR Systems

In this GPR experimental measurement, we used two different array GPR instruments in terms of central frequency because it directly affects GPR image. The concept of array GPR system is shown in Figure 3. This array GPR system is becoming to be common due to its efficiency afforded by multi antenna pair resulting in a reduced survey line.

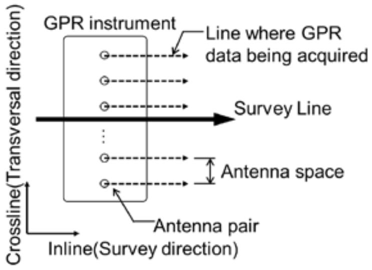

Figure 3 Concept of Array GPR System

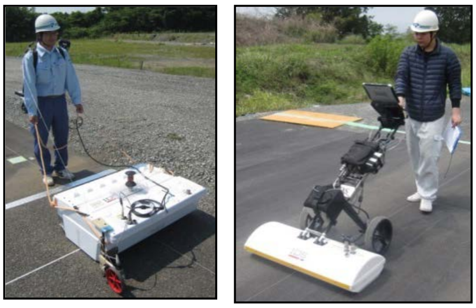

Figure 4 Used Two kinds of Array GPR Instruments

Since array GPR systems contain several antennas in one instrument we can acquire several vertical images as 2D at one GPR survey. Figure 4 shows two kinds of array GPR instruments which we used in this GPR measurement. Both instruments are manufactured by IDS Inc., Italy. The left photo of this figure is Stream-X we adopted. It is having 30 antenna pair works with a central frequency of 200MHz. The right photo is Hi-BrigHT. It is having 8 antenna pair works with a central frequency of 2 GHz. Generally, a GPR working with a higher central frequency has higher has higher resolution but shallower penetration depth. Therefore, Hi-BrigHT can acquire a better quality image than Stream-X but only for shallow exploration depth.

4.2 Data Acquisition and Data Processing

At first we determined the survey line of GPR movement which corresponds to the inline direction. Used GPR instrument was scanned two dimensionally along with the survey line in order to cover target anomalies (see figure 2, Anomalies Deployment).

Acquired GPR data was procced as following steps: 1) Bandpass filter was applied then 2) the time zero was adjusted to the ground surface. 3) Background removal was applied to suppress undesirable horizontal signals such as antenna ringing. 4) Gain control was also applied to compensate for weak signals from deeper area. 5) Depth was calculated from arrival time of the reflected wave by assuming the dielectric constant as 9, i.e., the propagation velocity of electromagnetic wave was 10 cm/nsec.

4. RESULTS AND DISCUSSION

4.1 GPR Image as Results

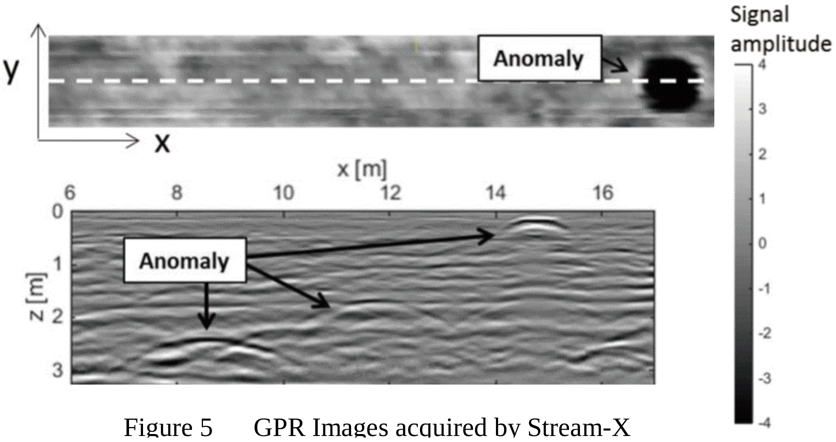

Figure 5 GPR Images acquired by Stream-X

Figure 5 shows a GPR images acquired by Stream-X as one of sample results.

The upper image is a horizontal GPR slice image at depth of 20cm. Here, the horizontal and vertical axis of each two images is the inline and crossline direction respectively. The gray scale represents amplitude of reflected signal. One anomaly indicated by the arrow can be seen on the image from its rectangular shape.

The lower image is vertical cross-section image along inline. The horizontal axis and vertical axis of the image are inline direction and depth from the surface respectively. Three anomalies can be seen on the image.

4.2 Discussion

Through GPR experimental measurement and data analysis, Stream-X could be applied to a road cavities exploration. Especially, if cavities are shallower than 50cm, approximate size of cavities could be estimated. If they are deeper than 150cm, they also could be detected. However both shape and size are not clear. Thin pipes of diameter of 1.5cm could be detected by Stream-X and their direction could be identified up to 60 degree oriented pipes with respect to the survey line.

Hi-BrigHT could be applied to a road cavities exploration, too. It is suitable for shallower exploration than 50cm with detailed information. For road cavities exploration in deeper area, Stream-X is more suitable than Hi-BrigHT. On the other hand, for precise exploration with shallower than 50cm, Hi-BrigHT is more suitable than Stream-X. Hi-BrigHT was confirmed to be able to detect and determine direction of pipes up to 60 degree orientations. Although this result is almost the same as Stream-X. If pipes are closely arranged in the horizontal direction, Hi-BrigHT could yield a better result.

4. CONCLUSION

In this study, the authors focused on GPR as one of latest investigation methods without any destruction for subsurface with few meters depth and constructed our own experimental field. And we also conducted the GPR experimental measurement in order to understand the exploration capability of GPR. At this experimental field, we deployed various anomalies which consist of simulated cavity and pipes at different depths. As a consequence of experiments, we confirmed empirically how many meters depth GPR can detect anomalies and how subsurface anomalies can be visualized. According to our empirical verification experiment, we confirmed that array GPR instruments' effectiveness and applicability to subsurface exploration. However we could examined under limited conditions. In future works we will accumulate actual field works under different conditions.

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