The application of radar in detecting underground pipeline, tunnels: a case study in Xining City

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Abstract. With the development and progress of the city, underground pipelines play an increasingly important role in urban planning. So it’s particularly important to find out the number, direction and depth of underground pipelines. In order to accurately find out the distribution of underground pipelines in Xining and reduce the risk and loss of buildings construction, this paper uses ground penetrating radar to detect underground pipelines and tunnels. By analysing the intensity, waveform characteristics and arrival time of each reflected wave in radar reflection profile, we can deduce the complex geological environment and the distribution of underground pipelines, so that we can summarize the characteristics of complex geological medium, typical media and radar data param of underground pipeline project in Xining, and establishing the fitting param model, which can provide a reference basis for urban construction.

1. Introduction
At present, due to Ground Penetrating Radar (GPR) technology has little disturbance to underground works and will not cause damage to underground pipeline network, so it is widely applied to non-contact detecting of invisible underground project.

GPR pipeline detection technology was originated in Germany. In 1910, German scientists, Letmbach and Lowy, formally expounded the concept of GPR in their patent application for the first time[1-6]. In 1926, Hulsebeck firstly used pulse technology to detect underground objects and put forward the theory that electromagnetic waves can reflect at the interface of objects with different dielectric constants. In the late 1970s, with the emergence of GPR instruments and the rapid development of theoretical research, many ground penetrating radar systems had been developed by foreign organizations, such as the SIR series radar of Geophysical Survey System Inca (GSSI), the Pulse EKKO radar of Sensor & Software Inc (SSI) in Canada, the RIS-2K radar of Ingegneria Dei Sistemi Company in Italy, the SPRScan radar of ERA Company in Britain, the RAMAC/GPR borehole radar series produced by MALA Geosciences Company in Sweden[7-14], etc. In the 1980s, radar detection technology was introduced into China. Through the researching by many experts and scholars, GPR has made many breakthroughs. In 1988, Pan Zhongying and others verified the accuracy and superiority of GPR in pipeline detection through engineering practice[15]. At the end of the 20th century, the detection of
underground pipelines was no longer limited to metal pipelines, and the detection results showed that ground penetrating radar could not only recognize metal pipelines, but also responded well to non-metal pipelines[17]. In 2005, Yang Xiangdong et al. proved that ground penetrating radar can effectively identify non-metallic pipelines under complex geological conditions[18-20]. In the same year, Zhao Yonghui et al. developed a radar detection image processing and analysis system, which realized data processing and interpretation of radar data[21]. Since then, many domestic ground penetrating radar systems have emerged, such as the CAS-Series Radar of Chinese Academy of Sciences, the GR-Series Radar independently developed by China University of Mining and Technology (Beijing), the LTD-Series Ground Penetrating Radar independently developed by China Radio Propagation Research Institute, the CBS-9000V Vehicle Pulse Ground Penetrating Radar developed by Edil International Detection Technology Limited Company in Beijing, the DTL-1 Ground Penetrating Radar developed by Dalian University of Technology, etc. The emergence of these ground penetrating radar systems shows that ground penetrating radar technology has been widely used and developed rapidly.

2. Engineering applications

2.1 Layout of detection points
In order to obtain the radar param characteristics of different pipelines in different media, we select several typical detection points in Xining City for detection experiments, including Baozicun of Xingxing Substation, Xianghe Substation, Park Substation, Xiaoqiao Substation, Nanjiao Substation, Haihu Avenue and Kunlun Avenue crossroads, etc. Among them, we laid iron pipes and PVC pipes in different depths of Quaternary loess cover in Baozi Village, Huangzhong County and set up four E-W direction measuring lines. What’s more, we laid two NE-SW and NW-SE direction measuring lines on cement pavement in Xingxing Substation, two E-W and NE-SW direction measuring lines on asphalt road outside Xianghua Substation and two N-S direction and E-W direction measuring lines on the asphalt road outside the park substation.

In additional, an E-W direction measuring line is arranged on the miscellaneous fill outside the Xiaoqiao substation and an E-W direction measuring line is arranged on the pavement, the asphalt road and the green belt at the South 500 m, and two NEE-SWW direction measuring lines are laid on the sandy silt of the Nanjiao substation. At the crossing of Haihu Avenue and Kunlun Avenue, two NNE-SSW and NWW-SEE lines are laid along the asphalt road. The underground medium of these detection points is relatively single, and the type and distribution of underground pipelines are relatively clear. It is convenient to get the radar detection image and param characteristics of pipelines. Therefore, we can establish the param model of fitting the geological environment characteristics and radar data information characteristics of underground pipeline project of Xining, which can be used to support the exploration of unknown areas or objection areas.

2.2 Settings of radar detection param
In this paper, we select GR-IV portable ground penetrating radar developed by China University of Mining and Technology (Beijing) for relevant detection work. The transmitter and receiver of the radar are integrated. Portable GPR is a geophysical technology which by using electromagnetic wave to detect underground buildings pipeline. Its main frequency is tens of megahertz to gigahertz band electromagnetic wave, and transmitted from the ground to the underground through antenna transmitter in the form of short pulses of broadband, it is reflected by the underground target or stratum interface, then, returned to the ground, and the receiver of the radar antenna receives simultaneously the signals.

Before the measurement, we’re supposed to the param of the instrument. The acquisition points are related to the time window, and the time window is determined by the acquisition depth. The selection of the time window (W) can be calculated according to the maximum detection depth (H) and electromagnetic wave velocity (V), which means it satisfies the relation of W=1.3*2H/V. Generally
speaking, the greater the depth of measurement, the larger the time window; the more the number of overlays, the more obvious the suppression effect of random interference, but at the same time, the more time spent, the data acquisition speed will slow down. Moreover, the more points of acquisition, the more intensive the information, the less the corresponding acquisition depth. Gain adjustment can give prominence to the effective information and make the detection results more obvious. The acquisition mode is triggered by measuring wheel, so the number of pulses is needed to set the acquisition channel spacing.

2.3 Detection steps
When using GPR for surveying, the first thing is to arrange the surveying line. Generally speaking, the measuring line is arranged vertically along the direction of the pipeline, and the length of the measuring line is 20-50 m. Besides, a tape ruler is placed beside the measuring line to determine the abnormal position, then, the instrument is connected at the starting point of the measuring line correctly, and the appropriate detection param are set according to the geology conditions. After the trigger of the measuring wheel is selected, the trolley loaded with antenna is dragged slowly by the staff at a uniform speed to drive the measuring wheel forward.

In the measurement process, the instrument operator can fix the location of the pipeline by piling, which is convenient for later interpretation. If the pipeline in the image is not clear or the position difference between the two pipelines is greater than 3 cm, the param are modified and observation repeated. If this is still the case, the influence of surrounding media is analysed, and the interference factors are reduced by changing the acquisition frequency and application methods. If it is less than 3 cm, the plane position is determined by its average value. Data acquisition needs real-time monitoring. When random conditions affect the detection results, we need to retest on site to ensure all data are valid.

2.4 Processing and interpretation of detection data
2.4.1 Pipeline detection in xingwang substation
During the experiment, the image received by the radar antenna receiver is recorded in the form of pulse reflection wave, and the positive and negative peaks of the waveform are expressed in black and white, gray scale or color, so that the reflection surface of the stratum interface or target can be visually represented by the event axis, equal gray scale or isochromatic line. At this detection point, we measured two groups of round trip data for comparison. After drift removal, background denoising and gain processing, we obtain the depth profile of the actual underground situation.

Figure 1 is measured in the direction of vertical pipeline from NE to SW in Xingwang Substation. The length of the line is 27 m and the medium is cement. The last 18m of the line is given in the figure. Because of the complexity of the cables and the inconsistent distribution direction, we select two sections of pipelines to measure in a single direction.

Param settings: delay adjustment 200-500, acquisition point 1024, pulse number 1, time window 30, superposition number 1, acquisition frequency 40K, acquisition channel number 10.
Figure 1. Gray-scale Radar Detection Record Image of Substation

Figure 1, the horizontal coordinate of the radar detection image is the line distance (unit: m), the right longitudinal coordinate is the two-way travel time (unit: ns) of the radar wave, and the left longitudinal coordinate is the depth (unit: m). After filtering and gain data processing, it can be clearly seen that the medium has changed at 1.5 m of the survey line. The anomaly range is 9.5-11.5 m in horizontal position and 0.2-0.6 m in depth direction. It is very close to the surface, and the electromagnetic wave has attenuated. According to the shape, it can be inferred that it is a void. According to the shape of the cavity reflection wave, there is a metal conductor inside the cavity, which leads to the sudden increase of the reflection amplitude of the electromagnetic wave. The depth of the conductor is between 0.4 m and 0.5 m. After verification by the later substation engineering drawings, it is confirmed that there is really a cavity and a metal cable pipeline inside the cavity. Another abnormality occurs at 9.5 m of the survey line. The range is 1.5-4.2 m in horizontal position and 0.2-0.6 m in depth direction. This anomaly is that the reflection wave in-phase axis is curved upward, the reflection amplitude at the top is the strongest, the diffraction wave amplitude at both ends of the curve is the weakest, and the attenuation is very obvious in the depth. It can be determined that it is a metal cable. This is because the relative dielectric constant of the metal tube is small, but the conductivity is very strong, and the electromagnetic wave attenuates greatly in the interior, so that the energy attenuates rapidly when the electromagnetic wave propagates downward.

2.4.2 Detection of underground pipelines at an intersection

There are many pipelines in the intersection, which are not only various, but also complex. In order to find out the distribution characteristics of pipelines at intersections, we set up two lines along the cross direction, which are NNE-SSW direction (Figure 2) and NWW-SEE direction (Figure 3). The length of the two measuring lines is 25 m, and the medium is asphalt. Two groups of round-trip data were measured in the experiment. After various digital signal processing, we got the actual section of the underground pipeline at the intersection. And the param are set as follows: delay adjustment 4000-4300, measurement wheel trigger, acquisition point 512, pulse number 2, time window 80, superposition number 4, acquisition frequency 40K, acquisition channel number 10.
After data processing, it can be clearly seen that the distribution of pipelines at this point is very complicated. There are not only sewage pipelines, but also cables, underground pedestrian passages, traffic signal lines and so on.

On the first line, the No. 1 anomaly is located in the horizontal position of 2-4 m and the depth direction of 1.50-2.50 m. The reflection wave on the upper part of the anomaly is a black arc with smaller curvature. It is judged that the reflection arc in the depth of 2 m in the hole is more curvature and the reflection polarity on the top is normal. Based on the field investigation results, it can be inferred that this is a sewage pipe (PVC pipe). The second anomaly is located in the horizontal position of 5-12 m and the depth direction of 1.80-2.50 m. In the depth area, the amplitude of the anomalous reflected wave is obviously stronger than that of the surrounding medium, which indicates that there is indeed a strong reflector (cable pipeline) in this position, and the width of the pipeline is about 6cm. And the No. 3 Anomaly is located in the horizontal position of 13-15 m and the depth direction of 1.35-1.80 m. The curvature of its reflection arc is large, which is similar to that of No. 1 anomaly. So it is judged to be a sewage pipeline. The No. 4 anomaly is located in the horizontal position of 22.5-25 m, and the depth direction of 1.50-2.00 m, this could be a sewage pipeline.

On the second line, the No. 5 anomaly is located in the horizontal position of 7-9 m and the depth direction of 0.90-1.30 m. The amplitude of reflected wave is very similar to that of No. 1 anomaly, which is judged to be sewage pipeline; The No. 6 anomaly is located in the horizontal position of 13-19 m and the depth direction of about 1.10-1.50 m. There are obvious anomalous reflected waves in this area. The amplitude of reflected waves is strong, the curvature is large, and the attenuation is more
obvious in the deeper part. This indicates that there is a metal pipeline in this position, it is cable pipeline presumably, the width of the cable is about 5 cm.

2.4.3 Pipeline detection in Nanjiao substation

Figure 4 is measured in the direction of vertical cable from NE to SW in Nanjiao Substation. The measuring line is 25 m long and the medium is sandy silt. The 6-20 m part of the measuring line is given in the figure. Because the number of pipelines is small and the distribution direction is single, the measurement work is easy to carry out.

Param settings: delay adjustment 4000-4400, measurement wheel trigger, acquisition point 512, pulse number 2, time window 70-80, superposition number 4, acquisition frequency 40K, acquisition channel number 10.

![Figure 4. Color Profile of Radar Detection in a Substation in Xining City](image)

Two anomalies can be clearly seen in the Figure 4 One of them is located in the horizontal position of 3.5-4.5 m and the depth direction of 2.50-2.70 m, where the top of the radar reflection curve is relatively smooth, the curvature is small, the signal intensity is strong, and the signal to the depth is weakened. It is judged that this is a cable and pipeline. The other is situated in the horizontal position of 10-11 m and the depth direction of 2.50-2.70 m. The top of the anomalous unilateral hyperbola is horizontal, which is presumed to be a drainage ditch. And the width of the anomalous body can be clearly interpreted from the profile, which is 0.6 m. Combined with the later engineering verification, this is indeed a drainage ditch, which was filled and buried in the later stage, resulting in invisibility on the surface.

3. Discussion and conclusion

3.1. Discussion

When the underground geological environment is cement or asphalt medium, the detection effect of geological radar is more prominent. Because the relative dielectric constant of medium and pipeline is different, the reflection of radar wave at the interface between them is enhanced, and the anomaly is obvious. When the underground is sand, silt and other quaternary covering materials, the medium and pipeline are different. The difference of relative dielectric constant of pipeline is small, so the reflection curve of radar wave is not obvious and the abnormal signals are not prominent.

Through the processing and analysis of radar detection images, it can be found that the transmitting wave amplitude of the cable pipeline is very strong and the curvature of the arc is large, which is caused by the strong conductivity of the metal. Then, with the depth increasing, the radar wave energy attenuates greatly and the waveform weakens obviously. But the reflective waveform of non-metallic pipelines has smaller curvature and the reflection energy attenuates little in the interior. This is because the dielectric constant of non-metallic pipelines is generally high, the conductivity is small,
the reflection polarity of the top of radar wave is normal, and the reflection coaxiality of the bottom of the pipeline is obvious.

3.2 Conclusion
The application results of the project shows that GR-IV has good recognition ability for non-metallic pipelines, and the effect of detecting underground pipelines by using the GPR is good, which can meet the needs of the project.

For different media environments, the selection of radar detection param will directly affect the accuracy of detection results, so a lot of experiments should be done at different detection points to sum up experience. In this paper, experimental measurements show that:

1) Reference param range of cement road: delay adjustment 200-500, acquisition point 1024, pulse number 1, time window 30-60, superposition frequency 1, acquisition frequency 40K, acquisition channel number 10.

2) Reference param range of asphalt road: delay adjustment 4000-4300, measurement wheel trigger, acquisition point 512, pulse number 2, time window 70-80, superposition number 4, acquisition frequency 40K, acquisition path number 10.

3) The reference param range of Quaternary coverage: delay adjustment 4000-4400, measurement wheel trigger, acquisition point 512, pulse number 2, time window 70-80, superposition number 4, acquisition frequency 40K, acquisition channel number 10.

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