Research on application of Ground Penetrating Radar in road Inspection

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Abstract. Traditional road quality inspection is time-consuming, laborious and not highly accurate. As a new type of non-destructive detection tool, Ground Penetrating Radar (GPR) has the advantages of fast, efficient, continuous, simple and accurate operation, and is widely used. This research uses GPR to conduct non-destructive testing of cement road in a cold storage base to detect quality problems such as road diseases. Through detection, it was found that the cold storage base had no obvious cavities within 10m depth in the detection area, but there was a phenomenon of incompact and loose water accumulation. The foundation should be strengthened during construction. The thickness of the cement road was uniform, and its construction quality was good. Through on-the-spot detection, it provides reference for the ground-penetrating radar non-destructive detection of concrete roads and disaster warning.

Keywords: Ground Penetrating Radar; non-destructive testing; cement road.

1. Introduction

As a new type of non-destructive detection tool, ground penetrating radar has the advantages of fast, efficient, continuous process and accurate operation [1-2]. Its ability to acquire information on underground targets non-destructively is a hot spot in current detection research and has been widely used in hydrology, mining, archaeology, geological advanced forecasting and other fields [3]. Related scholars have also carried out some research on the application of GPR in some projects such as irrigation and drainage and roads. Liu Ning[4] used GPR to obtain the profile image of the medium, and realized the non-destructive detection of the thickness of the overburden, road surface and channel lining through key technologies such as ground position positioning, electromagnetic wave propagation velocity calibration and reflection layer pickup. Song Wenwen et al[5] showed that the maximum relative error of GPR detection of road thickness is not more than 1.43%, and the standard deviation is between 0.06–0.08, which is accurate and reliable; in addition, the radar image can clearly understand the uniformity of the road layer and the base layer medium, which can provide effective help for the
acceptance and quality evaluation of road engineering. Lu Hongkui et al [6] used vehicle-mounted GPR to detect underground holes in the main urban roads in Kunming city, and proved that the base penetrating radar has a good effect in detecting urban road holes. This paper summarizes the detection principles and methods of GPR, and conducts non-destructive detection of a certain cold storage foundation road, providing effective technical means for road non-destructive detection and disaster warning.

2. Detection principle
Ground penetrating radar (GPR) is a broad-spectrum electromagnetic wave technology equipment which can be used to determine the distribution of underground media. It has the advantages of high resolution, high efficiency, and real-time display [7]. As long as there is a significant difference in the dielectric between the detected target and the surrounding material, this device can be used for detection. Under the control of the radar host, the transmitter emits electromagnetic waves into the ground, and any discontinuity of underground electrical parameters such as dielectric constant, permeability and conductivity will cause the backscatter of electromagnetic waves and form reflection echo[8]. GPR uses the characteristic that electromagnetic waves reflect when passing through two media with different dielectric constants, and detects the target according to the propagation path of the reflected wave, the changes of the intensity and waveform of electromagnetic field with the properties and geometry of the medium passed by[9]. Based on the processing and analysis of the radar echo received by the receiving antenna, the spatial position, structure, electrical properties and geometric form of the underground medium can be inferred based on its waveform, intensity, time, etc., so as to achieve the Detection of underground stratum or target body[10]. The greater the electrical difference between the target and the medium, the clearer the interface between the two, which is shown in the radar profile as the discontinuity of the phase axis[11-12]. The schematic diagram of the GPR is shown in Figure 1.

![Figure 1. The schematic diagram of GPR](image)

3. Site detection

3.1. Equipment
This detection uses the latest GPR equipment of SEEKER SPR produced by US RADAR, which can realize small and medium-scale non-destructive measurement. It is widely used in road crack detection, concrete pavement thickness, foundation detection, etc [13], so the radar the system configuration meets the requirements of this detection. In this paper, a 250MHz antenna is selected for detection according to the profile method, and the collection point distance is 25 cm.
3.2. Detection method

(1) Select two main roads (cement roads) in the project area for road disease detection, and set three survey lines with 50 m length in the excavation area and the filling area of each level (the area with the filling layer within 30 cm).

(2) When using GPR to collect data, perform detection along the survey lines according to the profile method, and record the data of each survey line. The profile method is a measurement method in which the receiving antenna and the transmitting antenna keep a fixed distance and move along the ground to obtain radar wave information[14]. During the movement, the transmitting antenna emits electromagnetic wave pulses underground at a certain time interval, and the echo signal formed after reflection is received by the receiving antenna and forms a two-dimensional time-distance profile image.

In the profile, the abscissa is the position where antenna moves along the survey line on the ground, and the ordinate is the two-way travel time when the electromagnetic wave starts from the transmitting antenna and reaches the reflecting surface and the receiving antenna. After depth conversion, a depth-distance profile image can be formed. The profile method can accurately record the reflection surface of the formation directly below the survey line and the abnormal target body. The propagation path of the profile method in the medium is shown in Figure 2 (t represents the transmitting antenna and r represents the receiving antenna).

![Figure 2. The processing principle of profile method](image)

(3) Observe the spectral image in the control panel on the spot, find the deviation point of the radar image along the survey line direction, and conduct a field comparison at the abnormal point to analyze the cause of the abnormal information.

(4) The starting point and end point of the survey line can be recorded with the Orville map to form the distribution map of the radar survey line and the tightness determination.

3.3. Data collection

When radar data is collected, firstly record the installation and debugging of the instrument and the on-site situation, and then arrange the survey line, set the parameters and check. The actual layout of this survey line is shown in Table 1.

![Table 1. Survey line list](image)

| Code | Location type | Latitude and longitude | Actual length of survey line/m |
|------|---------------|------------------------|-------------------------------|
| L1   | Cement road   | 34.259181 N 108.093855 E | 72                            |
| L2   | Cement road   | 34.259203 N 108.094973 E | 148                           |

4. Processing and analysis of detection results

4.1. GPR image processing

The radar spectrum image processing adheres to the principle of using the least image processing techniques and steps, and obtaining high-resolution upper soil profile information. The analysis is performed with ReflexW software, which mainly includes 3 steps:
(1) The basic filtering process aims to eliminate unnecessary low-frequency signals and retain high-frequency signals.
(2) Air wave correction aims to obtain the accurate starting position of the radar image.
(3) The time window is set to 1, and the maximum gain value is set to 5000.

4.2. Radar spectrum characteristics
At the 15-25m position of the survey line L1, a single hyperbola appears at a depth of 1m. This spectral feature indicates that there is a pipeline buried in the lower part. The electromagnetic wave reflection signal amplitude is strong in the 60-90m area on the right side of the pipeline, and the event axis is not continuous and the phase is disordered, showing a regional distribution, which indicates that, the soil in this area is disturbed and loose (Figure 3) [15].

Figure 3. Radar spectrogram of L1

Figure 4. Radar spectrogram of L2

The cavity under the road is mostly air, so electromagnetic waves enter the cavity from the soil and the reflection coefficient is positive. The ceiling of the cavity is in the same phase as the incident wave, leading to the strong reflection amplitude and developed multiple waves and diffracted waves sometimes. The loose body is a mixture of soil and air [16]. Since the dielectric constant of air is 1, the relative dielectric constant is smaller than that of the surrounding soil. When the electromagnetic wave enters the loose soil from the dense soil, the reflection coefficient is positive, which causes a phenomenon that the incident wave and reflected wave are in the same phase. The unevenness of the soil will cause the discontinuity of the amplitude and the phase axis, and the chaotic difference of the waveform [17-18]. As shown in Figure 4, near the 10m distance of the survey line L2, and the underground location is about 2m, the discontinuity of the same axis appears, indicating that the soil density in this area is not uniform.

5. Conclusions
Through GPR detection, it can be seen that no obvious cavities are found in the study area within a depth of 10m, and there is a phenomenon of incomplete and loose soil accumulation in the study area. In sum,
there is no obvious disease on the road in the study area. The thickness is uniform and the construction quality is good. In view of the complex underground conditions such as poor uniformity, electromagnetic attenuation blocks in the soil and many electromagnetic interference factors, it is recommended to use other technical means for further verification. Otherwise, the traditional management mode of radar data can be changed with the help of ArcGIS's spatial data management function, so as to find out the hidden dangers of road holes in the first time, and provide an effective method for the rapid detection of road holes in the future.

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