Application of GPR Technology in Engineering Dam Leakage Detection

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Abstract

Geological radar has been widely used in various industries. In order to solve the problems of reservoir dam seepage and waterlogging, according to the requirements of engineering characteristics and disease control, the use of geological radar detection technology to detect the dam body is helpful to realize the detection of hidden disaster bodies inside the dam body. By analyzing the electrical difference and boundary characteristics of the detection target body, combined with the abnormal signal response caused by abnormal leakage, the abnormal detection of dam cracks, euryale grain voids, water points, copper sheets and small cracks at concrete joints is realized. The results show that the use of geological radar detection technology can detect the existence of anomalies and the characteristics of abnormal scale, and provide reference materials for the analysis of dam disease assessment and treatment.

Keywords

GPR; Reservoir Engineering Dam; Diseases.

1. Introduction

Geological radar testing technology has important applications in various fields such as archaeology, architecture, railway, highway, water conservancy, electric power, mining and aviation. It solves problems such as site exploration, route selection, engineering quality inspection, disease diagnosis, advanced prediction and geological structure research. There are many detection methods in the field of engineering geophysics, including reflection seismic, seismic CT, high-density electrical method, seismic surface wave and geological radar. Among them, geological radar has the highest resolution, intuitive image and convenient use. It is one of the important methods for reservoir dam foundation leakage test [1].

Although Ground Penetrating Radar (GPR) is widely used, it is used for reservoir dam foundation detection. The increase of test depth, the improvement of test accuracy and the improvement of data interpretation level have been the direction of researchers ' efforts to improve [2, 3, 4, 5]. Ground Penetrating Radar (GPR) is a geophysical method developed in recent decades, which uses antenna to transmit and receive high frequency electromagnetic wave to detect the characteristics and distribution of material inside the medium. Compared with other conventional underground detection methods, GPR has the advantages of fast detection speed, high resolution, convenient and flexible operation, low detection cost and so on. It is widely used in the field of engineering investigation such as dam structure safety detection [6, 7]. At present, the commonly used GPR technology still cannot meet the needs of practical engineering detection, mainly in the following aspects: (1) The high water content of the dam body causes the dielectric constant of the dam body to increase, and the electromagnetic wave attenuation is serious; (2) Affected by interference factors, the detection

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accuracy is low [8, 9, 10]. In view of the above problems, this paper uses the low-frequency combined antenna with a center frequency of 50 MHz to carry out leakage detection experiments on the dam body of the reservoir project.

2. The Principle of GPR Detection

Ground penetrating radar is a physical exploration method that sends high-frequency pulse electromagnetic waves to the ground. In the process of electromagnetic wave propagation, when encountering objects with electrical differences, such as underground pipelines, holes and other objects, the electromagnetic wave will be reflected and received by the ground receiving antenna. Through the processing, analysis and interpretation of the radar signal, the exploration task of the established target can be completed according to the waveform, intensity, travel time, wave velocity and spectrum of the radar wave. Figure 1 is a schematic diagram of ground penetrating radar exploration.

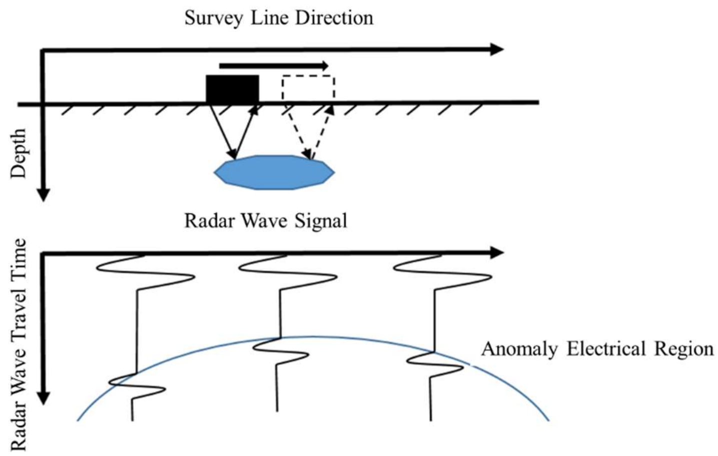

Figure 1. Detection principle of ground penetrating radar

Through various measurements and studies, it is found that air is the material with the smallest dielectric constant in nature, and the electromagnetic wave propagation speed is the fastest and the attenuation is the smallest; water is the material with the largest dielectric constant in nature, and the propagation speed of electromagnetic wave is the slowest. The electrical difference of dry rock and soil is small, and the relative dielectric constant is only slightly different. However, different rock and soil are affected by their own physical properties. There are large and small pores, and a certain amount of water is stored in different degrees. This leads to a large difference in dielectric properties, which makes the relative dielectric constant of the medium have a large difference, and thus leads to a large difference in the propagation speed of electromagnetic waves in the medium. This has also become the theoretical basis for the application of geological radar to detect dam leakage.

3. Processing and Interpretation

The goal of ground penetrating radar data processing is to suppress random and regular interference, to display the reflected wave on the ground penetrating radar image profile at the maximum possible resolution, and to extract various useful parameters of the reflected wave (including electromagnetic wave velocity, amplitude and waveform, etc.) to help explain. During the propagation of the pulse in the underground, the energy will produce spherical attenuation, which will also be weakened by the absorption of the wave energy by the medium. Scattering, reflection and transmission also occur when the underground medium is uneven. Therefore, the digitally recorded geological radar data is similar to the reflected seismic data. Many effective techniques of reflected seismic digital processing can be applied to the processing of geological radar data through some form of change.

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Geological radar data processing includes preprocessing (marking and pile number correction, etc.) and post-processing analysis. Its purpose is to suppress rules and random interference, display reflected waves on the geological radar image profile at the highest resolution possible, and highlight useful anomaly information (including electromagnetic wave velocity, amplitude and waveform, etc.) to help explain. Radar data processing is an important step in the interpretation of the final results of geological radar. Commonly used analysis methods include conventional filtering and other filtering processing. The main work includes : zero line setting, one-dimensional filtering, background denoising, automatic gain or manual gain control, moving average, etc. Other filtering methods can be selected according to the specific detection conditions, including wavelet transform, two-dimensional filtering, deconvolution, mathematical operation, etc., which can be divided into digital filtering and time filtering.

In the process of ground penetrating radar measurement, in order to maintain more reflected wave characteristics, broadband is usually used for recording, so while recording various effective waves, various interference waves are also recorded. Digital filtering technology is to use the different spectral characteristics to suppress the interference wave and highlight the effective wave. Digital filtering is the use of mathematical operations to filter the discrete signal. Therefore, the input and output of digital filtering are discrete data.

(1) One dimensional filtering: using a frequency domain digital filter, the filtering process only involves one variable function, and this type of filtering is called one-dimensional filtering. This variable can be frequency or time, or wavenumber and space. Frequency is the most commonly used, and three types of low-pass filters, high pass filters, and bandpass filters are designed for frequency.

(2) Offset diffraction processing: Ground penetrating radar measures reflected waves from underground media interfaces. The reflection point at the interface of the underground medium that deviates from the measuring point can be recorded as long as its normal plane passes through the measuring point. In data processing, it is necessary to move each reflection point in the radar record to its original position, and this processing method is called offset positioning processing. The radar profile processed by offset reflects the true position of the underground medium.

(3) Background denoising: Select the range of background data, calculate the background trace within the selected range, and subtract the background information from all data. The main function of background denoising is to remove consistency or the same interference information, highlight abnormal information in the background, and at the same time, background denoising will remove direct waves.

(4) Gain processing: Gain processing is a function that can be used multiple times in data processing. During the propagation of electromagnetic waves, energy attenuation is significant. By increasing the corresponding gain multiple of the channel data, the amplitude of the entire data is balanced to improve the identification of abnormal information. The selection of gain multiples is based on the magnitude of the data amplitude, with small gains for larger data amplitudes and large gains for smaller amplitudes. The automatic gain in the processing software basically meets the requirements. When the automatic gain cannot make the data display meet the requirements, manual gain can be used to draw a gain curve that can meet the requirements using the mouse.

(5) Sliding Average: The commonly used functions of sliding average are divided into two types: low-pass and high pass. When using the sliding average function, it is necessary to set the size of the sliding window and calculate the average value of data within the window. If this average is used instead of the profile data, this bit is low-pass and its main function is to suppress white noise interference, making the data smoother and the abnormal shape more complete; If the average value is subtracted from the profile data, this bit is high and the purpose is similar to background denoising, which is to remove the background in a certain area near the calculation data point. The selection of the background changes with the change of the calculation point, and the removal of this background is more powerful than background denoising.

The data processing flow of geological radar is shown in Figure 2.

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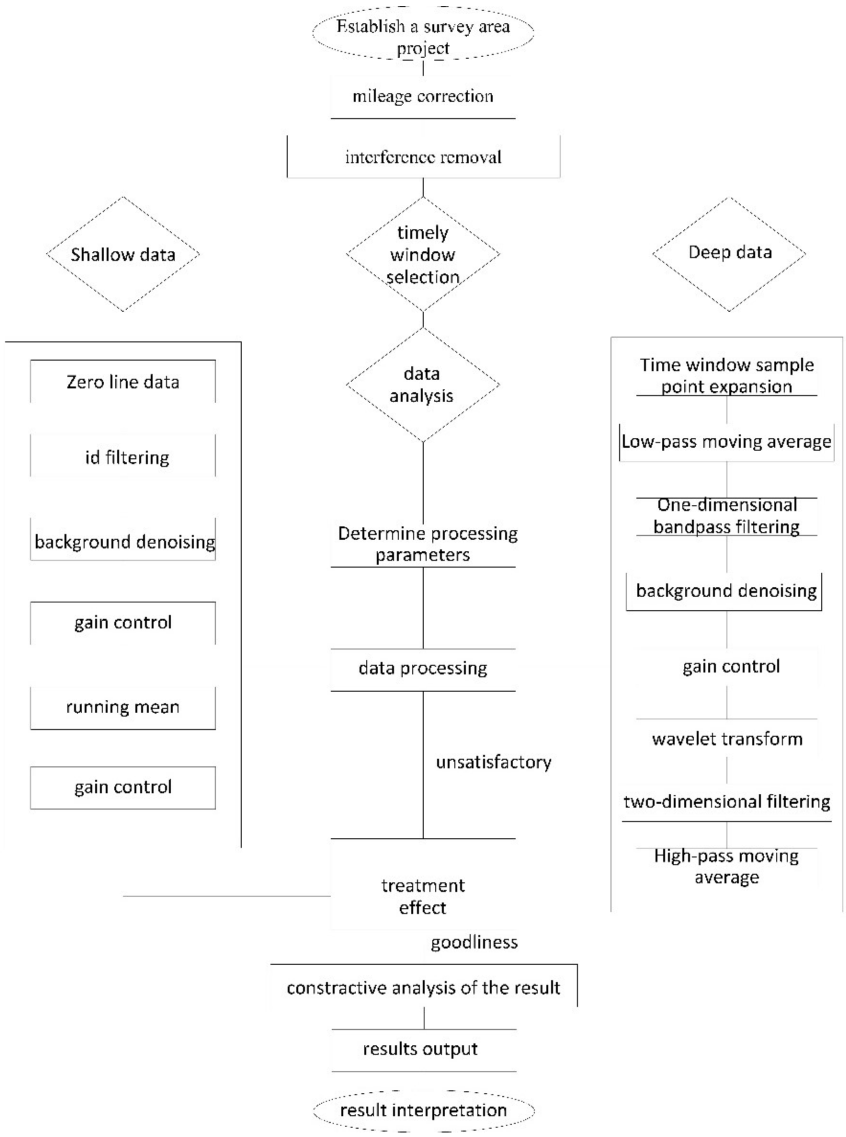

Figure 2. Radar data processing flow

The interpretation of the radar profile is mainly aimed at the analysis of the radar time profile, which mainly analyzes the lateral variation of the radar wave along the horizontal direction at the same time depth. For commonly used materials, the relative dielectric constant of water is the largest, the relative dielectric constant of air is the smallest, and the relative dielectric constant of other materials is between the two. Therefore, when the dam body is damaged, the ‘solid, liquid and gas’ three-phase ratio of its structural layer components will also change accordingly. The change of its relative dielectric constant becomes one of the theoretical basis for the detection of dam leakage, cracks and hollowing out of gorgon nuts by geological radar method.

4. Application Experiments

4.1 Experimental Instruments

This detection uses the GR-IV portable geological radar host independently developed by China University of Mining and Technology (Beijing) and a 50 MHz single-transmit single-receiver shielded antenna (Figure 3). This type of geological radar series antenna has the advantages of detection distance, accuracy and directivity. The specific equipment information is shown in Table 1.

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(a)Host (b)Connector (c)Antenna

Figure 3. Geological radar equipment diagram

Table 1. Technical parameter information of GPR

Equipment	Technical parameters	
GR series radar hosts	Overall dimension	300mm×200mm× 65mm
	Weight	<3kg
	Battery design	Snap-on type
	A/D conversion	16-bit
	Display modes	Curve, variable area, color section
	Data acquisition modes	Continuous, single point, range wheel control
	Sampling time window	5~3000ns
	Minimum Resolution	5ps
	Sampling points	512, 1024, 2048 available
	Pulse repetition frequency	100KHz
50Mhz shielded antenna	Overall dimension	2500 mm×800 mm ×180mm
	Antenna types	Transmission and reception split type
	Shielding modes	Shielded coupled TE polarized antenna
	Front-end analog noise amplifier	-20dB~+40dB

According to the propagation law and detection depth requirements of electromagnetic waves in geotechnical media. Set the instrument parameter sampling time window to 500ns, with 1024 sampling points and a sampling frequency of 100k. Use the ranging wheel mode for triggering and positioning for continuous detection.

4.2 Experimental Plan

Due to the limitations of the water surface conditions, this exploration was conducted at the top of the embankment, with a 50 MHz single transmitter and receiver antenna arranged on a measuring line with a total length of 29 meters. During on-site inspection, the radar antenna is tightly attached to the detection surface, continuously dragged along the measuring line, and triggered and positioned using the ranging wheel mode.

4.3 Result Analysis

The leakage channel of a dam usually has a high water content, and water is a good conductor, which leads to a higher conductivity of the leakage channel compared to the surrounding medium. At the same time, the leakage channel of a dam is usually caused by poor geological conditions or hidden engineering defects, and the wave speed of the leakage channel is lower than that of the surrounding normal medium. Therefore, when there is a leakage channel in the dam body or foundation, there will be significant differences in electrical properties and wave impedance between the leakage channel and the surrounding medium. The radar images obtained during radar detection will show significant differences. Based on this characteristic, the moisture content of the detected soil can be identified to determine whether there is a potential leakage hazard. In soil with water content, radar

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electromagnetic waves will experience significant attenuation, reflected wave frequency will decrease, and amplitude will increase.

The dam body detected this time has an abnormal area of water enrichment, and the detection results are shown in Figure 4 From the radar profile, it can be seen that the single transmitter and single receiver antenna has an effective detection depth of up to 28 meters. Within the range of mileage (K1+501 to K1+525) and depth of 11-15 meters, there may be obvious water rich areas. The specific manifestation is that the radar image waveform is chaotic and disorderly, and the layering of the strata is good within the first 10 meters. The layering of the strata at depths of 10-17 meters is unclear, and the coaxial axis in the figure is intermittent with significant amplitude changes. The waveform response in the 11-15m section is relatively strong, and it is speculated that the poor continuity of the formation is caused by rock fragmentation. This is because the cracks may contain water, resulting in a strong waveform response, and multiple strong reflections with certain regularity will also occur in the lower strata. Therefore, it is inferred that the area from mileage K1+501 to K1+525, with a depth of 11-15m, is a strong leakage zone and a clear water rich area.

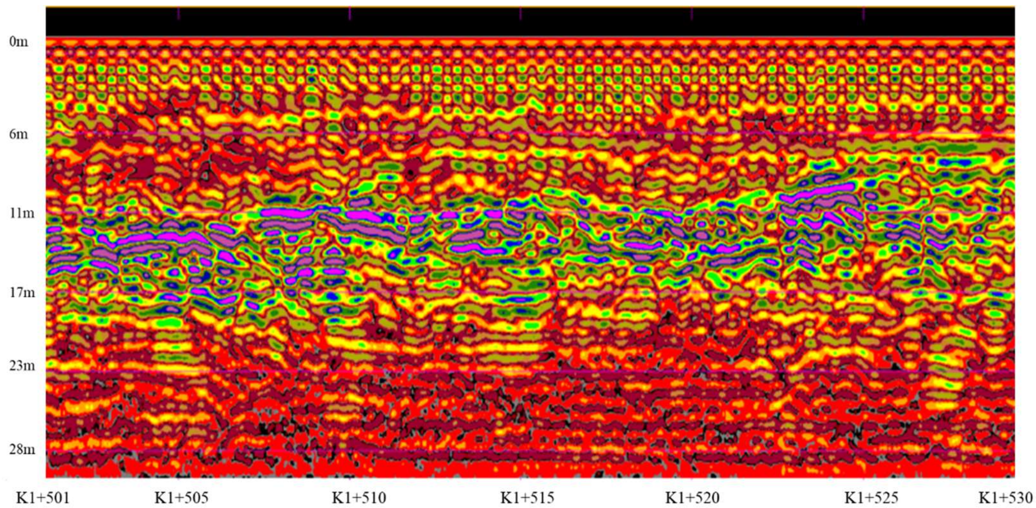

Figure 4. Radar Line Detection Results

5. Conclusion

The serious leakage of the dam body poses a threat to the safety of the dam structure. The application of ground penetrating radar technology in engineering dam leakage detection experiments shows that the effective detection depth in the dam environment can reach 28 meters, realizing the detection of water rich areas and seepage channels, identifying relatively weak wall sections and hidden dangers in engineering construction, and effectively solving the problem of leakage related to the reservoir dam foundation. This detection technology method and scheme are in line with reality, achieving the expected goals, providing data support for dam safety management, and having important significance for dam engineering and the safety of surrounding residents.

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