Application Research of Ground-Penetrating Radar in the Quality Inspection of Concrete Anti-seepage Panels

Meng Li[1], Changde Ren[2], Lei Zhao [3] and Shijiao Luo[4,*]

[1]China Institute of Water Resources and Hydropower Research, Beijing 100038, China
[2]Shandong Huahai Group Co., Ltd, Dezhou Shandong 253000, China
[3]Shanxi Xilongchi Pumped Storage Power Station Co., Ltd, Xinzhou Shanxi 035503, China
[4] School of Soil and Water Conservation, Beijing Forestry University, Beijing 100083, China

Abstract: If the sand-free cushion of concrete anti-seepage panels of reservoir is void, it will cause local instability or even crack and collapse of the panel, which will lead to large leakage of reservoir and affect the safe operation of the project. In this paper, the ground-penetrating radar (GPR) method is used to scan the concrete panel. The results show that the quality of the panel is good overall, the distribution of rebar is uniform, and the contact between the panel and the sand-free cushion is dense. Some panels have internal voids and the contact between the cushion and the rock foundation is not dense, while no obvious hollowing is found in the sand-free cushion.

1 Research background

The normal impounded water level of a reservoir in Shanxi is 838 m, the dead water level is 798 m, the working water depth is 40 m, the total storage capacity is 502.99×104 m^3, and the regulated storage capacity is 432.2×104 m^3. Mixed lining scheme is adopted for seepage control. The rock foundation of reservoir bank is lined with concrete panels, and the main dam and reservoir bottom are lined with asphalt concrete panels [1]. The concrete panel of reservoir bank has a thickness of 40 cm, the longest length of 110 m and a maximum slope of 1:0.75. It is one of the steepest concrete panels in China with only vertical joints and no horizontal joints. In order to avoid the influence of uneven foundation excavation on the deformation of panels and to reduce the restraint of panels, there is a 30 cm thick sand-free concrete drainage cushion between the panel and bedrock, and anchor bars are used for anchoring between the panel and the rock foundation.

After the operation of the reservoir, cracks appear in the panel of reservoir bank, the surface water stop of some joints is damaged, and the leakage is obvious. After two treatments, the total amount of leakage decreases, but the leakage of the connecting gallery and other parts of the reservoir bank is too large, and more precipitates from the drainage gallery need to be cleaned up, which indicates that leakage causes corrosion damage of the anti-seepage body [2, 3]. Because of the high strength and good compactness, the corrosion resistance of concrete panels is stronger than that of sand-free concrete, so the sand-free concrete is more likely to be corroded. Therefore, comprehensive evaluation of the quality of concrete panels should be carried out to provide the basis for the next treatment.

GPR is a nondestructive testing technology which has developed rapidly in recent years. It was first used in the detection of pavement thickness of highway. The composition of concrete panels is similar to that of highway pavement. The difference of dielectric constants of various layers is the physical basis of GPR detection [4].

2 Basic principle of GPR

The radar system transmits broadband high frequency electromagnetic wave to the ground by antenna. When the electromagnetic wave signal propagates in the medium, it will reflect, transmit and refract when it encounters the dielectric interface with great dielectric difference. The greater the difference of dielectric constant between the two media, the greater the reflected electromagnetic wave energy. After the reflected electromagnetic wave is received by the receiving antenna which moves synchronously with the transmitting antenna, the motion characteristics of the reflected electromagnetic wave are accurately recorded by the radar host, and then processed by the signal processing technology to form a full-section scanning map. Through the interpretation of the radar image, the engineers and technicians can judge the actual structure of the underground target [5]. The formulas for calculating the main parameters used for detection are as follows:

(1) Round trip time of electromagnetic wave

*Corresponding author's e-mail: 704982475@qq.com

$$t = \frac{\sqrt{4z^2 + x^2}}{v} \tag{1}$$

Where: z ——Burial depth of the detected target object;

x ——Distance of transmitting and receiving antennas;

v ——Propagation velocity of electromagnetic wave in medium.

(2) The propagation velocity of electromagnetic wave in medium

$$v = \frac{c}{\sqrt{\varepsilon_r \mu_r}} \approx \frac{c}{\sqrt{\varepsilon_r}} \tag{2}$$

Where: c ——Propagation velocity of electromagnetic wave in vacuum (0.29979 m/ns);

ε_r ——Relative dielectric constant of medium;

μ_r ——Relative permeability of medium. For non-magnetic medium, the value is generally 1.

(3) Reflection coefficient of electromagnetic wave

When electromagnetic wave propagates underground, reflection and transmission will occur at different electrical interfaces. The magnitude of reflected electromagnetic wave is one of the main bases for identifying defects in medium. Its reflection coefficient can be expressed as:

$$R_{12} = \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}} \tag{3}$$

Where: ε_1 and ε_2 are the relative dielectric constants of the dielectrics on both sides of the electrical interface.

(4) Relationship between GPR recording time t and detection depth z

$$z = \frac{1}{2} vt \approx \frac{ct}{2\sqrt{\varepsilon_r}} \tag{4}$$

Formula (3) shows that the greater the difference of dielectric constants between the two sides of the reflection interface, the greater the reflection coefficient, the stronger the reflection of electromagnetic wave, and the easier the medium interface to identify. By comparing the difference of dielectric constant between concrete lining and surrounding rock and the internal defect of lining concrete, the void part of surrounding rock and the internal defect of lining concrete can be detected [6,7].

3 Detection scheme

There are 122 concrete panels on reservoir bank slope, including 7 toe boards at the intersection of bank slope surface. The total length of the concrete panels along the axis of reservoir bank is about 1055.3 m, which is divided into 12 areas from right to left. The slope ratio of panel slope in areas: YPQ1-YPQ3, YPQ5-YPQ8 and YPQ10-YPQ11 is 1:0.75. The field construction photos are shown in Figure 1. The slope of the area YPQ12 area is from 1:2 to 1:0.75, which is a twisted panel; the slope of the area YPQ4 is 1:1.2; and the slope of the area YPQ9 is 1:0.8. In areas YPQ3 and YPQ4, the slope of some slope sections is adjusted to 1:1.053, and the rest are twisted panels. The standard width of concrete panel is 12 m, 10 m and 8 m. The joint between the panel area is densified, and the width of the panel gradually decreases from standard width 12 m to 6 m.

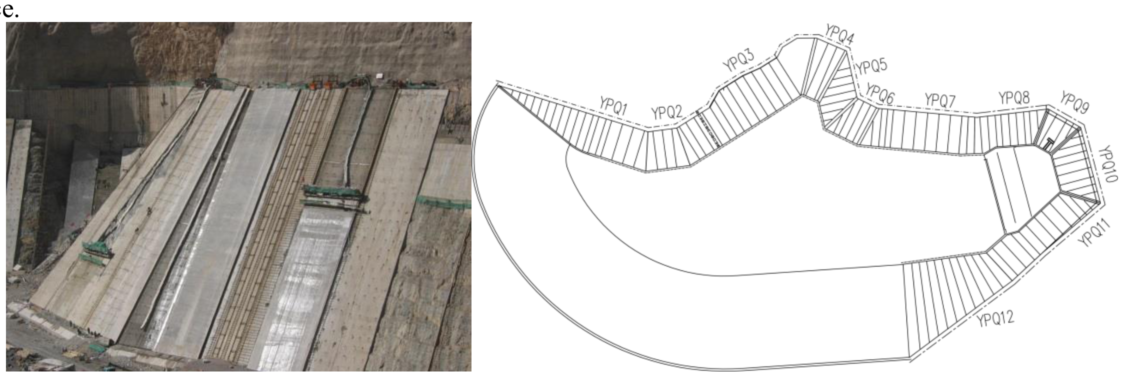

Figure 1. Construction process of concrete anti-seepage panels

The field survey found that there were four areas with large leakage, of which area YPQ3 accounted for 25%, area YPQ6 accounted for 14%, area YPQ7 accounted for 14%, areas YPQ8, YPQ9 and YPQ10 near the intake connecting gallery accounted for 14%. Therefore, the four areas with large leakage were selected for comprehensive detection by ground-penetrating radar.

A measuring line is laid every 1m along the length direction of the panel. Considering that the surface of the panel is not smooth enough, which will affect the rotation of the ranging wheel, the hoisting machine is used to provide lifting power on the spot. The measuring line is marked first and then the antenna is manually supported to conduct the detection (Figure 2). The hoisting machine with uniform speed and slow rotation is more conducive to antenna moving. Manually pressing the antenna to keep it in close contact with the panel can ensure the detection quality. Because the slope of the panel is not uniform, the length of each measuring line from the dam top to the water surface is different, and the longest line length is 18 m.

Figure 2. Field inspection of concrete anti-seepage panels

The GPR is a SIR-4000 type of ground-penetrating radar produced by GSSI Company of the United States. The data acquisition is set as range mode. The 900 MHz antenna, as the main antenna, measures the internal quality of the panel and the void between the panel and the sand-free cushion, while the internal quality of the cushion and the rock foundation are measured with 400 MHz antenna as the auxiliary. For 900 MHz antenna, the recording time is 22ns, the sampling points are 512, the gain points are 8, the IIR low-pass filter is 2500, the high-pass filter is 225; for 400 MHz antenna, the record time is 40ns, the sampling points are 512, the gain points are 8, the IIR low-pass filter is 800, the high-pass filter is 100. Because the relative dielectric constant of different media is slightly different, it needs to be measured separately in different projects. The radar scanning figure shown in Figure 3 is measured by using the known thickness of the wave wall in this field test. The corresponding relative dielectric constant is 8.0.

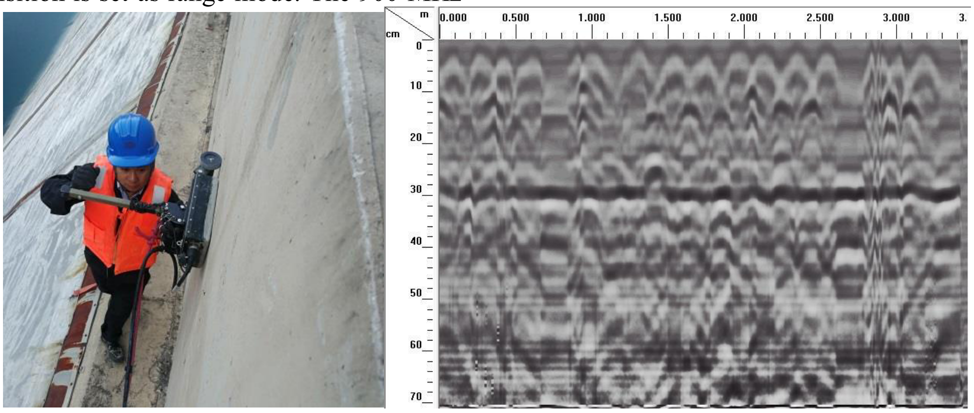

Figure 3. Construction process of concrete anti-seepage panels

4 Detection result

In order to eliminate interference factors, zeroing, spatial filtering, gain recovery and deconvolution filtering are carried out after data acquisition. In the processing, the deconvolution filtering method can obviously eliminate multiples and improve the resolution of data. The results obtained are more intuitive and easier to interpret. Keep processing until the image can reflect the information under the concrete panel most clearly. There are many kinds of radar images, and different positions have different image characteristics. Typical images are selected for analysis and display.

The GPR detection of four regions shows that the quality of the panel is good overall, the distribution of steel bar is uniform, and the contact with the bottom cushion is dense. Figure 4 is a typical scanning image of 900 MHz antenna of good quality of the panel. Because the material of concrete itself is similar to that of the cushion and the dielectric constant of both is similar, the waveform of electromagnetic wave is uniform in the process of conduction, so it is difficult to distinguish the demarcation line between the two materials. The panel fits well with the cushion and deforms together to resist external action. The scanned image with clear image and good imaging effect can be regarded as the best working state image of concrete panel structure, which can be used as the standard image to judge whether the reinforcement treatment for void defects is in place. It also shows that the frequency accuracy of 900 MHz is moderate, and the detection depth is close to the thickness of concrete panel, which can be used as the basic frequency to judge whether the void character is good or not.

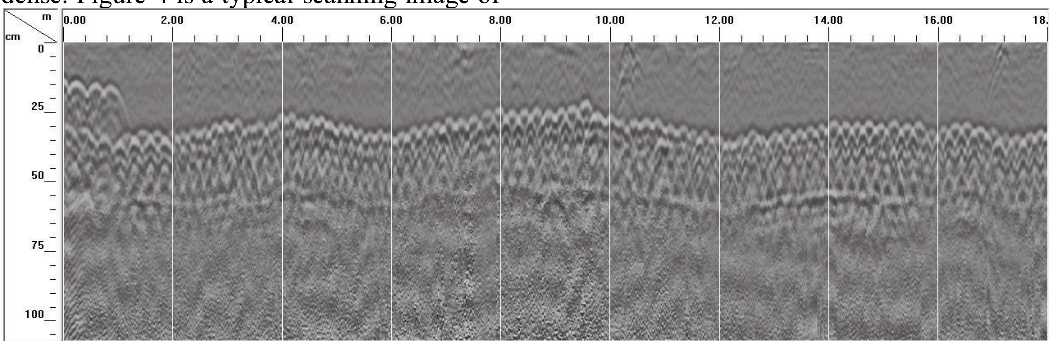

Figure 4. Typical radar scanning image of concrete panels with good quality (900MHz antenna)

Some panels have internal voids and the contact between the cushion and the rock foundation is not dense, as shown in Figure 5. Comparing with several similar lines, it can be seen that the voids all occur above the steel bar of the concrete panel, which indicates that the casting quality of concrete panels is uneven.

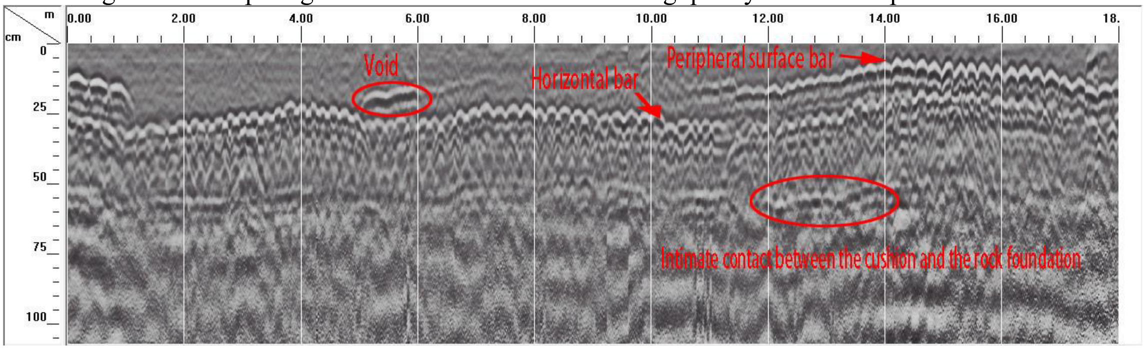

Figure 5. Radar scan image of defective concrete panels (900MHz antenna)

Typical images detected by 400 MHz antenna are shown in Figure 6. The bottom of concrete panel fits well with cushion, and in radar images which show no obvious void in panels, the panel combines well with the bottom cushion, but it is difficult to distinguish the interface between cushion and rock foundation. This indicates that although the detection accuracy of 400 MHz antenna is low, it can observe the compactness of the bottom cushion, and it can play a role in quality monitoring of the construction of the panel cushion.

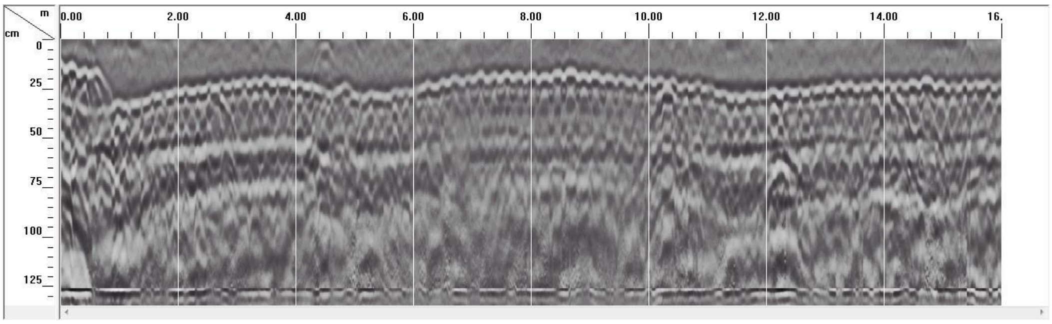

Figure 6. Typical radar scanning image of concrete panel with good quality (400MHz antenna)

5 Conclusion

By conducting the GPR detection of the concrete panel of the rock foundation of the reservoir, the results show that the quality of the panel is good overall, the distribution of rebar is uniform, and the contact between the panel and the sand-free cushion is dense. Some panels have internal voids and the contact between the cushion and the rock foundation is not dense, while no obvious hollowing is found in the sand-free cushion. Comparing the test results of 400 MHz antenna and 900 MHz antenna, it can be seen that both of them can detect the contact between lining and cushion, but 900 MHz antenna has higher accuracy and can clearly show the internal defects of panel, which can provide reference for similar engineering detection.

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