Journal of World Architecture, 2023, Volume 7, Issue 2
http://ojs.bbwpublisher.com/index.php/JWA
ISSN Online: 2208-3499
ISSN Print: 2208-3480

Application of Non-Destructive Testing Technology in Quality Testing and Control of Water Conservancy Projects

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Abstract: In view of social development, the demand for water conservancy engineering applications continues to increase. The number and scale of water conservancy projects in China have been in a state of continuous expansion in recent years. As a result, how to achieve efficient testing and effective control of the quality of water conservancy projects has always been a topic of discussion in the field of water conservancy engineering in our country. This paper summarizes the application of non-destructive testing technology in the quality testing and control of water conservancy projects. On the basis of explaining the connotation and application advantages of non-destructive testing technology, the non-destructive testing application strategies for concrete strength, steel corrosion and shallow cracks in water conservancy projects were studied.

Keywords: Hydraulic engineering; Non-destructive testing; Quality inspection; Quality control

Online publication: April 25, 2023

1. Introduction

Water conservancy projects are not only the development of infrastructure for the country, but also an important force for economic development. The quality of water conservancy projects is closely related to the vital benefits of the public. The projects should be able to withstand natural disasters such as heavy rainfall and floods. As a technology widely used in engineering projects in recent years, quality testing and control of water conservancy projects is crucial to the improvement of the quality of water conservancy projects in our country and the sound development of economy and the people's livelihood.

2. Meaning of non-destructive testing technology

Non-destructive testing involves using the properties of sound, light, magnetism, and electricity to detect any defects or inhomogeneities in the tested object *in situ* without damaging or affecting its performance, including quantitative and qualitative information such as defect size, location, nature, quantity, and many more. Non-destructive testing has three meanings, which are non-destructive examination, non-destructive detection, and non-destructive evaluation. Traditional non-destructive detection refers to the most basic content of non-destructive testing, but with the development of related technologies and requirements in recent years, non-destructive testing has expanded from non-destructive examination to non-destructive examination and non-destructive detection, and its technical connotation has expanded. Non-destructive evaluation covers non-destructive examination and non-destructive detection, so non-destructive evaluation has a broader definition. Traditional detection only includes defect detection and evaluation of the test object according to the design requirements, but the non-destructive involves quantitative testing and qualitative evaluation on the reliability, integrity and design satisfaction of the test object. The meaning and scope of detection have been generalized and expanded. Non-destructive testing has the following characteristics.

(1) Does not damage the performance of the detected object when doing the detection

(2) Capable of performing a comprehensive detection of the sample, which is impossible for destructive detection

With the rapid development of non-destructive testing technology, non-destructive testing has been applied in the field of quality control of water conservancy projects, so that the structures under construction can be well tested without damage, and the quality supervision and management of water conservancy projects can be developed [1].

3. Advantages of non-destructive testing technology in quality testing and control of water conservancy projects

The advantages of applying non-destructive testing technology to water conservancy project quality testing and control are mainly reflected in its continuity of testing operations and physical characteristics [2].

(1) Continuity of testing operations

The traditional testing method of water conservancy projects requires a sample of the detection object, and there are many intermittent operations throughout the test, thus continuous testing cannot be achieved. In addition, traditional quality testing methods require repeated sampling and testing, and the duration of testing is long, and the results cannot be obtained immediately. In large-scale water conservancy projects where many areas need to be tested, traditional detection methods can be costly and time-consuming, and quality control during the construction process has a negative impact on the subsequent construction process. With non-destructive testing technology, the collected data also has high continuity reliability, and real-time, which can improve the collection of raw data and the analysis and evaluation of data [3].

(2) Physical characteristics of testing technology

As a physical quantity measurement method, the application of non-destructive testing technology in the quality testing and control of water conservancy projects can be done based on systematic calculation and analysis without damaging the object of interest, so the water conservancy project's structures can be effectively protected [4]. At the same time, on the basis of timely acquisition of test results, accurate data feedback can be obtained whether it is material consumption, construction technology or project quality, and continuous and reasonable judgment on construction quality can be achieved [5].

4. Application strategy of non-destructive testing technology in water conservancy project quality testing and control

(1) Non-destructive testing of concrete quality in hydraulic engineering

Ultrasonic rebound comprehensive method is a non-destructive testing technology developed based on rebound testing. Taking a water conservancy project as an example, the bridge of the water conservancy project is 6.0 m wide and 30 m long. It is a three-span bridge with a length of 30 m, 10 m for each span. The components include web, support, lower flange and upper flange. The concrete strength of the girder flange, web, and support was tested. The procedure of ultrasonic rebound comprehensive method are as follows:

(i) The procedure is based on the "Technical Regulations for Testing the Compressive Strength of Concrete by Ultrasonic Rebound Comprehensive Method" (T/CECS02-2020) [6].

(ii) In terms of detection methods, the area of springback measurement was arranged on the girder web; the two sides of the support, the upper flange, and the lower flange, and the surface of the measurement area was cleaned with a grinding wheel to ensure that the surface flatness of the measurement area met the test requirements. Then, a rebound tester was used to obtain the rebound value, and an acoustic wave transducer was set in the coaxial symmetrical rebound area, and an ultrasonic testing equipment was used to test the wave velocity.

(iii) The final step was the organization of test data. Firstly, when calculating the average rebound value of the measurement area, one maximum value and one minimum value were respectively deleted from the 10 rebound values in the self-test area, and then equation (1) was used for calculation.

$$R_m = \sum_{i=1}^{I^d} R_i / 10 \tag{1}$$

In equation (1), R_m represents the average springback value of the measurement area, which requires a sensitivity of 0.1MPa; R_a represents the specific rebound value of the i-th measuring point. Then, the ultrasonic sound velocity value test was carried out, and the volume of each measurement area is tested according to equation (2), and three measuring points were arranged axisymmetrically at the test point:

$$\begin{aligned} V &= L/t_m \\ tm &= (t_1 + t_2 + t_3)/3 \end{aligned} \tag{2}$$

In equation (2), V, L and t_m represent the sound velocity value (km/s) of the survey area, and the average sonic time (μ_s), respectively, of the ultrasonic range based on the test area; t_1, t_2, and t_3 represent the sonic time of the three measuring points in the measuring area. After calculating the wave velocities, each value was corrected. Lastly, a strength measurement curve or regional strength measurement curve was plotted to calculate the concrete strength conversion value and determine the concrete strength of the component.

The ultrasonic-rebound comprehensive method does not damage the concrete structures, and the data obtained is accurate and reliable. It is suitable for the determination of strength of structural components such as pier walls, wing walls, and bent frames in water conservancy projects. Quality problems such as holes and honeycombs in concrete structures can be directly detected. However, this method has higher technical level requirements for the operators [7,8].

(2) Non-destructive testing of steel bar corrosion in water conservancy projects

For the detection of steel corrosion, the traditional method involves using the self-potential method or the measurement of carbonation depth + thickness of steel protective layer, while the non-destructive testing technology mainly adopts the self-potential method to carry out continuous detection.

In terms of traditional measurement of carbonation depth + thickness of steel bar protective layer, to measure the carbonation depth, an electric hammer is first used to drill a small hole on the north side. After cleaning the powder in the hole, one drop of 1% phenolphthalein solution is added into the hole, and a carbonation depth meter or a vernier caliper was inserted into the hole to measure the distance from the surface to the deep discoloration to obtain the carbonation depth [9]. Subsequently, the thickness of the concrete cover was measured using an electromagnetic steel bar scanner, and the distribution of the steel bars in the component and the thickness of the steel bar cover can be accurately displayed digitally. The disadvantage of this method is that it causes certain damage to the concrete components because drilling is required in the process [10].

Under the non-destructive testing technology based on the self-potential method, the steel bar is wrapped in concrete, which is equivalent to the steel bar being immersed in a saturated $Ca(OH)_2$ solution.

In the solution, an electric double layer will be formed at the interface of the metal due to the interaction, and at the same time, a potential difference will be generated on both sides of the interface. Then, the natural point position of the steel bar in the concrete is measured using high internal resistance natural potential meter. The measurement data is obtained directly, so as to realize the analysis of the corrosion of steel bars, and the measurements are carried out continuously at different points. The potential difference of -100mV to -300mV indicates that the steel bar will be in a passivated state. The potential difference of -300mV to -400mv indicates that the steel bar may be corroded. If the potential difference is lower than -400mV, it means that the steel bar has been corroded.

In a project example, the steel bar corrosion test was carried out on the pier wall of the sluice chamber of a drainage sluice station. A copper electrode was connected to the exposed steel bar, move the other saturated copper sulfate electrode on the pier wall of the sluice chamber in sequence at an equal distance of 30cm, and the potential difference for each point was measured. After measuring the potential difference at multiple measuring points, a potential contour line was plotted based on the results obtained. The points with potential difference more than -400mv are displayed as shadows, and the corrosion of steel bars of those parts were analyzed. After the test was completed, the on-site damage verification shows that the results of the two methods were consistent [11].

(3) Non-destructive testing of shallow cracks in water conservancy projects

For the detection of shallow cracks in concrete engineering, the traditional detection method is the core drilling method. In this method, a core drilling machine is used to drill through the seam, and the core samples are tested. The advantage of this method is that it is easy to operate, and the conclusion is intuitive and clear. The disadvantage is that the components will be damaged, and in the process of core drilling and sampling, the intermittent testing of multiple measuring points takes a long time and is costly. Therefore, this method is not suitable for structures that require water stop and water closure [12].

Ultrasonic pulse velocity test is a non-destructive testing technology widely used in the detection of shallow cracks in hydraulic engineering. Based on the "Hydraulic Concrete Test Code" (SL/T 352-2020) [13], it can realize efficient non-destructive testing of cracks in hydraulic structures. The working principle of the ultrasonic pulse velocity test is to use an ultrasonic detector with a waveform display function to measure the propagation velocity of the ultrasonic pulse in the concrete structure, the amplitude of the first wave, and the frequency of the received signal, and defects inside the concrete are detected based on the analysis of the parameter signal changes.

Using a water conservancy project as an example, shallow crack detection was performed using the HC-U91 concrete ultrasonic detector, and the testing line was first arranged in the testing stage. The measuring points were then arranged at the maximum width of the crack for different distance measurements according to whether the gap is crossed or not, and the sonic time measurement was carried out. To measure the sound without crossing the crack, the receiving and transmitting transducers were placed on the same side of the crack, and the sonic time of the transducers were read at a distance of 50 mm, 100 mm, 150 mm, 200 mm, 250 mm... respectively. To measure the sonic time across the gap, the transmitting and receiving transducers were arranged on both sides of the crack respectively, and the sound time values were read at a distance of 50mm, 100mm, 150mm, 200mm.... The data obtained were then processed, and the crack depth was calculated according to equation (4).

$$h_{ci} = l_i / 2 \cdot \sqrt{(\mathrm{t}_i^0 / l_i)2 - 1}$$
$$m_{hc} = l / n \cdot \sum_{t=1}^{io} h_{ci} \qquad (4)$$

In equation (4), l_i represents the actual propagation distance of the ultrasonic waves at point i in the non-spanning evaluation stage, h_{ci} represents the crack depth value calculated at point i, and t_1^0 represents the sonic time during the wind crossing evaluation at point i. m_{hc} is the average value of fracture depth calculated at each measuring point, and n is the number of measuring points. Using the same project as an example, there are cracks with a width of 0.12–0.44 mm, a length of 0.93 m, and a depth of 187 mm in the pier on the left side of the sluice chamber of the drainage sluice station.

(4) Non-destructive testing of the integrity of concrete underground cut-off walls

For the non-destructive testing of the integrity of underground cut-off walls in water conservancy projects, the high-density resistivity method can be used. Core drilling method is usually required in the traditional testing of the integrity of the underground anti-seepage wall in water conservancy projects. The disadvantage of this method is that a special drilling rig is needed to drill core samples from the concrete underground anti-seepage wall for strength or internal quality testing, which will cause damage to the wall. In contrast, the high-density resistivity method explores the distribution of underground conduction current based on the electrical difference of the medium under the background of an applied electric field. Compared to the conventional electrical method, the high-density resistivity method sets a higher density of measuring points. The simulation of three-dimensional images can be formed based on the two-dimensional information obtained by its application nodes.

Using a project as an example, the first stage of this test was to first confirm the type of electrode device and the measurement layout plan. A table was prepared based on the measurement sequence, and the electrode layout was outlined, and the grounding resistance was minimized. Secondly, a column was set for every 3m, and 16 rows were set for continuity testing. The testing and K value calculation were automatically completed by the equipment. Thirdly, the dielectric resistivity inversion calculation was carried out by using full waveform inversion. The first step of calculating the dielectric resistivity inversion was to establish a dielectric resistivity model based on the apparent resistivity obtained from the test and other known information. Next, the three-dimensional potential distribution was obtained through the resistivity model. Subsequently, the obtained potential value was compared with the measured value, where the difference between to two values are calculated. If the difference was within the predetermined range, the resistivity model can be used calculate the real resistivity of the regional medium; otherwise, the resistivity model should be corrected based on the error and sensitivity matrix, and recalculated until the obtained difference is less than the acceptable value.

The apparent resistivity of the test area of the concrete underground anti-seepage wall of the project was measured to be < 20 **Ω•**m, which was quite different from other areas. After data analysis, it was confirmed that the cementation of the concrete underground anti-seepage wall of the project was poor, and there was mud in some areas, but the overall anti-seepage density was good. After completing the high-density resistivity method test, the average permeability coefficients of different pile numbers were obtained through the penetration test of the pressure water test at different pile positions (**Table 1**).

Table 1. Permeability coefficient of concrete underground anti-seepage wall in different pile positions in pressurized water test of the case project

Station number	**0+170.5**	**0+202.7**	**0+242.5**	**0+309.5**	**0+122.4**	**0+119.00**
Average permeability coefficient (10^7 cm/s)	6.42	6.65	6.47	7.15	7.77	7.61

5. Conclusion

To ensure the quality of water conservancy projects, it is very important to adopt scientific and advanced testing technology. Non-destructive quality testing method proposed in this paper can be used to realize rapid and continuous testing without destroying the foundation of structural components. At the same time, to maximize the advantages of non-destructive testing technology, water conservancy testing units should strengthen the training of their staff so that they are proficient in various non-destructive testing techniques.

Disclosure statement

The author declares no conflict of interest.

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