Safety Test on the Regulating Gate of Fengtanggou Irrigated Area in Qixing Canal Ningxia Autonomous Region

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Abstract. In water projects, the water gate is widely used as a kind of construct to intercept water, discharge water or retain water. It is an essential measure to fulfill regular safety appraisal on the water gate so as to ensure the safe operation of sluice project. As of now, the regulating gate of Fengtanggou in Qixing Canal, Ningxia Autonomous Region has been in service for more than twenty years since its establishment. To obtain an overall comprehension of its operation status, as well as carry on thorough test on its safety, this paper introduced the tests on its concrete structure and metal structure, thus providing basis for the management of engineering operation.

1. Introduction

The water gate is a type of low-head hydraulic engineering architect. It is used to regulate the water level and control the water flow. Furthermore, the water gate works as a controller among the numerous hydro-junction projects in plain area. It possesses dual functions: retaining water and discharging water. In the process of operation, the water gate suffers from ageing damages step by step. And the structure undertakes a decline in safety, applicability and durability. Accordingly, it cannot give full play to its normal functions when latent risks arise progressively.

Therefore, it is imperative to carry on regular safety assessment on the water gate. The Fengtanggou regulating gate of Ningxia Qixing Canal is located at the high trunk canal of the Phase I water source in Ningxia Yellow River Pumping Irrigation Project. The regulating gate belongs to type (1) project. Its designed flow rate is 30m³/s; and its enlarged flow rate is 33.1m³/s. It has three holes which net size is 4*3.8m respectively. The total length of the water gate is 55.5m. It is composed of the upstream bedding section, the chamber section and the downstream fencing section. The main structural part of regulating gate is made of concrete. Its design strength is C20. It used Mu20 rubble as the grouted rubble, mixed with the M7.5 mortar and jointed with M10 mortar. The Fengtanggou regulating water gate was founded in 1999. To date it has worked for over twenty years. In 2020, the water gate has passed the safety inspection and reached the engineering safety level of assessment, analysis and evaluation. This provides the scientific foundation for engineering operation and management.
2. Structural Test of Reinforced Concrete

2.1. Visual Defects of Concrete
The inspection on the visual defect of concrete is mainly carried on by the engineers and technicians who have engineering test experiences. They find out the external damages and defects by visual inspection on site.

Through test, the overall quality of Fengtanggou regulating gate is good. The gate chamber is free from apparent sedimentation, tilt, slippage or else abnormal situations. However, cracking and tiny erosion occur to some of the concrete structural parts. The operating bridge has cracks along the reinforcing bar that is exposed to rust expansion. And the wing wall in the downstream suffers from penetrated cracks.

2.2. The Concrete Strength
Rebound method and core drilling method were used to test the strength of concrete. The rebound method is currently the most common non-invasive method to test the concrete strength. On this basis, the core strength sampling method was applied to obtain the real compressive strength of the concrete, consequently reviewing the test value by rebound method.

The above methods were used to test the concrete strength of the flood-recession sluice pier, the apron, the bent frame and else essential structural parts. The test values of these selected typical positions were shown in Table 1.

Table 1 Test results on the rebound strength of concrete at the typical positions

| Detection position       | Rebound value (MPa) | Carbonization depth (mm) | Specified value (MPa) | Standard deviation (MPa) |
|--------------------------|---------------------|--------------------------|-----------------------|--------------------------|
|                          | Maximum value       | Minimum value            | Average               |                          |
| Left pier                | 46.9                | 42                       | 44                    | 2.1                      | 41.6                   | 4.9                       |
| Right pier               | 50.2                | 33.2                     | 41.7                  | 2.2                      | 33.7                   | 1.4                       |
| Intermediate pier 1#     | 53.4                | 41.3                     | 47.3                  | 2                        | 40.8                   | 3.9                       |
| Intermediate pier 2#     | 51.9                | 39.5                     | 45.3                  | 2.3                      | 39.6                   | 3.5                       |
| Downstream guardian      | 56.3                | 38.1                     | 48.9                  | 2                        | 41                     | 4.8                       |
| Bent shelf 3#            | 34.1                | 28.9                     | 31.7                  | 23                       | 28.7                   | 1.8                       |
| Bent shelf 4#            | 37.6                | 30.6                     | 34.3                  | 21                       | 29                     | 3.2                       |

Totally four Φ100 core concrete samples were taken from the apron and the right pier of sluice. In accordance with the experimental method on testing the compressive strength of core concrete samples from the “Testing Regulations of Hydraulic Concrete” (SL 352-2006), the core concrete samples were processed into standard stress-resistant specimen as per aspect ratio 1:1 before compressive test. The experimental results were shown in Table 2 as follows.

Table 2 Test results on strength of core-drilling concrete sample

| Core sampling position   | Number of specimens | Average value of core sample (MPa) | Description of core sample appearance                      |
|--------------------------|---------------------|------------------------------------|------------------------------------------------------------|
| Downstream apron         | 2                   | 44.8                               | The concrete is dense without obvious pores                 |
| Right pier               | 2                   | 35.2                               | The concrete is dense, without obvious pores                |

Shown from Table 1 and Table 2, the strength of concrete in Fengtanggou regulating gate meets the requirements on original design strength, and the concrete was proved to possess superior quality.
2.3. Test on the Corrosion Status of Reinforcing Bar

The corrosion status of reinforcing bar in hydraulic concrete is a considerable factor to scale the durability of reinforced concrete structure. In case the reinforcing bar gets rusted, it often leads to expansion and cracking on the concrete and causes its protective layer to peel off. Under this case, the structural bearing capacity reduces and it even threatens the safety of the construct.

This test used GECOR8 steel corrosion tester from Swiss PROCEQ Company to detect the corrosion status at the operating bridge, the gate pier and other positions of the sluice. The typical isograms of erosion potential were shown in Figure 1 and Figure 2.

Through analysis on the isograms of erosion potential in the reinforcing steel, the half-cell potentials of the operating bridge in Fengtanggou regulating gate, the left and right pier as well as the gate chamber was between -200 ~ 350mv. It reflected an uncertain state of the reinforcing steel erosion. In combination with the general survey, it determined that the reinforcing steel inside the operating bridge has gone rusty, but erosion was not likely to occur at other positions.

2.4. Contacting Status of the Sluice Floor by GPR Test Method

The GPR is a type of non-invasive testing method. It can detect the internal cavity and voids of the sluice floor. Through a transmitter, the GPR sends high-frequency electromagnetic pulse wave to the tested body. According to the diversity of electromagnetic properties in different media, the receptor received various amplitudes, wave patterns, frequencies, the co-phase axis patterns and else characteristics from different electromagnetic waves. Then it analyzes and deduces the structure and physical property of the medium, thus deciding the internal defects of the medium structure. The operating principle of GPR was shown in Figure 3.
The SIR-4000 type of GPR from the American GSSI Corporation was used in this ground penetrating radar test. It was equipped with a 400M high-frequency antenna. Three measuring lines (three holes from left, middle to right) were laid from the upstream to the downstream. The typical test results were shown in Figure 4.

![Figure 4. Radar testing results of the left-hole sluice floor.](image)

Indicated from the measuring line at the left hole, the reinforced cover on the floor surface was not even. It was relatively thicker on the whole. Additionally, the floor and the foundation were tightly contacted to each other. And the stilling basin in the downstream possessed aquifer. The testing results at the middle hole and the right hole were identical to those at the left hole.

Furthermore, it also conducted the detection on the carbonation depth, the thickness of protective layer along with the width and depth of cracks for the concrete. After comprehensive analysis, the test results of concrete quality in Fengtanggou regulating gate basically fulfilled with the standard requirements. The quality defects that exposed in test were incapable of bringing about major effects on the project safety.

3. Test of the Hoist Equipment and Sluice Gate

3.1. Sluice Gate

The general status of three water gates in Fengtanggou regulating sluice was alike from one another. The overall situation of water gate is intact, and the structural parts of the gate were absent from damages or deformation. What’s more, the coating on the structural parts of water gate was almost intact. Its erosion level was A. That was, tiny erosion. Although the surface of weld joint on water gate was inferior in quality; small amount of manufacturing defects even existed in the weld joints, it didn’t affect the safe operation of water gate. The lifting lug device was in good connection; the supporting device of water gate possessed complete parts and they were connected perfectly. The sealing device of water gate also possessed complete components which fit together well; the embedded parts of the gate slot and the sill as well as the surrounding concrete were intact as well.

After detection on site, it eliminated the latent risk in the process of water gate operation. The Fengtanggou regulating gate can keep on servicing safely.

3.2. Hoisting Equipment

Three pieces of hoisting equipment and their components at the Fengtanggou regulating gates were under good condition. The equipment and operating system were arranged in a standard and reasonable way; moreover the auxiliary facilities were fully equipped. The power control system and the operational system of hoisting devices were functioning normally. No ageing was found in the circuit or the components; and the wiring was aligned in order; otherwise it had complete operating and controlling functions as well as clear interface. The screw was in good condition and it had normal functions. The frame of hoisting equipment was also under good condition. The operating and maintenance system was well established; the maintenance was done properly. In the meanwhile, the
The electrical parameters of hoist motor all accorded with the requirements on safety operation; and the hoist operated smoothly.

In accordance with the detection on site, the hoisting device was free from latent risk. Therefore, the three hoists at Fengtanggou regulating gate are able to continue their service safely.

4. Other Tests
The electric installation was reasonably selected and arranged. And the equipment in use received favorable maintenance. In addition, its power supply was secure and reliable. No apparent defects were found on the equipment so it could be put into normal use.

The silt in the upstream of water gate was filled up seriously. The sedimentation could decrease the flow section of canal and thus greatly raised the water level in front of the sluice. These problems arose to partly interfere with the safe operation of water gate.

5. Conclusions
After testing the quality of concrete in the Fengtanggou regulating gate at Qixing Canal, the existing defects are incapable of bringing great impact on the safety of project. On the other hand, latent dangers were eliminated by testing the sluice gate and the gate hoist. Furthermore, three hoists can still be used securely. To ensure the safe operation of water gate, three suggestions were provided for subsequent engineering management as follows: (1) The administrative unit is supposed to formulate the engineering safety assessment system in strict accordance with the relevant regulations of the Ministry of Water Resources; (2) The operating unit is advised to reinforce the engineering observation on the operation of water gate project, particularly prior to and after the flood season; (3) It advises to strengthen the tour inspection and review on the project, as well as to intensify later maintenance for normal operation.

Acknowledgments
This paper is supported by the National Key Basic Research Programs of China (No.2016YFC0401609), IWHR Basic Research Fund (No. SM0145B632017, SM0145B952017).

References
[1] Li M, Ren C, Zhao L, et al. Application Research of Ground-Penetrating Radar in the Quality Inspection of Concrete Anti-seepage Panels[C]//E3S Web of Conferences. EDP Sciences, 2019, 136: 04032.
[2] Li M, Wang H, Feng M, et al. Quality Inspection and Evaluation of Lining of Flood Discharge Tunnel in Nam Lik 1-2 Power Station[C]//IOP Conference Series: Earth and Environmental Science. IOP Publishing, 2019, 304(3): 032052.
[3] DING Z, TAN G, Chen L, et al. Study of Sluice Gate Regulating Speed and Changes of Water-surface Profile in Transportation Channels [J]. South-to-North Water Transfersomd and Water Science & Technology, 2005, 6.
[4] WU J, ZHANG L, Ling Y, et al. Verification of Perfect Hydroelastic Model Test of Flow Induced Gate Vibration by Prototype Observation [J]. Journal of Yangtze River Scientific Research Institute, 2005, 5.
[5] McEntyre T, Parker D, Hegseth D. Dam Safety Inspection Of Spillway & Sluice Gate Operating Machinery At TVA Dams[C]//WATERPOWER. AMERICAN SOCIETY CIVIL ENGINEERS, 1993, 2: 885-885.
[6] Halabi S F, Lin C F. Assessing the Relative Influence and Efficacy of Public and Private Food Safety Regulation Regimes[J]. Food and drug law journal, 2017, 72(2): 262-294.
[7] Nanotechnology environmental health and safety: risks, regulation, and management[M]. William Andrew, 2018.