Research and Application of Repair and Reinforcement Technology for Typical Aqueduct in Northwest Region

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Abstract. The old aqueduct has some defects, such as the difficulty of upgrading and increasing the water demand in the irrigation area. Combined with the environmental characteristics of the northwest region, this paper relies on the Ningxia Hongjingkeng aqueduct maintenance project and uses the repair and reinforcement technology of large-scale aqueduct structure, which can completely solve the shortage of the aqueduct project. It can provide important scientific and technological support for ensuring the safety of water delivery in irrigation areas and improving the water supply capacity of irrigation areas.

1. Introduction

By the end of 2017, a total of 22,780 irrigation areas have been built in China, including 458 large-scale irrigation areas, with an irrigation area of 270 million mu. Aqueduct is a connecting project that spans valleys, rivers, depressions and roads. Due to its unique structural characteristics, it has an important position in the water delivery of irrigation areas. It also plays a pivotal role in the safety of water delivery. According to statistics, there are more than 20,000 aqueducts in China. Most of them were built in the 50s and 70s of the last century, which means that they are now approaching or even exceeding their service life. Their safety and durability have attracted people’s attention. For example, some of the aqueducts have experienced major problems such as broken, fallen, collapsed and massive leakage. This has a huge impact on the normal operation of the irrigation area. About 60% of the aqueducts in China were built before the 1970s. Many are "trilateral" projects, and some have design and construction flaws. In addition, after many years of operation, due to various loads (such as dead weight, water pressure, etc.), temperature changes, alternating dry and wet conditions, and environmental erosion, defects such as steel corrosion, carbonization, and cracks are likely to occur. In addition, according to statistics, China's aqueduct which needs to be improvement accounts for about 45%. At present, China often pays more attention to the problems in water conservancy construction, while the research on the diagnosis and safety assurance technology of water conservancy engineering buildings that have been in operation for many years is relatively backward. As the operation of the water conservancy project and the aging of the project continue to intensify, the impact on the safety and efficiency of the project becomes greater. For the repair and protection technology of the aqueduct project, the use of materials has not been mature, and technical standards have not yet been formed. There is even a situation of "year-to-year repair and year-to-year damage" in the implementation of the project, which leads to waste of investment and low economic efficiency. The imperfect repair and
protection technology is an important factor that affects the safety and durability of the aqueduct structure, and it also makes the aqueduct a prominent problem in irrigation projects.

Ningxia Hongjingkeng Aqueduct is one of the main constructions on the main canal. It has been in operation for more than 20 years, and aqueduct deterioration is becoming more and more serious, which means that there are many hidden safety hazards. Furthermore, it has the engineering characteristics of high bent (bent height 17m), long distance (length 880m), and harsh operating environment in the northwest region. Combined with the actual problems and needs of the project, we mainly studied the repair technology and related materials and equipment. We have established a repair, reinforcement and protection system for the aqueduct project to solve the defects during the operation of the aqueduct project and provide important scientific and technological support for the safe operation of domestic irrigation district projects.

2. Engineering issues

After site investigation, the main problems of aqueduct concrete are:(1) There is part of V-shaped waterstop damaged and shed, and there is a leakage problem.(2) Pasting the waterstop on the surface of the expansion joint has water blocking and flow resistance, and it is more likely that the waterstop will deteriorate and fall off.(3) The original surface of the concrete in the aqueduct has been protected by a cement mortar layer, and there is currently a problem (such as partial shedding).(4) The mortar material on the inner wall of the aqueduct has a large surface roughness after repairing treatment, which is not conducive to the improvement of the aqueduct's discharge capacity.(5) Cracks appeared in the concrete of the aqueduct. Part of the concrete fell off, and the steel bars were exposed and corroded. The bearing capacity of bent concrete reduced. (6) The outer wall of the aqueduct was partially eroded, and the concrete was seriously deteriorated.

Figure 1. Damage and failure of expansion joint waterstop.

Figure 2. The condition of the original mortar repairing material falling off and partial damage.
3. Repair and reinforcement technical solutions

In order to comprehensively solve the defects of the concrete of Hongjingkeng Aqueduct, such as improving the operation safety of the aqueduct project and increasing the water delivery efficiency of the project, we have adopted large-scale aqueduct repairing and strengthening treatment technology for the overall reinforcement and protection of the aqueduct inner wall, external row frame and outer wall of the tank shell.

3.1. Water-stop repair treatment of damaged expansion joints of aqueduct

Firstly, we need to remove the damaged waterstops and mortar on the surface of the expansion joints, and polish the base surface. Then, the bitumastic oakum is embedded in the joint, and the filling should be dense and firm. The upper part is reserved with a 3cm groove, and the GB flexible water-stopping filler and closed-cell foam board are embedded to make it flush with the concrete surface. After that, the surface of the repaired expansion joint is treated with a SK doctor-coated polyurea surface water-stop structure, and a SK doctor-coated polyurea coating with a width of 30 cm and a thickness of 4 mm is applied along the surface of the expansion joint.

The water-stop scheme can effectively adapt to the expansion joint deformation. On the basis of bitumastic oakum, GB flexible water-stopping filler and closed-cell foam board, we use SK scrape coating polyurea on the surface for anti-seepage treatment. This means that it can protect the bottom caulking water-stop material to achieve the water-proof and anti-seepage effect, and the expansion joint will no longer block water and flow.
3.2. Repair of concrete defects and erosion

Before the roughening protection treatment on the surface of the aqueduct, we need to remove the original mortar material on the inner wall of the tank body and repair the inner areas where the concrete wall is eroded and damaged. In addition, before the protective treatment of the outer wall of the aqueduct and bent concrete surface, we need to remove and repair the eroded parts of the concrete. The repairing contents include the derusting of the steel bars, the repairing of the partial erosion (the erosion depth is greater than 0.5cm) and the treatment of the slight erosion (the erosion depth is less than 0.5cm).

The construction process mainly includes the removal of corroded concrete, steel bar rust removal, polymer cement mortar construction, and maintenance.

1. For the removal of eroded concrete, we use an electric hammer to chisel away the eroded concrete and inferior concrete. The edges are as vertical as possible, and the depth is not less than 1cm.

2. We need to remove rust from the steel bar and then apply rust inhibitor.

3. We use a high-pressure water gun to clean and inspect the treated base surface. It has to be firm and dense, and it cannot have sanding, shedding, cracking, loose layers and honeycomb pits.

4. The ambient temperature for polymer cement mortar construction should be 5 ~ 35 °C, and it is not suitable for construction in windy or high temperature environment.

   The base surface after washing with high-pressure water needs to be kept in a wet state, but there must be no water accumulation. In the construction of polymer mortar, we need to apply a layer of interface agent first, and then spread the polymer cement mortar evenly after the application. After the paving is completed, it should be immediately smeared and smoothed once. In addition, we need to stagger the construction of polymer cement mortar. The strip width is not greater than 1m, and the area of each block is generally not greater than 10m2. The interval between staggered construction is not less than 24 h. During layered construction, the positions of the joints should be staggered from each other. When the thickness of the surface layer of the facade is greater than 10mm, we need to perform layered construction. The thickness of each layer of the surface should be 5-10 mm. The next construction can be carried out after drying.

5. When the face is dry and not sticky, we need to maintain it. A layer of polymer cement slurry is applied to the surface layer to close the surface gaps, and the plastic film is used to cover the moisture. After 1d, we use sprinkling for maintenance. Generally, after 3d of curing, we will proceed to the next process.

3.3. The inner wall of the tank body coated with SK scrape coating polyurea protective layer

When the polyurea coating is applied, we need to polish the base concrete surface. After that, we apply...
a 2mm thick polyurea coating, which has little effect on the cross-sectional size of the aqueduct. This factor has a negligible effect on the aqueduct's water delivery capacity.

The construction process mainly includes polishing of the concrete surface, repairing holes with special putty, painting SK scrape coating polyurea, and maintenance. The specific construction process is as follows.

1. Substrate processing. We use an angle grinder to polish the concrete surface, and then use a high-pressure water gun to rinse the surface of the dust and scum. After the water is completely volatilized, we need to fill some holes on the concrete surface with putty, and the putty needs to be well bonded with the concrete. After the putty is cured, the concrete is required to be flat, strong, and free of holes.

2. Brushing the interface agent. We use a special moisturizing interface agent to bond the SK scraping polyurea coating to the substrate. After the bottom surface treatment, we apply a special wet surface interface agent on the concrete surface. The thickness of the application is thin and uniform, and there is no leakage.

3. Brushing SK scrape coating polyurea. We need to brush a large area of SK scarp coating polyurea with 2mm thickness. When the surface of the interface agent dries, the first pass of polyurea is brushed. The number of times that SK scarp coating polyurea is applied in a large area is 6 to 8 times, and the thickness should be greater 2mm. In addition, the thickness of the SK scarp coating polyurea should be uniform and the adhesion between the layers should be good.

4. The maintenance of SK scrape coating polyurea

In the process of applying SK scrape coating polyurea, when encountering strong wind and rain, the construction must be stopped immediately, and the polyurea coating should be covered with a cloth to protect it. After the rain stops, we need to wipe off the attachments on the surface. After the brushing is completed, it should not be soaked in water for 12 hours, and it needs 3 days as normal temperature curing.

3.4. Reinforcement treatment of concrete structure of aqueduct bent frame

For the cracks and reduced bearing capacity of bent concrete bars, we adopted a single layer of carbon fiber to reinforce the entire section. The construction process of pasting carbon fiber cloth includes cleaning the concrete base, repairing the defects with epoxy putty, brushing the bottom coating, pasting the carbon fiber sheet, and maintenance.

1. Cleaning of concrete base

We polished the concrete surface of the paste area. Then, we need to remove the dust on the surface and clean it. The surface of the reinforced building should be dry without water.

2. Leveling the base surface

After the cleaned base surface is dried, the concave part of the surface is filled with epoxy putty, and then repaired until the surface is flat.

3. Pasting carbon fiber sheet

We cut the carbon fiber cloth according to the reinforcement size, then formulate the impregnating adhesive according to the process provided by the product manufacturer, and apply it evenly to the sticking part. We lightly press the carbon fiber cloth to the sticking part by hand, and roll it along the fiber direction with a special tool to eliminate air bubbles, so that the impregnating glue can fully penetrate the carbon fiber cloth. When rolling, we do not damage the carbon fiber cloth; when pasting in multiple layers, we need to repeat the above steps and apply the impregnating glue evenly on the surface of the last layer of carbon fiber cloth. The lap width of carbon fiber cloth (in the direction of carbon fiber) should be greater than 200mm.

4. Maintenance

After we stick the carbon fiber sheet, we need maintenance for 24 hours to achieve initial curing. During curing period, we need to ensure that it is not disturbed.
3.5. Anti-carbonization treatment of the outer wall of the tank shell and the surface of the bent frame
We use polymer cement mortar to repair the outer wall of the tank shell and the surface of the bent frame, and we use a flexible polymer cement anti-carbonization coating on the surface. The coating thickness is 1mm, which can effectively enhance the durability of concrete.

We removed the damaged parts of the concrete surface. Then, we continue to restore the incomplete parts. For example, for the repair of eroded concrete surfaces, we use polymer cement mortar repair treatment. We use an angle grinder to polish the base concrete and then rinse it with high-pressure water. On the cleaned concrete surface, we apply anti-carbonization coating with a roller. When painting, the anti-carbonization coating needs to be brushed 3 to 4 times, and the coating is even.

4. Conclusion
According to the characteristics of typical projects in the northwest region, we use the repair and reinforcement technology of large-scale aqueduct structural defects to comprehensively repair the Hongjingkeng aqueduct. This technology can comprehensively solve the problems related to the aqueduct and ensure the safe operation of the project. We use SK scraping polyurea to reduce roughness protection technology on the inner wall of the aqueduct, which means that the water delivery capacity of the project can be significantly improved, avoiding the demolition and reconstruction of the water delivery project. We also have achieved the elimination of old water conveyance building defects and the improvement of durability, which provides important scientific and technological support for ensuring the safety of water delivery and improving the water supply capacity of the irrigation area.

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