Discussion on the Design and Implementation Scheme of Cofferdam Reconditioning Concrete Slab in the Tunnel

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Abstract. This paper takes the water discharge tunnel of the Maopingxi in the Three Gorges area as an example, introduce a rapidly transferable, assembled cofferdam device for reconditioning tunnel in the case of water continuously flowing and its implemetation scheme.. By forming a water-tight space on one side of the tunnel with the cofferdam device, the defects such as cavities, damage, and exposed reinforcement in the concrete slab of the tunnel can be repaired within the water-tight space, while the outside of the cofferdam maintains water flow. The rapid turnover of the cofferdam enables the repair of defects in the entire concrete slab of the tunnel, providing a new method for the repair and reinforcement of defects in tunnels and other structures under normal water flow conditions.

Keywords: Water Discharge tunnel; cofferdam; watertight; defect repair.

1 Introduction

The Maopingxi water discharge structure project, is located in Yichang City, Hubei Province, China. The Maopingxi water discharge structure project in the overflow tunnel length 1480.86m, slab elevation 94~81.21m, bottom slope i=8.565‰, lining height 7.425m, circular arch height 3.175m, flow area 106.44m^2. The width of the tunnel with a 40m-long transition section gradually increases to 14m from the entrance of 1440.86m to the box culvert entrance. The tunnel is that of circular arch with vertical straight wall section, with reinforced concrete lining. The cross section of the tunnel is shown Fig.1: 12m high and 13~16m wide, and inside the tunnel, the clear height is 10.6m and the clear width is 11~14m, with walkways on both sides. Due to long-term water scouring of the tunnel slab, defects such as scour holes, damage, and exposed reinforcement in the concrete slab have emerged, which affect the safety of the structure in long-term operation.

Currently, the repair plan of the bottom slab is to use a cofferdam to block the flowing water in the tunnel and form a dry-land working environment for structural repair of the bottom slab [1~2]. The tunnel in the Maopingxi water discharge structure is designed as a single-hole tunnel, and so the method of setting up a barrier at the

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water inlet of the tunnel cannot meet the water flow requirements. Therefore, it is proposed to use a inspecting cofferdam device of rapidly transferable, assembled tunnel to provide a construction environment without interrupting flowing water and complete the repair of the bottom slab in sections under the premise of ensuring the safety of water flow in the tunnel, which is of great significance to the maintenance and long-term safety of the tunnel bottom slab in service.

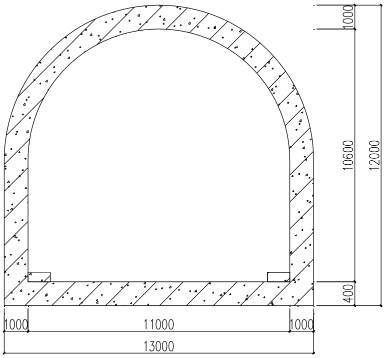
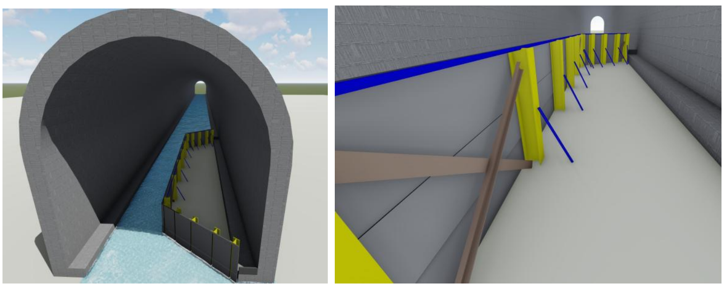


Fig. 1. Tunnel Cross-Section.

2 Key Technologies and Solutions of Bottom Slab Repair Construction Plan

The bottom slab repair construction plan proposed in this paper mainly includes the main body of the inspection cofferdam device of rapidly transferable, assembled tunnel and its supporting auxiliary installation devices. As shown in Fig.2, it is the three-dimensional schematic diagram of the inspection cofferdam. When the right side is being repaired through the cofferdam, the left side remains in a water-flowing state; when the left side is being repaired, the right side remains in a water-flowing state. The distance between the cofferdam plate and the supporting base is 1m, which is the area repeatedly enclosed by the cofferdam to ensure the full-section maintenance of the tunnel slab.



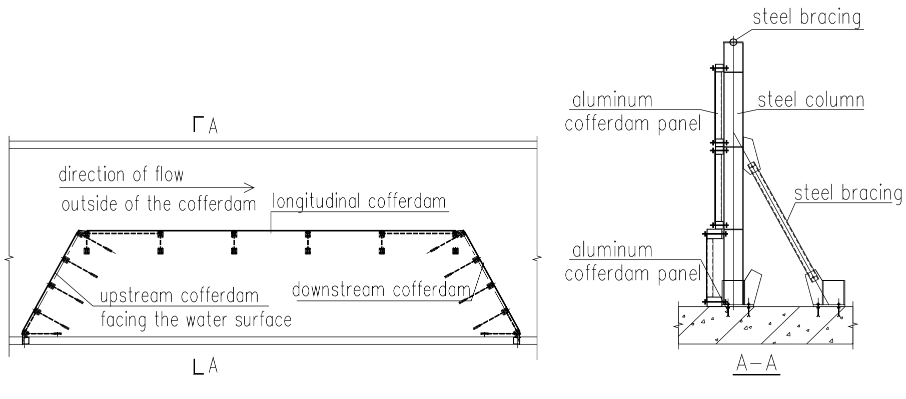
(a) Overall effect diagram (b) Partial schematic diagram of the cofferdam

Fig. 2. Three-dimensional schematic diagram of the cofferdam

2.1 Main Body of the Cofferdam Device

The main body of the inspecting cofferdam device of rapidly transferable, assembled tunnel, proposed in this plan (as shown in Fig.3), is used for the repair of the tunnel bottom slab under normal water flow conditions. The main body of the cofferdam device consists of three parts: steel structure skeleton of the cofferdam , aluminum plate of the cofferdam, and the sealing components. The cofferdam device is arranged on three sides, with the upstream cofferdam, the longitudinal cofferdam, and the downstream cofferdam, where the upstream and downstream cofferdams are diagonally arranged with the walls, which can be applied to the gradual-change transition section of the width of the tunnel by adjusting the angle.

The steel structure skeleton of cofferdam, composed of a base, steel columns, steel diagonal braces, and column supports, is arranged on three sides against the wall. The steel columns are arranged at every interval of 4 meters, and the base is fixed on the bottom slab through reaming self-locking anchor bolts as shown in Fig.4, and the steel columns are connected to the base by insertion. The connections between the supports and the steel columns are all detachable bolt connections, which is not only a reliable connection, based on the above, but also saves time for installation and improves efficiency. To form a reliable connection between the base of that and the foundation, reaming self-locking anchor bolts are implanted into the tunnel bottom slab and the lines are placed to determine the height. Due to the operation with water, so can not use chemical bonded rebar. The reaming self-locking anchor bolt, due to the expansion of the bottom hole, provides anchorage force by mechanically interlocking the anchor head at the bottom of the bolt with the expanded hole bottom after the anchor head opens [3~5], making the anchorage more reliable (as shown in Fig.5).



(a) (b)

Fig. 3. Main Body of the Rapidly Transferable, Assembled Tunnel Inspection Cofferdam Device.

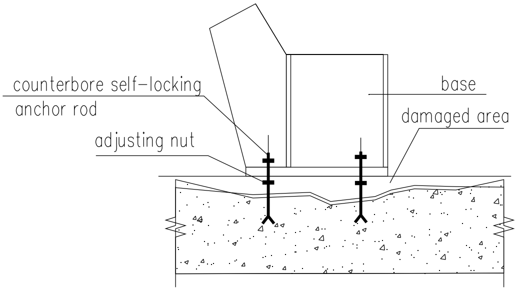


Fig. 4. Installation of Reaming Self-Locking Anchor Bolt and Base Positioning.

Fig. 5. Anchorage Mechanism of Expanded Hole Self-Locking Anchor Bolt.

The cofferdam aluminum plate consists of a large rectangular structure composed of horizontal ribs, vertical ribs, and thin aluminum plates, among which the thin aluminum plate is welded and sealed with a circle of horizontal/vertical ribs around it. The size of a single cofferdam aluminum plate is 4m×0.85m, and the height direction of the cofferdam device is composed of three cofferdam aluminum plates assembled. The horizontal ribs of the cofferdam aluminum are bolted to the steel column by bolting. Light in weight is a characteristic of the cofferdam aluminum, which is convenient for transportation and installation.

2.2 Design of Cofferdam Sealing and Water Stopping

The water stopping design is particularly import for the cofferdam to work normally. Due to the uneven surface of the bottom slab, in the water stopping, there is a large gap between the bottom of the cofferdam aluminum plate and the contact surface of the tunnel bottom slab, where the water stopping (as shown in Fig.6) is patched and filled by underwater high-strength rapid sealing materials [6~8]. This material, through the design of modification, can be constructed underwater with a fast reaction time and high strength after curing, and can also play a role in the effect of local repair of the bottom slab. In addition, both the horizontal seam and vertical seam among the cofferdam aluminum plates have the problem of water stopping. The horizontal seam can be sealed by the pressure provided by the horizontal rubber water stop and the U-shaped clips arranged at a certain interval (as shown in Fig.7), and the vertical seam is sealed by the pressure provided by the vertical rubber water stop [9~10] and the pressure provided by the bolts arranged at a certain interval (as shown in Fig.8). At the same time, the rubber water stop has a certain degree of elasticity, which can adapt to the vertical seams with different spacing caused by installation errors.

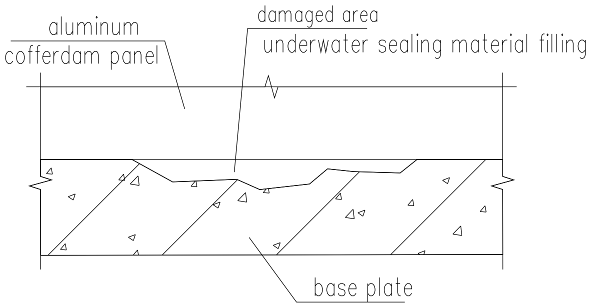
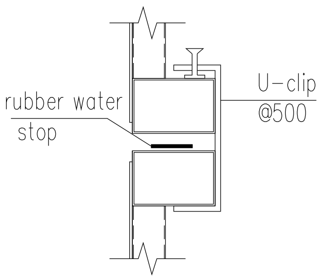


Fig. 6. Sealing between Cofferdam Aluminum Plate and Bottom Slab.



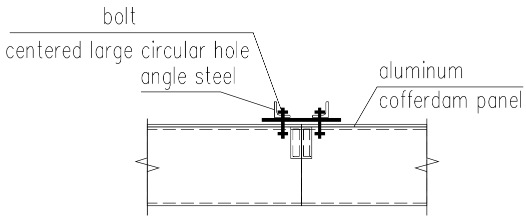


Fig. 7. Design of Horizontal Seam Sealing and Water Stopping.

Fig. 8. Vertical Seam Sealing and Water Stopping Design.

2.3 Design of Cofferdam Sealing and Water Stopping

The calculated water level for this project is 0.5m, and the height of one side of the cofferdam is about 0.8m after water level is high; the steel columns are set up at intervals of 4m, with a height of 2.7m, and lateral support is set up at 1.65m. The steel column uses Q235B-type steel HN200×100, cross-sectional area A = 2667 mm^2, bending moment of inertia I = 17530000 mm^4, and bending modulus W = 175300 mm^3. During the check [11], a 2.5m water head (extreme condition) is taken, and the bottom of the steel column is subjected to a triangular load of 100kN/m, and the top is 0kN/m. After calculation, the design value of maximum bending moment of the steel column is 31.6kN.m, that of the maximum shear force at the bottom is 73.6kN, and that of the maximum shear force at the lateral support is 92.7kN.

Maximum shear stress: $\tau = V_{max} * S / I / t_w$

$= 92.70 * 100076 / 17530000 / 5.5 * 1000$

$= 96.2\ \text{MPa} \leq f_v = 125\ \text{MPa}$

Maximum normal stress: $\sigma = M_{max} / \gamma / W$

$= 31.59 / 1.05 / 175300 * 10\text{\textasciicircum}6$

$= 171.6\ \text{MPa} \leq f = 215\ \text{MPa}$

The cross-section of the cofferdam aluminum plate uses aluminum alloy 6063T6, whose cross-section size of 4mx0.8m, and the bottom cofferdam aluminum plate is subjected to the maximum water pressure. The horizontal rib uses a section moment of 150X100X3, and the thin aluminum plate uses a 3mm thick aluminum plate considering the combined cross-section area A = 2064 mm², the bending moment of inertia I = 7225851 mm⁴, and the bending modulus W =129585 (upper edge). During the check, a 2.5m water head (extreme condition) is taken, and the horizontal rib is subjected to a uniform load of 7.6kN/m. After calculation, the standard value of maximum bending moment of the horizontal rib is 13.01kN.m, and that of the maximum shear force at the bottom is 14.06kN.

Maximum shear stress: $\tau = V_{max} * S / I / t_w$
$= 14.06 * 55364 / 7225851 / 3.0 * 1000$
$= 35.9$ MPa $\leq f_v = 85$ MPa

Maximum normal stress: $\sigma_{up} = M_{max} / \gamma_{up} / W_{up}$
$= 13.01 / 1.05 / 129585 * 10^6$
$= 95.6$ MPa $\leq f = 150$ MPa

2.4 Design of Cofferdam Sealing and Water Stopping

The auxiliary installation device (as shown in Figure 9) is used to install the cofferdam device and create a quasi-static water region. The auxiliary installation device is a key part of this plan, and this device is directly related to the installation of the cofferdam device and the sealing effect of the bottom. The auxiliary installation device consists of three parts: the steel structure skeleton, the drainage system, and the bottom contact material. The device need be able to float on the water surface under its self-weight conditions to facilitate the movement during the construction process, so as to ensure convenience and efficiency of construction. The steel structure skeleton is arranged in a U-shape, single side by two rows of two vertical small-angle steel welding molding, and both sides and bottom welded by thin steel plates to form a three-sided sealed space. The drainage system consists of water pipes, small pumps, and an electric control system. The small pump is set at the bottom of the skeleton, and the electric control system is set at the top of the skeleton, with a waterproof cover. The bottom contact material uses industrial sponge. When the interior of cavity of the auxiliary installation device is filled with water, the auxiliary installation device sinks, the industrial sponge is in contact with the bottom slab, and a quasi-static water region is formed inside the auxiliary installation device, and the slab of the cofferdam device can be installed. When the water inside the cavity of the auxiliary installation device is drained, the auxiliary installation device floats up, and workers can move to the next area for construction.

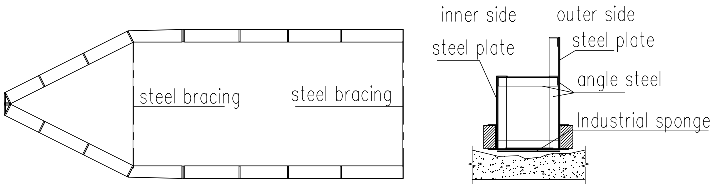


Fig. 9. Supporting Auxiliary Installation Device.

2.5 Overall Construction Plan of Cofferdam and Auxiliary Installation Devices

The steps of overall construction plan for the cofferdam and auxiliary installation devices is as follows:

(1) Install the auxiliary installation device to form a quasi-static water region;

(2) Lay out in the steel column position, install self-locking anchor bolts, position the base and install;

(3) Install the columns, install diagonal braces and inter-column supports, and top ties rods;

(4) Install the bottom cofferdam, and inject modified underwater rapid sealing material between the bottom cofferdam and the bottom slab;

(5) Install the upper cofferdam, install U-shaped clips, and seal the horizontal seams;

(6) Install vertical rubber water stops at the vertical seams, install pressure strips and bolts, and tighten the bolts to form a seal.

(7) Refers to the above steps for the installation of the upstream cofferdam, and finally, set up entrances and exits at the walkways.

2.6 Advantages and Innovations of the Cofferdam

The rapidly transferable, assembled tunnel inspection cofferdam device not only completes the segmental repair of the tunnel bottom slab under normal water flow conditions but also has the following advantages:

(1) The steel column base uses expanded hole self-locking anchor bolts with mechanical self-locking at the bottom, which provide instantaneous mechanical anchorage force to firmly anchor the base to the bottom slab, shortening the installation time, and also overcoming the problemthat chemical anchoring cannot be constructed and anchored underwater.

(2) The modified underwater sealing material is injected between the rectangular profile of the bottom cofferdam and the bottom slab, which can quickly play sealing effects, and also meet the strength requirements of repair materials, playing a role in local repair after the cofferdam is dismantled.

(3) The size and weight of each component of the assembled cofferdam is light, the maximum weight of a single component is 55kg, which can be easily moved and installed by two workers, with strong portability, fast assembling speed, and high comprehensive efficiency.

2.7 On-site Installation Test of Cofferdam

The on-site installation test of the cofferdam was carried out in the Maopingxi Water Discharge Tunnel in October 2024. The water flow on site was relatively small, so only one layer of cofferdam slabs was installed, and the repair construction of the tunnel bottom slab was carried out within the scope of the cofferdam. Through the revolution/rotation of the cofferdam slabs, the 400-square-meter repair construction test section of the bottom slabs was completed. Fig.10 shows the actual picture of the tunnel entrance and the cofferdam, with water flowing normally on the outside of the cofferdam; Fig.11 shows the actual picture of the inside of the cofferdam, where the inside has already been in a dry-land environment and the construction workers are binding steel rebars for the slab repair construction. The on-site test shows that the cofferdam is convenient to assemble and the water-stop scheme is practical and feasible, meeting the requirements for repair construction of the tunnel slab in partial dry-land environment.

Fig. 10. Actual picture of the tunnel entrance and the outside of the cofferdam.

Fig. 11. Actual picture of the inside of the cofferdam and the repair construction of the slab in dry-land environment.

3 Conclusion

This paper introduces an overall construction plan for a rapidly transferable, assembled tunnel inspection cofferdam and auxiliary installation device. Taking the tunnel in the Three Gorges Maopingxi water discharge structure as an example, this paper introduces the design of the cofferdam main structure, working principle, water stopping design, and installation steps of the construction plan, which provides a local barrier in the tunnel under normal water flow conditions, forms a dry working environment inside the cofferdam, and achieves segmental repair construction of the entire tunnel through the rapid assembly and turnover of the cofferdam. The on-site installation test of the cofferdam, carried out on the Maopingxi water discharge tunnel, verifies the feasibility of the scheme. Additionally, by using the device and its implement plan can solve the problems of scour holes, damage, and exposed reinforcement in the tunnel bottom slab caused by water scouring during service, and ensures the safe service of the tunnel, and meanwhile, it can provide a reference basis for the repair of similar water-flow tunnel.

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