Study on Brush-coated Waterstop Structure of CFRD Joints

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Abstract: The surface waterstop of CFRD joints commonly uses the flexible waterproofing roll as a protective cover plate. But this kind of protective cover plate has inherent defects, including gaps between the cover plate and the concrete surface, difficulties in construction of strap lap joints with irregular geometry, bolts installed at the water-level-fluctuating zone in cold areas being prone to freeze and fall off, etc. For these reasons, this paper proposes a new brush-coated waterstop structure of CFRD joints using the SK hydraulic flexible high-performance protective coatings. Lab and field tests have been conducted to prove the reliability of this kind of surface waterstop structure of CFRD joints, which shows good anti-seepage performance and durability as well as convenient construction.

Keywords: CFRD joints; waterstop structure; hydraulic flexible high-performance protective coating

1 Introduction

The concrete faced rockfill dam (CFRD) has become a popular and competitive dam type due to its good performance in safety, economy, and environment. By the end of 2012, the total number of the world’s CFRDs higher than 30m constructed and under construction is over 500 (Atlas 2013). A CFRD relies on the weight of rock-fill to withstand the force of water and uses the concrete face slab as an impervious layer to prevent leakage. The concrete face slab has vertical joints and peripheral joints with waterstops.

After the year of 2000, most high CFRDs constructed only adopted the surface waterstop and bottom copper waterstop without using the middle waterstop. It is indicated that the surface waterstop is an important part of the whole sealing system. In China, the flexible waterproofing roll is commonly used as a protective cover for the surface waterstop, such as ethylene-propylene-diene-monomer (EPDM) plate, rubber plate and composite rubber plate. For Hongjiadu CFRD, the GB three-layer composite cover plate, comprising of EPDM sheet, GB filler sheet and rubber sheet by vulcanization, was used as a separate waterstop. However,
it is often very difficult to guarantee the sealing quality of this sort of waterstop in practice. First, the surface flatness of concrete face during the construction has an error of above 1cm while the expansion bolt spacing is at least 15cm, resulting in gaps between the cover plate and the concrete surface. Secondly, peripheral joints of concrete face often have irregular geometry with T-shaped or L-shaped angles; and it is difficult to assure the quality of strap joint customization and angle steel installation. Thirdly, the cover plate is fixed on the concrete surface by bolts and angle steels with a trouble construction process of fastening bolts, of which the quality cannot be guaranteed. Fourthly, bolts installed on concrete face at the water-level-fluctuating zone in cold areas are prone to freeze and fall off; besides, steel plates and angle steels have poor rust resistance and tend to rust if staying in water or the water-level-fluctuating zone for a long time, further leading to the poor durability.

For these reasons, this paper proposes a new brush-coated waterstop structure of CFRD joints, which is made from the process of brush-coating the SK hydraulic flexible high-performance protective coatings on the plastic fillers and the concrete surface, forming a fully-enclosed flexible anti-seepage coat after solidification, and bonding with the concrete. It can not only serve as a separate surface waterstop, but also protect the plastic fillers below, which is a flexible surface waterstop structure that can effectively keep CFRD joints fully enclosed.

2 SK Hydraulic Flexible High-performance Protective Coating

The new brush-coated waterstop structure of CFRD joints adopts SK hydraulic flexible high-performance protective coatings. This kind of coating is a single component polyurea. Originally, take a liquid mixture composed of isocyanate prepolymer, enclosed amines and additives, after construction of brush-coating, roller-coating or blade-coating and under the effect of moisture in the air, the enclosed amines therein generate amino end group and produce crosslink point with the prepolymer, and the elastic coating is finally formed. The main technical indicators are shown in Table 1.
Table 1  Main technical indicators of SK hydraulic flexible high-performance protective coating

<table>
<thead>
<tr>
<th>Items</th>
<th>Technical Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength</td>
<td>≥15MPa</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>≥350%</td>
</tr>
<tr>
<td>Tear Strength</td>
<td>≥40kN/m</td>
</tr>
<tr>
<td>Rigidity</td>
<td>≥40</td>
</tr>
<tr>
<td>Adhesive Force (wet surface)</td>
<td>≥2.5MPa</td>
</tr>
<tr>
<td>Water Absorption (%)</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Color</td>
<td>Light Grey, Adjustable</td>
</tr>
</tbody>
</table>

SK hydraulic flexible high-performance protective coating is a kind of aliphatic material with the following advantages: (1) good ageing resistance without color change; (2) non-toxic, can be used for drinking water projects; (3) good anti-seepage and anti-abrasion performance; (4) high strength, high elongation and good bonding with base concrete; (5) good chemical resistance; (6) good anti-freeze performance, remaining flexible at minus 45 degree centigrade; (7) reinforced by being composited with tire base fabric for sealing concrete cracks or joints; (8) simple and convenient construction.

When SK hydraulic flexible high-performance protective coating is used in protective cover plate of CFRD joints surface, the bonding strength between the coating and the concrete is crucial. Therefore, the wet-type interface agent is specially developed. The bonding strength will be greatly enhanced if a thin layer of the interface agent is brush-coated on the concrete surface before brush-coating SK hydraulic flexible high-performance protective coatings. To verify the bonding strength between SK hydraulic flexible high-performance protective coating and concrete face slab as well as its durability at the above-water-level zone, the water-level-fluctuating zone or the below-water-level zone, SK hydraulic flexible high-performance protective coatings were locally brush-coated on the concrete face surface of the upper reservoir at Beijing Ming Tombs Pumped Storage Power Station for field testing. The test began from the year of 2008 and has been tracked until now. The testing results are shown in Table 2. It is indicated that the bonding strength at each zone is always greater than 2.0Mpa and basically constant over time, which proves good durability of the coating.
Table 2  Field test results on bonding strength (MPa)

<table>
<thead>
<tr>
<th>Year</th>
<th>Above-water-level zone</th>
<th>Water-level-fluctuating zone</th>
<th>Below-water-level zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>3.15</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2010</td>
<td>3.88</td>
<td>3.68</td>
<td>2.50</td>
</tr>
<tr>
<td>2011</td>
<td>3.44</td>
<td>2.96</td>
<td>-</td>
</tr>
<tr>
<td>2012</td>
<td>3.37</td>
<td>3.35</td>
<td>2.21</td>
</tr>
<tr>
<td>2014</td>
<td>3.02</td>
<td>2.22</td>
<td>2.26</td>
</tr>
</tbody>
</table>

3  Water Pressure Test at Positive Side

This test is to study the independent bearing capacity against positive side water pressure of the brush-coated waterstop structure of CFRD joints without the support of PVC rods or rubber rods due to the occurrence of joint opening. The model uses a steel drum of 48cm inner diameter within concrete block poured, which has a 25-cm-long and 2-cm-wide slot throughout the central block. Fill the slot with GB plastic fillers, and brush-coat the interface agent and SK hydraulic flexible high-performance protective coatings composited with 10-cm-wide tire base fabric in a range of 40cm (lengthwise direction) by 25cm (width direction) around the slot (see Fig. 1).

Fig. 1 Test specimen after modeling  Fig. 2 Positive side water pressure test device

Connect the concrete block casted with steel flanges and the flange with a steel cover on top and with a water inlet and a water pressure gauge attached (see Fig. 2). Use automatic pressurized equipment at the water inlet of the model that can automatically load and keep the
water pressure stable at setting values during the test. Set the initial water pressure of 0.2MPa, and gradually increase the pressure at the speed of 0.1Mpa/h.

It was found that GB plastic fillers were firstly squeezed into the slot under the water pressure; and the coatings at the center of the slot were pressed into the slot and became concave inward; then with the increasing water pressure, the degree of concavity was further increased until exceeding the strength limitation of the coatings, causing holes or splits on the weak parts of the coatings. Figure 3 showed the test specimen after unloading. When the central coating thickness was larger than 2.5mm, the coatings composited with tire base fabric can withstand the water pressure of 0.6MPa; when the coating thickness values were larger than 4mm and 5mm, the corresponding water pressure-bearing capacities are 1.5MPa and 2.0MPa, respectively.

![Test specimen after unloading](image)

**Fig. 3 Test specimen after unloading**

In practice, a PVC rod with enough plastic fillers on the top is at the "V"-shaped part of joint surface. If the displacement of joint opening exceeds a certain range, leading to the void below GB fillers, GB fillers will be squeezed into the joint under the water pressure. GB fillers can fill up the joint and effectively seal them up with large enough quantity, so that inward concave of the surface waterstop will not occur. Therefore, under normal operating conditions, surface waterstop coating is always in a state of bulging outward without inward concave under the water pressure. This test simulates the worst condition in the project operation.
4 Water Pressure Test at Back Side

This test is to study the independent bearing capacity against three-dimensional displacements of the brush-coated waterstop structure of CFRD joints under the internal water pressure. The model joint is required to simulate a CFRD joint, not only able to freely shift back and forth, left and right when the inner cavity of the model is filled with water, but also can freely open and close with the inner cavity under the water pressure of 1.50MPa. For conducting the joint surface sealing, a PVC rod was firstly put into the V-shaped slot; then the slot was filled with GB plastic fillers, of which the surface was brush-coated with tiered SK hydraulic flexible high-performance protective coatings. In addition, two-tiered tire base fabrics were pasted inside the coatings to assure the thickness and uniformity of the coatings.

The cavity of the model was filled with water for 1 day and then moved back and forth for 17cm and left and right for 21cm, respectively. A big model cover, as well as four jacks used for controlling the opening displacements, was installed. The loading process is described as follows: 1) Pressurize the cavity to 0.3Mpa and make the opening displacement 4mm, remaining for two days. 2) Continue to pressurize the internal water pressure with automatic pressurized equipment, from 0.3MPa to 1.55MPa within eight hours; when the opening displacement reaches 12mm, turn off the pressurized equipment, maintaining the water pressure of 1.5MPa. 3) After 15 hours when the internal water pressure drops to 0.5Mpa, a large amount of GB fillers were squeezed out from the model at all the directions. 4) Continue to pressurize to 1.45Mpa, a noise appears at the south corner of the model with the occurrence of seepage; and then drop the pressure to 0.35Mpa. 5) Open the model cover, and pump all the water out; a crack is found associated with the coating surface at the south corner due to the tensile force, and the void below the coatings is also found.

In the model test, the joint opening occurred due to the internal water pressure, and the bottom of the joint was not constrained (Actually constraints exist at the bottom of the joints, e.g., copper waterstop), leading to severe loss of GB fillers below the coatings caused by the high-pressure water (see Fig. 4). The stress state of the coatings at the corner was changed from compression to tension (this condition almost does not occur at CFRD joints), resulting in the destruction of the coatings (the thickness of the coatings at this location was 3mm) due
to concentrated tensions. After unloading and pumping, it was indicated that SK hydraulic flexible high-performance protective coating is a kind of flexible material; the coatings at the middle section of the joint (linear part) was compressed by the internal water pressure of 1.5MPa; due to the back-and-forth and left-and-right shear displacements, the coatings on the surface of GB fillers at the middle section of the joint were distorted, but still in the compression situation (see Fig. 5).

This model test only simulated the brush-coated waterstop structure on the joint surface. Since it was unconstrained at the bottom of the joint, after the occurrence of joint opening under the internal water pressure of 1.5MPa, a massive loss of GB fillers below the coatings led to the surface coatings at the corner of the model exposing to concentrated tensions. This test condition is actually worse than the real field condition. If the bottom of the joint is constrained to control the loss of GB fillers, which can be treated as effective waterstop.

5 Field Test

Pushihe Pumped Storage Power Station is located in Liaoning Province, China. The upper reservoir adopts CFRD as the water retaining structure. The maximum dam height is 78.5m, and the total storage capacity of the upper reservoir is 13.51 million m³. The annual maximum temperature is 35℃ while the lowest temperature is -38℃. The normal water level is 392.00m while the dead water level is 360.00m. Each day the maximum water level fluctuating range reaches 32m. In winter, the dam operation and maintenance are seriously
affected by freeze.

In June 2010, field test on the brush-coated waterstop structure was conducted at the
tensional joint between the 36th slab and the 37th slab with a length of 31m. The V-shaped slot
on the CFRD joint surface was filled with rubber rods and GB plastic fillers; and then SK
hydraulic flexible high-performance protective coatings (composited with tire base fabrics)
were brush-coated on the surface (see Fig. 6). After four years’ operation, it was found that the
testing joint using the brush-coated waterstop structure still performed well (see Fig. 7).

![Fig. 6 Field test at Pushihe Station](image1)

![Fig. 7 waterstop structure after four years’ operation](image2)

6 Conclusion

SK hydraulic flexible high-performance protective coating has high tensile strength, high
elongation, good bonding with base concrete, good aging resistance, etc. The lab and field test
results on the brush-coated waterstop structure show that this structure has a lot of advantages,
including reliable surface protection, good anti-seepage performance and durability,
convenient construction, etc. SK hydraulic flexible high-performance protective coating can
serve as not only a kind of surface protective coating, but also a separate waterstop layer, and
therefore greatly improve the reliability of the surface waterstop system of CFRD joints.

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Reference


