Construction Supervision for Concrete Faced Rockfill Dam of Zhejiang Dayankeng Hydro-Power Station

Chen Zhenhua

Sinohydro Bureau 16 Company Limited, No.82 Hudong Street, Fuzhou, 350003, chenzhenhua71@sina.com

Abstract: This article tries to illustrate the construction supervision for rockfill dam of Zhejiang Dayankeng Hydro-Power Station, to bring forward the viewpoint of guaranteeing the watering quantity to reduce the deformation during the last-period impounding, and to provide the suggestion that the design drawing for the special community includes plan drawing and elevation drawing.

Key word: Concrete faced rockfill dam, construction supervision, quality control, Dayankeng Hydro-Power Station

1 Introduction

The Dayankeng Hydropower Station is located on Dayankeng, a tributary of Nanyang Stream-the main stream of Oujiang River, in Zhangcun Town, Qingyuan County, Zhejiang Province. The dam site is situated in Chekeng village, upper stream of Dyankeng; and the powerhouse at the confluence of Dyankeng and Nanyang Stream, 62km away from Qingyuan County. Between the dam site and powerhouse are crudely built highways.

The project is of the third class, mainly consisted of diversion tunnel, dam, spillway, discharging pipe, water diversion and power generation system, power station, step-up substation and transbasin water division system. The reservoir rain gathering area is 100.2km², of which there is 22km² above the dam site, and 78.2km² for transbasin water diversion system. Its normal pool level is 829m, the total storage capacity of 11.25 million m³, installed capacity of hydropower station is 2×18MW and average annual energy output of 88.46 million kW.h.

The project design was conducted by Zhejiang Investigation and Design Institute of Water Conservancy and Hydropower, and supervised by Fujian Shuikou Supervision Advisory Center of Water Conservancy and Hydropower. The faced rockfill dam and spillway were constructed and observed by Sinohydro Engineering Bureau 12 Corporation Limited and Zhejiang Research Institute of Water Conservancy and Hydropower respectively.

The engineering construction was started in September 2000; in May 2002, the first generating unit began to work and the project was awarded civilized construction site of water system, MWR in the same year;
the whole construction was completed in July 2003.

2 Topography and geology conditions

The valley that the dam situated is V-shaped with symmetrical two sides and steep slope, its formation tendency generally 40°-55°. The river near the dam site is in zigzag shape.

The bedrock lithology of the dam is homogenous, i.e. the grayish green, steel-gray and grayish-brown crys-tal ignimbrite, the b member of upper Paul Age, mainly consisted of plastic vitric and crystal tuff, with some rock debris. The deposit at left and right bank is 1-4m and 1-8m thick respectively, the thickness of loose sand and gravel layer at riverbed is 1-2m.

3 Dam Design

3.1 Design theory

The dam is concrete faced rockfill dam, with flood design of 50 years return period and verified by 1000 years return period.

The concrete faced rockfill dam with 100m high is reasonable. The technology of 100 m concrete faced rockfill dam has developed mutually since the world’s first concrete faced rockfill dam with 110 m was constructed in Australia in 1971, and the dam construction experiment was carried out at Xibeikou Reservoir of Hubei province in China in 1985.

The empirical slope ratio of upstream and downstream 1:1.3 ha been used for slope stabilization, and that of 1:1.4 has been adopted in China. Self filtering cushion materials and proper partition material gradation were applied on seepage control. In order to reduce deformation of face slab, the compressibility of rockfill zone was minimized through strong vibration.

3.2 Dam section

The maximum dam height is 76.8m, crest elevation of 832.8m, crest width of 6m and bottom width of 194m. The vertical plane of concrete wave wall locates above el. 829.2m upstream. The vertical plane of concrete retaining wall locates above el. 830.4m downstream. The slope ratio of upstream and downstream below el. 829.2m is 1:1.3. A 2m wide berm was set at el. 775m and 800m respectively. The dam axis is the medial axis of the dam crest, with total length of 168m and total filling volume of 572 thousand m³.

3.3 Dam zoning

The static rolled area of dam crest locates above el. 829.2m. The dam zoning from upstream face slab to downstream below el. 829.2m are: 5m thick stone pitching, cushion zone with horizontal width of 1.5m, transition zone with horizontal width of 3.5 m, main rockfill zone, 3C rockfill zone, and 40cm thick dry stone pitching. The interface of the main rockfill zone and 3C rockfill zone incline to downstream, with slope ratio of 1:0.2. The crest elevation of 3C rockfill zone is 824m, and the crest is 3m away from the dam axis in horizontal direction. Special cushion zone was set near peripheral joint of slab.

3.4 Index of dam filling

According to design, the unconfined compressive strength of rockfill material
should be not smaller than 50Mpa, the softening coefficient of 3C rockfill zone downstream be not smaller than 0.7 and the softening coefficient of other zones be not smaller than 0.85. The design index of each zone is showed in table 1.

Table 1 The design index of each zone

<table>
<thead>
<tr>
<th>Zoning</th>
<th>Cushion zone</th>
<th>Transition zone</th>
<th>Main rockfill zone</th>
<th>3C rockfill zone</th>
<th>Special zone</th>
<th>Static rolled zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum grain size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>80mm</td>
<td>300mm</td>
<td>600mm</td>
<td>800mm</td>
<td>40mm</td>
<td>300mm</td>
</tr>
<tr>
<td>Content with size less than 5mm</td>
<td>30%~50%</td>
<td>&lt;20%</td>
<td>&lt;20%</td>
<td>&lt;20%</td>
<td>30%~50%</td>
<td>&lt;20%</td>
</tr>
<tr>
<td>Content with size less than 0.075mm</td>
<td>≤8%</td>
<td>≤6%</td>
<td>≤5%</td>
<td>≤5%</td>
<td>≤8%</td>
<td>≤6%</td>
</tr>
<tr>
<td>Nonuniform coefficient Cu</td>
<td>&gt;30</td>
<td>&gt;6</td>
<td>≥8</td>
<td>No requirement</td>
<td>&gt;30</td>
<td>&gt;6</td>
</tr>
<tr>
<td>Curvature coefficient Cc</td>
<td>1~3</td>
<td>1~3</td>
<td>1~3</td>
<td>No requirement</td>
<td>1~3</td>
<td>1~3</td>
</tr>
<tr>
<td>Allowed thickness in paving layer</td>
<td>≤40cm</td>
<td>≤40cm</td>
<td>≤80cm</td>
<td>≤80cm</td>
<td>≤20cm</td>
<td>≤60cm</td>
</tr>
<tr>
<td>porosity</td>
<td>≤20%</td>
<td>≤22%</td>
<td>≤24%</td>
<td>≤25%</td>
<td>≤20%</td>
<td>≤22%</td>
</tr>
</tbody>
</table>

3.5 Toe slab and face slab
The thickness and width of toe slab is 5m and 4~5m respectively, the applied concrete is C25, and single layer bidirectional mesh reinforcement with steel ratio of 0.4% is used.

The distance between the face slab joint is 6m or 12m, with applied concrete of C25 and middle single layer bidirectional mesh reinforcement with steel ratio of 0.4%.

Copper seals was set at middle part of slab vertical joint and peripheral joint, and the top using SP plastic caulking water sealing material.

4 Project characteristics and supervision countermeasures
(1) The terrain features and transportation conditions of the project are favorable to the layout of access and construction equipment, which can help to speed up construction.
(2) The pivot is an inter-basin water diversion and power generation project, the annual average runoff of the basin only accounts for 20% of designed reservoir inflow, in other words, flood control of the project is not so difficult.
(3) The construction unit, Sinohydro Engineering Bureau 12 Corporation Limited, have rich experience on faced rockfill dam construction. The 93.8m high Fujian Wananxi Concrete Faced Rockfill Dam they completed in 1994 has tackled the key issue on concrete face crack control. After many years of operation, the leakage at dam toe is stabilized at 5-7L/s, leading the advanced level of crack
control in our country. The 122m Concrete Faced Rockfill Dam of Fujian Ningde Qinshan Hydropower Station, which put into operation at the end of 1999, was also constructed by Sinohydro Engineering Bureau 12 Corporation Limited. The Sichuan Zipingpu Concrete Faced Rockfill Dam that began construction in 2001 was conducted by the joint venture of Sinohydro Engineering Bureau 12 Corporation Limited and Sinohydro Engineering Bureau 16 Corporation Limited.

(4) After undertaking the construction supervision work of Dayankeng Hydropower Station, Fujian Shuikou supervision center has established Nanyang hydropower supervision department and allocated necessary technicians and equipment. At the beginning, in accordance with engineering characteristics, relevant specifications and contract documents, some files have been compiled such as supervision framework, implementation details and report format in order to guide their work. In allusion to characteristics of transbasin water diversion for power generation and construction of faced rockfill dam, two offices have been built at sites of powerhouse and diversion tunnel respectively, and also a temporary office at the dam site for purpose of construction site supervision and test witness.

5 Construction technique

5.1 Cofferdam

The masonry cofferdam upstream is 7m, constructed after river closure.

5.2 Construction access road

There are 6 transportation roadways at the dam, with 4 at the right bank downstream of the dam connecting to the simple highway, width of 8m, road surface of mud rock mixture; 1 at the left bank downstream used for construction of dam foundation excavation, width of 6m; 1 roadway at the right bank of the reservoir running to the cofferdam crest upstream.

5.3 Layout of filling material yard

(1) The main material yard at the dam was arranged at 150m away from the right bank downstream, the excavated material volume is 540 thousand m³, providing 95% of filling materials, other needed materials were from the auxiliary material yard upstream, and from excavation of toe slab, spillway and diversion tunnel. The maximum exploration quality is 63 thousand m³/month.

(2) The excavated area of main material field is 120m long, and that of transition zone is 30m long.

(3) Cushion material and special zone material were obtained by smashing the blocks in transition zone by machine, and then mixed with artificial sand, with sand and gravel proportion of 1:2. During mixing process, dump truck was used to spread sand and gravel layer by layer, and then a loader machine used to mix the materials evenly.

(4) The stone for slope protection was acquired from processing the blocks at the upper dam.

5.4 Arrangement of facilities for production and living

The engineering spoil yard was arranged downstream to the outlet of diversion...
tunnel on the left bank. The spoil yard can be leveled to form the stone rolling yard, mixing yard of cushion material, storage yard of outsourcing yellow sand, concrete storehouse, and main mixing yard of face slab and spillway concrete.

The plants for steel bar processing, wood processing and machine repair and parking lot were set along construction roadways on the right bank downstream.

The working and living sites were set at the top of the mountain on the right bank, outside the dam area and blasting precautionary area of main material yard.

5.5 Blasting experiment of filling material

The experiment is comprised of three parts. The first and second experiment was for the main rockfill materials and transition materials. The third experiment was for secondary rockfill materials and transition materials. After each blasting experiment, in accordance with gradation analysis, draw the gradation curve and compare with design envelope to adjust the blasting parameter. The reasonable blasting parameter can be concluded after three to five blasting experiments.

5.6 Dam foundation excavation

The completely weathering layer within 2 m at dam foundation upstream of the dam axis and dam toe downstream should be cleared; in other areas, the surface vegetation and the topsoil should be cleared, and high pressure water was used to clean the surface; the partial backward slope within half width of dam foundation upstream should be scraped off.

Excavation of toe slab foundation should be deepened to the weakly weathering bedrock, and blasting excavation started with 1.5 m away from the design elevation.

5.7 Excavation, loading and transportation

Excavation and loading of damming materials mainly applied backhoe excavator, cushion material, special zone material using the loader, and transportation truck using 10T and 20T dumper truck.

5.8 Facilities for levelling and rolling

The bulldozer was used for levelling. The dam surface rolling equipment applied YZT-18 vibration rollers. The peripheral zone material applied 1T walk behind vibration rollers, and the slope used 10T slope roller.

The effective vibration depth of 16T vibration roller has reached 1.4-1.8m, the paving thickness of main rockfill material is half of the average value, YZT-18 vibration roller can satisfy the demand of this project.

5.9 Rolling experiment

After dam foundation excavation, firstly filled the 3C rockfill zone downstream of the dam axis, where the rolling experiment would be conducted.

According to the rolling experiment results of the faced slab rockfill dam at the Qinshan Hydropower Station in Fujian Province, in the curve of dry density and rolling times and settlement and rolling times, the settlement above the the minimum curvature radius was considered as the primary settlement, combining the settlement value, the corresponding rolling times to the terminal value of the curvature radius and
85% of the stable settlement is construction rolling times. According to rolling experiment results on scene and above mentioned experience, construction rolling took 8 times.

The typical samples will be screened in the rolling experiment to get corresponding correction coefficient.

5.10 Dam body filling
5.10.1 Filling sequence
(1) Pre-filling downstream
   After the acceptance of foundation clearing in the river bed, secondary rock-fill material was firstly pre-filled. After the toe slab of the river bed was placed, the front part would be leveled and the full section would be raised.
   (2) Inter-layer filling sequence
   The secondary rockfill material, main rockfill material, transition material, cushion material and special zone material were filled layer by layer from downstream to upstream.
   (3) Slope rolling and slope reinforcement with mortar
   The slope was rolled and reinforced with mortar with every increase of 25m.

5.10.2 Filling methods
(1) Bedding zone and transition zone
   The backward method is adopted. The material-placed layer is 40cm thick. The transition area was rolled by the YZT-18 vibration roller for 8 times with the added water more than 12% and dislocation distance of the rolling wheel of about 30cm.
   The vibration roller traveled parallel to the dam axis.
(2) Main and 3C rockfill zone
   The lodge method was adopted so as to facilitate leveling and rolling. The material-placed layer is 80cm thick. The area was rolled by YZT-18 vibration roller for 8 times with the added water more than 15% and dislocation distance of the rolling wheel of about 30cm.
   (3) Special cushion zone
   Each layer of the material is 20cm thick and rolled by the 1T walk behind vibration roller.
   (4) Upstream slope
   An extra 15cm of cushion material was filled along the upstream direction, as the margin for slope repairing and slope rolling. The slope was rolled for four times with the dislocation distance of the rolling wheel of 15cm. Areas which couldn’t be rolled would be tamped by manpower. M7.5 mortar is used to protect the slope after it was rolled.

5.10.3 Density detection and permeation test
   The density detection mainly employs the pit-digging and water-filling method. The location of the test pit is determined by the supervisor. When the pit was dug, the ring should be four times larger than the maximum particle size. The pit wall should be level to make the volume error less than 1%.

   The permeation test mainly employed the method of filling water in the pit. Sometimes the test is done by filling water to the double rings placed on the test layer.

5.11 Dam foundation against seepage
   Consolidation grouting and curtain grouting of the dam foundation are the covered weight grouting, belonging to conventional process.

5.12 Concrete placement of toe slab and
face slab

The toe slab was placed by erecting formworks and the face slabs adopted the trackless slip form. The slab concrete was assorted and mixed automatically by the 0.75m³/min mixing station. When the temperature was low, the mixing material can be heated by water. The concrete mainly uses the placement by the chute method. The cement coating, after placement, should be immediately covered with thin films and bags for heat preservation, and maintained by spraying water.

5.13 Water stop system

The copper water stops were used at the bottom and the SR material used on the surface. The construction procedure for the surface water stops is: Brush two coats of SR primer, stuff the SR filling material and cover the anti-seepage plate as well as getting rid of air bubbles. The joint of the plate was spliced by 5cm. Flat or angle steel was compressed on the plate every 2.5 m and on each joint and then fixed by expansion bolts.

6 Main methods of quality control for construction supervision

6.1 Controls over the filling material site.
(1) Useless layer stripped clean.
(2) Check and control construction of the drilling and blasting parameters which were determined by the blasting test.
(3) Supervise the strict management of initiating explosive device to ensure its quality.
(4) Control the material quality of the upper dam. Fresh rock should be used at the bottom of the dam and the over-sized material should be divided into small ones in the yard.

6.2 Controls over filling surface
(1) Check the boundary of different filling materials. Supervise inspection and scheduling during unloading and paving to prevent various rockfill materials occupying the upstream area. Those occupied, oversized stones should be excavated.
(2) Check and control the thickness of the material placed layer within the allowable range.
(3) Avoid particle separation and those separated parts should be mixed with fine materials or excavated and then refilled.
(4) Track the vibration roller and inspect the roller’s operation performance such as the exciting force.
(5) Field inspection should be performed to ensure that the construction is done in accordance with the rolling parameters which were determined by the rolling test.
(6) Witness and check the sampling inspection by digging pits and control the quality of filling construction.

6.3 Controls over Grouting Operation
(1) Visit and inspect the drilling and grouting operation
(2) Strictly check and accept the drills; the side station checked the pore water pressure test.

6.4 Control over steel concrete
(1) Check and accept the foundation cleaning of toe slab.
(2) Measure and check the repaired slope and ensure the uniform thickness of the slabs.
(3) Before placement of slab, confirm that the pre-settlement has met the set standards.
(4) Use the sequential method to place slabs so as to reduce the restrictions.
(5) Conduct an overall check of the steel and joints.
(6) Check the mixing station and placement surface to ensure the concrete workability.
(7) Check the heat preservation and maintenance.
(8) Conduct an overall check of cracks on toe slab and face slab.

6.5 Controls over water stop system
(1) Check the quality and specifications of water stops.
(2) 1~2 samples were taken from each crack to carry out destructive inspection.

7 Brief introduction of construction quality

7.1 Dam body filling
The results of the rock apparent gravity test and inspection of porosity and grain distribution by digging pits meet the design requirements. According to the safety monitoring results by Zhejiang Water Conservancy and Hydropower Research Institute, the monthly settlement after dam filling was within 1cm. The maximum settlement before water storage occurred at EL. 799m of 21.3cm, accounting for 0.28% (less than 1%) of the maximum dam height, which is basically equal to or slightly smaller than that of the dams of Sanchaxi Hypower Station and Shapulong Hypower Station of the same type in Zhejiang Province.

7.2 Dam foundation against seepage
The permeability rate of the tested holes of consolidation grouting and curtain grouting of the dam foundation is smaller than the required design value. The average unit consumption of curtain grouting decreased significantly, showing a good grouting effect.

7.3 Concrete placement of toe slab and face slab
The anti-compression, anti-permeability and anti-freeze strength of the sampled concrete specimen all reach the design value.
Through the inspection of the supervisor, there are two horizontal penetrating cracks on the right bank of the toe slab. Besides, the face slab develops four horizontal or near-horizontal penetrating cracks and three long near-horizontal cracks.
Measures for treatment of cracks: cut a trapezoidal groove about 3cm deep on the straddle of the cracks and caulk with epoxy mortar.

7.4 Leakage in dam body
After water impoundment, the leakage amount at the dam toe was relatively small and remains normal during four years’ operation.

8 Thoughts on quality control
(1) This project is an inter-basin water transfer project, so the water level increased slowly after the water impoundment and before the power generation. The effect of measures such as pre-filling of the 3C rockfill zone downstream and by-stage impoundment on pre-settlement of the filling material for the dam body is well proved in this project.
(2) The currently constructed Shuibuya concrete face dam was 233m high. As to the super-high concrete face dams with a height of 150–200m, the technology roadmap for the construction of super-high concrete face dams above 150m has shaped after the analysis of projects such as the Tianshengqiao I dam and the continuous improvement of follow-up construction. Although the experience and technology of the concrete face dams below 100m have been very mature, the quality control should still be strengthened. In particular, the compression modulus of the filling material should be guaranteed and improved as so to reduce the creeping amount, which has great practical significance for reducing deformation of the dam body after water storage, improving operational conditions of face slab and enhancing seismic capacity.

(3) During the rolling test of the concrete faced rock-fill dam at the Qishan Hydropower Station and at this project, neither the amount of the added water nor the rolling effect was inspected. And the amount of water added is taken according to the engineering experience. From the writer’s supervision practice on the site of the Dayankeng concrete face dam, one of the key points of quality control was that on the precondition of avoiding spring soil, the amount of water sprayed during rolling should be guaranteed to ensure rolling effect and reduce deformation after impoundment.

(4) The layout planning chart of special zone of this project is spatial chart, causing inconvenience to construction. It is suggested that the design drawing for the special community should include plan drawing and elevation drawing for the special cushion zone of the concrete face dam, to prevent the deviation in construction.

Reference

1. Deng Wengui, Preliminary Probing on Some Problems of Roller Compaction Test at Concrete Faced Rockfill Dam of Qishan Hydroelectric Power Station, Fujian Shuili Fadian, 2000(2).