Construction technique for high CFRD

Wu Guiyao  Huang Zongying  Jiang Jianlin

The 1st hydropower Corps of People's Armed Police,Jinzhou Road 23,in Nanning, 530028
wjhuzy123@sina.com  Tel: 13108590499

Abstract: The 1st hydropower Corps of People's Armed Police has finished the 200m-level rockfilled dams such as Tianshengqiao 1st cascade,Hongjiadu,Shuibuya, and maitained experiences in construction high CFRD with high constructuin technique which ranks the first place of worldlass.

Key words: Construction Technique  high CFRD hydropower  Corps

1  Headline

The CFRD is qucikly developed since it possesses the typical features as convenience,economic, safety, short construction period, less influence from the climate, especially high CFRD with attractive characteristics.

The hydropower Corps of People's Armed Police initially has build Tianshengqiao 1st cascade hydropower station, then finished Hongjiadu, including Shuibuya under construction which height(233m ) ranks the first place in world-class. The Corps has made great achievements in CFRD field both in construction and application. The following introduces the main construction technique and the application.

2  The project conditions

Tianshengqiao 1st hydropower station is the 1st cascade project in Hong river, the dam height is 178m , the crest length is 1168m , including semi-pervious zone (II A And plinth IIA material ), transition zone (IIIA), main rockfill zone (IIIB), secondary rockfall zone (IIID , IIIC), downstream cutoff wall (IIB material and clay material IV zone) and downstream pavement(IB ), upstream pavement (IA ,IB), the embankment began on January 10, 1996, completed on March 29,1999, the total placement volume is 18000.00 thousand M3. See drawing No.1.

Hongjiadu hydropower station is the 1st cascade project along Wu river, The Maximum height is 179.5m, the crest length is 427.79m, the crest width is 10.95m ,which belongs the narrow-valley high CFRD.The dam contains the unique
cushion material, main rockfill material, main compacted material, secondary rockfill material, rockfill drainage material. The dam placement began in January, 2002, completed in Sept, 2005, the total placement volume is 9000.00 thousand M$^3$. See the drawing 2.

Shuibuya dam is the highest dam of the worldclass under construction, the maximum height is 233m, the dam body is including of IA, IB, IIA, IIIA, IIIB, IIID zones, the total placement volume is 16600.00 thousand M$^3$. The dam placement began in February, 2003, finished in July, 2008. See the drawing 3.

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dr.1 Placement Zones Section in Tianshengqiao

dr.2 Dam Embankment in Hongjiadu

dr.3 Placement Zones Section in Shuibuya
3 The placement technique

3.1 The placement stages

The placement of high CFRD must be by stages to seek the safety in flood season, to plant power and prevent the flood. But that stages lead to the uneven settlement in dambody which is one of the main cause of the tension and bending crackes in the concreted face-slab. Since then, the placement stages of the high CFRD should be is well-distributed.

The placement of the Tianshengqiao 1st hydropower station divides 8 stages, see the drawing 4. During the construction, the following conditions emerged: ③stages just finished then began the construction of the 1st face slab. ⑤stages nearly finished then began the construction of the 2nd face slab. ⑦ stages completed then began the 3rd face slab, but over the 2nd and 3rd face slabs, there may be unexpections of the disconnections between the cushion material and the face slabs. While the 2nd face slab newly completed, a quantity of the cracks may be taken shapes which was concentrating nearby EL.740m.

Aiming to the unexpected conditions occurred in Tianshengqiao 1st hydropower station, adjusting measures has been adopted to protect the construction in both Hongjiadu and Shuibuya, before the face slab concreting, a stable dambody-settlement over 3 months must be accomplished. The distance should be less than 40m between newly finished two temporary sections. For Hongjiadu placement stages, see drawing 2.

3.2 The placement material

(1) IIA cushion materiel: specifications: ① Sound rock, endurance and fresh. ② The deformation and the strength of the cushion material must guarantee the slope stability, also meet the inter deformation requirements of face slab, transition layer and main rockfill zone. ③ Anti-segregation while in use. ④ Meet the requirementes of the seepage.
In Tianshengqiao 1st hydropower station, the dry density of the IIA material is 2.2t/m$^3$, seepage coefficient is $2 \times 10^{-3} \sim 9 \times 10^{-3}$ cm/s, it is the semi-permeable material. The batching plant in Tianshengqiao produced qualified IIA material which envelope curve can meet the design and this was also adopted in Hongjiade and Shuibuya, the construction progress has been increased obviously.

(2) IIA material production: in Tianshengqiao, after blasting in quarry and directly transported into site, this way is different from before, and honored a prize of China Electric Power Technique Progress. This technique has greatly increased the face slab construction in Hongjiadu and Shuibuya.

(3) Explioting of the main rockfill material: in Tianshengqiao 1st hydropower station, adopted the usual way of deep hole blasting in benches.

In Hongjiadu and Shuibuya hydropower station, the bulk ammonia dynamite is the economical way to exploiting the graded material after many careful studies. ① The bulk dynamite may be coupling with the gradation of the material, the fine material is much increasing than ever, the material quality is much better than before. ② For the sake of the safety while the bulk dynamite is in transportation or in storage. ③ Low cost. ④ The bulk dynamite can be charged mechanically and the efficiency is greatly improved over two times comparing with the normal dynamite.

3.3 Watering and spraying

The material in dam site is usually spraying with the hose pipe erected in both sides of the dam abutments, this may cause: ① The hose pipe can be hurdling the equipments while coming and going in the working site and easy to be damaged by them. ② The working site is wide and the hose pipe is not easy to be moved in place. ③ Causing water deficiency in site due to limited watering spots. In Hongjiadu and Shuibuya hydropower station, the watering is combined both in site and outside of the site where the watering stops is set up to have the loading dumping trucks showered less than 15-20s; also the damsite is watering by manual workers while the material is being flatted by bulldozer. The latter way is practicable.

3.4 Tackling with the reversed water pressure in dambody

In Tianshengqiao 1st hydropower station, the dam foundation level at downstream is higher than that of the upstream, in this case, the face slab or cushion material may take the risks of reverse water and be losing the stability. So the collecting well was built in Tianshengqiao at the plinth downstream, with a way of horizontal drainage besides the gravity drainage, also the pumping drainage, lead the water to reservoir so that the stability of the face slab and the cushion material were guaranteed. While backfilling the soil at upstream, the holes of the drainage including all the pipes and the collecting well had been closed. That way may be different from the specification and creative.
The experiences gained from the Hongjiadu and Shuibuya of no longer building the collecting well, adopting the way of imbedded pipes (binding with filtering mesh) connecting with the steel pipes extending outside the dam, drainage by gravity, the catchment area became wider and the drainage works well (see drawing 5). The collecting pipes will be closed with 1St grade concrete after it finish its commission.

3.5 Trimming the cushion layer with laser-guiding back hoe
IIA cushion layer must be qualified, graded, compacted and in suitable thickness, especially the formed slope must be flat and in available size, since it directly affect the size of the face slab, as well as the efficiency of the IIA material. For high CFRD, the cushion slope is in large area and in big quantity. In Tianshengqiao, the laser-guiding back hoe was used to remove the excess IIA material according to the standard angle (slope angle) based on the transmitter and the instrument data. The trimming result is acceptable and the equipment is easy to control, and the trimmed slope can meet the designed requirement. This equipment is used at 1St time in Asia. Until in Hongjiadu, this technique is more mature.

3.6 Pre-settlement quantity in cushion slope
As in Tianshengqiao, when the cushion layer was formed, which slope normal force would be settled guardfully due to the stages placement and the upper load, causing differency in face slab before concreting and disconnection with the nearby layer, so the slope must be filled with extra material which quantity only according to the experience and the comprehensive factors. In Hongjiadu, 25-70cm extra material has been filled, this can be useful for the similar construction for 200m-class CFRD.

3.7 Consolidating the upstream cushion layer
3.7.1 The application and improvement of the asphalt emulsion
The asphalt emulsion is the flexible material of being corrinted if deformation, reducing
the binding force between the face slab concrete and the cushion material, permeability, easy to trim, low cost. In Tianshengqiao, the upstream slope was coated with the asphalt emulsion instead of the grout. Until in Hongjiadu, this method was improved as: ① The manual workers can stand on the platform and works ② The everness of the asphalt onto the slope is guaranteed.

3.7.2 The technique of concrete crushing side wall
The technique of concrete crushing side wall is the new way of protection for upstream slope in CFRD. It first came into being in ITA Dam In Brazil. This way is obviously improving the quality of the compacted cushion material, reducing the lose of the material, any it is easy to make use. Shuibuya is the first 200m-high dam to undergo this technique.

3.8 The application of the GPS
GPS is the core technique of the GPRS, lifeless data communicating, computer and data processing and anally. In Shuibuya, the real-time monitoring for vibrator velocity and passes of the compaction has been achieved. The movable monitoring system is installing above the vibrator and in GPS operation, meanwhile; in the cabinet, the operation of the vibrator can display as the tables, and this can guide the operator to handle the vibrator accurately. This technique is applied in 186m-high Pubugou dam and 261.5m-high Nuozhadu dam. And the construction quality is under-control.

4 Plinth concreting

4.1 Slip form
In Tianshengqiao, the designed total length is 1262.46m, maximum slope angle (along X line) is 26.27 degree, maximum width is 10m, maximum thickness is 1.0m, the concrete is 10.00 thousand m³. The railed slip form was applied along the plinth. This way improve both the quality and the construction progress with a low cost, therefore, this technique was firstly used in face-slab dam. Consequently, Hongjiadu and the Shuibuya adopted this way and made some development about it.

4.2 Plith of concrete in skip way (omit this block and concreting another) to avoid temperature crack
In Tianshengqiao, the plinth concreting was completed continuously without laying deformation joint and water-stop. When concreting over 30m, the concrete may contract by itself, so the deformation and crack may occur in the plinth. In order to avoid this situation, the Hongjiadu and the Shuibuya applied the way of skip-concreting, concreting to 15-20 m at one time, the 1-2m may be reserved. After 28d, the micro-expansion concrete preform in blocks. If the II-blocks has not been concreted while the dam placement rising to this level, the timber form may be used to prevent the cushion material. Shuibuya applied this way and the plinth deformation was under control.

4.3 Concreting with polypropylene fiber
The polypropylene fibre-entrain-concrete can improve its initial yielding, elasticity and contraction, anti-crack, water flushing-resistance. Shuibuya adopted this kind of concrete and the concrete quality was improved obviously. Hongjiadu concrete mixing proportion, see table 1.

5  Face slab concreting

As the important anti-seepage structure, the face slab ensure the dam in safety operation. For 200m-high dam, how to prevent the face slab from crack is a question. Comprising among the Tianshengqiao, Hongjiadu and Shuibuya, concrete mixing proportion is as important factor to avoid crack in face slab as placement quality, face slab concreting stages, and also the time adjustment between the face slab and embankment.

Face slab concreting is usually applying slip form. In Tianshengqiao, during the face slab concreting, the 1st stage was using railed slip form, in the 2nd and 3rd stage changed to slip form without rail, the latter way simplified the works and enhanced the construction progress. Gradually, Hongjiadu and Shuibuya adopted this way and made some development about it.

5.1 The crack in face slab due to dam placement by stages

The face slab construction was divided by three stages both in Tianshengqiao and Hongjiadu. When the face slab concreting finished in Tianshengqiao, the crack was emerging especially in 2nd and 3rd stages face slab. Hongjiadu and Shuibuya made improvement about the dam placement, the face slab stages and the construction schedule. For construction stages, see drawing 4, 2. The following is the comparison about face slab in several stages:

5.1.1 The 1st stage face slab

In Tianshengqiao, few cracks was emerging after accomplishing the 1st stage face slab concreting, only one crack which width is over 0.3mm, disconnection with the cushion material in a maximum 10 cm. The analysis is below:

The Elevation difference between the top of the temporary section and the toe platform is: Tianshengqiao El.682-El.642, h=40m; Hongjiadu El.1010-El 1031,h= 21m, comparison the tension crack, Tianshengqiao is more severe than that of Hongjiadu.

The rear slope of the temporary section: see drawing 6. The settlement quantity in A spot is the Positive function from A to B, VA =f (H), the rear slope at Tianshengqiao 1:1.4, Hongjiadu 1:2.5, equivalently Tianshengqiao H=H1+H2, Hongjiadu.H= H1, so the conclusion is that the settlement in Hongjiadu is less than that of Tianshengqiao.
table.1 Mixing proportion of fibre coscrete in Hongjiadu

<table>
<thead>
<tr>
<th>No.</th>
<th>strength</th>
<th>Sand ratio%</th>
<th>Water-cement ratio</th>
<th>UNF-2C water-reducing admixture</th>
<th>AE Air-entraning agent</th>
<th>HE-U expansion agent</th>
<th>water</th>
<th>cement</th>
<th>fly ash</th>
<th>sand</th>
<th>fine rock</th>
<th>Medium gravel</th>
<th>fibre</th>
<th>UNF-2C water-reducing admixture</th>
<th>AE Air-entraning agent</th>
<th>HE-U expansion agent</th>
<th>Material consumption per cubic concrete (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.P.1</td>
<td>C30</td>
<td>0.45</td>
<td>0.007</td>
<td>8</td>
<td></td>
<td></td>
<td>148</td>
<td>263</td>
<td>66</td>
<td>731</td>
<td>656</td>
<td>536</td>
<td>0.9</td>
<td>2.303</td>
<td>0.023</td>
<td>26.5</td>
<td></td>
</tr>
<tr>
<td>M.P.2</td>
<td>C30</td>
<td>0.47</td>
<td>0.007</td>
<td>8</td>
<td></td>
<td></td>
<td>148</td>
<td>252</td>
<td>63</td>
<td>737</td>
<td>661</td>
<td>541</td>
<td>0.9</td>
<td>2.205</td>
<td>0.022</td>
<td>25.2</td>
<td></td>
</tr>
</tbody>
</table>

Temporary section crest width: from the drawing 6, when the crest width of the plasticity structure $b=\infty$, the D spot may make horizontal movement and the E spot may be 0; in other word, the B Spot becoming bigger, the horizontal movement in E spot would be less. Tianshengqiao $b=30m$, Hongjiadu $b=90m$, showing the yielding and deformation in Hongjiadu is less.

The period of dam deformation before face slab concreting. Tianshengqiao 0-15d; the 1st stage of face slab concreting in Hongjiadu is about 7 months, Hongjiadu is the better.

5.1.2 Comparison between 2nd and 3rd stage face slab

When the 2nd and 3rd stage face slab in Tianshengqiao has been completed, the deformation was emerging in large scale, and the crack and disconnection was coming out in 1st stage face slab. The 2nd and 3rd stage face slab in Hongjiadu deformed little. Analysing is given below:

Settlement period: while the placement in temporary sectional finished then began the 2nd stage face slab concreting. The
settlement period is 0-10d, but in Hongjiadu hold the 3.5 months for settlement.

The 3rd stage face slab began concreting while the placement was rising to the dam crest in Tianshengqiao, Hongjiadu had 3.5 months for settlement.

In a word, the dam placement and the face slab concreting by stages in Hongjiadu is reasonable to prevent from the crack and the disconnection. Based on the readings of the imbedded instruments in Tianshengqiao, there should be over 6 months for settlement to a 200M-High CFRD, the placement structure should be over 6 months for settlement to assure the 3rd face slab not to be deformed. In Shuibuya, the settlement period became more than 3.5 months before face slab concreting and effectively prevent from the crack.

5.2 The improvement of the concrete mixing proportion

Aiming to the cracks emerged in 2nd and 3rd stage face slab in Tianshengqiao, Hongjiadu has given the due consideration on anti-seepage and crack resistance. After observation, adopting the way of entraining polypropylene fiber and light burned MgO into concrete, the former way can reduce the concrete performance-index to be crack, the latter way can compensate the concrete to make contraction, reducing the concrete to be deformation and linear-expansion coefficient. These two methods had greatly improved the quality of face slab in Hongjiadu so as in Shuibuya.

The face slab concrete mixing proportion in Tianshengqiao, Hongjiadu, see table 2,3.

<table>
<thead>
<tr>
<th>No</th>
<th>location</th>
<th>Cement Kg/m³</th>
<th>Fly ash Kg/m³</th>
<th>w-c ratio</th>
<th>Water consumption Kg/m³</th>
<th>admixture(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1st stage face slab</td>
<td>240</td>
<td>60</td>
<td>0.48</td>
<td>144</td>
<td>RC-1:0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>AE:0.005</td>
</tr>
<tr>
<td>2</td>
<td>The second and the third stage</td>
<td>229</td>
<td>57</td>
<td>0.46</td>
<td>132</td>
<td>DH3-G:0.5</td>
</tr>
<tr>
<td></td>
<td>face slab</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6 Fabricating the copper water stop

As the copper water-stop shaper machine was firstly used in Tianshengqiao. Hongjiadu made to improvements: one is adjustment of the interspace between the upper and down wheeles to ensure the water stop to be shaped in size. The other is: the middle height of the water stop in Hongjiadu is 8cm, which is the biggest one(Tianshengqiao 5cm ) in China, the middleof the water stop is more higher, the worse if it was being shaped to broken. Eventually, this has been solved by add more wheels for the shaper machine.

7 Conclusion
Impounding have been recorded, which is the basis experience for construction of similar project.

As the reference gained from Tianshengqiao, Hongjiadu has applied new material, morden equipment and advanced techique to construct another 200m-high CFRD. And its experience is important reference for such project to-be-built.

Shuibuya has adopded advanced technique both native and abroad, and made a big move for CFRD. Which concetrated the advanced technique and greatly contributed to the development of world CFRD.

Tianshengqiao 1st hydropower station, Hongjiadu and the Shuibuya dam have been completed eventually, which are the symbol of CFRD in rapid development in our country. During the construction, advanced technique, new skill and morden equipment have been applied and improved, such as: dam embankment dividing zone and compaction control, plinth slip form, reverse water seepage treatment, laser-guiding back hoe trimming the slope, graded material exploiting and blasting control, cushion material protection and the operation observation, which are the useful experiences for designing and building the 200m-high CFRD.

About the author:

Wu Guiyao Men Hydro One People's Armed Police Corps Senior Engineer Engaged in technology management

Huang Zongying Men Hydro One People's Armed Police Corps Senior Engineer Engaged in technology management

Jiang Jianlin Hydro One People's Armed Police Corps Senior Engineer Engaged in technology management

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