TECHNICAL PROGRESS OF HIGH CONCRETE FACE ROCKFILL DAM

Yang Zeyan, Zhou Jianping, Wang Fuqiang
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Written by Yang Zeyan, Zhou Jianping, Wang Fuqiang

Report by Yang Zeyan

Oct. 27, 2011
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Development Process of CFRD

1 Morena Dam; 2 Dix River Dam; 3 Salt Springs Dam; 4 Paradela Dam; 5 New Exchequer Dam; 6 Areia Dam; 7 Aguamilpa Dam; 8 Campos Novos Dam; 9 Shuibuya Dam; 10 Xiaoshixia Dam & Dashixia Dam.
Development Process of CFRD

1 Morena Dam; 2 Dix River Dam; 3 Salt Springs Dam; 4 Paradela Dam; 5 New Exchequer Dam; 6 Areia Dam; 7 Aguamilpa Dam; 8 Campos Novos Dam; 9 Shuibuya Dam; 10 Xiaoshixia Dam & Dashixia Dam.
现代混凝土面板堆石坝综述

TECHNICAL PROGRESS OF MODERN CFRD

蒋国澄  JIANG Guocheng
徐泽平  XU Zeping

中国水利水电科学研究院
CHINA INSTITUTE OF WATER RESOURCES AND HYDROPOWER RESEARCH
2 Problems and Experiences of high CFRD construction
Development Process of 200m high level CFRD

Year of completion

1 Aguamilpa Dam; 2 Tianshengqiao 1 Dam; 3 Hongjiadu Dam; 4 Barra Grande Dam; 5 Campos Novos Dam; 6 El Cajon Dam; 7 Karahnjukar Dam; 8 Shuibuya Dam; 9 Dashixia Dam; 10 Cihaxia Dam
Typical section of 100 m-level high CFRD

Advised compaction parameters for 100 m-level high CFRD

<table>
<thead>
<tr>
<th></th>
<th>Rockfill</th>
<th>Cushion</th>
<th>Sand Gravel</th>
<th>Transition</th>
<th>Main rockfill</th>
<th>Downstream rockfill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Void ratio (%)</td>
<td>15~20</td>
<td></td>
<td></td>
<td>18~22</td>
<td>20~25</td>
<td>23~28</td>
</tr>
<tr>
<td>Relative density</td>
<td></td>
<td>0.75~0.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Aguamilpa Dam
设计正常水位 EL.780  EL.791
EL.682
EL.725
EL.748
EL.768
IIIC
IIID
IIIB
IIIB IIID
EL.658
EL.671
EL.642
EL.682
EL.725
EL.746
EL.768
EL.791 EL.787.3
EL.662
EL.709
EL.720
EL.723
EL.727
EL.748

Tianshengqiao 1 Dam

填筑共分8期
1. 填筑1996年6月25日完成
2. 填筑1996年6月25日～1996年8月25日完成
5. 填筑1997年6月25日～1997年12月31日完成
7. 填筑1999年8月25日～1999年12月25日完成
8. 填筑2000年6月11日～2000年7月10日完成

(a) 大坝河床段填筑施工分期横断面程序图
(b) 大坝填筑施工分期纵向立面程序图
Barra Grande Dam

Campos Novos Dam
Shuibuya Dam

Soft rock area

Soft rock area
## Defects statistics in some 200m-level high CFRD

<table>
<thead>
<tr>
<th>Project</th>
<th>Maximum settlement vs Dam height ratio</th>
<th>Number of cracks in concrete face</th>
<th>Leakage (L/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areia</td>
<td>358cm / 2.24%</td>
<td>Several</td>
<td>236</td>
</tr>
<tr>
<td>Aguamilpa</td>
<td>&gt;170cm</td>
<td>Horizontal concentration cracks</td>
<td>260</td>
</tr>
<tr>
<td>Tianshengqiao 1</td>
<td>354cm / 1.99%</td>
<td>4537, Vertical extrusion damage</td>
<td>140</td>
</tr>
<tr>
<td>Barra Grande</td>
<td></td>
<td>Vertical extrusion damage</td>
<td>1300</td>
</tr>
<tr>
<td>Campos Novos</td>
<td></td>
<td>Vertical extrusion damage</td>
<td>1300</td>
</tr>
<tr>
<td>Mohale</td>
<td></td>
<td>Vertical extrusion damage</td>
<td></td>
</tr>
<tr>
<td>Shuibuya</td>
<td>247.3cm / 1.06%</td>
<td>637, vertical extrusion damage</td>
<td>40</td>
</tr>
</tbody>
</table>
Hongjiadu Dam
Monitoring results of Hongjiadu Dam

Settlement process in rockfill below elevation 1002~1105m

Settlement in:
① bottom slope rockfill;
② mid-dium slope rockfill;
③ upper slope rockfill;
④ maximum settlement in rockfill;
Concrete face construction:
⑤ First stage;
⑥ second stage;
⑦ third stage

Water level in Hongjiadu Dam

Elevation (m)

Settlement process in rockfill below elevation 1002~1105m

- 17 -
Karahnjukar Dam
<table>
<thead>
<tr>
<th>Dam</th>
<th>Height (m)</th>
<th>3C e (E(MPa))</th>
<th>3B e (E(MPa))</th>
<th>Mean void ratio and deformability modulus</th>
<th>Maximum settlement at the end of construction (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>La Yesca</td>
<td>207</td>
<td>0.18</td>
<td>185</td>
<td>0.32</td>
<td>0.05</td>
</tr>
<tr>
<td>El Cajon</td>
<td>240</td>
<td>0.28</td>
<td>0.19</td>
<td>250</td>
<td>0.40</td>
</tr>
<tr>
<td>Aguamilpa</td>
<td>176</td>
<td>0.30</td>
<td>140</td>
<td>0.36</td>
<td>0.40</td>
</tr>
<tr>
<td>El Cajon</td>
<td>131</td>
<td>0.30</td>
<td>118</td>
<td>0.29</td>
<td>0.40</td>
</tr>
<tr>
<td>Aguamilpa</td>
<td>131</td>
<td>0.30</td>
<td>35</td>
<td>0.39</td>
<td>0.40</td>
</tr>
<tr>
<td>El Cajon</td>
<td>0.75</td>
<td>0.30</td>
<td>1.7</td>
<td>0.8</td>
<td>0.40</td>
</tr>
</tbody>
</table>
3 Latest research achievements of high CFRD
3.1 Research Background

<Adaptability and countermeasure research of 300m-level high CFRD>
3.3 Main technical problems
3.3 Main technical problems

1. Define compaction indexes and section zoning to be adaptive to dam height, valley shape and rock materials.
2. Predict dam deformation based on constitute models and parameters, and define deformation control indexes.
3. Concrete with high cracking resistance and high extrusion resistance, water stops adaptive to large deformation.
4. Deformation control and construction technology program for 300m-level high CFRD
3.4 Organization of the Subject

- Hydrochina Corporation
- HydroLancang Corporation
- HydroNujiang Corporation

Subject

- 6 design institutes
- 5 research institutes
- 3 construction organizations

- 3 construction organizations
### 3.5 Projects relied on

<table>
<thead>
<tr>
<th>Dam</th>
<th>River</th>
<th>Design stage</th>
<th>height (m)</th>
<th>crest length (m)</th>
<th>discharge flood (m$^3$/s)</th>
<th>Normal water level (m)</th>
<th>reservoir capacity ($10^8$m$^3$)</th>
<th>Installed capacity (MW)</th>
<th>Design seismic intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gushui</td>
<td>Lancang</td>
<td>Preliminary feasibility</td>
<td>240~310</td>
<td>540</td>
<td>14300</td>
<td>2340</td>
<td>40</td>
<td>2600</td>
<td>8 degree /0.268g</td>
</tr>
<tr>
<td>Cihaxia</td>
<td>Yellow River</td>
<td>Preliminary feasibility</td>
<td>253</td>
<td>700</td>
<td>9110</td>
<td>2980</td>
<td>41</td>
<td>2000</td>
<td>8 degree</td>
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<tr>
<td>Maji</td>
<td>Nujiang</td>
<td>Programming</td>
<td>270</td>
<td>800</td>
<td>14100</td>
<td>1570</td>
<td>47</td>
<td>4200</td>
<td>8 degree/0.227g</td>
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<tr>
<td>Rumei</td>
<td>Lancang</td>
<td>Programming</td>
<td>315</td>
<td>800</td>
<td>13400</td>
<td>2900</td>
<td>37</td>
<td>3000</td>
<td>8 degree/0.1g</td>
</tr>
</tbody>
</table>
## 3.7 Main research contents

<table>
<thead>
<tr>
<th>Sub topic No.</th>
<th>Main objective</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Technical summary for 200m level high CFRD</td>
</tr>
<tr>
<td>2</td>
<td>Economic advantages and construction conditions for 300m level CFRD</td>
</tr>
<tr>
<td>3</td>
<td>Compaction indexes, section zoning and deformation characteristics of 300m level high CFRD</td>
</tr>
<tr>
<td>4</td>
<td>Slope stability and deformation control standard for 300m level high CFRD</td>
</tr>
<tr>
<td>5</td>
<td>Seepage control and water stops for 300m level high CFRD</td>
</tr>
<tr>
<td>6</td>
<td>Construction technical requirements and quality control for 300m level high CFRD</td>
</tr>
</tbody>
</table>
### 3.9 Technical summary for 200m level CFRD

**Statics of 150~200m high CFRD**

<table>
<thead>
<tr>
<th>No</th>
<th>Project</th>
<th>Country</th>
<th>Stage</th>
<th>Year of Completion</th>
<th>Height(m)</th>
<th>Crest length(m)</th>
<th>Filling amount($10^4$m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>New Exchequer</td>
<td>U.S.A</td>
<td>1</td>
<td>1966</td>
<td>150</td>
<td>427</td>
<td>400</td>
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<td>2</td>
<td>Foz do Areia</td>
<td>Brazil</td>
<td>1980</td>
<td>160</td>
<td>828</td>
<td></td>
<td></td>
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<td>3</td>
<td>Aguamilpa</td>
<td>Mexico</td>
<td>1993</td>
<td>186</td>
<td>660</td>
<td></td>
<td></td>
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<td>4</td>
<td>Yacambu</td>
<td>Venezuela</td>
<td>1996</td>
<td>162</td>
<td>150</td>
<td>300</td>
<td></td>
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<tr>
<td>5</td>
<td>Messochora</td>
<td>Greece</td>
<td>1996</td>
<td>150</td>
<td></td>
<td>1400</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Barra Grande</td>
<td>Brazil</td>
<td>2005</td>
<td>185</td>
<td>665</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Campos Novos</td>
<td>Brazil</td>
<td>2006</td>
<td>202</td>
<td>590</td>
<td></td>
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<tr>
<td>8</td>
<td>El Cajón</td>
<td>Mexico</td>
<td>2007</td>
<td>186</td>
<td>550</td>
<td></td>
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<tr>
<td>9</td>
<td>Kárahnjú</td>
<td>Iceland</td>
<td>2007</td>
<td>198</td>
<td>730</td>
<td></td>
<td></td>
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<tr>
<td>10</td>
<td>Bakun</td>
<td>Malaysia</td>
<td>2008</td>
<td>203.5</td>
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<td>750</td>
<td>1650</td>
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</table>

<table>
<thead>
<tr>
<th>No</th>
<th>Project</th>
<th>Location (China)</th>
<th>Stage</th>
<th>Year of Completion</th>
<th>Height(m)</th>
<th>Crest length(m)</th>
<th>Filling amount($10^4$m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tiaosheng qiao 1</td>
<td>Nanpan River</td>
<td>1</td>
<td>2000</td>
<td>178</td>
<td>1104</td>
<td>1800</td>
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<tr>
<td>2</td>
<td>Hongjiadu</td>
<td>Liuchong Rivier , Guizhou</td>
<td>2</td>
<td>2005</td>
<td>179.5</td>
<td>427.79</td>
<td>909</td>
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<tr>
<td>3</td>
<td>Zipingpu</td>
<td>Min River, Sichuan</td>
<td>3</td>
<td>2006</td>
<td>158</td>
<td>663.77</td>
<td>1117</td>
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<tr>
<td>4</td>
<td>Jilintai 1</td>
<td>Kashe River, Xinjiang</td>
<td>4</td>
<td>2006</td>
<td>157</td>
<td>445</td>
<td>836</td>
</tr>
<tr>
<td>5</td>
<td>Sanbanxi</td>
<td>Qingshui River , Guizhou</td>
<td>5</td>
<td>2007</td>
<td>185.5</td>
<td>423.75</td>
<td>830</td>
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<tr>
<td>6</td>
<td>Shuibuya</td>
<td>Qing River, Hubei</td>
<td>6</td>
<td>2008</td>
<td>233</td>
<td>660</td>
<td>1526</td>
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<tr>
<td>7</td>
<td>Tankeng</td>
<td>Xiaoxi, Zhejiang</td>
<td>7</td>
<td>2008</td>
<td>162</td>
<td>507</td>
<td>955</td>
</tr>
<tr>
<td>8</td>
<td>Basha</td>
<td>Renhe, Chongqing</td>
<td>8</td>
<td>2008</td>
<td>—</td>
<td>477</td>
<td>—</td>
</tr>
<tr>
<td>9</td>
<td>Dongqing</td>
<td>Beipan River, Guizhou</td>
<td>9</td>
<td>—</td>
<td>150</td>
<td>678.63</td>
<td>1016</td>
</tr>
<tr>
<td>10</td>
<td>Malutang 2</td>
<td>Panlong River, Yunnan</td>
<td>10</td>
<td>—</td>
<td>154</td>
<td>493.4</td>
<td>700</td>
</tr>
<tr>
<td>11</td>
<td>Jiangpinghe</td>
<td>Loushui, Hubei</td>
<td>11</td>
<td>—</td>
<td>219</td>
<td>414</td>
<td>704</td>
</tr>
</tbody>
</table>
（1）On basis of safety and reliability of foundation, stability against sliding, seepage stability and deformation stability of the dam should be guaranteed. The difficulty is deformation stability.
3.9 Technical summary for 200m level CFRD

（2）Integrated techniques for deformation control including:

- Utilizing rock of high compressive strength
- Defining reasonable graduation and void ratio
- Decreasing deformation modulus difference between down and upstream rockfill
- Employing higher degree of compaction
- Dam body filling rising evenly
- Adopting pre-settlement measures
- Preloading by water storage with temporary section
3.9 Technical summary for 200m level CFRD

（3）Numerical results generally reflects stress and deformation response of the dam, settlement agree well with the measured value, while lateral displacement has lower accuracy. And difference still exist between parameters from back-analysis and tests.

（4）Experiences from 200m high CFRD provide technological reserve for construction of 300m high dams.

（5）Deformation control techniques from 200m high dams are instructive and meaningful to construction of 300m high CFRD.
3.10 Conclusions for 300m level CFRD

（1）Compared to concrete arch dams and earth core rockfill dam, 300m high CFRD have strong economic advantages and good adaptability.
（2）Deformation control is still the key technique for construction of 300m high CFRD.
（3）Deformation of the dam could be controlled in a reasonable level with engineering measures.
3.10 Conclusions for 300m level CFRD

（4）Deformation and nonuniform deformation of rockfill after face slabs construction is very important for deformation control.

（5）Deformation prediction is still difficult for 300m high dams, improvement is still need for numerical method through monitoring results.

（6）Compacted density of rockfill is defined mainly based on experience, dam height, valley shape and rock characters should be considered, and then verified by tests and computation. Current situation will exist for a long time.
3.10 Conclusions for 300m level CFRD

（7）It is expected that intensive study could be carried out on key techniques relying on projects with good construction conditions. The study includes dam slope stability, stress-strain response, crack control of concrete face, and corresponding construction technology.
4 Review of the papers on CFRD of the symposium
Classification of the papers

• 23 papers related to CFRD presented to the Symposium
• 3 papers on general introduction
• 11 papers on design
• 5 papers on research
• 2 papers on construction
• 2 papers on monitoring
Classification of the papers

- Summarizing papers
  - CFRD 05 “Considerations on the Seismic Design of High Concrete Face Rockfill Dams” by B. Materón

Observed behaviors of two dams under significant seismic loading were summarized, and some aspects of CFRD dynamic response were discussed. Suggestions were also provided on design adjustments to minimize deleterious effects on embankment behavior subject to large seismic loads that the authors are already applying in high CFRD structures under design and construction.
4 Review of the papers on CFRD of the symposium

Classification of the papers

- Summarizing papers
  - CFRD 05 “Considerations on the Seismic Design of High Concrete Face Rockfill Dams” by B. Materón

In view CFRDs ranged 300 m high being designed currently, the article comments design criteria and construction procedures to face this challenge target and aiming progress in these future extra high Dams.
4 Review of the papers on CFRD of the symposium

Classification of the papers

☐ Summarizing papers

✓ CFRD 05 “Considerations on the Seismic Design of High Concrete Face Rockfill Dams” by B. Materón


✓ CFRD 09 “Development of Concrete Face Rockfill Dams in China” by Yang Zeyan and co-authors.

The paper reviewed the development of CFRDs in China in the past 25 years, and a brief summary is put forward on construction profile, technical progress, experiences and lessons and development direction of CFRD.
4 Review of the papers on CFRD of the symposium

Classification of the papers

- Construction
  - CFRD 10 “Extruding technology of plastic filler on slab joint of CFRD” by Hao Jutao
  - CFRD 21 “Underwater Rehabilitation of A 113 M High CFRD: Experiences from Turimiquire” by A. Scuero

- Monitoring
  - CFRD 20 “The Detection Example of CFRD Seepage Entrances” by Bai Guangming
4 Review of the papers on CFRD of the symposium

Classification of the papers

- Zipingpu CFRD
  - CFRD 01 “Assessment of the Post-Earthquake Safety and the Maximum Anti-Seismic Capability of Zipingpu Concrete Face Rockfill Dam” by Zhao Jianming.
  - CFRD 11 “Inspirations from ‘5.12’ Seismic Damage of Zipingpu Dam for Aseismic Measures of CFRD” by Wen Yanfeng.
  - CFRD 14 “Post-earthquake Repair and Advanced Research on Earthquake Damage for Zipingpu Concrete Face Rockfill Dam” by Jia Jinsheng
Classification of the papers

- Shuibuya CFRD
  - CFRD 12 “Joints Waterstop Design Features of Shuibuya CFRD” by Xiong Zebin

- Mazar CFRD
  - CFRD 08 “Design Issues and Performance of Mazar Dam: A 166m High CFRD in a Narrow Canyon (Ecuador)” by E. Frossard
  - CFRD 13 “Mazar CFRD (Ecuador) Construction and Performance after Two Years of Operation” by MS Feitas Jr.

- Bastelos CFRD
  - CFRD 02 “Bastelos dam: A self-spillway rockfill dam” by António Veiga Pinto
4 Review of the papers on CFRD of the symposium

- Classification of the papers

- Shanxi Baiyekou CFRD
  - CFRD 03 “Comparison and Selection of Dam Types for Shanxi Baiyekou Reservoir” by Sun Wangong

- El – Agrem CFRD
  - CFRD 06 “Deformation Analysis of El – Agrem Concrete Face Rockfill Dam” by Belkacem Moussai

- Puntilla Del Viento CFRD
  - CFRD 15 “Puntilla Del Viento Dam Design” by Luis San Martín M

- La Yesca CFRD
  - CFRD 16 “Relevant Aspects of the Geotechnical Design for La Yesca Hydroelectric Project and its Behavior during the Construction Stage: The Mexican Experience in Concrete Face Rockfill Dams” by Juan de Dios Alemán-Velásquez
4 Review of the papers on CFRD of the symposium

Classification of the papers

- Reventazón CFRD
  - CFRD 17 “Reventazón Dam Geotechnical Design” by Roy Ruiz Vásquez
- El Cercado CFRD
  - CFRD 18 “Rio Ranchería Project - “El Cercado” Dam and Annexed Works” by Roy Ruiz Vásquez
- Ancoa Dam CFRD
  - CFRD 22 “Vertical Plinth Desing In” by Mquezada
- Foz Do Areia`S CFRD
  - CFRD 23 “Statistic Model for Prediction and Seepage Control in Foz Do Areia`S Dam” by Kironi Oliveira Pires
Thanks for your attention!