THE SUMMARY OF SAFETY MONITORING AND OPERATION ABOUT RCC GRAVITY DAM IN CHINA

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ABSTRACT

Many world-class high roller compacted concrete gravity dam have been constructed in the western mountainous area in China for example the Longtan, Guangzhao, Jinanqiao, Guandi and etc. The operation state which is important for the engineer about those projects was shown in this paper by analyzing the monitoring data. The achievement about those projects design, construction and management are demonstrated and the existing problems are also discussed.
1. THE CONSTRUCTION ACHIEVEMENT OF RCC-DAM IN CHINA

The concrete gravity dam has been widely used in China for its advantages, including strong adaptability to topography geological condition, flexible arrangement of discharge structure, clear structure stress, and high reliability. The Roller compacted concrete dam construction technology has also many advantages, including high construction speed, short time limit for a project, low investment, high degree of mechanization, simple construction, adaptability etc, are widely used in gravity dam construction.

The Chinese technology of roller compacted concrete dam (Rcc-dam) with low cement content, high-doped admixture, high dust content, low VC values, distorted concrete, thin layer of paving, section Rcc continuous construction characteristics. The Chinese engineer has completely mastered the RCC dam construction in high temperature, cold, wet and dry areas.

Accompanied with the development of Rcc construction technology, China has built the world's highest rcc gravity dam of Longtan and Guangzhao projects in the beginning of this century, which marking the Chinese Rcc-dam construction technology has stepped into the 200m high level. Chinese Rcc dam construction technology has been at the forefront of the world, and formed a complete set with Chinese characteristics and independent intellectual property rights of the roller compacted concrete construction theory and construction technology system\textsuperscript{[1-3]}. The statistical table of roller compacted concrete gravity dam high over 160m built and building in China are shown in table 1\textsuperscript{[4]}.

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\textsuperscript{[1]}

\textsuperscript{[2]}

\textsuperscript{[3]}

\textsuperscript{[4]}
<table>
<thead>
<tr>
<th>Serial Number</th>
<th>Projects</th>
<th>River</th>
<th>Height (M)</th>
<th>Storage Capacity ($\times 10^8$m$^3$)</th>
<th>Installed Capacity (MW)</th>
<th>Project Layout</th>
<th>Construction Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jinanqiao</td>
<td>Jinsha</td>
<td>160.0</td>
<td>9.13</td>
<td>2400</td>
<td>5 table bore, 2bottom bore, Powerhouse behind the dam on the left bank</td>
<td>2011</td>
</tr>
<tr>
<td>2</td>
<td>Xiangjiaba</td>
<td>Jinsha</td>
<td>162.0</td>
<td>54.1</td>
<td>6400</td>
<td>12 table bore, 10middle bore, power house behind the dam, ship lift on the left, underground powerhouse and flushing hole on the right</td>
<td>building</td>
</tr>
<tr>
<td>3</td>
<td>Guanyinyan</td>
<td>Jinsha</td>
<td>168.0</td>
<td>22.50</td>
<td>3000</td>
<td>7table bore, 2middle bore, 2bottom bore, powerhouse behinding dam on the left</td>
<td>building</td>
</tr>
<tr>
<td>4</td>
<td>Guandi</td>
<td>Yalong</td>
<td>168.0</td>
<td>7.6</td>
<td>2400</td>
<td>5table bore, 2middle bore, underground powerhouse on the right</td>
<td>2012</td>
</tr>
<tr>
<td>5</td>
<td>Guangzhao</td>
<td>Beipanjiang</td>
<td>200.5</td>
<td>32.45</td>
<td>1040</td>
<td>3table bore, 1bottom bore, Powerhouse on the right bank</td>
<td>2009</td>
</tr>
<tr>
<td>6</td>
<td>Huangdeng</td>
<td>Lancangjiang</td>
<td>202.0</td>
<td>16.13</td>
<td>1900</td>
<td>4table bore, 2bottom bore, underground powerhouse on the left bank</td>
<td>building</td>
</tr>
<tr>
<td>7</td>
<td>Longtan</td>
<td>Hongshui</td>
<td>192.0/ 216.5</td>
<td>162.1/ 298.3</td>
<td>4900/ 6300</td>
<td>7 table bore, 2bottom bore, underground powerhouse on the left bank</td>
<td>2008 (prospect)</td>
</tr>
</tbody>
</table>

**TABLE 1:** The Statistical Table of Roller Compacted Concrete Gravity Dam High Over 160m Built and Building in China

### 2. THE MONITORING DESIGN OF RCC-DAM IN CHINA

Chinese high Rcc-dam is generally built in the Midwest mountains and canyons area, where the topographic and geologic conditions are very complex. The safety of the project is the starting point and foothold to engineers. With the safety monitoring system, the engineers can keep a firm grip on the status of the dam in construction period and operation period, and make a reasonable evaluation.

Chinese high rcc-dam Safety monitoring design is based on national norms and technical standards of China. The “practical, reliable, advanced economy” is the main principle of design. The layout of monitoring instruments should be tight combination with the project practice and take into account the comprehensive reasonable...
arrangement. Monitoring programs and the measuring points meet the forecast models and data analysis requirements, and are able to monitor the main building character, considering the interaction of various internal and external factors.

Rcc-dam monitoring includes the following contents:

- Deformation monitoring, including the dam foundation and dam level displacement, vertical displacement, deflection, tilt and crack changes;

- Seepage monitoring, including the foundation, the dam and the uplift pressure on stilling pool board, osmotic pressure, and seepage flow around the dam and groundwater monitoring and water quality analysis;

- The stress-strain and temperature monitoring, including the concrete stress-strain, temperature and reinforced stress monitoring;

- Environment element monitoring, including the upstream or downstream water level, water temperature, air temperature and rainfall, upstream and downstream of river bed deformation;

- Special monitoring, including the seismic response of dam and dam foundation, hydraulics.

According to engineering their own characteristics, the monitoring projects are slightly different, the corresponding adjustments of the layout and number of monitoring instruments are also done.

The monitoring instruments about Jinanqiao, Guandi, Guangzhao and Longtan projects are shown in Table 2.

<table>
<thead>
<tr>
<th>Monitoring Project</th>
<th>Instrument</th>
<th>Unit</th>
<th>Jinanqiao</th>
<th>Guandi</th>
<th>Guanzhao</th>
<th>Longtan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deformation Control Network</td>
<td>Plane Network</td>
<td>Piece</td>
<td>12</td>
<td>9</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Vertical Network</td>
<td>Piece</td>
<td>10</td>
<td>16</td>
<td>18</td>
<td>25</td>
</tr>
<tr>
<td>Internal Monitoring</td>
<td>Reinforced Gage</td>
<td>Piece</td>
<td>163</td>
<td>49</td>
<td>18</td>
<td>124</td>
</tr>
<tr>
<td></td>
<td>Steel Plate Gage</td>
<td>Piece</td>
<td>40</td>
<td>4</td>
<td>8</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Strain Gage</td>
<td>Piece</td>
<td>381</td>
<td>267</td>
<td>129</td>
<td>410</td>
</tr>
<tr>
<td></td>
<td>No-Stress Gage</td>
<td>Set</td>
<td>79</td>
<td>43</td>
<td>30</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>Compression Stress Gage</td>
<td>Piece</td>
<td>37</td>
<td>/</td>
<td>/</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Anchor Dynamometer</td>
<td>Set</td>
<td>17</td>
<td>77</td>
<td>21</td>
<td>28</td>
</tr>
<tr>
<td>Deformation Monitoring</td>
<td>Multi-Point Extensometer</td>
<td>Piece</td>
<td>48</td>
<td>22</td>
<td>32</td>
<td>36</td>
</tr>
</tbody>
</table>
### Monitoring Project | Instrument | Unit | Jinanqiao | Guandi | Guanzhao | Longtan
--- | --- | --- | --- | --- | --- | ---
Static Force Level | Set | 25 | 4 | 20 | 44
Vacuum Laser Collimation System | Set | 30 | 30 | 19 | 25
Positive Vertical Gage | Set | 20 | 4 | 12 | 13
Tension Wire | Set | 4 | / | / | 23
Inverted Plumb Hole | Piece | 7 | 5 | 6 | 8
Surface Deformation Monitoring Point | Piece | 21 | 47 | 11 | 33
Benchmark | Piece | 57 | 106 | 18 | 166
Crack Monitoring | Joint Gage | Piece | 149 | 84 | 44 | 149
Crack Gage | Piece | 24 | 7 | 24 | 23
Temperature Monitoring | Temperature Gage | Piece | 210 | 394 | 161 | 534
Measure Temperature Fiber | Piece | 41 | 89 | 30 | /
Seepage Monitoring | Seepage Gage | Piece | 58 | 14 | 21 | 74
Piezometric Tube | Piece | 46 | 32 | 29 | 72
Wager Constant Monitoring Hole | Piece | 11 | 12 | 37 | 32
Measuring Weir | Unit | 9 | 8 | 23 | 28
Hydraulic Monitoring | Base | Piece | 131 | 14 | 31 | 114
Environment Parameters | Water Gage | Piece | 2 | 2 | 9 | 3
Reservoir Thermometer | Piece | 23 | 20 | 7 | 31
Strong Motion Safety Monitoring | Acceleration Instrument | Unit | 14 | 8 | 6 | 11
Summation/Intact Rate | / | / | 1669/92.94% | 1367/90.3% | 771/95.1% | 2127/95.2%

**TABLE 2: Typical Engineering Monitoring Projects And Equipment Layout**

3. **THE OPERATION STATE OF RCC DAM IN CHINA**
The Jinanqiao hydropower station is located in the Jinsha River in China, the fifth level of the power plant of the Jinsha river hydropower planning. The distance from the dam to Lijiang City is 52.5km. The Rcc-dam height is 160m and the normal reservoir water level is 1418m. The project was impounded in November 25, 2010, and now it has reached the normal water level. The monitoring data analysis showed that the dam deformation, seepage, stress, is in line with the general rules and the dam is working normally.

- After the project impoundment, the dam maximum displacement along the river is 11.5mm, which has nothing to do with the reservoir water level, and the Deformation is reduced and tends to stability. The dam settlement displacement is within 6.0mm. Dam transverse joint maximum opening degree 1.02mm; Dam foundation concrete and bedrock contact intact.

- The stresses of dam are characterized by compressive stress, ranged from -4.16MPa to 1.595MPa, which is less than the tensile strength of concrete. The stress is consistent with the general law of concrete dam.

- The monitoring measurements shown that the concrete temperature rise fast and some temperature reach 50°C in initial time. After the water cooling measures, concrete temperature is controlled within 33°C, but later the temperature decreases very slowly.

- After the project impoundment, the dam foundation uplift pressure reduction coefficient is less than 0.17 behind the curtain, which can meet the requirements of specification; the dam inner level seepage pressure is very small, seepage pressure reduction coefficient most smaller than 0.03; the both sides around the dam seepage flow has nothing to do with reservoir water level.
The Guandi hydropower station is located in the Yalong River, which in the border between xichang city and yanyuan county in the Liangshan Yi Autonomous Prefecture of Sichuan Province in China. The Rcc-dam height is 168m and the normal reservoir water level is 1330m. The project was impounded in November 17, 2011. The reservoir water level is 1317.8m by the end of March 28, 2012. The monitoring data analysis showed that the dam deformation, seepage, stress, is in line with the general rules and the dam is working normally.

- After the project impoundment, the dam maximum displacement along the river is 15mm. The dam foundation settlement displacement is very small and tends to be stability. Dam transverse joint maximum opening degree 3.7mm and tends to be stability.

- The strain measurement of dam is in -200με～50με, and the majority is compressive strain.

- The monitoring measurements shown that the concrete maximum temperature is about 48°C in initial time. After the water cooling measures, concrete temperature is 15.3°C～38.5°C.

- After the project impoundment, the dam foundation maximum seepage pressure head is about 5m behind the curtain. The seepage flow is about 100m3 / h by using the capacity method.
The Guangzhao hydropower station is located in the Beipan river, which in the border between guanling county and qinglong county of Guizhou Province in China. The distance between the dam and Guliang city is 222Km. The Rcc-dam height is 200.5m and the normal reservoir water level is 745.0m. The project was impounded in December 31, 2007. The reservoir water level is 740.32m by the end of October 16, 2010. The Guanzhao hydropower station has run well for 5 years since water impoundment.

- The dam displacement along the river is 10.98mm and the dam ssettlement displacement is within 3.0mm, which is accord with design requirement. Dam transverse joint maximum opening degree is 1.32mm; dam foundation concrete and bedrock contact intact.

- The strain measurement of dam is -369.67με ~ 62.27με, and the majority is compressive strain. Most of the region is compressive stress, and the maximum is 0.35MPa.

- The dam body maximum temperature is about 38℃ before the water storage. The concrete temperature is 27℃ ~ 35℃ in recent years, and the temperature trend slow decline.

- After the project impoundment, the dam foundation uplift pressure reduction coefficient is less than 0.13 behind the curtain, which can meet the requirements of specification; the seepage flow of dam foundation is 8.15L/s ~ 21.10 L/s, and the leakage has nothing to do with the reservoir water level. Design of dam foundation seepage prevention effect is good. The seepage flow phenomenon about the both sides around the dam is not obvious.
The Longtan hydropower station is located in the hongshuihe river of the guangxi autonomous region in China. The distance from the dam to tianhe county is 15km. The one phase of the Rcc dam height is 192m and the normal reservoir water level is 375m. The second phase of the Rcc dam height is 216.5m and the corresponding normal reservoir water level is 400m. The one phase of the project was impounded in September 30, 2006. In November 13, 2008, the reservoir reaches the highest level 374.88m in operation period[5]. The monitoring data analysis showed that the dam deformation, seepage, stress, is in line with the general rules. Since the project impoundment, the dam has worked normally for 4 years.

- After the project impoundment, the dam maximum displacement along the river is 6.65mm. The dam foundation settlement deformation is very small and tends to be stable; Dam transverse joint maximum opening degree is1.0mm～2.0mm; Dam foundation concrete and bedrock contact intact.

- The strain measurement of dam is 4με～ 386.55με, dam body vertical, longitudinal and axial stress is 1MPa to 5MPa. After the project impoundment, the dam present the tensile stress decreased and compressive stress increased. Most of the region is compressive stress.

- The dam body maximum temperature is about 40°C before the water storage. The concrete temperature is 23°C～36°C in recent years, and the temperature trend slow decline.

- After the project impoundment, the dam foundation uplift pressure reduction coefficient is less than 0.13 behind the curtain, which can meet the requirements of specification; the seepage flow of dam foundation is very small, the maximum is 17.01m³/h (4.725L/s) and the average is 4.0m³/h (1.1 L/s), which is accord with the design requirements. Design of dam foundation seepage prevention effect is good. The seepage flow phenomenon about the both sides around the dam is not obvious.
4. COMPREHENSIVE ANALYSIS

The above 4 projects, excepting guandi project in initial impoundment process, the remaining 3 dams have been subjected to long time water storage test. The dam deformation, stress and strain, temperature and seepage monitoring data analysis shows that, the projects are running well. But the large leakage problem is also exposed in individual project.

The water leakage problem about Rcc-dam is appear due to the construction quality defects in concrete layer. Therefore, one hand the builder should pay attention to the "concrete layer is tightly combined" qualities, in strict compliance with spreading, control rolling requirements time, take the necessary measures after rainfall. On the other hand, to do a good job handling the cooling water pipe joints, to prevent the destruction of the cooling water pipe joints in the upper concrete rolling time. In general, the water cooling should be done after the implementation of the initial setting of the upper concrete.

In practical work, some individual projects often exposed the leakage problem after water storage, due to the pursuit of the construction schedule and these measures failed to fall to real point. The builders should sum up those experiences, establishing reasonable construction process and quality control measures.

The water cooling measures is applied in the above 4 projects to control dam concrete temperature during construction, and achieved expectant goal basically. Longtan and Guanzhao dams have reserved water for 5 to 6 years, the dam body concrete temperature decrease slowly.

5. CONCLUSION

From the early 1980s, China began to introduce the Rcc-dam construction technology. By accumulating experience and constant innovation, the Chinese engineers have formed a complete set of Rcc-dam theory and rapid construction technology system with Chinese characteristics and independent intellectual property rights. Chinese high Rcc-dam construction has been a world leading level.

Ultra-high Rcc gravity dam are built in the region with mountains and canyons in Midwest of China, where has complex topographic and geologic conditions and large-scale spillway, the dam building is very difficultly. Therefore, the dam management department and engineers attached great importance to dam safety. In order to ensure the dam safety operation, a complete set of design, construction and management systems have been found about the dam safety monitoring from design, review and acceptance. These systems can be effectively used to evaluate the dam work state.
Through analysis the Longtan, Guanzhao and other high Rcc-dams monitoring data, Chinese high Rcc-dams are in normal operation. But some individual projects were exposed that the leakage problem after water storage, due to the quality defects of roller compacted concrete layers. These problems need to be attention for the builders in future.

6. KEY WORDS

Roller Compacted Concrete Gravity Dam, Safety Monitoring, Design, Operation.

7. REFERENCES


