Several Main Technical Issues in the Design of High RCC Gravity Dam of Longtan Hydropower Station

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Abstract: The roller compacted concrete (RCC) gravity dam of Longtan Hydropower Station is remarkable in terms of its engineering quantities. The max. dam height was 192m at the early stage of construction and was later finalized to be 216.5m. Therefore, it is featured by great technical difficulties. In the design, with regard to the features of roller compacted concrete, in-depth research has been done in the aspects of main structure layout, dam structure, anti-seepage measures, concrete mixing ratio, interlayer anti-shearing parameter, temperature controlled anti-cracking measures and construction scheme. By doing so, an unique design scheme for such a high RCC dam was developed.

Key words: Longtan  Roller compacted concrete  Design  Main issues

1 General

The design and research work for Longtan Hydropower Station took about 40 years. Since 1989 after the preliminary design had passed the examination, in order to shorten the construction period and save cost, a lot of research was done to improve the layout of the main structures. The whole powerhouse at the dam toe was moved to the underground. The project was designed as per a normal pool level of 400m and was constructed as per a normal pool level of 375m at the initial stage, corresponding to a dam height of 216.5m and 192m respectively, being the highest RCC dam with the biggest engineering quantities of the dam body in the world today. With the efforts made in tackling the scientific and technical problems in high RCC dam construction, systematic studies have been done in respect to the main issues in high RCC dam design and construction techniques. This paper, based on the results of the design research, discusses about the main issues in the high RCC gravity dam design for Longtan Hydropower Project.

2 Improvement of Main Structure Layout

According to the requirement on the multi-purpose utilization in power generation, flood control, navigation and salt tide control by fresh water etc., Longtan Multi-purpose Hydropower Project is mainly consisted of the dam, the flood releasing structures, the powerhouse and the navigation structures.

In the main structure layout scheme, which was approved by the preliminary design review, the dam was a normal concrete gravity dam and, to avoid the impact of the creeping rock mass at the upstream on the left bank, the powerhouse was arranged according to the “5 sets at dam toe+4 sets of underground” scheme. Thereafter, at the stage of layout optimization and feasibility study supplement, in-depth study was made on the structure layout scheme, with the emphasis placed on two major issues, which are ① the structure layout scheme fitting to quick RCC dam construction and ② the method of creeping rock mass treatment at left dam head.
The main structure layout should make the best of the advantages of quick RCC construction and should:

1. Simplify the impact of the power intake and the approaching waterway on the dam body;
2. Make sure that the parts of compactable concrete at dam body are concentratedly distributed and openings and holes of the dam body should be minimized;
3. Simplify the dam structure to reduce the disturbance on construction and the RCC scope of the dam body should be expanded as much as possible.

Only by doing so could achieve the goal of saving cement quantity, simplifying construction process, accelerating construction progress and cutting down project cost.

For the toppling creeping rock mass (Area A) that may have considerable impact on the arrangement of the power intake at underground powerhouse, through further investigation and special study, especially through studying on key issues, it is considered that the creeping rock is generally stable. For part of the rock mass subject to stability failure, overall excavation scheme was adopted. During construction, as long as excavation by layers, timely consolidation, intensive supervision, duly response and such normal construction procedures are followed, the intake slope stability and deformation could meet the design requirements. As is known from the construction results, it is of exact consistency with the results of design research.

According to the research results, the final layout scheme of the main structures adopted the scheme of 9 units, all arranged underground on left bank. Such a scheme enables the full play of quick construction of roller compacted concrete. See Fig. 1 and Pic. 1 for the main structure layout.

![Fig. 1 Main Structure Layout](image-url)
The main advantages of such a main structure layout scheme are as follows:

(1) Dam construction was a key item on the straight line of construction period and the riverbed section was especially important to the construction period of the first unit power generation. Therefore, the key to early project operation was to reduce the disturbance on construction and to accelerate the rising speed of the dam. In this plan, as there is no powerhouse at dam toe, no intake at dam and no penstock within the dam, disturbance on the powerhouse and dam construction was minimized while the scope of RCC application was expanded, which were in favor of quick RCC construction. Therefore, the project was completed one year ahead of the construction schedule, bringing about huge economic benefits.

(2) Hongshui River is featured by long flood season and high flood flow. Therefore, risks existed relating to flood control and energy dissipation. The full-style underground powerhouse could simplify the diversion measures. At the initial stage, construction diversion followed the standard of 10-year flood of the actually measured series; at the interim and later stages, a gap was reserved at the dam body for flood control, which enabled a more flexible arrangement of the permanent releasing structures, leaving bigger margin for the
adjustment and improvement of energy dissipation works.

(3) This scheme did not have dam-toe type powerhouse and the dam was not provided with penstock. This increased the stiffness of the upper part of the dam body and was favorable for improving the stress of dam body while enhancing the seismic resistance ability of the dam.

(4) This scheme had only one powerhouse, which enabled easy operation, management and maintenance. At later stage when normal pool level was increased, the higher dam body would have little impact on the normal operation of the power station.

3 Research on RCC Dam Structure

The arrangement of the dam body should firstly follow the pattern of main structure layout and the improvement and adjustment of the structure locations were carried out only in a partial manner. Secondly, before deciding the location and the structural type of the structure, it is necessary to make sure that not only the requirements on the structure were met in terms of their scales and functions but also that their engineering quantities should be cut down as much as possible to save the cost. Thirdly, the area of the dam body using roller compacted concrete should be expanded as far as possible to simplify the dam structure, reduce the openings and holes in the dam and minimize disturbance on construction, which would facilitate construction and shortened the construction period.

Longtan dam was 192m high at initial stage, corresponding to a concrete volume of 6.6 million m³, among which the roller compacted concrete works took about 68%. At the latter stage, the dam height reached 216.5m. Both dam heights are far above the existing dam construction level at home and abroad.

(1) Dam material based zoning. In the design, the dam height was finalized at 216.5m and was divided into 3 zones. For the area with a dam height of more than 156m, C₃₀/25 was applied; for the area having a dam height between 64.5m to 156m, C₃₀/20 was used; for the area below, C₃₀/15 was used. The upstream face of the dam body adopted 3m to 7m thick 2nd grade roller compacted concrete and 0.5m to 1m thick distorted concrete for anti-seepage purpose.

(2) Flood releasing system arrangement. The flood releasing structures are arranged in the middle of the main river channel and flood releasing is realized by 7 surface outlets. The energy dissipation is of ski-jump type. The low-level outlet does not serve for the purpose of flood releasing but mainly for later stage diversion, reservoir emptying and sand flushing and draining. In order to go together with RCC construction, the low-level outlets are of pressured type and the outlets are arranged horizontally with the ski-jump energy dissipation adopted at downstream. Besides, the dam is not provided with longitudinal joints so as to fit with RCC construction.

(3) Dam face anti-seepage system. As is known from the design characteristics of Longtan RCC gravity dam, the anti-seepage structural type on upstream side of the dam body could meet the requirement on quick RCC construction to simplify the construction supply. As the dam construction was carried out throughout the year, the anti-seepage structure of the dam body should be featured by good thermal property and anti-cracking performance for the convenience of temperature control. Research had been done with emphasis placed on the anti-seepage scheme with normal concrete, anti-seepage scheme of precast concrete plank with PVC film pasted inside, anti-seepage scheme of cast-in-situ reinforced concrete face slab and 2nd grade RCC combined, anti-seepage scheme with bituminous mixture and anti-seepage scheme of distorted concrete and 2nd grade RCC combined. A great deal of design research and tests had been done. With the deepening of the scientific research, the development of RCC construction practice at home and abroad and the advancement in dam construction techniques, through the comprehensive comparison and analysis on the above-mentioned anti-seepage schemes in terms of their effect, reliability, durability, construction schedule and project
cost and so on, the anti-seepage scheme of distorted concrete and 2\textsuperscript{nd} grade RCC combined was adopted as the anti-seepage structure for Longtan Dam. The test result showed that the permeability coefficient generally reached $10^{-10}\text{cm/s}$, being able to meet the requirement on high dam seepage proofing.

(4) Dam body drainage system. The dam body drainage system was the key to dam body seepage control. Therefore, the RCC dam should be provided with a proper drainage system. As long as the drainage system was properly arranged with some margin provided, the partial deficiency in the anti-seepage structure would not lead to the rapid increase in the uplifting force at the dam body or the layers. The drainage system of the dam body is closely connected to the upstream anti-seepage works and includes drainage gallery and vertical drainage pipes. To lower the pressure at interlayer and to make sure that the uplift force at interlayer did not exceed the design value, 3 to 4 rows of vertical drainage pipes were arranged at the lower part of the dam body to connect the RCC layer to the drainage gallery at the bottom. See Fig. 2 for the typical profile of dam crest.

![Fig. 2 Typical Dam Section Profile](image)

4 Study on RCC Mixing Ratio and Interlayer Anti-shearing Parameter

The structural type of Longtan Dam was designed and optimized according to normal concrete gravity dam. Thus the dam section was of advanced technique and had high requirement on anti-shearing parameter of RCC layer. As a result, the research on the RCC mixing ratio and the interlayer shearing parameter was critical. See Table 1 for the technical indicators of RCC for Longtan Dam.

For a 200m-high order dam, RCC was applicable for most height scope, depending mainly on dam structural type, interlayer shearing strength indicator, interlayer uplift force, anti-sliding stability safety factor along the layer and other factors.

As is known from the calculation and analysis results, with the increase in dam height, the interlayer shearing strength required in the design increases as well. In the design research over these years, a large number of laboratory tests had been done. At the initial stage, three large-scale field compaction tests were done at Yantan dam of similar ambient conditions. Besides, in-situ anti-shearing test and concrete core shearing test were done with samples from Longtan project site. These tests have demonstrated that the application of rich cementing
material could achieve the goal of constructing a 200m-high order RCC dam of full height and full section. Meanwhile, with the core sampled for dam quality test, concrete core shearing test was done and a number of measured data was obtained.

### Table 1 Technical Indicators of Roller Compacted Concrete

<table>
<thead>
<tr>
<th>Design Indicator</th>
<th>Dam Body Part</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower Part R I (RCC)</td>
</tr>
<tr>
<td>90d Strength indicator (MPa) (90d, 80% reliability)</td>
<td>25</td>
</tr>
<tr>
<td>Impervious grade (90d)</td>
<td>W6</td>
</tr>
<tr>
<td>Antifreeze grade (90d)</td>
<td>F100</td>
</tr>
<tr>
<td>Limiting extended value (εp)(90d)</td>
<td>0.8×10⁻⁴</td>
</tr>
<tr>
<td>Vc value(s)/slump (cm)</td>
<td>5-7</td>
</tr>
<tr>
<td>Max. water-to-binder ratio</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>In-situ interlayer shearing strength (180d, 80% reliability)</td>
<td>1.0~1.1</td>
</tr>
<tr>
<td></td>
<td>C⁹₀ (MPa)</td>
</tr>
</tbody>
</table>

The main parameters affecting the RCC interlayer shearing strength were: the quantity of cementitious material, intermittence time of RCC layer, ambient temperature conditions, RCC layer treatment technologies and so on.

From Oct. 1990 to June 1993, field compaction tests of 10 working conditions were for three times based on Yantan dam, 129 groups of field in-situ shearing strength tests were performed and 186 groups of laboratory RCC layer shearing strength tests with the samples from the field were carried out. The values of the RCC layer shearing strength should follow three principles that priority should be given to the peak shearing strength by field multi-point method, the value of the untreated layer and the strength with a 180d strength. The field in-situ RCC layer peak shearing strength of the typical operating condition should be served as the primary basis for choosing the interlayer shearing parameter. As the factors that may affect the concrete quality during construction period were far more than those during testing period, the value taken for Cᵥ should be higher than as obtained from the test. The statistic and analysis results of the test are shown in Table 2.

### Table 2 Statistic and Analysis Results of Longtan RCC Field Test based on Yantan dam and Suggested Standard Values

<table>
<thead>
<tr>
<th>Concrete Strength</th>
<th>Quantity of Cementitious Material (kg/m³)</th>
<th>Grading</th>
<th>Conventional Statistical Method</th>
<th>Comprehensive Value Analysis Method</th>
<th>Suggested Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>F</td>
<td>Synthetical value</td>
<td>Mean average value</td>
<td>Reliability 80%</td>
</tr>
<tr>
<td></td>
<td>ε₀</td>
<td>ε'</td>
<td>f'</td>
<td>C'</td>
<td>f'</td>
</tr>
<tr>
<td>Cw25</td>
<td>90</td>
<td>110</td>
<td>3</td>
<td>1.29</td>
<td>2.80</td>
</tr>
<tr>
<td>Cw20</td>
<td>75</td>
<td>105</td>
<td>3</td>
<td>1.17</td>
<td>2.10</td>
</tr>
</tbody>
</table>

After the commencement began and before the dam construction started, field compaction tests were done for three times at Longtan project site, with one time under normal temperature and two times under high
temperature, to make test demonstration on mixing ratio, construction techniques and so on. A total of 91 groups of tests (38 groups for 90d concrete and 53 groups for 180d concrete) were made under different temperature conditions, based on different concrete mixing ratio and with different concrete layer treatment technology. The statistic and analysis results from the tests (see Table 3) showed that, the RCC layer shearing strength was able to meet the design requirements.

As was known that, as long as the RCC mixing ratio was appropriately designed, an effective quality testing and control system was constructed in the construction to ensure the RCC construction quality, except for the foundation mat concrete of Longtan Dam, RCC was able to be applied from the place above the foundation mat.

<table>
<thead>
<tr>
<th>Concrete Zoning</th>
<th>Quantity of Cementitious Material (kg/m³)</th>
<th>Grading</th>
<th>Operating Condition</th>
<th>Age (d)</th>
<th>Standard Value of Anti-shearing Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>C′s=0.20、C′w=0.30</td>
</tr>
<tr>
<td>C9025</td>
<td>190~200</td>
<td>3</td>
<td>High temperature: the intermittence time of interlayer should not last for more than 4h, the layer needs no treatment</td>
<td>180</td>
<td>1.19 1.67</td>
</tr>
<tr>
<td>C9020</td>
<td>170~180</td>
<td>3</td>
<td>Low temperature: the intermittence time of interlayer should not last for more than 10h, the layer needs no treatment</td>
<td></td>
<td>1.15 1.66</td>
</tr>
<tr>
<td>C9015</td>
<td>160</td>
<td>3</td>
<td>Cold joint: grinding and mortar application</td>
<td></td>
<td>1.15 1.22</td>
</tr>
</tbody>
</table>

Through the laboratory and field tests, the feasibility of applying the full RCC section for a 200m-high order dam was proved. It showed that the recommended mixing ratio of Longtan Dam was acceptable and could provide good physical and mechanical property and working performance for the dam body RCC. Only slight adjustment was made to the actually applied mixing ratio based on the design recommended ratio. In the dam core sample test, the mean availability ratio of the RCC core was 97.2%, the longest core sample was 12.74m and the joint face break-off ratio was 19.8%. See Table 4 for the design recommended concrete mixing ratio and construction mixing ratio for longtan project.

<table>
<thead>
<tr>
<th>Design Indicator</th>
<th>Dam Body Part</th>
<th>Lower Part R I (RCC)</th>
<th>Middle Part R II (RCC)</th>
<th>Upper Part R III (RCC)</th>
<th>Upstream Side R IV (RCC)</th>
<th>Upstream Side Distorted Concrete Cb 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design strength</td>
<td>C9025</td>
<td>C9020</td>
<td>C9015</td>
<td>C9025</td>
<td>C9025</td>
<td></td>
</tr>
<tr>
<td>Water-binder ratio</td>
<td>0.42(0.41)</td>
<td>0.46(0.45)</td>
<td>0.51(0.48)</td>
<td>0.42(0.4)</td>
<td>0.42(0.4)</td>
<td></td>
</tr>
<tr>
<td>Max. aggregate size/grading</td>
<td>80/III</td>
<td>80/III</td>
<td>80/III</td>
<td>40/II</td>
<td>40/II</td>
<td></td>
</tr>
<tr>
<td>Fly ash replacement (kg/m³)</td>
<td>110(106)</td>
<td>105(107)</td>
<td>105(109)</td>
<td>140(121)</td>
<td>140(121)</td>
<td></td>
</tr>
</tbody>
</table>
5 Temperature control and anti-cracking measures

5.1 Characteristics of RCC Temperature Control

For a highest RCC dam in the world like the dam of Longtan Project, which is featured by tremendous concrete volume and a more than 160m bottom width, if it is constructed all over the year under high temperature with heavy rainfall and free from temperature control, it is difficult to meet the anti-cracking requirement and it is even more difficult to make full use of the quick RCC construction. Through the analysis on the RCC temperature control system, the following characteristics are found out:

1. Temperature status of RCC dam. Generally, the roller compacted concrete is mixed with a large quantity of fly ash to reduce the cement consumption. Therefore, the adiabatic temperature rise of the RCC was comparatively low. Secondly, after a large quantity of fly ash was applied, the hydration heat ratio went down rapidly, which was unfavorable for the early-stage heating. Although the RCC casting layer was thin and helped heat dissipation, considering the interlayer bonding quality, the intermittence time between layers was normally kept short. Therefore, heat dissipation from RCC layer during construction period was not very much and most of the hydration heat was stored within the dam body, leading to a considerably high temperature.

2. Foundation constraint of RCC dam. As the RCC dam was cast by thin layer in whole block style without providing longitudinal joint, the foundation was of considerable constraint effect and was very sensitive to the unlevelness. Therefore, compared with the casting of normal concrete column, the RCC dam was unfavorable in terms of foundation constraint. Under the same temperature difference condition, the more effective the foundation constraint, the higher the temperature stress.

3. Crack resistance of roller compacted concrete. The ultimate tensile value of RCC was lower than that of the normal concrete and thus the anti-cracking ability was poorer than that of the normal concrete.

4. Horizontal and vertical cracks. For the dam cast throughout the whole block, as the inner temperature of the dam went down slowly and with the effect of low temperature in winter and the rapid temperature drop, the internal and external temperature difference was remarkable and it was easy to have horizontal and vertical cracks occur at the surface.

5. Loads on dam body. As the internal dam temperature went down very slowly, when it reached the quasi-stationary temperature field, i.e. the occurrence of the max. temperature stress, the dam began impounding and operation and the three major loads, which were the water load, the dead weight and the temperature stress, will begin action simultaneously.

6. Heat preservation at casting face. As the RCC construction layer was thin, when precooling measures were taken, in the process of construction, as was affected by the high ambient temperature, the precooling effect of concrete would be severely affected, leading to a poor precooling effect. Therefore, heat preservation at casting face must be done properly.

5.2 Temperature Control Standard

<table>
<thead>
<tr>
<th>Cement quantity (kg/m³)</th>
<th>90(89)</th>
<th>75(68)</th>
<th>60(56)</th>
<th>100(99)</th>
<th>100(1+A) (99(1+4.6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vc value at mixer outlet (s)/slump (cm)</td>
<td>3<del>5(1</del>4.2)</td>
<td>3<del>5(1</del>4.2)</td>
<td>3<del>5(1</del>4.2)</td>
<td>3<del>5(1</del>4.2)</td>
<td>3<del>5(1</del>4.2)</td>
</tr>
</tbody>
</table>

Notes: figures in the parentheses of the table above are the values of construction mixing ratio.
According to the analysis results of 3D temperature field and temperature stress simulation at each dam section during construction period and operation period, in combination with relevant engineering experience, the temperature control standard was formulated.

5.2.1 Foundation temperature difference
For the allowable temperature difference at the foundation of each dam section, see Table 5 for details.

<table>
<thead>
<tr>
<th>Location</th>
<th>Allowable foundation temperature difference [T₀]</th>
<th>Allowable max. temperature [Tmax]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0~0.2)L Normal concrete cushion</td>
<td>16</td>
<td>32</td>
</tr>
<tr>
<td>Roller compacted concrete</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.2~0.4)L Roller compacted concrete</td>
<td>19</td>
<td>35</td>
</tr>
</tbody>
</table>

Note: L—max. side length of casting block, in m.

5.2.2 Upper and lower layer temperature difference
For the long intermittence time occurring between the normal concrete and roller compacted concrete layers, the upper and lower layers’ allowable temperature differences were taken as 16~18°C and 10~12°C respectively. In case of long term exposure of the side faces of casting block, the allowable temperature differences of the upper and lower layers should take their min. values.

5.2.3 Internal and external temperature difference
The internal and external temperature difference of the dam body should be no more than 20°C. For the convenience of construction management, in order to ensure that the max. concrete temperature was below the allowable value, for the concrete at the upper part of the dam body that had broken away from the foundation constraint area (where the dam height was more than 0.4L), the max. temperatures for normal concrete and roller compacted concrete were controlled as per no more than 38°C and 36°C respectively.

5.3 Temperature control measures
5.3.1 Lowering mixer-outlet concrete temperature and casting temperature
1) Take such measures as making sure that the pile-up height of finished aggregate quarry should be no smaller than 6m, building shade-shed, spraying water mist to lower ambient temperature, transporting aggregates by ridge or belt conveyor;
2) The batching plant aggregates should be pre-cooled by using secondary air-cooled;
3) Mix the concrete with ice or cold water.

Through taking the above-mentioned measures, the mixer outlet temperature could be controlled within 12°C in summer.

5.3.2 Controlling casting temperature
1) An auto-dumper should be provided with thermal-insulation and sun-shade measures and a belt conveyor should be equipped with an enclosing and mist spraying facility;
2) Shorten the concrete’s time of sun exposure and the whole process from concrete batching to compaction should be completed within 2h;
3) In case of casting in high temperature season, such measures as spraying mist should be taken to lower the temperature at casting face and the mist should cover the whole casting face as much as possible. The mist spraying applied at the casting face could lower the temperature by 4℃ to 6℃.

5.3.3 Bringing down temperature rise of concrete hydration heat

1) Moderate-heat cement with low hydration heat should be selected;

2) Improve the concrete mixing ratio; at the premises of ensuring concrete strength, durability and workability, improve the aggregate grading of the concrete by adding quality admixtures and properly reducing the unit cement consumption;

3) Follow reasonable block thickness and intermittence time

The normal concrete was about 1.0m to 1.5m in layer thick at foundation constraint part and old concrete constraint part and the intermittence time of the layers was normally 5d to 7d. The roller compacted concrete was about 1.5m in layer thick at foundation constraint part, old concrete constraint part and the part constructed during high temperature period and the intermittence time of the layers was normally 3d to 5d. The concrete layer at the non-constraint part of the foundation could be 3m (or more than 3m) thick and the intermittence time was shorter while the concrete was cast up.

4) Arrange construction sequence and schedule reasonably

Foundation concrete casting should be carried out in low temperature seasons. For the important structural part like the foundation constraint area and the peripheral concrete at the bottom, long intermittence time of thin layers should be avoided as far as possible and construction should be arranged in seasons with no high temperature. For the rest parts, the concrete casting should rise continuously in an evenly manner with short intermittence time. For the part constructed in high temperature season, measures like even layer paving should be adopted to carry out construction in the morning and evening as well as at night. Except for the special parts (such as dam section at power intake, dam section at navigation works), the elevation of adjacent dam sections was generally no higher than 12m.

5) Stress on curing and surface protection

During construction, the RCC casting face should be kept moisture. During construction intermittence, after the RCC had got set finally, it should be watered for curing purpose. In high temperature season, heat dissipation was realized by applying flowing water at surface for cooling. When the average temperature was lower than 3℃ or in case of sudden temperature drop, thermal insulation material should be covered and the time before removing the formwork should be properly delayed.

6) Water cooling

For the normal concrete and RCC at foundation mat and constraint area of the dam body as well as the RCC constructed during high temperature period, cooling water pipe should be embedded for water cooling. For the initial cooling, water supply should begin 24h after the upper layer concrete casting. To bring down the internal and external temperature difference of the dam body and to prevent or minimize the surface cracking, dam body temperature should be lowered to reach the design requirement before the low temperature season was coming.

From the result of implementation, the application of the temperature control measures above during construction successfully enabled the all-year-round construction under high temperature condition and no harmful crack has ever occurred.

6 Study on Construction Scheme of High RCC dam

6.1 Construction Features of Longtan RCC Dam
(1) The project is of ultra-large scale and the concrete volume of the dam is tremendously big. The RCC took 2/3 of the total dam concrete consumption. Construction was of high intensity and was unevenly arranged. Concrete casting of the dam took 33 months, the monthly concrete casting intensity reached 200,000 m³ and the mean monthly casting intensity in peak period was up to 316,000 m³. With such engineering quantity and construction intensity, it was of great significance to choose a proper construction scheme.

(2) The left bank of the dam was arranged with the power intake dam section mainly made of normal concrete while the right bank was set with the navigation dam section made of normal concrete. The roller compacted concrete was located in the middle of the river bed. Therefore, neither of both banks was conditioned for arranging a construction access to enable auto-dumpers to perform concrete casting directly.

(3) The dam site is in subtropical zone. The flood season (from May to Sep.) is also the high-temperature season (with a max. mean monthly temperature of 32.8°C over the years) as well as rainy season (with a mean annual rainfall of 1343.5mm and an average number of rainy days of 125.4d over the years). In the construction schedule, however, it was required that RCC construction must be done continuously in high-temperature and rainy season. Meanwhile, due to the influence flood, in the flood control scheme, during flood season, a gap was reserved at the spillway dam section in the middle of riverbed for flow passing. Dam sections on both banks were kept with the same altitude difference for continuous construction.

6.2 Dam Concrete Construction Scheme

(1) Concrete aggregate

In selecting the source of concrete materials, limestone quarry with quality parent rock is chosen to produce concrete aggregate. The artificial aggregate system has a treatment capacity of 3,000t/h, a design productivity of 2,400t/h; the system uses a crusher and a rod mill in conjunction to produce aggregate and adjust the fineness module and crusher dust content. For the first time in selecting the fine aggregate transportation scheme for hydropower projects, the long-tunnel rubber belt transportation scheme (4.5km long) is adopted, which is favorable for high-efficiency low-cost aggregate transportation and temperature control and is also beneficial for environmental protection. See Fig. 2 for system layout.
(2) Concrete batching system

The concrete batching system was equipped with 3 sets of $2 \times 6 \text{ m}^3$ compulsory batching plants and 1 set of $4 \times 3 \text{ m}^3$ gravity-type batching plant and was consisted of an upper system and a lower system. The batching system had a total production capacity of $1,080 \text{ m}^3/\text{h}$, among which the capacity for RCC production was $900 \text{ m}^3/\text{h}$ and the capacity for pre-cooled RCC production in high temperature season was $660 \text{ m}^3/\text{h}$. For the lower system, two sets of $2 \times 6 \text{ m}^3$ compulsory batching plants were connected with the two high-speed belts of a tower-type belt feeder and one mobile extension-type belt conveyor was equipped at the outlet of each batching plant to feed each of the tower-belt machine. To avoid the shutdown of the tower-belt machine due to the malfunction occurring to the batching plant of the lower system, one belt conveyor of the compulsory batching plant in the upper system was arranged to connect to the transport line of the tower-belt machine so that any of the tower-type belt feeder could be fed when the belt reached the three compulsory batching plants. In addition, each batching plant was arranged with an access for vehicle transportation to avoid the suspension of concrete casting face due to the malfunction of the belt feeding line. See Fig. 3 for the arrangement of the concrete batching system.
(3) Dam Casting Scheme

Longtan RCC dam is featured by tremendous engineering quantities and high construction intensity. Based on these features, the dam casting scheme should not only enable the quick and continuous construction to meet the highly intensive continuous operation of big casting face but also adapt to the dam casting style during flood season when gaps were left for casting by blocks. Meanwhile, the scheme should also meet the requirement on
normal concrete casting intensity.

According to the construction features of Longtan high RCC dam, with reference to the construction practice at home and abroad, after researching on a number of combined scheme with high-speed belt, tower-belt machine, vacuum chute and high-speed cable crane, a casting scheme was finalized to use 2 high-speed belt conveyors complete with 2 sets of tower-belt machine for the RCC dam section as the primary scheme and to adopt 1 high-speed belt conveyor complete with vacuum chute and 2 sets of 20t medium-speed cable crane as the supplementary scheme.

Based on the detailed analysis on analogue simulation and casting face construction strength, whether even-layer paving method or inclined-layer paving method was to be adopted, both the dam casting intensity and the rising speed could meet the requirements on master construction schedule and casting face construction intensity.

In configuration of the casting equipment, in order to make full use of the continuous and quick single-point feeding function of the tower-type feeder and to adapt to the RCC construction features of big casting face, high intensity, quick construction and so on, highly efficient advanced vibrating roller and concrete spreader were equipped. Besides, the casting blocks and strips were reasonably divided to enable quick and efficient RCC construction.

Longtan RCC layer was 30cm thick. For the allowable intermittence time of direct paving, it was 4h in summer and 6h in other season. In case that it took longer time during construction, the RCC should be treated as per cold joints.

As the technologies and equipment for aggregate production and transport, concrete batching and transport as well as casting face spreading and compacting were properly provided and the casting faces were comparatively simple, it was possible to achieve quick RCC construction as the casting layers could be quickly covered, which was favorable for ensuring the RCC’s quality.

During actual construction, construction equipment was of high efficiency, tower-belt machine reached the design requirement in terms of its productivity, a single tower-belt machine reached 326m³/h at its peak strength (considered as per the allowance time of 20h) and the two material feeding lines reached 270,000 m³/month in terms of its monthly max. transport capacity. The actual casting intensity of dam RCC reached the design indicators and the max. casting intensity of a single block of RCC per day reached 20,000 m³. In Jun. to Aug. of 2005, the RCC volume was 480,000m³, realizing the continuous RCC construction in high-temperature rainy season. In 2005, the max. monthly intensity reached 316,000 m³/month, the annual RCC casting volume was 2.4 million m³, giving a full play of the features of quick RCC construction. See Pic. 3 for the RCC transport system for Longtan Project.

7 Conclusion

Longtan high RCC gravity dam is ultra-large in scale and sophisticated in construction techniques. At the initial stage of design and during the project construction, research was done on a series key issues of this project. With the help of the technical strength from a number of domestic colleges, universities and scientific research institutes, thanks to the coordination and organization of the design institute and under the guidance of the well-known experts from home and abroad, a number of problems have been solved and a great deal of research achievements representing international advanced level have been obtained. The design scheme is a full play of RCC features and ensures the implementation of quick construction. Longtan high RCC gravity dam was awarded
with the second prize of National Scientific and Technological Advancement in terms of its construction techniques and was granted with the honor of “International RCC Milestone Project” by International Commission on Large Dams.