OVERVIEW OF THE DESIGN, CONSTRUCTION, MATERIALS AND INNOVATIVE INSTRUMENTATION FOR ROLLER COMPACTED CONCRETE DAMS

By

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Introduction to the Author

Engr. Chaudhry Foad Hussain has earned his Master's in Water Resources & Environmental Engineering from Saint Anthony Falls Laboratory at University of Minnesota, Twin-cities, USA.

He worked with HDR Incorporation which is among the leading Civil Engineering consulting companies in United States. He was involved in multi-disciplinary Civil Engineering projects with United States Army Corps of Engineers (USACE) & United States Environmental Protection Agency (USEPA) during his 3 year tenure at HDR. He has also earned his Professional Engineer certification for Sediment & Erosion Control (CPESC) in 2005-2006. He became a member of Society of American Military Engineers (SAME) in 2006.

He has joined the Diamer Basha Consultants team as Sediment and Hydraulic Design Expert in 2007. Recently, he had the opportunity of visiting Longtan Hydropower Project as study tour visit component of 5th International Symposium on RCC Dams held in China on November 5 -7, 2007 at Guiyang Town in China. During his visit, he was profoundly impressed by the Innovative Design and Construction Methodologies used in Longtan Hydropower Project, China and evinced keen interest in all of its aspects. The current article is his humble effort to hoard some basic design and construction methodologies employed at the Longtan Hydropower Project.

5th International Symposium on RCC Dams – General Introduction

During past three decades, great progress and innovation have been made on the design, construction, materials and instrumentation of roller compacted concrete dams. Fifth international symposium on roller compacted concrete dams was held in Guiyang China from November 2nd to 8th, 2007 to promote the construction and development of RCC dams. The engineers and experts from more than 20 countries including, America, England, Germany, France, Spain, Switzerland, Australia, Canada, South Africa, Mexico, Morocco, Malaysia,

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India, Pakistan, Iran, Iraq, Vietnam, Burma and China, participated in the conference. The 450 participants (170 foreigners), produced 127 papers and exchanged construction experience and study achievements which will help to promote innovative technology in the design and construction of the roller compacted concrete dams across the world.

International Milestone RCC Projects

There are number of RCC dams constructed in last three decades around the globe. Eight RCC projects are recognized as International Milestone RCC Projects at the symposium based on the engineering design accomplishment and innovative instrumentation. There names are as follow:

- Longtan Dam – China (216.5 m , 6300 MW)
- Miel I Dam – Colombia (188m, 375 MW)
- Miyagese Dam – Japan (156m)
- Olivenhein Dam – USA (97.1m)
- Ralco Dam – Chile (155m , 690 MW)
- Rible Dam, -- Spain (101m)
- Salto Caxias Dam – Brazil (67m, 1240 MW)
- Wolwedans Dam – South Africa (70m)

Introduction of Longtan Hydropower Project

The Longtan RCC Dam is erected on Hongshui (Red) River, 15 km from the Tian-e county of Guangxi Autonomous Region. It is one of the strategic projects in the China’s western development and Power Transmission from West to the East. The Longtan Hydropower Project is also a pivot point in the cascade development of the Hongshui River as shown in Figure 1. It is primarily a power generation project along with the flood prevention, navigation and other comprehensive benefits.

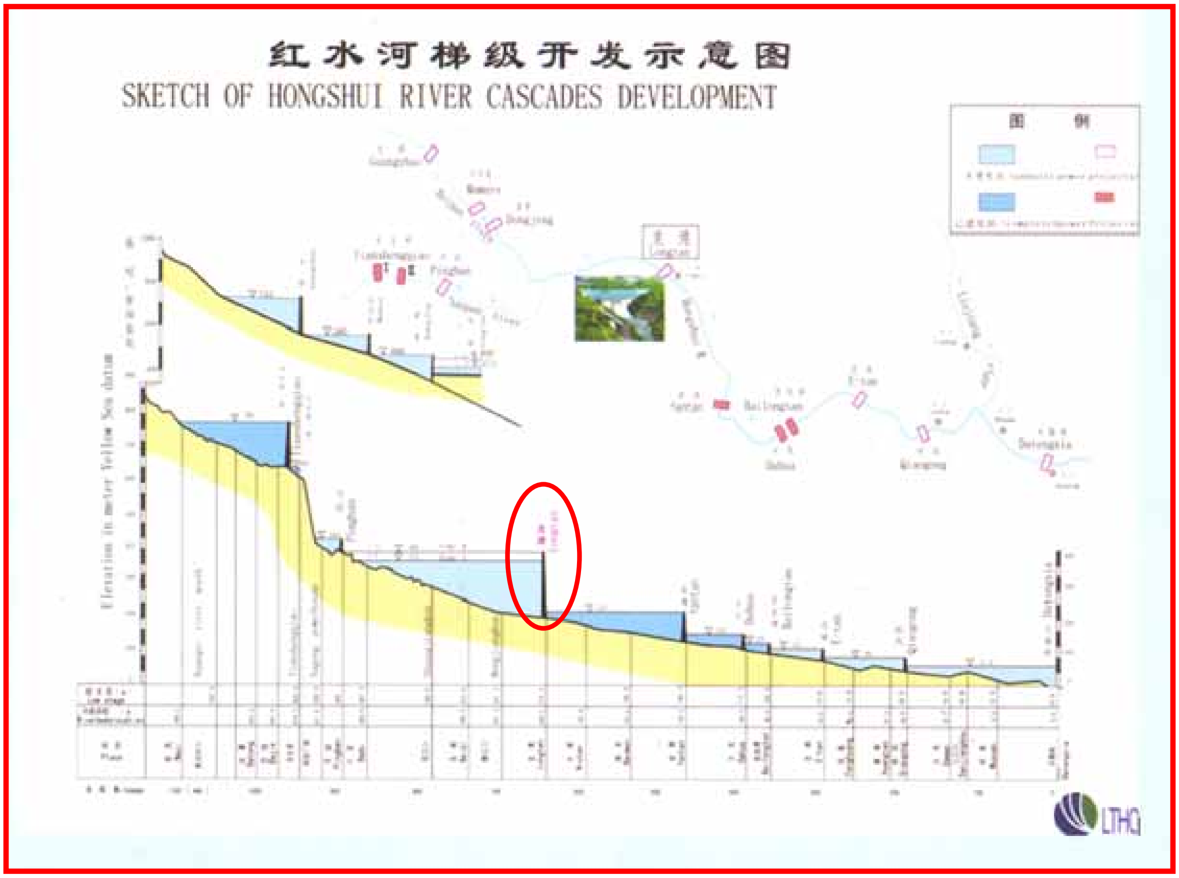

Figure 1: The Longitudinal Profile of Hongshui River Cascade Development

Description of Longtan Hydropower Project

The hydraulic complex of Longtan Hydropower Project is composed of the water retaining structure, the flood release structure, the headrace, power generation structure and navigation structure. The Spillway is situated in the riverbed dam section, consisting of 7 surface bays and 2 bottom outlets. The underground headrace tunnels and power house is located on the left bank and accommodates 9 hydro-generator units. The navigation structure is located on the right bank and adopts world's tallest double-step vertical ship elevator system as shown in Figure 2. The diversion arrangement during construction consisted of one diversion tunnel one each bank.

The Longtan Hydropower project was started in July 2001. The river closure was done successfully in late 2003 and impoundment was finished by September 2006. The power generation of the first unit was achieved in May 2007 about 1 year in advance. The project completion date is December 2009 and total construction period as per schedule is 9 years.

The underground power house comprises of 9 head race tunnels having a diameter of 10m. The dimensions of the powerhouse are 388.5m×30.3m×74.4m (L×W×H). The head race tunnels leads to the machine hall chamber & main transformer chamber. The three tail race surge shafts are located downstream of transformer chamber. A single tail race tunnel originates from each surge shaft having a diameter of 21m. The excavation of the main powerhouse had been completed in 32 months, with a maximum monthly excavation as high as 116×103m3, a yearly maximum excavation of 1,247 ×103m3.

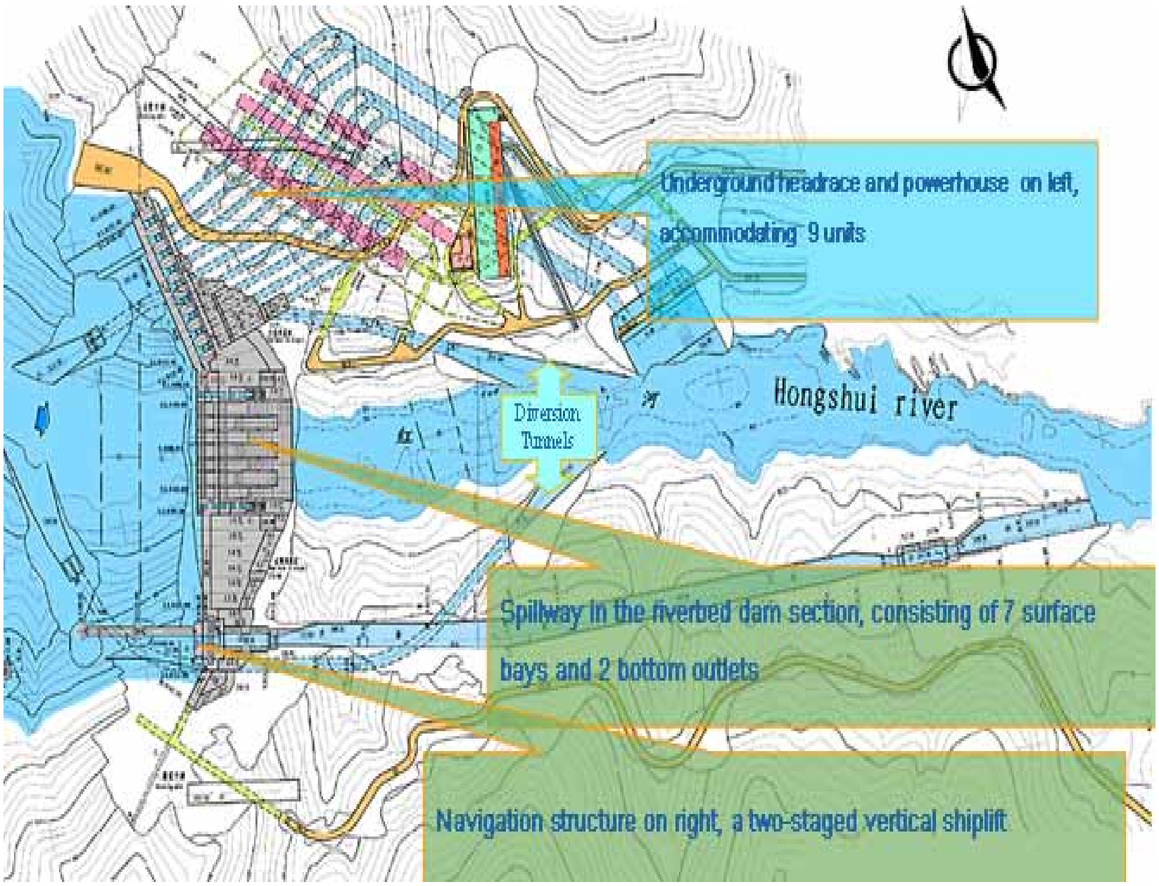

Figure 2: General Layout Plan of Longtan Hydropower Project

Configuration Optimization & Stability and Stress Analysis

The min. normal stress on the dam foundation face of Longtan Dam is 0.02MPa and -1.07MPa in seismic case. The maximum normal stresses on the dam foundation face and in seismic case are 4.9MPa and 5.83MPa, respectively. The anti-sliding stability safety factor along the dam foundation face is larger than 3.0 for the basic case, larger than 2.83 for special case and larger than 2.43 for seismic case. Table 1 indicate the downstream dam slope in the water retaining dam section and spillway dam section to be 1:0.73 and 1:0.68, respectively. The upstream dam slope for water retaining dam section and spillway dam section is 1:0.25.

Table 1: Configuration of Longtan RCC Dam

Typical dam section	Downstream dam slope	Upstream dam slope	Dam bottom width/Dam height
Water retaining dam section	**1 0.73**	**1 0.25**	**0.8**
Spillway dam section	**1 0.68**	**1 0.25**	**0.78**

Mix Design

On the basis of a lot of laboratory and field test and research, finally the *mix proportions for the three RCC zones* of Longtan dam were determined. In order to meet the requirement of all-year-around construction of Longtan dam under high temperature, *high effective retarding water reducer and aeration agent* suiting Longtan RCC were selected. The maximum length of a single drilled RCC core is 15.03m as shown in Figure 3. The core has smooth surface, compact structure and evenly-distributed aggregates.

Figure 3: The RCC Cores of Longtan Dam

Rapid RCC Construction Technology

Limestone artificial aggregates are used in preparation of the roller compacted concrete at Longtan Hydropower Project. The topographical conditions are made full use for application of 4 km long (1.2 m wide, 4 m/sec belt velocity, design carrying capacity of 3000 t/h) tunneled conveyer to realize efficient and low cost aggregate transportation. Mixing plant is equipped with three sets of 2×6m^3 force batching plants and one set of 4×3 m^3 gravity type batching plant with total capability of 1080m^3/h.

Three high speed belt conveyer concrete supply lines and two tower belt cranes have been used for horizontal and vertical concrete transportation and pouring system. The total concrete volume for Longtan dam is up to 6.6 million m^3, of which RCC accounts for 4.48 million m^3 and conventional concrete is 2.12 million m^3. Total product aggregate required is up to 14.12 million tons. The aggregate is made of limestone and the capability of sand and stone processing system is 2500t/h.

Figure 4: The High Speed Conveyer Belt & Tower Belt Cranes System at Longtan RCC Dam

In the high temperature season, i.e. June, July & August of 2005, 480,000m^3 RCC was placed, and in the same year 3,160,000m^3 concrete was placed, including 2,500,000 m^3 RCC, accounting for about 48% of the total quantity. The monthly highest concrete pouring target of 342,700 m^{3}and highest daily concrete of 15,816 m^3 is set using rapid RCC construction technology.

The rapid RCC construction technology features the Horizontally-proceeding slope placement method adopted at the Longtan Hydropower Project. The placement proceeds from the downstream side to the upstream side and compaction for the gentle sloped section is done along the water flow direction while the compaction for ending section is done along the direction vertical to the water flow.

Seepage Control Technology

Systematic studies and comparison had been for Longtan RCC dam among five dam seepage control schemes:

- ✓ Conventional concrete seepage control (3~5m thick)
- ✓ Precast board pasted in the inner side with PVC film
- ✓ Asphalt mix seepage control
- ✓ Surface reinforced GEVR (1m thick) and
- ✓ Reinforced concrete facing for seepage control.

In the early design stage, the dam uses a seepage control combining reinforced concrete facing and gradation II RCC. Extensive research was conducted on impermeability of gradation II RCC and GEVR at Jiangya dam laboratory, including 102 specimens for laboratory seepage test of RCC cores. It is determined, based on the research, that the upstream seepage control of all RCC sections of Longtan Dam are built with Grout Enriched Vibrated RCC (GEVR) and gradation II RCC.

Figure 5: Pouring and Vibrating Process of GEVR

The seepage control scheme developed at for Longtan RCC Dam combines GEVR and gradation II RCC. The GEVR Thickness varies between 0.5 m – 2m from top to bottom and the thickness of Gradation II RCC varies from 8m - 15m.

An Anti-crack reinforcement mesh is also set on the upstream section of Longtan dam and three (3) layers of Copper Water stops are also installed on the upstream dam section and two (2) layers on the downstream dam section. The 2 – 6 m thick conventional concrete was poured for Foundation Cushion and the spillway structure (overflow surfaces, pier heads and guide walls) at the overflow dam sections were built with conventional concrete.

RCC Thermal Analysis & Temperature Control

The thermal stress analysis of Longtan RCC gravity dam was carried out by means of a complete set of calculation methods such as zoned variable step length resolution method with simulation compound element, dam block joint element, thermal field and stress field, as well as consideration of post cooling, which greatly improves the efficiency of the calculation and analysis. The thermal control criteria had been put forward as follows:

- ✓ controlling temperature of RCC at the outlet of the batching plant
- ✓ reducing temperature rising during handling and spreading
- ✓ water spraying in the placing area
- ✓ thermal insulation at the lift surfaces
- ✓ rational arrangement of construction schedule
- ✓ provision of cooling pipes in the dam

The temperature control at Longtan Hydropower Project was carried out using evaporative cooling of stockpiles as shown in Figure 4.1. The aggregates were pre-cooled by utilizing a double stage (primary and secondary) wind cooling mechanism.

The rise in temperature of concrete during the conveyance and placing was found to be significant. In order to overcome this problem, the Ice Plant and cooling tower of concrete batching system were installed to mix the ice with concrete. In general, filling 10 kg ice for 1 m^3 can lower temp upto 1.2 degree C. Since the ice mixing with concrete did not bring the temperature down to the desirable placing temperature specifications, post cooling phenomenon was ultimately adopted which reduces the concrete temperature significantly. The roller compacted section of the dam were covered with the sheets in the summer season to reduce the amount of heat absorbed the concrete. The curing of RCC at later stages has been found to effective in controlling the cracks at Longtan RCC dam.

Figure 6: Evaporative Cooling of Stockpiles

Figure 7: The Ice Plant and Cooling Tower at Longtan RCC Dam

Recommendations & Conclusions

- The RCC Dams are growing at high rate both in terms of the numbers being constructed and also in terms of height of the dam. A significant number of RCC Dams in Pakistan are either in design phase or under-construction, particularly Diamer Basha Dam. The knowledge gained from the innovative instrumentation at Longtan Dam such as for thermal stress & thermal control, seepage control technology and rapid RCC technology can be used as a comparative technical data base for the smooth design and rapid construction of Diamer Basha RCC Dam.

- The GEVR along-with the RCC can be used as seepage control measure for the upstream facing. However replacement of GEVR with Geo-membranes and reinforcement mesh should also be considered.

- The Ice plant and wind cooling tower should be installed at the dam site for controlling the RCC temperature. Moreover, the use of post-cooling technology is also recommended.

- Since flyash is unavailable locally, the Pozzolan mix can be developed utilizing the locally available materials.

- The in-situ stress testing must be carried out in order to avoid any structural failures in the Power house caverns.