Research on Structural jointing & Temperature Control For Gravity Dam of Xiangjiaba Hydropower Station

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Abstract: Xiangjiaba Hydropower Station is located on the main steam of Jinsha river. The main water retaining structures is the concrete gravity dam, and the dam top elevation is 384m, the maximum height of dam is 162 m. The original construction design of the dam is pouring without longitudinal joint. However, this dam is considerably large and it is disadvantage in temperature control and crack prevention, structural safety and seepage controlling. Additionally, the treatment of creak will have a direct bearing on construction schedule, in company with great increase in costs.
Based on researches of different designs, the 2- longitudinal-joint construction design is recommended in this paper, with individual temperature controlling measures according to concrete blocks. It will provide a technical supporting and also have a good effect in preventing against cracks and improving dam quality, as well as lower project costs.
Key words: Concert dam; temperature control; structural jointing ;Xiangjiaba Hydropower Station

1. preface

Xiangjiaba Hydropower Project is located on the main steam of Jinsha River, It is the last cascade of the lower reaches Jinsha River cascade development. After being put into operation, Xiangjiaba Project will serve as a large scale hydropower plant with comprehensive function of flood control, navigation improvement, and irrigation for the downstream area. 8 sets of Francis hydroturbines will be installed to form a total installed capacity of 6000MW, with each volume of 750MW. Thus the mean annual generating output will be 30.75 billion KWH.

Xiangjiaba Project consists of the main dam, flood discharging and dissipation structure, sediment flushing structure, dam-toed left bank powerhouse, right bank underground water-diversion & power generation system, left bank vertical ship lift and water intakes for irrigation.

The dam is the concrete gravity dam, with the crest elevation at 384 m, the maximun height of 162 m, the maximun bottom width of 166 m,and the crest length of 909.26 m. in the aggregate, The concrete is more than 112 million cubic meter.

To meet the requirement for diversion,

the construction of major structures is divided into 2 stages: the first stage construction is implemented at the left bank with the protection by first stage cofferdam. In the foundation pit, we are going to build the second stage longitudinal concrete cofferdam, left-bank non-overflow dam and sector with the sand flushing hole. the contracted natural river channel can take the function of diversion and navigation.When the left-bank outlets and opening gap are finished and can be operated for diversion, the river closure will be implemented . Then the construction will go into the second stage sediment With the protection of second cofferdam ,the flushing structure, dam-toed left bank powerhouse and right-bank non-overflow dam will be built.

The preparetory works began from the year of 2004, the construction of the major structures is officially started in November 2006. The river closure is scheduled in the year of 2008, and the first generating units will be put into operation in the year of 2012, all the construction of project will be completed in the year of 2015.

The time limit for the Xiangjiaba project is so urgent,the design of structural jointing has a directly influence to temperature control and crack prevention,also in schedule. Using the finite element method,Typical dam section is selected,the procedure is then applied to analyze temperature and internal temperature stress. Recommending the 2-longitudinal-joint construction design , proposed the rationalization proposal for structural jointing.

2.Naturalness condition and construction characteristic

2.1.Naturalness condition

The drainage area of Jinsha river is tropical monsoon climate, the annual average air temperature is 18.4℃ around the location of Dam, the tiptop monthly average air temperature is 27 ℃ (1998′ s),the lowest monthly average air temperature is 8.4℃. The average air temperature is higher than 25℃ during June to August, the season of high temperature is lasting five month. The average rainfall is 896.2mm in the location of Dam. The weather data of XiangJia Dam refer to table 1:

2.2 Concrete and bedrock physical mechanical parameters

2.3 Construction characteristic

Pouring of overflow part of the dam will be started from Jan 2010, and will the level of 305m by the year of 2011. The restraint part at the foundation of the dam will be cast layer by layer, and layer thickness is 1.5m for the strong restraint section, 2.0m for the week restraint section, and 3.0m for disengaged restraint section.

3 Division of the dam and relevant calculations

3.1 Method-1: Single longitudinal slit

The longitudinal slit is placed at CH:0+036m, and the top end is merged in the corridor located at the level of 320m. As shown in Figure-1, the transversal profile of the dam was divided by the longitudinal slit into two blocks, having the dimensions forwarding the flow of 70m and 96m.

3.2 Method-2: Double longitudinal slit

The 2 longitudinal slits No. Ⅰ and No. Ⅱ are placed at Ch:0+015m and Ch:0+070m separately. The top end of No. Ⅰ is merged in the corridor located at the level of 280m.As shown in Figure-2, the transversal profile of the dam was divided by the two slits into three blocks, having the dimensions forwarding the flow of 49m, 55 and 62m.

Note: Strong restraint part, having a layer thickness of 0–0.2L, is started from the top of base plane; Week restraint part, having a layer thickness of 0.2L–0.4L, is started from the top of strong restraint part. L, means dimension forwarding the flow of base plane of the dam.

3.3 Calculation

3.3.1 Calculation for temperature of concrete

In the calculating field, the temperature field of each point therein shall be complied with the equation of heat conduction in solid materials, as following.

$$\frac{\partial}{\partial x}(a_x \frac{\partial}{\partial x}) + \frac{\partial}{\partial y}(a_y \frac{\partial T}{\partial y}) + \frac{\omega}{c\rho} - \frac{\partial T}{\partial \tau} = 0$$

$(\forall(x, y, z) \in R)$

Supposing that no heat is released from the inside of materials, viz. $\omega = 0$, Or in a certain time, the aforesaid equation can be simplified as following.

$$\frac{\partial}{\partial x}(a_x \frac{\partial}{\partial x}) + \frac{\partial}{\partial y}(a_y \frac{\partial T}{\partial y}) = \frac{\partial T}{\partial \tau}$$

note: $a_x = \frac{\lambda_x}{c\rho}$; $a_y = \frac{\lambda_y}{c\rho}$; a_x、a_y-Temperature conductivity; λ_x、λ_y- Heat conductivity; c- Specific heat of material; ρ - Volumeweight of material; τ, T- time and temperature at any time.

Finite element calculation for temperature field is referred to Doc.[1].

3.3.2 Stress field of temperature creeping

Under complicated stress conditions, strain increment includes flexible strain increment, Creeping strain increment, Temperature strain increment, Shrinkage strain increment and Self-volume strain increment. So it comes the following.

$$\Delta\varepsilon_n = \Delta\varepsilon_n^e + \Delta\varepsilon_n^c + \Delta\varepsilon_n^T + \Delta\varepsilon_n^s + \Delta\varepsilon_n^o$$

Note: $\Delta\varepsilon_n^e$ - flexible strain increment; $\Delta\varepsilon_n^c$ - Creeping strain increment; $\Delta\varepsilon_n^T$ - Temperature strain increment; $\Delta\varepsilon_n^s$ - Shrinkage strain increment; $\Delta\varepsilon_n^o$ - Self-volume strain increment.

Finite element calculation for stress field is referred to Doc.[1].

4. Analysis of the peak temperature inside the concrete dam during construction period

Simulation calculation of temperature field was carried out on the overflow part both with single longitudinal slit and double longitudinal slits.

For method-2 with double longitudinal slits, it supposed that height of strong restraint section was less than 12.4m. Considering the work of consolidation grouting, it will take 4 to 5 months to disengage the strong restraint section, and concrete pouring of the first block would not be carried out during hot weather. So the maximum concrete temperature is satisfactory to the requirement.

For method-1 with single longitudinal slit, it supposed that height of strong restraint section was less than 14m-20m. Concrete pouring of the first and the second block would be carried out under the hot weather, and the specified maximum concrete temperature would be exceeded partly. Compared to the above method, it will take more time, at least 1month, to disengage the strong restraint section.

Considering the above, the method of double longitudinal slits is better in temperature control than the other one. Detailed comparison of the two methods is list hereunder.

5. Results analysis on temperature stress of dam body

The maximum riveralong temperature stress of the 1-longitudinal-joint and 2-longitudinal-joint construction design plans are both in the foundation restraint area. When we select 1-longitudinal-joint construction design plan, the maximum riveralong temperature stress in the foundation restraint area of the two storehouses are both 1.26 MPa. But when we select 2-longitudinal-joint construction design plan, each storehouses' maximum riveralong temperature stress are 0.88 MPa, 1.04 MPa and 1.02MPa which don't exceed the standard value of tensile strength of concrete. The maximum temperature stress of 2-longitudinal-joint construction design plan is lower than the maximum temperature stress of 1-longitudinal-joint construction design plan by 17.5%~30%. So in the view of temperature stress and anti-cracking, the 2-longitudinal-joint construction design plan is beneficial to the dam structure.

The maximum temperature stress and its occurring place at spillway section of the 1-longitudinal-joint and 2-longitudinal-joint construction design plans can be seen in Table 7.

6. Temperature control measures

According to many successful engineering projects, we take the following temperature control measures in the construction process of the first phase project of Xiangjiaba Hydropower Station and good results are obtained. Up to now there is no harmful temperature crack in the dam body.

6.1 Lowering the temperature of concrete in the mouth of mixer plant

When measure of aggregate precooling is taken in concrete mixing process, it needs aggregate tins of concrete batching system are filled as full as possible in order to ensure the effect of precooling. It makes clear the quality control index of aggregate precooling by first wind cooling and second wind cooling. It also establishes some temperature control systems such as early-warning on lack of aggregate storehouse, temperature measuring of aggregate and concrete mixing with ice or ice-water.

6.2 Lowering the placing temperature of concrete

It prohibits transporting concrete with automobile which the exhaust is in the carriage. In the transportation, we must set sun shade awning to avoid intense-insolation. So it can reduce concrete's temperature increases in concrete transportation. The time of opening storehouse should avoid high temperature period. In order to prevent concrete's temperature increases we must take measures of spraying and covering insulation quilt on concrete storehouse surface.

6.3 Water cooling

The cooling pipe of first layer is black pipe of 1 inch. The arrangement of cooling is 1.5m(thickness of the layer)×1.5m(spacing of the cooling pipe). When the thickness of the layer is above 3m, the middle layer should add PVC cooling pipe of Φ25mm. At the beginning of pouring concrete, artificial cool-water of 8℃ should be pumped in the cooling pipe. The main water-supply pipe should be covered by rubber plastic with thickness no less than 6cm to keep temperature and reduce temperature loss. The length of each single cooling pipe should not be more than 200m. The water flow direction in cooling pipe should be changed every day. Every day's decreased temperature should not be more than 1℃. We must take individual circulating water measures according to the actual situation.

6.4 Maintaining the surface temperature of concrete

Strengthen watering on the concrete surface for curing in summer and thermal insulation in winter to prevent concrete crack.

6.5 Management measures

It establishes temperature control system of holding a meeting every week. The project owner should organize supervision unit, design unit and construction unit to analyze and summarize the situation of temperature control by holding a meeting every week. Moreover it must perfect the temperature control system and establish workgroup of temperature control. So it can form the coordinated process of temperature control from concrete production, transportation, pouring, maintenance, water cooling to monitoring of internal temperature.

7. Conclusion

Based on the analysis of the concrete's maximum temperature and internal temperature stress, we can know that the risk on temperature control and crack prevention of 2-longitudinal-joint construction design plan is lower than which of 1-longitudinal-joint construction design for Xiangjiaba Hydropower Station. It is beneficial to concrete quality control. At the same time, we must take comprehensive temperature control measures and strengthen supervision and management of temperature control to prevent crack effectively.

Table 1 The fruit of weather stat around the location of Dam

Month	Unit	Jay	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual average
Average air temperature	℃	8.4	10.6	14.2	19.5	23.1	25.2	27.0	26.5	23.0	18.6	14.6	10.1	18.4
Average lowest air temperature	℃	6.4	7.8	10.9	15.2	18.8	21.4	23.2	22.6	19.8	16.0	12.1	7.8	15.2
Average highest air temperature	℃	11.4	13.3	18.1	23.7	28.0	29.7	31.6	31.4	27.2	21.7	17.8	12.7	22.2
Average water temperature in river	℃	11.6	13.1	16.3	19.5	21.9	22.8	23.1	22.9	21.5	19.2	15.9	12.9	18.4
Average precipitation month by month	mm	9.3	15.1	21.4	47.2	85.3	159.6	209.9	185.4	76.7	57.5	17.8	8.8	894

Table 2 Dam mechanical properties of concrete

Place	strength grade	Compressive Strength			splitting tensile strength,			Ultimate Tension	
		1d	28d	90d	1d	28d	90d	28d	90d
Concrete inside	$C_{90}15$	10.2	19.8	29	0.83	1.75	2.45	0.9	1.06
Concrete in	$C_{90}20$	14.6	26	37.9	1.22	2.14	2.91	0.92	0.99

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Table 3 bedrock physical mechanical parameters value

Elasticity Moduli（GPa）	Poisson ratio	bulk density（kg/m^3）	Tensile Strength (MPa)	Compressive Strength (MPa)
10～20	0.1～0.25	2570～2740	1.01～5.18	69.8～141

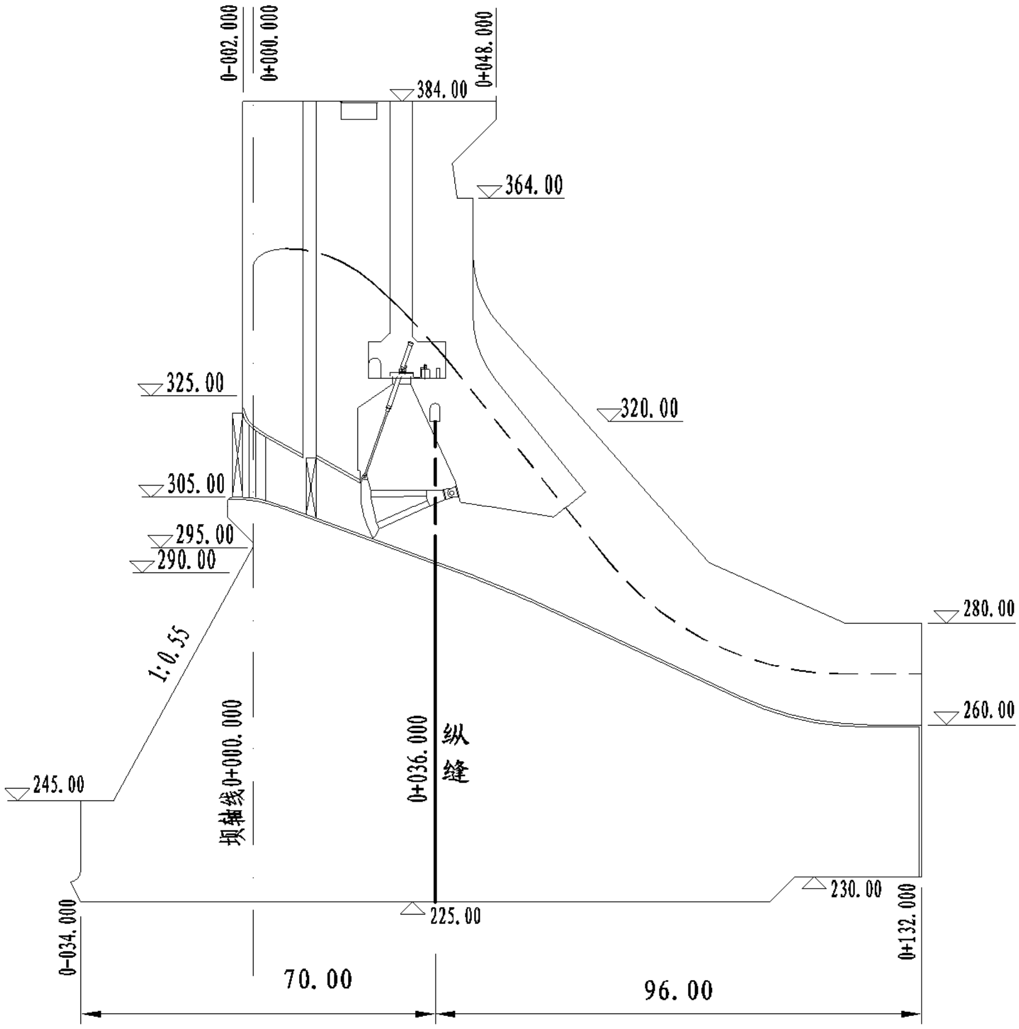

Figure-1 Placing single longitudinal slit at overflow part of the dam

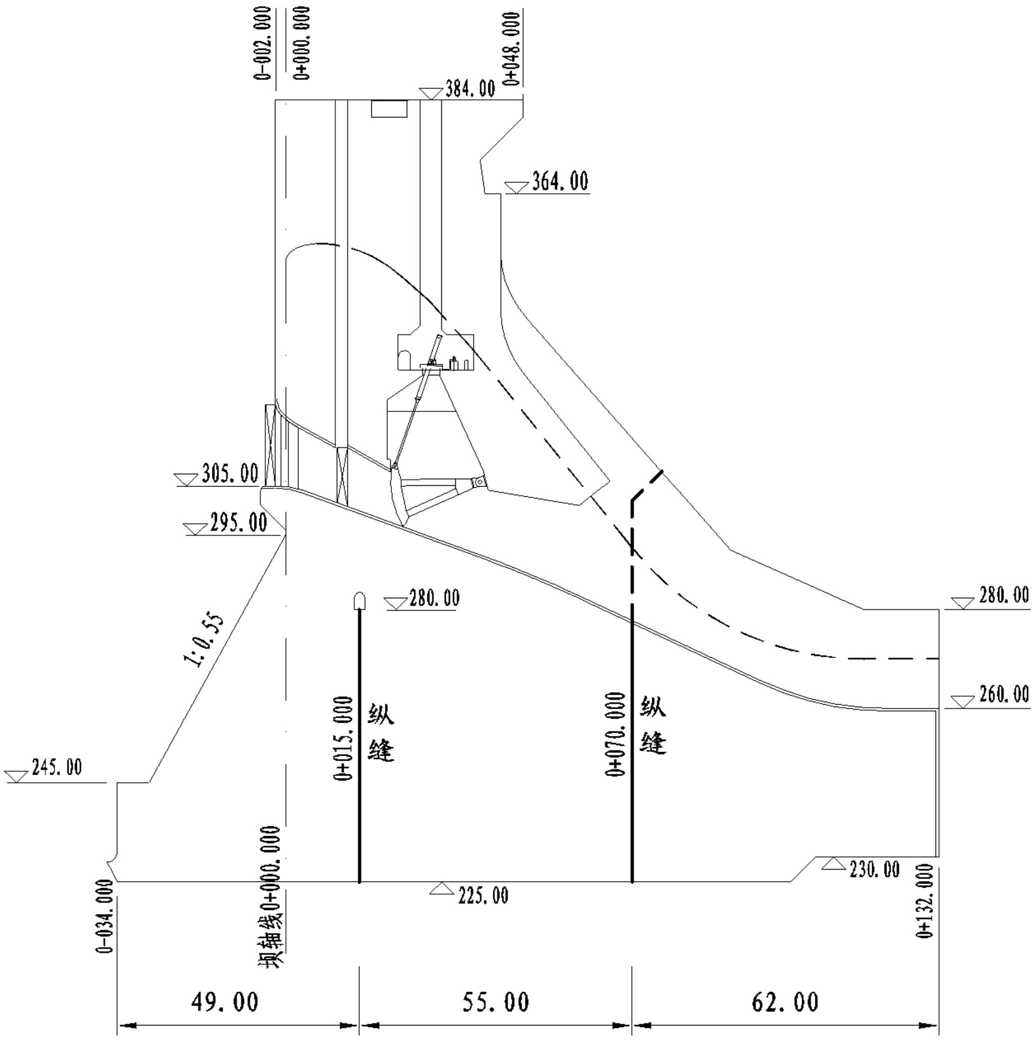

Figure-2 Placing double longitudinal slit at overflow part of the dam

Table 4 Comparison for levels of the restraint part at the foundation (Unit: m)

		Method-1		Method-2		
		Block 1	Block 2	Block 1	Block 2	Block 3
Overflow Part	Dimension forwarding the flow	70	96	49	55	62
	Level of base plane	225	225	225	225	225
	Top Level of strong restraint part	239	244	235	236	237.5
	Top Level of Week restraint	253	263.5	244.5	247	250

	part					

Table 5 Concrete's maximum temperature during construction of 1-longitudinal-joint design plan (unit: ℃)

region	concrete mark	pouring month	pouring temperature	1[st] storehouse		2[nd] storehouse	
				maximum temperature	maximum allowable temperature	maximum temperature	maximum allowable temperature
the strong constraint region of foundation	$C_{90}20$	1~2	12	23.2~25.7	26	23.4~25.8	27
		3	16	26.2~26.9	29	26.3~26.9	30
		4		27~27.8	29	27.3~28.1	30
		5	14	27.8~29.4	29	28.1~28.9	30
		6~8		20.1~20.6	29	29.7~31	30
the weak constraint region of foundation	$C_{90}15$	7~8	20	32~32.7	32	32.3~32.7	33
		9		30.8~31.4	32	30.5~31.9	33
		10		29.1~29.9	32	29~29.8	33
		11	16	25.8~26.7	29	25.7~26.8	30
		12	12	——		26.5~26.6	27
		12~2	12	25.8~26.9	27	25.4~26.6	27
the unconstraint region of foundation		3	16	25.4~26.7	30	24.9~26.7	30
		4	20	28.8~29.7	33	28.9~29.8	33
		5		30.5~31.3	35	30.6~31.4	35
		6~8		31.9~32.9	36	32~32.9	36

Table 6 Concrete's maximum temperature during construction of 2-longitudinal-joint design plan (unit: ℃)

region	concrete mark	pouring month	pouring temperature	1[st] storehouse		2[nd] storehouse		3[rd] storehouse	
				maximum temperature	maximum allowable temperature	maximum temperature	maximum allowable temperature	maximum temperature	maximum allowable temperature
the strong constraint region of foundation	$C_{90}20$	1~2	12	23.1~25.7	26	23.3~25.7	27	——	——
		3	16	26.2~26.7	29	26.3~26.9	30	26.0~27.0	30
		4	16	27.4~29.0	30	27.6~28.6	31	27.8~28.8	32
		5	14	29.1~29.7	30	28.7~30.2	31	29.0~30.6	32
		6~7	14	——	——	30.9~31.4	31	31.2~32.1	32
the weak constraint region of foundation	$C_{90}15$	5	20	29.4~30.1	33	——	——	——	——
		6~8	20	30.5~31.1	33	30.6~31.2	34	30.6~31	35
		9	20	——	——	——	——	29.3~30.2	35
the unconstraint region of foundatio		8	20	30.6~30.8	36	——	——	——	——
		9	20	29.3~30.2	35	29.5~30.0	35	——	——
		10	20	27.8~28.8	33	27.5~29.0	33	27.8~28.8	33
		11	16	25.5~26.5	30	25.8~26.8	30	25.5~26.8	30
		12~2	12	26.5~27.3	27	26.8~27.4	27	26.5~27.4	27

n		3	16	26.3~26.8	30	——	——	26.2~26.8	30
		4	20	27.5~28.8	33	——	——	——	——
		5	20	29.3~29.8	35	——	——	——	——
		6~7	20	30.2~31.0	36	——	——	——	——

Table 7 The maximum temperature stress and its occurring place

	1st storehouse		2nd storehouse		3rd storehouse	
design plan	maximum stress(MPa)	place (altitude:m)	maximum stress(MPa)	place (altitude:m)	maximum stress(MPa)	place (altitude:m)
1-longitudinal-joint	1.26	231.5~235.5	1.26	228.5~232.5		
2-longitudinal-joint	0.88	231.5~234	1.04	230.5~232.5	1.02	228.5~230