SUCCESSFUL APPLICATION OF RCC INTERLAYER JOINT BONDING TECHNOLOGY WITH SURFACE LONG TIME EXPOSED IN DRY AND HIGH TEMPERATURE AREAS

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ABSTRACT

This paper is depended on the Kafue Gorge Lower Hydropower Project in Zambia. For the RCC dam construction, the Contractor conducted a comprehensive study on the influences of interlayer joints bonding quality from RCC mix performances. The contents is including: 1) The joint type judged by Modified Maturity Factor (MMF) with joint surface long time exposed in the region with dry and high temperature; 2) Technical measures of layer bonding quality control under condition of joint surface long time exposed; 3) Effect of joints shear strength and impermeability if the RCC Layer compacted existed in the condition of plastic and elasticity; 4) Joints construction craftsmanship. The achievements and experiences of the Project could be used for reference of similar RCC dam construction.

***Key Words** : RCC mix; RCC joint exposed time; Modified maturity factor (MMF); Dry and high temperature area; RCC Joint bonding quality control measures; impermeability; Craftsmanship.*

1. INTRODUCTION

Roller Compacted Concrete (RCC) dam construction technology has been widely popularized and applied in the around world with advantage of its low cost and short construction period. Since the first RCC dam in the world was built in Japan in 1981, up to now there are nearly 1070 RCC dams (incomplete statistics) have been built in the world. By the engineering practice and technological Improvement in the past 40 years, the technology of RCC dam construction has made matures gradually. However, there are still many problems to be further understood and studied on RCC dam construction technology. This paper has carried out some study on the characteristics of RCC interlayer joint and its quality control method in the region with dry and high temperature climate.

Project description: The Zambia - Kafue Gorge Lower (750 MW) Hydroelectric Project (herein referred to as the KGL Project) is located on the Kafue River, a primary tributary of the Zambezi River, some 55km upstream from the confluence of the Kafue River and the Zambezi River. KGL is located some 17.3km downstream from the the Kafue Gorge Upper Hydropower Project (herein referred to as KGU) and some 5.9km downstream from the KGU tail-water Outlet.

The catchment area upstream the Dam Site measures 153,000km^2. The annual average inflow is 268.8m^3/s, the main purpose is for power generation. At FSL of 579.00m, the reservoir capacity is 83×106 m^3, and the active storage is 61×106 m^3.

The main Dam is of RCC gravity-type, with a maximum height of 130.5m tentatively, 374.5m in length. Dam crest is 8m wide and footprint width with120m. The upstream slope of the dam is designed by 1:0.2 (V : H) and change to vertical at EL530m, while the downstream slope is designed by 1:0.75 (V : H) and change to vertical at EL569.5m. The dam is divided into 19 monoliths in which 7 monoliths of non-overflow section at left bank and 4 monoliths of over-flow section(spillway) and 8 monoliths of non-overflow section at right bank. Typical dam up-stream view sees the Fig. 1.

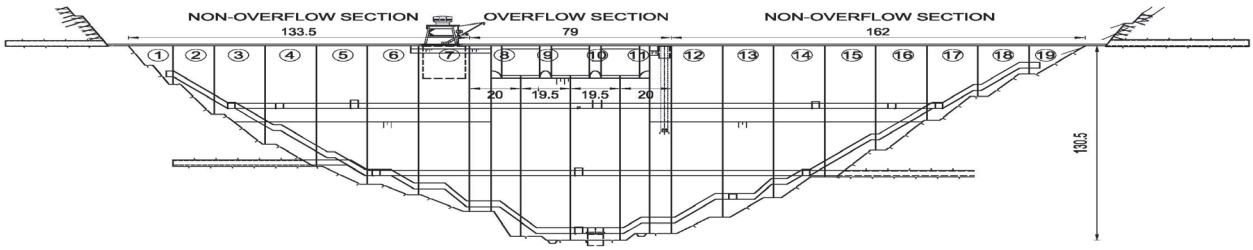


Fig. 1 : View at U/S of Dam

In general, the Zambia weather is subtropical continental. Rainy season starts in November and end in March, occasionally it rains in September and October. In Zambia, there are four seasons: the weather is cold and dry in winter from April to August with lowest temperature 7.5 ℃; the temperature rise and the weather becomes hot and dry from September/ October which the temperature reaches at circa 40 ℃ according to site monitoring; Raining usually starts in November, it is humid and stuffier at this time; the temperature start dropping from February to March, it is humid and cool along occasionally raining. Meteorology data see Table 1.

Table 1 : Meteorology Data of Kafue Gorge Lower Area

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Year Aver.**
Average Rainfall	205	153	68	26	2	0	0	0	1	19	81	210	766
Average Temperature	26.4	26.1	25.7	24.5	22.1	20.1	20	22.5	26.1	28.5	28	26.8	24.7
Average Evaporation	149	133	160	166	163	144	158	195	232	259	202	159	2120
Ralative Humidity	78	80	77	68	63	62	57	50	43	44	56	73	62.6
Average wind velocity	1.6	1.6	1.8	2	2.1	2.2	2.5	2.7	3	2.9	2.5	2.1	2.2

Raise of problems: As well known, RCC dam seepage is often occurred from the interlayer joints, it is very important issue how to improve the quality of joint's bonding. During KGL dam RCC construction peak period, the maximum placement block area is at circa 14000m2 from the EL470 to EL.510. The single layer (30cm thick) RCC maximum volume reaches at 4250m^3 (see Fig. 2). Based on the comprehensive capacity of the batching plant production, transportation and site placement progress etc., the interlayer joint surface maximum exposure time needs at least 16 hours which does not consider the condition such as the malfunction of batching plant or other equipment. The joint exposure time could need within 20-24hours that is considered all of emergency events situations.

In order to ensure the quality of interlayer joint bonding, the project technician carried out some exploration and researches as follows: (a) Optimizing of RCC mix proportion. (b) Study of characteristic of joints under different exposure time and treatment. (c) Establishing the control standard of Maturity degree at the placing site. (d) Site quality control system.

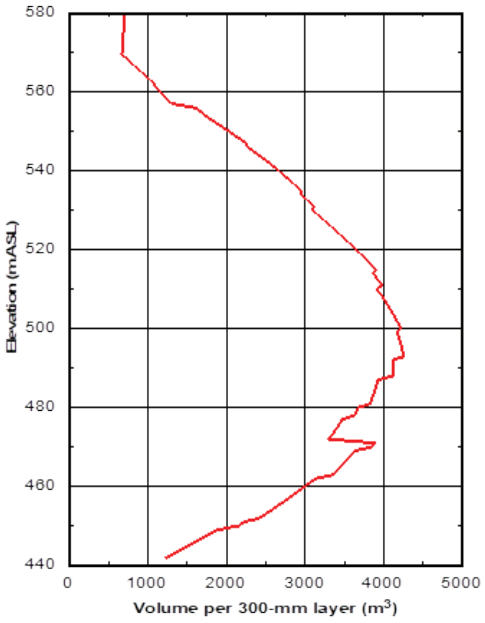


Fig. 2 : Single layer(30cm), RCC volume, m^3

Based on the final evaluation of the joint quality by the core samples extraction and water pressure test, the results meet the technical requirement and the quality is satisfied. The main results and achievements applied KGL Project are introduced as below.

2. OPTIMIZING OF RCC MIX

KGL project adopted one type RCC mix with 12MPa @ 365d in full section of the dam, so that simplifying the placement procedures and improving the site placement rate. The technical requirement of RCC mix is shown in Table 2. The concrete materials and final selection of RCC mix and its properties is introducing as bellows.

Table 2 : Performance requirements of RCC mix

Compressive strength (Cylinder), MPa	Tensile strength (MPa)		Age (day)	Impermeability coefficient (cm/s)	M.S.A (mm)
	Indirect	Direct			
12	≥1.99	≥1.14	365	$\leq 10^{-8}$	63

2.1 Properties do raw materials

2.1.1 *Cement*

The Lafarge Cement in Zambia was chosen as the main supplier. The Lafarge Cement Plant is relatively close to the site, and its output can reach 4000t/day. It can be supplied steadily during the peak period of dam RCC construction. Type CEM-I 42.5N cement is selected for RCC mix design. The cement complies with BSEN 197-1. The test results are shown in Table 3.

Table 3 : Cement test results

Item	Density (g/cm^3)	Soundness (mm)	Fineness (%)	Setting time (min)		Compressive strength, (MPa)	
				initial	final	2d	28d
Results	3.11	1.0	1.5	163	216	28.4	54.9
BS EN 197-1	/	≤10	≤10	≥60	/	≥10	42.5≤f≤62.5

2.1.2 *Fly ash*

After the investigation, Mammba thermal power plant in Zambia is with 5×150 Mw units. The fly ash is collected by electrostatic collection system, and with production of 2000 t/day fly ash qualified. It meets the maximum demand of dam RCC construction peak period with 500 tons per day. The fly ash meets the requirements of ASTM C618 class F. The test results are shown in Table 4.

Table 4 : Fly ash test results

Item	Density (g/cm^3)	Soundness (mm)	Loss on ignition (%)	Fineness (0.045mm sieve), %)	Water requirement (%)	Activity index (%)		
						7d	28d	90d
Results	2.34	0.5	3.79	17.7	104	85.3	93.7	113
ASTM C618	≥2.0	0.8	F,C: ≤6 N: ≤10	N, F, C: ≤34	F,C: ≤105 N: ≤115	≥75	≥75	/

2.1.3 *Aggregates*

The aggregate is made of artificial aggregate produced by on-site crushing plant. Previous exploration confirms that there is no potential alkali aggregate reaction in quarry rocks, and quality meet the technical requirements of ASTM C33, EM1110-2-2006 and ACI 207.5R-2011. The test results of artificial sand are shown in Table 5.

Table 5 : Test results of artificial sand

Item	Density (g/cm^3)	Absorption (%)	Fineness modulus	Soundness (%)	Light Materials (%)	Organic matter	Clay (%)	< 0.075 mm
Results	2.61	2.2	2.73	5.8	0.1	0	0.3	12.8
EM1110-2-2006	>2.5	/	2.1-31	<12	<0.5	No allowed	<3.0%	/

The coarse aggregate is divided into three groups: 4.75-19 mm, 19-37.5 mm and 37.5-63 mm. The technical properties of the coarse aggregate are in accordance with ASTM C33 and EM1110-2-2006. The test results are shown in Table 6.

2.1.4 Admixtures

The admixtures used for RCC mix are type SN-2 super plasticizer and SN-GH retarder produced by the Additive Factory of Bureau No.11 of PowerChina, China. The admixtures performances meet the technical requirements of ASTM C494. The test results are shown in Table 7.

Table 6 : Coarse aggregates test results

Item	Density (g/cm^3)	Absorption, %	Los Agles abrasion,	Soundness	Flat & Elongation	Clay lump	Light matter	<75μm
4.75-19mm	2.62	0.8%	25%%	5.0%	3.7%	0.30%	0.08%	0.8%
19-37.5mm.	2.63	0.6%	27%	5.8%	2.5%	0.25%	0.08%	0.6%
37.5-63mm	2.64	0.3%	28%	7.0%	8.8%	0.20%	0.06%	0.3%
ASTM C33	>2.5	/	<50%	<12%	<30%	<3%	<0.5%	<1%

Table 7 : Admixture test results

Item	Dosage %	Setting time (h: min.)		Rate of Water reduction %	Ratio of strength, %		
		initial	final		3d	7d	28d
Reference concrete	/	8:11	10:15	/	100	100	100
Reducer type SN-2 Test results	0.8	≥ 1:30	≥ 3:15	15.9	130	122	123
	1.0	≥ 5:15	≥ 6:30	20.4	127	145	142
ASTM C494, Type F		≥1:00	≥3:30	>12	>125	>115	>110
Retarder type SN-GH Test results	0.15	≥2:00	≥ 1:50		102.2	102.1	100
	0.3	≥5:15	≥ 6:15		98.9	106.3	100.9
	0.6	≥ 9:00	≥10:45		93.3	114.7	100.8
ASTM C494, type B		≥ 5:00	≥ 5:45	/	>90	>90	>90

2.2 Final RCC Mix design and Its Performances

2.2.1 *Determined parameters of RCC mix*

Table 8 : Construction RCC Mix

Ratio of W/C	Fly-ash %	Reducer %	Retarder %	Quantities of materials in $1m^3$, kg/m^3							
				water	cement	Fly ash	C+F	sand	Agg. 4.75~19 mm	Agg 19~37.5 mm	Agg 37.5~63 mm
0.71	65	1.0	0.3	122	60	112	172	752	403	539	406

2.2.2 *Properties of fresh RCC mix*

Table 9 : Test result of fresh mix

Density(kg/m^3)	Vebe time(s)	Air content %	Initial Setting time (h:min)	Final Setting time (h:min)
2375	6-8	0.8	26:40	52:15

2.2.3 *Mechanic properties of RCC mix*

Table 10 : Mechanic properties test results of RCC mix

Compressive strength (d/MPa)						Direct tensile, (d/MPa)					Indirect tensile, (d/MPa)				
7	28	56	90	180	365	28	56	90	180	365	28	56	90	180	365
5.6	10.8	12.3	12.8	15.1	17.3	0.7	1.06	1.14	1.33	1.44	0.61	1.27	1.29	1.78	1.80

Table 11 : Developing rate of compressive strength

Age	7d	28d	56d	90d	180d	365d
Rate, %	0.59	1.00	1.19	1.24	1.43	1.60

2.2.4 *Deformation properties of RCC mix*

Table 12 : Test results of deformation properties of RCC mix

Modulus of elasticity, (GPa)						Poisson ratio					Ultimate tensile strain value, (10^{-6})				
7	28	56	90	180	365	28	56	90	180	365	28	56	90	180	365
5.6	12.2	13.5	14.1	17.8	18.8	0.11	0.12	0.13	0.16	0.2	60	68	74	81	88

2.2.5 *Thermal properties of RCC mix*

The thermal properties test was executed by Nanjing Hydraulic Research Institute, China. The main test results are shown in Tables 13.

Table 13 : Thermal Performance Test Results of RCC mix

Specific heat, kJ/(kg·℃	Thermal conductivity, kJ/(m·h·℃	Thermal conductivity coefficient, m^2/h	Coefficient of linear expansion $\times 10^{-6}$/℃
0.915	9.215	0.0038	0.84

Study on Characteristics of Joint with Different Maturity and Treatment

3.1 *Test joint maturity and bonding strength*

Before the commence of dam RCC construction, the RCC trial section placement was executed, the different exposure times of joint at 4, 10, 16, 22, 36, 48 and 60 hours was arranged. The trial section was separated into 3 zones with treated separately mortar, grout and no any treatment. The test results of joint bonding strength under different treatment and maturity are shown in table 14. The modified maturity factor (MMF) calculation method is MMF= (average ambient temperature + 12℃) ×joint exposure time (hours).

3.2 *Criteria for joint treatment*

According to the bonding strength shown in the table14, the longer the exposure time of joint will make the lower the bonding strength. Beyond 22 hours of exposure time, the strength of treated joint was higher than without treatment. For hot joints, the joint bonding strength is greater than 60% of parent RCC within 16 hours. Based on the bonding strength results and the modified maturity factor value, the conditions of Hot, Warm and Cold joints can be initially determined as follows: (1) when the maturity is less than 757 C. H, it is defined as "Hot" joint without any treatment. (2) When the maturity is between 757 - 1200 C. H, it is defined as "Warm" joint. 3) When the maturity is more than 1200 C. H, it is defined as "Cold "joint.

In order to ensure the joint bonding strength of joints, the control criteria were defined for the dam RCC construction. The criteria for judging hot joints, warm joints and cold joints are determined shown in table 15. The hot joint condition does not need any treatment. If the joint maturity reach at warm joints condition to need treatment with applying grout, after then the placement can be continued. If the joint maturity reaches the condition the joint will be treated as cold joint, the placement operation shall be stopped, the joint surface have to roughening by green-cutting machine, clean up, and before restarting the next placement the joint shall be treated with grout.

Table 14 : Test results of Joint bonding strength with different treatment method

Joint	Exposed time (Hrs)	MMF (℃.H)	Joint bonding strength with different treatment method (MPa.)					
			By grout		By mortar		Without treatment	
			Average MPa	% by parent RCC	Average MPa	% by parent RCC	Average MPa	% by parent RCC
7/8	60	2064.9	0.9*	65.7	0.76*	55.5	0.50	36.5
6/7	48	1866.8	1.02*	74.5	0.80*	58.4	0.36	26.3
5/6	36	1330.1	1.10	60.3	0.73	53.3	0.44	40.1
4/5	22	757.1	1.02	58.6	1.25	71.8	0.64	36.8
3/4	16	589.7	1.34	77.0	1.28	72.0	1.04	59.8
2/3	10	300.1	1.47	84.5	1.33	75.0	1.28	73.6
1/2	4	178.5	1.43	82.2	1.55	88.0	1.44	82.8

*treated by green-cut as well.

Table 15 : Defined control standard of joints as to exposing time and MMF

Month	Temperature of Ambient, °C	Defined control standard of joints as to exposing time and MMF					
		Hot joint		Warm joint		Cold joint	
		Exposed time, hrs	MMF, H.°C	Exposed time, hrs	MMF, H.°C	Exposed time, hrs	MMF, H.°C
1	22.8	≤16	557	16-28	556-974	>28	> 974
2	22.5	≤16	552	16-28	552-966	>28	> 966
3	22.1	≤16	546	16-28	546-955	> 28	> 955
4	20.9	≤20	658	20-30	658-987	> 30	> 987
5	18.5	≤22	671	22-32	671-976	> 32	> 976
6	16.5	≤22	627	22-32	627-912	> 32	> 912
7	16.4	≤22	625	22-32	625-909	> 32	> 909
8	18.9	≤22	680	22-32	680-989	> 32	> 989
9	22.5	≤20	690	20-30	690-1035	> 30	> 1035
10	24.9	≤16	590	16-28	590-1033	> 28	> 1033
11	24.4	≤16	582	16-28	582-1019	> 28	> 1019
12	23.2	≤16	563	16-28	563-986	> 28	> 986

4. EFFECT OF RCC LAYER COMPACTED EXISTED IN THE CONDITION OF PLASTIC AND ELASTICITY

During RCC construction, as the existing RCC layer compacted is in the condition of plastic and elasticity, some RCC dam is not allowed. For this issue have conducted some study on the affection of the joint quality. The phenomenon is occurred when the Vebe time is less the 5 seconds. During the RCC trial section construction the test carried out in KGL project. Based on the core sample test result, there is no any influence on the joint shear strength, impermeability, bonding strength. Also the core sample compressive strength and density meets the requirement. So the compacted RCC in condition of plastic and elasticity is not limited in the KGL project.

5. QUALITY CONTROL SYSTEM OF RCC CONSTRUCTION

In order to ensure the interlayer joints quality, the key control points are as follows :

Temperature control measures, RCC temperature at batching plant: through taking the measures of primary air cooling of coarse aggregate, adding cold water and ice chips in mixer, RCC mixture temperature was controlled less than 20 °C at the plant and less than 25°C at placing site; sunshade used for RCC transport Truck and belt convey system, Fogy system measures was adopted to reduce the temperature placement site and to keep the joint surface in the SSD condition. Height of aggregate pile stock is higher than 6m and set up shading measures for aggregates etc. the partial test results of temperature control see Fig. 3

RCC mixture Vebe time, shall be adjusted according to the ambient temperature, Vebe time controlled within 8±2s at placing site. The partial test records of VeBe time see the Fig 4.

The bedding grout mix quality control, ratio of water/cement within 0.6-0.65, the flow value within 40±3s.

RCC Mixture segregation control, RCC discharging on RCC surface un-compacted, so that the mixture is remixed when the spreading and leveling operation by bulldozer to reduce the segregation.

Applying of grout, for the warm and cold joint shall be treated with grout, and the distribution shall be uniformed on the joint surface.

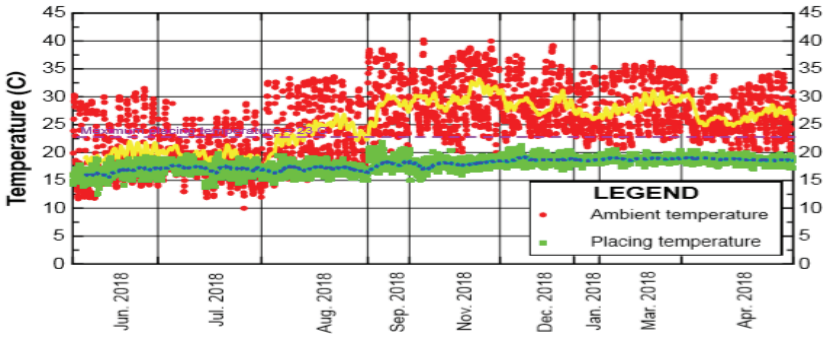
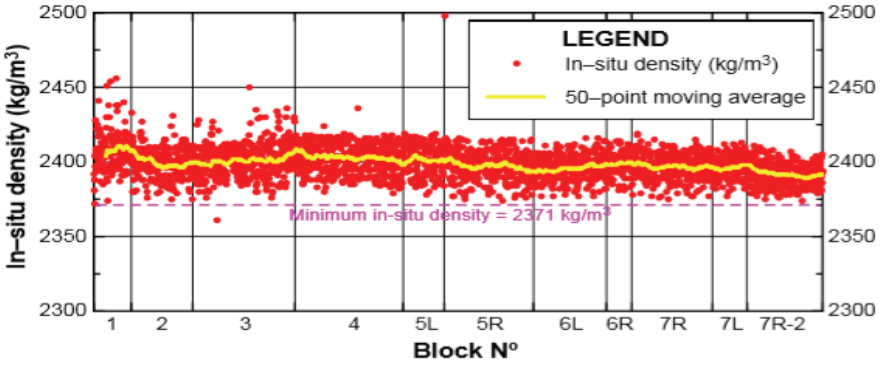


Fig 3 : Temperature control at site



Fig, 4 : VeBe time control

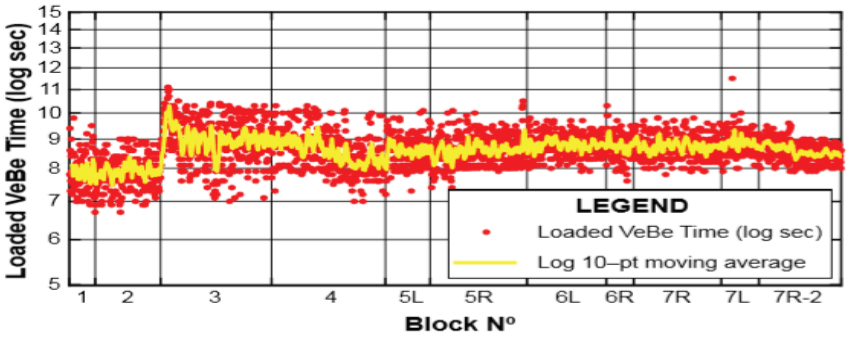


Fig. 5 : Density test at site

6. EVALUATION OF INTERLAYER JOINT QUALITY CONTROL

During construction of the KGL RCC dam, for the hot joint the interlayer joint exposed time reached at maximum 22hours, and the warm joint exposed time reached at 30hours. Based on the extraction of core samples and water pressure test results, the joints bonding quality and impermeability are satisfied.

Picture 1 : Core sample

Table 18 : Water Pressure Test Results

Item No.		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Depth	From(m)	0.7	0.7	0.7	0.7	0.7	20	25	0.7	15	0.7	0.7
	to (m)	10.1	10.7	25.7	28.5	32.8	20.0	29.9	5.0	20.0	22.5	19.7
Test Length	m	9.4	9.9	25.0	27.8	32.1	5.0	4.9	4.3	5.0	21.8	18.9
Lugeon Average Value	L/Min/m	0.17	0.31	0.29	0.28	0.29	0.00	0.00	0.01	0.11	0.31	0.41

7. CONCLUSION

By using the MMF criteria applied to the quality control for RCC interlayer joint, and the practice application of the joint longer time exposed in KGL RCC dam construction.in the region of dry and high temperature climate is successful, as well as construction quality control is reasonable. With the long-time exposed makes continuously RCC placement which improve the placement rate and progress. This practice can be a reference for other projects that in hot and dry area, or the placement intensity is high, or the batching plant capacity is lower than the requirement, or include these conditions together.