Trial mix and full-scale trial embankment for RCC dam at Nam Ngiep 1 hydropower project

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ABSTRACT

The Nam Ngiep 1 Hydropower Project (290MW) in Lao PDR is presently under construction (2014-2019). A Roller Compacted Concrete (RCC) gravity dam, 167m height is being built in a narrow V-shaped gorge. A total of 2.3 million cubic metres of RCC is planned to be placed in 26 months, as a continuous process through wet and dry seasons using the Slope Layer Method (SLM) for placing RCC.

The principal materials are cement and fly ash, imported from Thailand, and locally quarried sandstone/conglomerate aggregate. This Paper discusses the programme of off-site and on-site trial mixes that were conducted between 2008-2015 to obtain a stable, durable and economical RCC mix design, the full-scale trial embankment, and the construction of the left bank wing wall of the regulating dam and the secondary upstream cofferdam to the main dam, that were carried out from 2015-2016. The full-scale trial embankment confirmed and evaluated the variability of RCC and the Grout Enriched RCC (GE-RCC), the placement characteristics, with respect to the machinery used, the layers thickness, compaction amount, joint treatment, compressive and direct tensile strength, in-situ permeability testing, and finally as observed in full section cuts made through the trial embankment by band sawing cutting.

1. INTRODUCTION

A main dam with powerhouse of 273 MW installed capacity and a regulation dam with its own powerhouse generating 18 MW of installed capacity are being built as part of the Nam Ngiep 1 Hydro-electric Power Project (NNP1HPP) in the Lao People's Democratic Republic. RCC is being used to construct the main dam of 167 m height, embankment wing walls for the regulation dam, and a secondary cofferdam located upstream of the main dam. Around 2.3 million cubic metres of RCC are being placed in the main dam starting in April 2016 and finishing in May 2018, in an approximate 26-month continuous process of placement through the wet and dry seasons adopting the SLM (Forbes B.A. 2012) for placing RCC.

The study of RCC trial mixes has been carried out from 2008 to 2011 for off-site trial mixes at the Asian Institute of Technology (AIT) in Thailand. From 2013 to 2015, off-site trial mixes were conducted at Rajamangala University of Technology in Thailand (RMUTT). On-site trial mixes and a primary Full-Scale Trial Embankment (FSTE) on site followed effectively by a second and a third trial embankment through construction in RCC of the left bank wing wall of the regulating dam (LBWW) and the secondary upstream cofferdam to the main dam (SUC) from 2015 to 2016.

In the off-site trial mixes, various tests were conducted to confirm the applicability of each component material of RCC; being cement, fly-ash, course and fine aggregates, and set retarding admixture, to determine the preliminary design mix proportions. In on-site trial mixes, the optimised mix proportions for achieving higher quality were pursued and by increasing the total amount of fine aggregate under 75 μm in the particle size distribution. This fraction of less than 75 μm is variously referred in publications as ‘dust of fracture’ and ‘stone powder’. There is a proportion of stone powder already present in the fine aggregate produced in the crushing plant. Further amounts of manufactured stone powder (SP) are sometimes required to be added to the mix to supplement the particles in the fine aggregate that pass 75 μm. In RCC, material passing 75 μm can be used at a higher percentage of total fine aggregate, while it is restricted in conventional concrete when it can have a deleterious effect on the mix. In the primary FSTE, studies were carried out to check the performance of RCC and GE-RCC as would be placed at the upstream face of the dam to ensure good water tightness, through observation of consistency, workability, placing method, concrete strength, lift joint condition, permeability and finish of concrete.

In this paper, the results of the off-site trial mixes and on-site trial mixes are reported and a process of determination of RCC placing specifications are introduced based on the results of the study during the FSTE and their application to actual RCC placement in the main dam.

2. OFF-SITE TRIAL MIXES (2008 TO 2015)

Initial trial mixes were implemented in the period 2008 to 2011 at AIT, in order to confirm the applicability of aggregates produced at the quarry of the Nam Ngiep 1 Project, with cement and fly-ash from Thailand, and set-retarding admixture, to ensure the required concrete strength and to establish and be able to specify mix proportions. The aggregate is composed of medium-hard conglomerate and sandstone and has good properties, small absorption factor, high density, and small flakiness index. In the initial stages of the Project a high paste RCC was tested with proportions of cement (C) of 100 kg/m^3, fly-ash (F) of 100 kg/m^3, or (C + F) = 200 kg/m^3 to obtain basic information by referring to the practice in Yeywa Hydropower Project in Myanmar and to target a more economical, middle cementitious content mix since any impact of ground motion by earthquake is considered to be small in Lao PDR. The application of stone powder was studied to retain the necessary consistency and workability of the concrete, and mix proportions of C80F90SP30 was set for the trial where SP is the amount of stone powder passing 75 μm that is not already part of the fine aggregate. In cases where the amount of cementitious material is reduced, there is a possibility that permeability, adhesive strength at the lift joint, segregation resistance and workability may be affected, and therefore these matters were verified carefully.

Further trial mixes were conducted from 2013 to 2015 at RMUTT for the purpose of confirming the consistency and workability of the RCC. The long term concrete strengths were obtained through compressive strength, direct tensile strength and shear strength tests at 365 days. The mix proportions including those for lower paste of C70F80SP50, C60F70SP70 and C50F60SP90, expected to be applied at the higher elevation and inner core of the dam by zoning, were studied. Minimization of the amount of admixture and incremental replacement of fly-ash by up to 60 or 70 percent were studied. In the off-site trial mixing, tests were carried out repeatedly by trial and error to obtain the mix proportions satisfying the requirements and targets, and preliminary mix proportions were proposed as designed and are shown in Table 1.

Table 1. Preliminary Design Mix Proportions for RCC Determined by Off-Site Trial Mixes

Mix code	G_{max} (mm)	Vebe value (sec)	Air content (%)	W/(C+F) (%)	FA/a (%)	Unit Weight (kg)								Admixture (%)
						W	C	F	SP	G1	G2	G3	FA	
No.1	50	12-20	1.5	65.3	34.0	111	80	90	30	674	403	268	700	(C+F)*0.3%
No.2	50	12-20	1.5	76.7	35.0	115	70	80	50	661	395	262	717	(C+F)*0.3%

Note: a: Aggregate (G1+G2+G3+FA), W: Water, G1/G2/G3: Coarse aggregate (G1: 50-25mm, G2: 25-12.5mm, G3: 12.5-5mm), FA: Fine aggregate
The admixture dosage of 0.3% is adjusted along with placing speed of between layers.

3. ON-SITE TRIAL MIXES (2015 TO 2016)

Following the provisional mix proportions determined through off-site trial mixing, on-site trial mixes were carried out with the target being to further improve the consistency, segregation resistance, workability and strength of the concrete by adjusting particle size distribution of aggregates. A fully-equipped laboratory was established on site and material were used from the on-site quarry and aggregate crushing plant that was operational from early September 2015. The same sources of material used in the off-site trial mixes for RCC, that is, for cement, fly-ash and admixture, were used for the on-site trial mixing. The imported material sources for Portland cement (ASTM, Type I) were from TPI Cement in Thailand and fly-ash (ASTM, Class C) from Mae Moh Power Plant in Thailand. Different admixtures to ASTM (Types B & D) were also used in the trial mixes.

3.1 Programme and Studies of Fines Content

The consistency and workability of RCC with non-segregation characteristics were optimized by adjusting the total amount of fine aggregate particle size passing 75µm being both the amount included in the fine aggregate crushing process and the supplemental amount of manufactured material (referred to as SP), along with the coarse aggregate, cement, fly-ash and admixture. In the off-site trial mixes, the amount passing 75 µm in the fine aggregate was set to be about 8.0 to 10.0 % by weight. It was considered desirable to increase this to 12.0 to 14.0 % and to shift aggregate particle size distribution towards the finer side in order to increase the material segregation resistance and workability. The programme of the on-site trial mix development is summarized in Table 2.

Table 2. On-Site Trial Mix Programme

Purpose	Programme
To improve consistency, workability, non-segregation and quality of RCC including strength	Step 1: The proportion less than 75 µm in fine aggregate is increased to 12.0 %. (The total amount under 75 µm of materials of cement, fly ash and stone powder (including SP in the fine aggregate) is increased to 13.0 %) This RCC mix is more appropriate.
	Step 2: Coarse aggregate of G1 is reduced by 40 kg. G2 and G3 is increased by 24 kg and 16 kg respectively. This RCC mix is confirmed as improvement in non-segregation and workability. (Fine tuning will be carried out in consideration of actual aggregate particle size distribution.)
	Step 3: Fine aggregate is increased by 25 kg. Coarse aggregate is reduced by 25 kg proportionally. This RCC mix was confirmed as improvement in non-segregation and workability. (Fine tuning will be carried out in consideration of actual aggregate particle size distribution.)

As shown in Figure 1, firstly, the amounts of cement, fly-ash, SP were fixed and the total amount of fine material passing 75 µm was varied. A workable concrete, not too plastic and not too harsh was found in Case 3 (using fine aggregate passing 75 µm at 13.9 %). Secondly, three cases were studied with the total amount of fine aggregate passing 75µm set to 12.0 %, 13.0 % and 14.0 %. The mix containing 13.0 % was considered the optimum concrete mix as shown in Figure 1 and it was determined that the total amount of fine aggregate passing 75µm would be controlled to be in the range 12.0 % to 14.0 % in the RCC actually placed in the works.

Item	Case 1	Case 2	Case 3	Case 4
75 µm in fine aggregate	0.0 %	7.7 %	14.4 %	18.0 %
Vebe value	9.8 sec	8.0sec	7.5 sec	9.5 sec
Concrete characteristic /Workability	Too harsh, segregation	Too harsh	Good plastic	Too plastic
Total amount under 75 µm of all materials	8.7 %	11.5 %	13.9 %	15.2 %

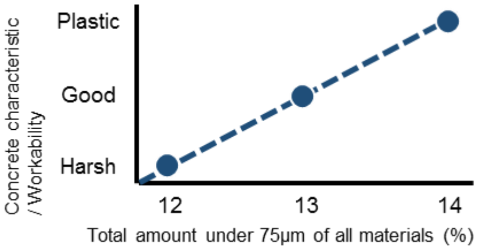


Figure 1. Workability of Concrete through On-Site Trial Mixes

Adopting the SLM and expecting around 3 to 5 hours of placing time for each layer, the on-site trial mixes were carried out to control the setting time of the concrete by varying the amount of the admixture.

3.2 Revised Mix Proportions

The mix proportions for off-site trial mixes were modified for the primary FSTE as shown in Table 3. The mix proportions used for the LBWW and SUC as the second and third FSTE are Mix Nos. 3 and 4, of which stone powder was temporarily replaced with fly-ash since stable supply of SP was not established at the initial stage of RCC placing works.

Table 3. Designed Mix Proportions for On-Site Trial Mixes of RCC

Mix code	G_{max} (mm)	Vebe value (sec)	Air content (%)	W/C (%)	FA/A (%)	Unit Weight (kg)								Admixture (%)
						W	C	F	SP	G1	G2	G3	FA	
No.1	50	12-20	1.5	65.3	38.4	111	80	90	30	600	401	263	780	(C+F)*0.3%
No.2	50	12-20	1.5	76.7	39.4	115	70	80	50	587	392	257	796	(C+F)*0.3%
No.3	50	12-20	1.5	55.5	38.4	111	60	140	0	600	401	263	780	(C+F)*0.3%
No.4	50	12-20	1.5	57.5	39.4	115	70	130	0	587	392	257	796	(C+F)*0.3%

Note: a: Aggregate (G1+G2+G3+FA), W: Water, G1/G2/G3: Coarse aggregate (G1: 50-25mm, G2: 25-12.5mm, G3: 12.5-5mm), FA: Fine aggregate
The admixture dosage of 0.3% is adjusted along with placing speed of between layers.

4. FSTE (2015 to 2016)

As stated above there were effectively three opportunities to carry out FSTE. The primary FSTE was a purpose-made embankment constructed close to the RCC mixing plant and the concrete laboratory. In size it measured 30 m long, 14 m wide and 3 m high, plus a single access ramp at one end. The total RCC volume was therefore 1,260 m^3 excluding the ramp. Layers were constructed using 2 mixes, Mix Nos.1 and 2 above to confirm the performance of RCC and GE-RCC. The second FSTE was implemented at the LBWW, being of 12,500 m^3 volume, was constructed as permanent works and a third FSTE was also constructed as temporary works to provide the SUC, 30,000 m^3 in volume, both using Mix Nos.3 and 4 as detailed in Table 3 above. The purpose of the second and third FSTE was to verify Mix Nos.3 and 4 mix in the same manner as the primary FSTE and to train the workers. Major test results of the FSTE are shown in Table 4.

Table 4. Test Results of FSTE

Material	Test item
Aggregate	Grading, particle shape, combined grading, unit weight and absorption, moisture content
RCC Mix	Bulk density, VeBe value (12 to 20 sec), VeBe density (< 22.56 kN//m^3)
RCC Placement	VeBe value (12 to 20 sec), VeBe density (< 22.56 kN//m^3), air content (1.5 %), temperature of fresh concrete (< 28 deg), in-situ density (< 22.56 kN//m^3), washed grading, compressive strength, direct tensile strength, density, setting time, in-situ permeability, 150 mm diameter core observation, full section cut by band sawing
GE-RCC	Slump (10 to 20 mm), compressive strength, density, Marsh Funnel Viscosity (< 34 sec), grout density

By coring horizontally and vertically, and band sawing the full section of 3 m depth of the primary FSTE at each end, it was possible to see the quality of concrete placed and to visually recognize where different jointing has been imposed, or compaction carried out both for the RCC and the GE-RCC placement and compaction techniques used and the effect of hot, warm cold or super-cold joints which are before initial setting time, between initial and final setting time, after final setting time and over 3 days and what measures were or should have been taken.

4.1 Application of GE-RCC

Since GE-RCC at the upstream face of the dam plays a significant role in providing water tightness it is necessary that the concrete has higher quality than that constructed in RCC. The trial mix was conducted focusing on (a) mix proportions of the cement-water grout which is added to the RCC, (b) the procedure for GE-RCC placement, (c) the Marsh Funnel Viscosity (MFV) value, and (d) the amount of grout, as detailed below. GE-RCC is formed by pouring grout into holes driven into the loose RCC by 20 mm diameter and 300 mm long spiking rods attached to the underside of a steel foot plate and compacting with a poker vibrator.

4.1.1 Mix Proportions of Grout

Tests were carried out using varying water/cement (W/C) ratios from 0.6 to 0.8, with and without superplasticizers. The criterion for such as the value of MFV was set at less than 34 seconds. Figures 2 and 3 show a photograph of the MFV testing and the results. The mixes without superplasticizer required higher W/C ratio, while the mixes with superplasticizer satisfied the criterion with less fluctuation in the variation of W/C ratio. It is noted that the MFV value varied by 10 seconds along with fluctuation of temperature of grout by 10 degrees Celsius. It was evaluated that W/C = 0.8 with superplasticizer was preferable to obtain stable performance of grout mixture.

Figure 2. MFV Test

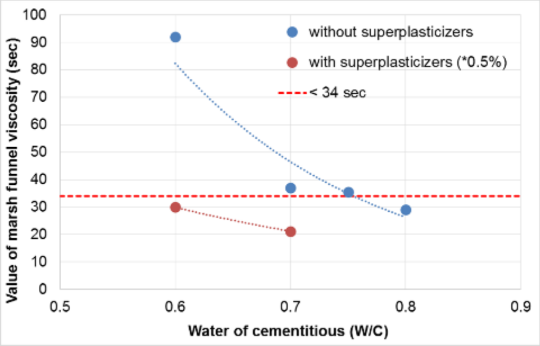


Figure 3. Results of MFV

4.1.2 Procedure for Placing GE-RCC

The procedure for GE-RCC placing was considered using two different methods as shown below.
Method 1: Grout is deposited on the previous surface and RCC is placed over the grout and compacted.
Method 2: RCC is spread, grout is poured into holes formed in the RCC and compacted as in Figure 4.
Method 1 is not appropriate since it took time to evenly mix RCC with grout, and this led to less workability. In comparison, Method 2 worked fine since a uniform GE-RCC mix could be achieved with sufficient workability. Therefore, Method 2 was adopted for the primary FSTE.

4.1.3 MFV Value of Grout

The following 2 methods were checked:
Method 1: MFV value of grout was 34 seconds or more.
Method 2: MFV lower than 34 seconds.
It was difficult to compact the grout into the RCC in Method 1 resulting in the occurrence of non-uniform GE-RCC with honeycombing and voids. Method 2 showed a uniform GE-RCC surface as in Figure 4.

Placing GE-RCC (Method 2) Compacting GE-RCC (Method 2) Finish of GE-RCC (Method 2)

Figure 4. Procedure for Placing, Compacting and Completion of GE-RCC

4.1.4 Amount of Grout

To obtain an effective GE-RCC workability, being a slump of 10 to 20 mm, and minimum bleeding and laitance, tests were conducted by varying the grout amount of 1.5, 2.0, 2.5 litres and it was evaluated that 2.0 litre/0.075 m^3 was the most suitable. The theoretical density of RCC of more than 22.56 kN/m^3 and RCC and GE-RCC compressive strengths of 24.3 MPa and 24.9 MPa were achieved at 210 days.

4.2 Plan of Primary FSTE

4.2.1 General

The primary FSTE was carried out close to the RCC batching plant and laboratory. Material used for this FSTE is the same as for the on-site trial mixes. The principal plant and equipment used for the primary FSTE were a 22 tonne dump truck, a 15 tonne bulldozer, a 15 tonne single drum vibrating roller, a 2.5 tonne vibrating roller, rotary brushes for joint treatment including green cutting, vacuum truck, mechanised joint cutter, plate compactor, poker vibrators and mobile grout mixing tank.

4.2.2 RCC Placing and Horizontal Joint Treatment

The mix proportions used for the FSTE are Mix Nos.1 and 2, and various lift joints (hot, warm, cold and super-cold joints) are set in each area (Layers 0 to 8) and Blocks (A1 to A4 and B1 to B4), as shown in Figure 5 and Table 5.

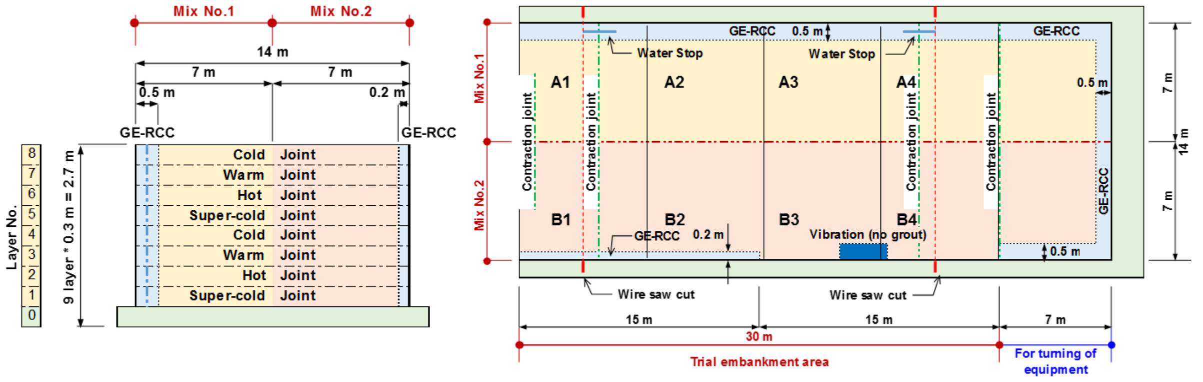


Figure 5. End Elevation and Plan of Primary FSTE

Table 5. Arrangement of Horizontal Joint Treatment

layer	Horizontal joint	Joint treatment			
		Block A1/B1	Block A2/B2	Block A3/B3	Block A4/B4
7-8	**Cold joint**	Green-cut + Grout	Green-cut + Mortar (crushed sand)	Green-cut	Green-cut + Mortar (river sand)
6-7	**Warm joint**	Grout	None	Rotary broom + Grout	Rotary broom
5-6	**Hot joint**	None	None	None	None
4-5	**Super-cold joint**	Green-cut+ Mortar (crushed sand)	Green-cut + Grout	Green-cut + Mortar (river sand)	Green-cut
3-4	**Cold joint**	Green-cut+ Grout	Green-cut + Mortar (crushed sand)	Green-cut	Green-cut+ Mortar (river sand)
2-3	**Warm joint**	None	Grout	Rotary broom	Rotary broom + Grout
1-2	**Hot joint**	None	None	None	None
0-1	**Super-cold joint**	Green-cut+ Grout	Green-cut + Mortar (crushed sand)	Green-cut	Green-cut + Mortar (river sand)

4.3 Evaluation of Primary FSTE

4.3.1 Placing Procedure of RCC and GE-RCC

The placing procedure of RCC and GE-RCC in the primary FSTE is shown in Figure 6.

4.3.2 Degree of Compaction

The required degree of compaction was set at 98.0 % of the theoretical air-free density or more. It was confirmed how frequent compaction was required with passes from a large 15 tonne vibratory roller in order to achieve the requirement of 98.0 % or more. The frequency of compaction was set as follows.
Case 1: static compaction of 1 pass (result: 97.1 %)
Case 2: static compaction of 1 pass and dynamic compaction of 1 pass (result: 98.1 %)
Case 3: static compaction of 1 pass and dynamic compaction of 2 passes (result: 98.5 %)
Case 4: static compaction of 1 pass and dynamic compaction of 3 passes (result: 98.5 %)
It was confirmed that Case 3 satisfied the requirement. However in consideration of having a safety margin, frequency of compaction as Case 4 was adopted.

1.General view of primary FSTE

2. Green-cut using high pressure jetting

3. Good green-cut of GE-RCC

4. Beddting grout (3 mm thick)

5. Dumping RCC and levelling

6. GE-RCC compaction

7. Compaction of RCC by large roller (RCC and GE-RCC at interface)

8. Creating contraction joint

9. After removal of formwork(left no GE-RCC and right GE-RCC)

Figure 6. Principal Procedures of RCC Placement for Primary FSTE

4.3.3 In-situ Density

The density of RCC is set at 22.56 kN/m^3 or more. The mean density measured in each layer was 23.05 kN/m^3 with the maximum 23.15 kN/m^3 and the minimum was 22.75 kN/m^3. Thus it was confirmed that the in-situ density satisfied the requirement at all measured points.

4.3.4 Concrete Temperature

The concrete placing temperature is set to be 28 degrees Celsius or less according to thermal stress analysis by using physical properties obtained through material tests and an adiabatic temperature rise test. The RCC plant is equipped with a cooling system which produces cool water and ice flakes for cooling aggregate and concrete. It was confirmed that concrete temperature is achieved by the facilities.

4.3.5 Vebe Value

Originally, the criteria of the Vebe values was set to between 12 and 20 seconds. As a result of evaluating RCC dumping, levelling, compaction, and finished condition, it was confirmed that the Vebe value that ensures the optimum workability is 16 to 18 seconds. In actual placing works, Vebe loss of 2 to 3 seconds should be considered since RCC will be transported from the RCC plant to the dam site for about 2.0 km by belt conveyor. The mix proportions were adjusted to ensure a Vebe value of 16 to 18 seconds was achieved at the dam site.

4.3.6 Air Content

The standard value of air content was set to 1.5 %. The air content is directly related to the unit volume to density compaction ratio, or density. RCC compaction after testing was considered to be appropriate since the test result of air content was 1.5 % on average, varying from 1.4 to 1.6 %.

4.3.7 Setting Time

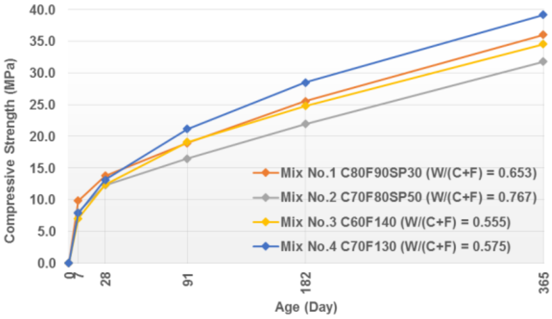
The relationship between initial and final setting times and the amount of admixture is shown in Table 6. The mean initial setting time of Mix No.1; (C+F)*0.5 % was 19 hours with maximum 22.1 hours and minimum14.3 hours, and its fluctuation at 7.8 hours was quite large. That of Mix No.2; (C+F)*0.5 % was also large, being 6.9 hours. It was assumed that the concrete is prone to be affected by concrete temperature, air temperature, amount of cementitious materials, and so on. As it is necessary to apply hot joints within initial setting time to ensure quality, the amount of admixture was designed by adding margin time of 2 hours. In addition, the characteristics of concrete are determined to be checked by a setting time test which shall be carried out for every layer, since the relationship between temperature, cementitious materials and initial setting time is quite sensitive. Originally the horizontal layer method was chosen with a placing interval of 20 hours or more. By adopting SLM, the placing interval is shortened to 3 to 5 hours and contributes to reduce the amount of the admixture to about 0.35 %.

Table 6. Setting Time of Mix No.1 and Mix No.2: (C+F)*0.35 and 0.5 %

Item	Mix No.1 (C80F90SP30)		Mix No.2 (C70F80SP50)	
% Dosage	0.35	0.50	0.35	0.50
Average initial setting time	10.30	19.00	7.20	16.50
Maximum / Minimum	12.30 / 7.30	22.10 / 14.30	8.40 / 6.10	20.30 / 13.40
Difference (max. – min.)	5.00	7.80	2.30	6.90
Average final setting time	24.50	25.60	10.30	22.10
Maximum / Minimum	16.60 / 10.50	29.30 / 22.20	13.00 / 8.60	25.10 / 18.50
Difference (max. – min.)	6.10	7.10	4.40	6.60

4.3.8 Compressive Strength of Specimen

Compressive strength tests were conducted for Mix No.1 for which W/(C+F) = 0.653 and for Mix No.2 for which W/(C+F) = 0.767 at 3, 7, 28, 91, 182 and 365 days as in Figure 7.



Age (Days)	Mix No.1 C80F90SP30 (MPa)	Mix No.2 C70F80SP50 (MPa)	Mix No.3 C60F140 (MPa)	Mix No.4 C70F130 (MPa)
7	9.8	8.0	7.0	7.9
28	13.8 (*1.41)	12.3 (*1.53)	12.4 (*1.77)	13.1 (*1.66)
91	18.9 (*1.37)	16.5 (*1.34)	19.1 (*1.54)	21.2 (*1.61)
182	25.5 (*1.35)	21.9 (*1.33)	24.8 (*1.30)	28.5 (*1.25)
365	36.0 (*1.41)	31.8 (*1.45)	34.5 (*1.39)	39.2 (*1.37)

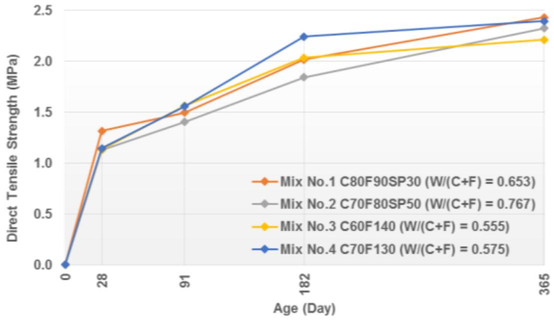
Note: * Percentage increase in strength

Figure 7. Development of Compressive Strength

All specimens satisfied the requirement of concrete compressive strength of 30 MPa to achieve the required direct tensile strength of 1.8 MPa (that is, 30 MPa*6 % = 1.8 MPa). An increase in the long term strength of the concrete at 91 days to that at 365 days was estimated to be 1.5 times according to US Army Corps of Engineers (EM 110-2-2006) due to an assumed high placement rate of 50 % and poor quality of Mae Moh fly-ash (currently and nominally Class C, but varies sometimes to the lower Class F fly-ash). However the rate of increase achieved was 1.9 times. In addition, the RCC compressive strength increased by 1.2 to 1.4 times that achieved during the off-site trial mixes in Thailand, though W/C was equivalent. The reason for this is thought to be due to the modified particle size distribution of aggregates, increase in the fine materials completely filling the aggregate-sand voids. The compressive strength of Mix No.3 (W/(C+F) = 0.555) and Mix No.4 (W/(C+F) = 0.575) is higher than Mix Nos.1 and 2 because the W/C is lower. The continuing development of RCC strength is expected as the replacement rate of fly-ash reaches 60 to 70 %.

4.3.9 Direct Tensile Strength of Specimen

The direct tensile strength tests were carried out with the mix proportions of Mix Nos.1, 2, 3 and 4 at age of 28, 91, 182 and 365 days as summarized in Figure 8. All the specimens satisfied the requirement of the tensile strength of 30 MPa*6 % = 1.8 MPa. The ratio of direct tensile strength to compressive strength was summarized as shown in Figure 8. Though the direct tensile strength was assumed to be 6.0 % of the compressive strength according to USACE, the mean tensile stress is 6.8 % and the future development of the tensile strength more than 6.0 % at 365 day age is ensured in all cases.



Age (Day)	Mix No.1 C80F90SP30 (MPa)	DT/C (%)	Mix No.2 C70F80SP50 (MPa)	DT/C (%)	Mix No.3 C60F140 (MPa)	DT/C (%)	Mix No.4 C70F130 (MPa)	DT/C (%)
28	1.3	9.5	1.1	9.2	1.1	9.1	1.1	8.7
91	1.5 (*1.14)	7.9	1.4 (*1.24)	8.5	1.6 (*1.38)	8.2	1.6 (*1.36)	7.4
182	2.0 (*1.25)	7.9	1.8 (*1.32)	8.4	2.0 (*1.30)	8.2	2.2 (*1.44)	7.9
365	2.4 (*1.21)	6.7	2.3 (*1.26)	7.3	2.2 (*1.09)	6.4	2.4 (*1.07)	6.1

Note: * Percentage increase in strength
DT/C is direct tensile strength / compressive strength

Figure 8. Development of Direct Tensile Strength

4.3.10 Direct Tensile Strength of Core Specimen of FSTE

Core specimens (150 mm diameter) were extracted by drilling at each joint for all types (hot, warm, cold and super-cold) for the primary FSTE and direct tensile strength testing was conducted.

(a) Hot joint
The direct tensile strength of the hot joint as summarized in Table 7 was about 20 % lower than the tensile strength presented in Section 4.3.9. However they are more than 6 % of compressive strength and satisfy design strength. Therefore the hot joints were judged to be applicable to actual RCC placing.

Table 7. Direct Tensile Strength of Hot Joint

Item	Treatment	Strength Mix No.1	Braking point	Strength Mix No.2	Braking point
Compressive strength	-	25.5 Mpa@182 days	Parent/Joint	21.9 Mpa@182 days	Parent/Joint
Direct tensile strength	-	2.02 Mpa@182 days	Parent/Joint	1.84 Mpa@182 days	Parent/Joint
Direct tensile strength with hot joint	None	1.59 MP@215 days (6.2 %*)	Parent/Joint	1.50 Mpa@215 days (6.8 %*)	Parent/Joint

Note: * Direct tensile strength / compressive strength

(b) Warm joint
The direct tensile strength of the warm joint (surface treatment being none, by rotary broom, by grout, by rotary broom and grout) and super-cold joint was evaluated. The strength of the warm joint with each treatment is compared in Table 8 and Figure 9.

Table 8. Direct Tensile Strength of Warm Joint

Item	Treatment	Strength Mix No.1	Braking point	Strength Mix No.2	Braking point
Compressive strength	-	25.5 Mpa@182 days	Parent/Joint	21.9 Mpa@182 days	Parent/Joint
Direct tensile strength	-	2.02 Mpa@182 days	Parent/Joint	1.84 Mpa@182 days	Parent/Joint
Direct tensile strength with warm joint	None	No core	-	0.91, 0.85 MPa@212 days (4.1 %, 3.8 %*)	Joint
	Rotary broom	1.02 MPa@207 days (4.0 %*)	Joint	1.58, 1.42 MPa@210 days (7.2 %, 6.4 %*)	Joint
	Grout	1.24, 1.36 MPa@212 days (4.8 %, 5.3 %*)	Parent	1.41, 0.45 MPa@212 days (6.4 %, 2.0 %*)	Joint
	Rotary broom + Grout	0.34, 0.45 MPa@207 days (1.3 %, 1.7 %*)	Joint	1.13, 1.30 MPa@212 days (5.1 %, 5.9 %*)	Joint

Note: * Direct tensile strength / compressive strength

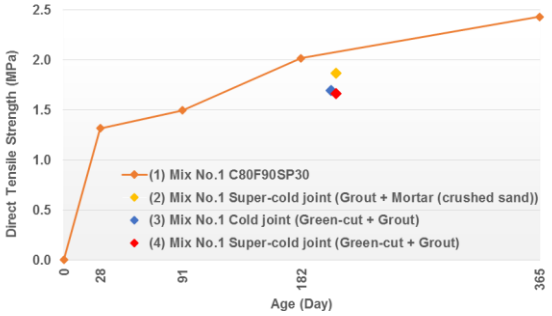
Figure 9. Photograph after Direct Tensile Strength Test of Warm Joint Treatment

Although a warm joint is treated as in Table 5, laitance remained between layers, and the lift joint become non-uniform. Since the initial setting time had passed, the penetration of the aggregate between the layers was not always seen. It was estimated that the strength was non-uniform and the tensile strength was low. It is important to avoid a warm joint as much as possible. Even if such a condition occurs, a warm joint might preferably be left to become a cold joint.

(c) Cold joint, super-cold joint

Direct tensile strength of the lift joint (hot, cold, super-cold), with mortar (W/C=0.6) and grout (W/C=0.6)) was evaluated to establish a treatment procedure of the lift joint. Although mortar is commonly to be used for the treatment of the lift joint, it has some risks. These are (i) workability and economy are inferior to grout, (ii) there is no means to transport mortar from the RCC plant to the dam site, (iii) measurement error of mortar when mortar is mixed locally.

Direct tensile strength tested under each condition are shown in Figure 10. The direct strength of the treatment of green-cutting + grout or mortar achieved design strength, therefore the treatment of green-cutting + grout (W/C = 0.6) on cold and super-cold joints are evaluated as applicable in actual placing works. Green-cutting refers to the process of exposing aggregate of one RCC layer by high pressure water/air jetting or by mechanical wire brushing prior to placing the next layer.



Item	Strength (MPa)
Mix No.1 Compressive strength at 182 days	25.5
(1) Mix No.1 Direct tensile strength at 182 days	2.02 (*7.9%)
(2) Mix No.1 Direct tensile strength of lift joint (Super-cold joint Green-cut + Mortar (crushed sand)) at 209 days	1.86 (*7.3%)
(3) Mix No.1 Direct tensile strength of lift joint (Cold joint Green-cut + Grout) at 205 days	1.69 (*6.6%)
(4) Mix No.1 Direct tensile strength of lift joint (Super-cold joint Green-cut + Grout) at 209 days	1.66 (*6.5%)

Note: * Direct tensile strength / compressive strength

Figure 10. Strength of Cold and Super-Cold Joints

4.3.11 In-situ Permeability Testing

The standard value of permeability coefficient was set to 10^{-8} cm/s based on the logged record for RCC dams. Lugeon tests and in-situ permeability tests were conducted in the primary FSTE. The specifications of the in-situ permeability tests detail the use of a double packer, maximum pressure of 10 bar, setting a pressure for each stage, an injection rate of 1 litre/minute/m, 10 minutes/stage for the Lugeon test, and 300 minutes/test for permeability test. There was found to be no leakage through lift joints as in Figure 12. Even the warm joint with the uncertainty of the concrete strength as described in Section 4.3.10 (b) also produced a quite low level of permeability of $2.5*10^{-8}$ cm/s. Referring to the case referred by International Commission on Large Dams (2003), test results are above the 95 % in confidence limits as shown on the right in Figure 11. Hot joint, cold/super-cold joint with green-cutting plus grout /mortar are judged to be applicable for actual placing works in terms of water-tightness.

Item	None	Rotary broom	Green-cut	Green-cut + Mortar	Green-cut + Grout
Hot joint	Lu = 0.0 (<1.0) K = 0.0 cm/s	-	-	-	-
Warm joint	Lu = 0.0 (<1.0) K = 0.0 cm/s, T=300 min Calculated $9.9*10^{-8}$ cm/s K = 0.0 cm/s, T=600 min Calculated $2.5*10^{-8}$ cm/s	Lu = 0.0 (<1.0) K = 0.0 cm/s	-	-	Lu = 0. 0(<1.0) K = 0.0 cm/s
Cold joint	Lu = 0.0 (<1.0) K = 0.0 cm/s	-	Lu = 0.0 (<1.0) K = 0.0 cm/s	Lu = 0.0 (<1.0) K = 0.0 cm/s	Lu = 0.0 (<1.0) K = 0.0 cm/s
Super-cold joint	-	-	Lu = 0.0 (<1.0) K = 0.0 cm/s	Lu = 0.0 (<1.0) K = 0.0 cm/s	Lu = 0.0 (<1.0) K = 0.0 cm/s

Note: Lu = Lugeon value, K = Permeability value

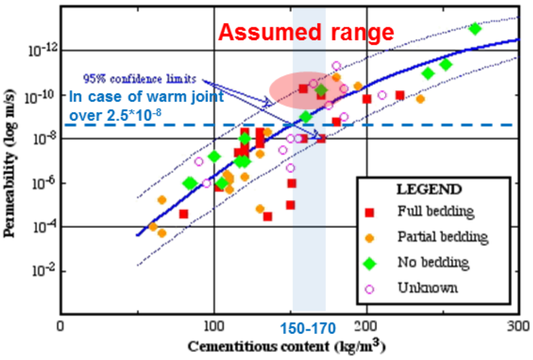


Figure 11. Relationship between Results in NNP1 and ICOLD (2003)

4.3.12 Observations of Full Section and Cores

The full section of the primary FSTE was observed after band sawing cutting (Figure 12)**.** It is found that the hot joint, cold/super-cold joint with green-cutting plus grout or green-cutting plus mortar performed well as at the boundary between RCC and GE-RCC, since there was no defect in the lift joints and the strength tests showed good results. These lift joint treatments were judged to be applicable for actual placing. Also, warm joints and cold joints without treatment and no green-cutting were determined not to be applied to actual placing works, since insufficient adhesion was found in the primary FSTE.

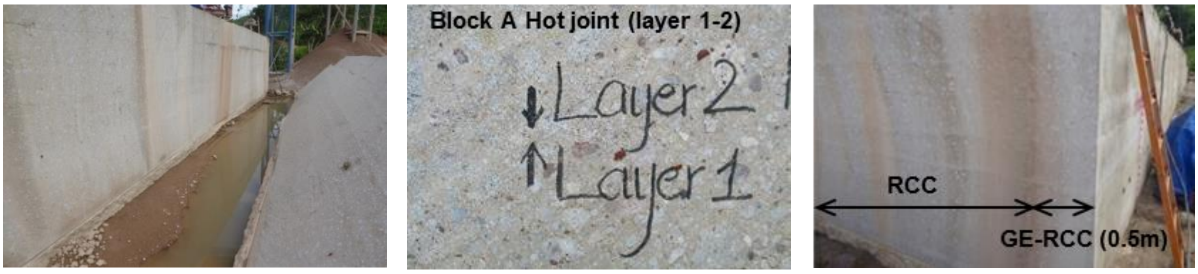


Figure 12. Band Sawing Cut in Primary FSTE, Hot Joint, Interface of GE-RCC and RCC

4.3.13 Second FSTE

In the second FSTE, a series of construction procedures being preparation work for formwork, RCC placing and so on were checked at the LBWW and the SUC, and the worker's ability was seen to improve through this practice as shown in Figure 13.

Figure 13. Second FSTE at LBWW and Third FSTE at SUC

5. CONCLUSIONS

(1) Through the off-site trial mix, the preliminary design mix proportions, which are middle cementitious content, were specified by confirming the applicability of each material of RCC for NNP1HPP.
(2) Through the on-site trial mixes, optimal and high quality mix proportions to improve workability were realized with a target for the total amount of fine material passing 75 μm taken as 13.0 %, and with an improved particle size distribution of aggregates.
(3) The procedure and specification of RCC placing made by the Contractor were reviewed and modified through all the FSTE. The primary FSTE in particular ensured the performance and quality of the RCC. Specifically the importance of the lift joint treatment was recognised by determining the direct tensile strength, in-situ permeability test, core observation, observation of full section cuts by band sawing were recognised together with the method of treatment.
(4) With the second and third FSTE, the ability of workers related to RCC placement activities was significantly improved, and other RCC mix proportions were tested.

After completion of the main dam foundation excavation in March 2016, placing of dental concrete and levelling RCC was started and RCC placement started from 19 April 2016. In this time NNP1 has been implementing many ideas and improvements related to the proportion of stone powder used, GE-RCC placing methods, the sloped layer method, optimising mix proportions in zones of dam construction, and so on, in order to improve the quality and performance of the concrete and the finished dam, the concrete workability and economy of materials, construction speed and safety.

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6. REFERENCES

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