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Tallest RCC gravity dam in Lao PDR - need for high speed and solutions adopted at the Nam Ngiep 1 Hydropower

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ABSTRACT: The high production rate of roller-compacted concrete placing which achieved during the construction of the main dam of the Nam Ngiep 1 Hydropower Project in Laos is outstanding.

The demand for the high production required the mobilization of materials, equipment, system and human resources to satisfy the Project's need for the rapid RCC placing rates averaging 97,500 m^3/month and led the Project to select the compatible and optimum production, transporting and placing facilities. The optimization and selection of all in relating to RCC facilities are discussed in this paper. Furthermore, this paper discuss construction techniques and solutions adopted during construction to achieve the high productivity and efficiency while retaining the best quality and safety, and which includes the following 6 items,

1) Materials: Supply of materials from outside which are cement, fly ash and quarry; 2) Equipment: Optimization of all equipment which are crushing plant, aggregate stockpiling; RCC batching plant and RCC delivery conveyor belt; 3) System: Remarkable success of Sloped-Layer Method to achieve high production rates; To obviate manual trimming of feathered edges; 4) Safety procedure in regard to RCC placing; 5) Systematization of procedure in regard to dam zoning; 6) Human resources: Education and establishment of human relations.

RÉSUMÉ: Le taux de production élevé de la mise en place de béton compacté au rouleau, obtenu lors de la construction du barrage principal du projet hydroélectrique de Nam Ngiep 1 au Laos, est remarquable.

La demande pour une production élevée nécessitait la mobilisation de matériaux, d'équipements, de systèmes et de ressources humaines pour répondre aux besoins du projet concernant les taux de placement rapides du RCC, d'une moyenne de 97 500 m^3/mois, et a conduit le projet à sélectionner des installations de production, transport et placement compatibles et optimales. L'optimisation et la sélection de tout ce qui concerne les installations RCC sont discutées dans le présent document. En outre, cet article traite des techniques de construction et des solutions adoptées pendant la construction pour obtenir une productivité et une efficacité élevées tout en préservant la meilleure qualité et sécurité, et qui comprend les 6 points suivants

1) Matériaux: Fourniture de matériaux provenant de l'extérieur (ciment, cendres volantes et carrière); 2) Equipement: Optimisation de tous les équipements qui sont des installations de concassage, stockage de granulats; Installation de traitement par lots RCC et convoyeur de livraison RCC; 3) Système: Succès remarquable de la méthode des couches en pente pour obtenir des taux de production élevés; Pour éviter la coupe manuelle des bords amincis; 4) Procédure de sécurité concernant la mise en place du RCC; 5) Systématisation de la procédure concernant le zonage des barrages; 6) Ressources humaines: éducation et établissement de relations humaines.

1 INTRODUCTION

The Nam Ngiep 1 (NNP1) main dam is 167 m high and constructed predominantly in roller-compacted concrete (RCC) as shown in Figure 1. The Project is located in central Laos, some 145 km northeast of Vientiane, the capital of Lao PDR. The annual power generation is planned to be 1,546 gigawatt-hours (GWH). Excluding the pre-construction of access roads prior to financial close and notice to proceed in August 2014, the overall period of construction of the Project will be 52 months and the RCC placing is expected to take 24 months. The RCC placing was completed in April 2018. The adopted RCC placing methodology on the dam was transportation by truck on the dam after dumping by the belt conveyor and spreading and compacting by dozer and vibratory roller using the sloped-layer method (SLM). NNP1 dam recorded considerable high speed concrete placing speed among ever constructed RCC dams using the SLM and ranking the ninth in the all-time list of RCC dams constructed (Aosaka et al. 2018a).

In order to make the project profitable, it is essential to complete the dam construction within the planned term and cost. However, the owner suddenly came across an unforeseeable geological risk and was forced to delay the start of the dam concrete placing. As a result, the Owner had to modify the dam construction planning through investigation, analysis and evaluation of the risks and their impacts. And the owner made efforts together with the contractor to compensate for the shortened construction period and increased cost by challenging the construction techniques and systems. Finally we achieved the completion of the RCC dam within the planned term with less cost increment mainly by redesign of mix proportion.

This paper discusses construction techniques and solutions adopted during construction to achieve the high productivity and efficiency while retaining the best quality, safety and reduction cost, which includes mobilization of materials, equipment, construction system and human resources as described.

Figure 1. RCC dam in NNP1 in November 2018

2 MATERIALS AND SUPPLY OF MATERIALS

2.1 *Cement*

Type I cement (TPI cement), of which quality was found to be stable by the material test and mix test, was exported from Saraburi in Thailand with transportation of 1,000 km in land with 30 ton jet back. Six 550 ton-silos and two 750 ton-silos (total 4,800 ton) were mobilized at the site for storage of the cement and the maximum monthly consumption of the cement reached 11,822 ton. In order to secure transportation vehicles, the contractor made several contracts with transportation companies, and a relay point was set on the midpoint of the route, Udon Tani in Thailand 750 km from Sarauri to shorten the transportation time by reducing the resting time by drivers and to mitigate the fatigue of drivers. And exclusive vehicles to transport cement from Udon Tani to the site enabled passing through the customs at the border between Thailand and Lao PDR smoothly. The convoy of 5 vehicles with one leading car was formed to transport materials safely, supported by the frequent monitoring by the local police, which contributed to avoidance of traffic accidents and quick reporting in case of accidents.

2.2 *Fly ash*

Class C fly ash at Mea Moh, of which quality was confirmed to be stable by the material test and mix test, was exported from Thailand with inland transportation of 1,000 km by 30 ton jet back. Six 550 ton-silos and two 750 ton-silos (total 4,800 ton) were mobilized at the site for storage of the fly ash. In case of emergency, two 750 ton-cement silos were used for fly ash (total 6,300 ton). The maximum monthly consumption of the fly ash was 16,422 ton. In order to secure transportation vehicles, the contractor made several contracts with transportation companies same as cement. However it had difficulties in procurement of the necessary volume of fly ash during the wet season due to lowered combustion efficiency of lime and during the dry season due to sudden suspension of production for maintenance at the factory. Therefore 4 silos for cement were temporarily used for fly ash and additional silos (4,000 ton) were lent at Vientiane. In addition, it took time to obtain the permit at the customs for importing fly ash to be used the following year and frequently we had problems with delivery of fly ash and it more or less affected the schedule of the concrete placing. The convoy of 5 vehicles with one leading car was formed to transport materials safely, supported by the frequent monitoring by the local police, which contributed to avoidance of traffic accidents and quick reporting in case of accidents.

2.3 *Quarry*

The quarry is located downstream of the dam, on the right bank of the river as shown in Figure 2. The quarry consists of bulk layers of usable sandstone and conglomerated sandstone and thin layers of unusable mudstone that exists between the bulk usable layers. The peak production rate of aggregates was recorded in the month of January 2017 having a production of aggregates of around 500,000 ton. The emergence of weak layers at the riverbed during dam foundation excavation and the following installation of a shear key at the bottom of the dam body led to an increase in the volume of aggregates. And it was feared that the weathered rock was thickly distributed at the overburden of the quarry site. From the above reason at the early stage it was planned to expand the quarry area to supplement the increased volume of aggregates - this early decision mitigated the geological risk that the boundary with sandstone with conglomerate, which cannot be used for aggregates production, at the quarry existed at a higher elevation than expected.

Figure 2. Arial photo of the quarry

3 EQUIPMENT

3.1 *Optimization of all equipment*

The system for the RCC placing was well planned to integrate all working steps at quarry, crushing plant, stockyard, batching plant, belt conveyor, placing location, in order to cope with the large volume of the dam and the typical weather in Southeast Asia having two clear wet and dry seasons and to make high speed concrete placing rate practical.

3.2 *Crushing Plant*

The crushing plant as shown in Figure 3 is located some 200 m downstream of the quarry on the right bank of the river. 4 groups of aggregates were produced by the crusher. The fact that the contractor choice of construction did not adopt a large aggregate stockpiling made the choice of the crushing equipment of paramount importance to keep up with the anticipated high production rate. The crushing plant consist of 2 x 1,000 ton/hour nominal capacity jaw crusher, followed by 4 secondary cone crushers and 4 vertical impact crushers at tertiary position.

Figure 3. Aerial photo of the crushing plant

The maximum monthly consumption of aggregates was 394,200 ton, and it was required to continuously produce aggregates of 300,000 ton or more per month when the mean monthly concrete placing rate reached 160,000 m^3 in February to June 2017. Firstly, the capacity of the transportation of aggregates from the crushing plant to RCC batching plant was periodically monitored whether it had the capacity of 70 ton per hour or not and the plants were controlled to work in 20 hours and to stop in 4 hours for maintenance. Multiple equipment for crushing and sieving were mobilized at the crushing plant to handle with constant production of aggregates even in the case of machine trouble, and they normally work in 14 hours and stop for maintenance in 10 hours per day. In order to secure the volume of rock for throwing into crushing machines, rocks were temporarily piled around the machines and thrown together with dumping by dump trucks hauling from the quarry. Additionally the size of sieving was adjusted to crush rocks effectively in spite of difference in water content of rocks between the wet and dry seasons.

3.3 *Aggregate Stockpiling*

According to practices of aggregates stockpiling RCC in the world it was recommended to store aggregates with the volume of 3 month consumption or equivalent to one-third of the total to cope with troubles with equipment and/or deterioration of rock production at quarry in the wet season. To secure the production of aggregates through the year with enough stockpiling, the plan of quarrying was modified to extract rocks including soils in the dry season and leaving the sound rock portion at the quarry for the wet season since the efficiency of sieving of rocks including soils was lowered in the wet season. This selection worked well because the concrete placing rate was reduced in the wet season. The most important point was to continue maintenance of equipment definitely with reserve of enough spare parts.

3.4 *RCC batching plant*

Two independent but adjacent batching plants as shown in Figure 4, each comprising two 4.5 m^3 twin-shaft mixers were provided for RCC production. Each plant was fitted with its own cement and fly ash silos, aggregate weigh system and feeder belts. Both batching plants shared the same discharge belt that feeds the RCC to the main conveyor to the dam. The two mixers were totally refurbished prior to starting RCC production to ensure sustained production throughout the duration of the project.

Among 4 mixers, 3 mixers worked and 1 mixer was standby for troubles and in maintenance, and the facility was equipped with the bathing plant and the belt conveyor system to convey

Figure 4. Arial photo of aggregate stockpiling, RCC batching plant and cooling belts

concrete with dump trucks as an alternative in case of troubles in the belt conveyor. The batching plant was controlled to stabilize and maximize the concrete batching rate at the high level by adjusting the production rate of each equipment below the nominal capacity of each; 3.0 to 4.0 m^3 mixing rate per batching, 2 to 4 numbers mixing, 30 to 45 seconds mixing time and so on.

RCC cooling system: The maximum RCC placing temperature was specified as 28 ºC for the 2.4 m lift height and 25 ºC for the 3.6 m lift height. To achieve this a composite system of cooling belts and an ice plant were used as following:

Cooling Belts: A 200 m long, 20 m wide cooling tunnel was constructed under the active aggregate storage in which 3 wet belts were installed to cool the 3 coarse aggregate sizes. To provide sufficient chilled water, 4 chillers were installed to cool the water used on the wet belts.

Ice Plant: In addition to the cooling belts, the batching plant was also fitted with two flaked ice plants, each with a capacity of 80 ton/day. During the hot season, an average of 40 kg of ice per m^3 of RCC were used constantly to keep the temperature of RCC below the specified limit.

3.5 *RCC delivery conveyor belt*

A 2.0 km long, 1,000 mm wide conveyor belt, running at 3 m/s, was installed between the RCC batching plant and the dam a shown in Figure 5. The conveyor was deigned to carry a maximum of 400 m^3/hour of RCC. About 350 m downstream of the dam, the conveyor delivered the RCC to a distribution hopper that allowed the RCC to pass to one or the other of two separate feed conveyors to distribute the RCC to either the left abutment or the right abutment. The distribution hopper was able to feed the RCC to one conveyor at any given time allowing maintenance and erection activities to progress on the other conveyor with little interruption to RCC production and placement activities. The final element of the conveyor belt system is the swinger, a delivery short conveyor that can rotate through almost 270 degrees which feeds the RCC directly into the dumper trucks on the dam surface as shown in Figure 6. The belt conveyor was the fatal line for concrete placing, therefore a conveyor system was imported from Japan, Nihon-conveyor rather than mobilization of unreliable multiple conveyor lines. This facility equipped with function to stop the system by automatic sensor for any extraordinary event. When even slight signs to lead troubles were found, the system was continually repaired and maintained with enough storage of spare parts, and for emergency case two mouths for dumping concrete conveyed by truck were equipped with the conveyor system near the dam site where the belt conveyor was branched towards right and left abutments surface.

Figure 5. Arial photo of RCC delivery conveyor belt and swinger delivery to trucks

Figure 6. Arial photo of RCC delivery conveyor belt and swinger delivery to trucks

4 SYSTEM

The system for achieving high efficiency and productivity was expanded to the field of concrete placing as described below; application of slope layer method, application of steel form to feather edge, concrete placing of two mix proportions at the same lift, and the subsequent safety management.

4.1 *Sloped-Layer Method*

At the planning stages, the merits of the Sloped-Layer Method (SLM) were discussed and a consensus was reached quite early by the Owner including RCC expert and Contractor that this method would provide the optimum solution to RCC placement for NNP1 dam and provide advantages in various aspects of construction. As RCC placing approaches completion, there is no doubt that the decision to use SLM was absolutely validated, by demonstrating that the SLM technology proved to be efficient, economical and sustainable during the all the different phases such as the different season, changing construction yard, values of each machine on site and so on during construction.

4.2 *Advantages of sloped-layer method*

4.2.1 *SLM provides the solution to sustain high production rates*

One superior characteristic of SLM is that it allows flexibility to change its design and construction parameters when needed, i.e. changing lift height and angle of slope of the layers as shown in Figure 7 when required. With SLM a lift is defined as the block constructed over the full width and length of the dam (or such part as the construction may be required) to the full height required, and a layer is defined as the thickness of the spread and compacted layer of 300 mm where RCC is placed with one layer over another to form the lift. The construction team use this flexibility to change the parameters and technique of SLM placing during the various phases of construction to maintain a high rate of placing as follows:

Lift height: the maximum quality benefit of SLM is obtained by using the maximum height of lift by increasing the lift height, because the number of cold joints decreases. Various lift heights of 1.2 m, 2.4 m and 3.6 m depend on height of 1.2 m of downstream forms used during the different phases of construction when required.

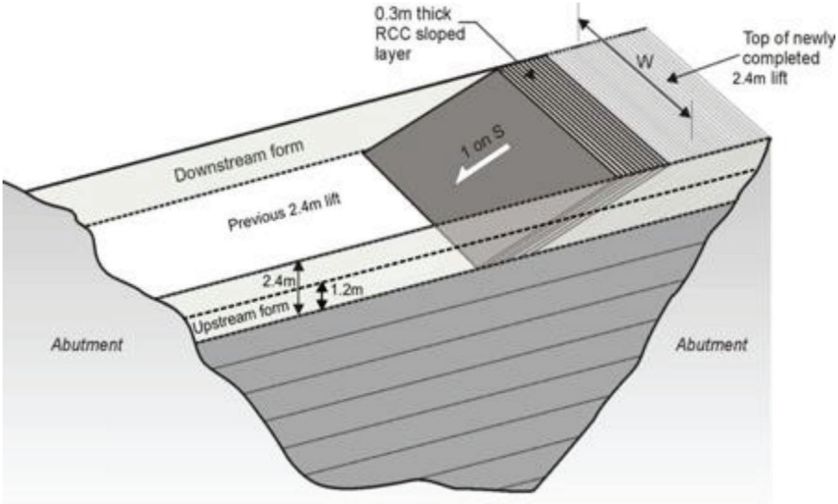

Figure 7. Sloped-Layer Method

Lift slope: in the case of NNP1, it was concluded that when the cycle time of one layer was set between 3 or 4 hours, the maximum rate of RCC production and placing was continuously achieved. Taking into consideration the batching plant capacity of 400 m^3/hour, this resulted in the optimum layer quantity to sustain high-speed construction between 1,200 m^3 to 1,600 m^3. This meant that, if the layer is less than 1,200 m^3 in volume, the RCC production would be idle (because of lower RCC production capacity), and if the layer volume exceeded 1,600 m^3, there would be a high probability that warm joints would occur because of over RCC production capacity, requiring more treatment and preparation. In both cases this does mean a reduction in the placing efficiency, and hence the production rates. This conclusion led the construction team to adjust the slope of each layer to keep the RCC volume for the layer within these two limits. The slope of RCC layers during construction varied between 1V:10H to 1V:30H laterally.

4.2.2 *SLM provides solutions for abutment final excavation and consolidation grouting activities*
Due to the nature of the main dam foundation that comprised sandstone, conglomerate and mudstone layers, the designer decided to continue with final excavation and rock clean-up until the very last minute before the start of placing RCC against it, and to carry out the consolidation grouting from RCC surface every 3 to 5 m spacing as shown in Figure 8. If the horizontal layer methodology had been adopted, this decision would add a huge constraint on RCC placing resulting in a lowering of the production rates. The SLM provided a superior solution to that problem. Since RCC is placed in lifts from abutment to abutment, which basically each takes 5 to 7 days to be completed for one lift, SLM provided the necessary time and platform on the cold joint to carry out final rock excavation and consolidation grouting while RCC was placing. If the SLM was not adopted, the construction team considers that the rate of production would be lowered by 30 to 40 % of the achieved rates.

In addition to the above, the SLM also added a value to many other construction activities as following items by allowing them to progress smoothly, increasing the production rates of the project and leading to successful completion of the dam around 5 months earlier than the contractual completion date.

- RCC placing in wet weather (because there is a relatively small placing area to be treated after rain and minimize admixture amount);
- The ease of formwork erection and treatment of cold joint activities as it is off the critical path and placing activities due to different location;
- The ease of installation of both inclined and horizontal galleries.
- Simplicity of conveyor erection activities because these are off the critical path;

Figure 8. Rock foundation excavation and treatment

4.3 *Disadvantages of slope layer method and innovations created to solve the quality concerns*

Although the SLM provided some ideal solutions to the construction team of NNP1 RCC dam, the method also brought some construction difficulties and quality concerns. Some of those that were addressed and solution were innovated to overcome the quality concern, the feather edge being the most important aspect.

As stated by (Forbes 2012), the feathered edges running in upstream to downstream direction over a cold joint at the bottom of the sloping layer need to be properly dealt with. At NNP1 a uniquely original solution was created by forming a 70 mm high RCC stop-end to make a foot in the RCC. The RCC foot edges were created by using a 120 mm high steel channel. The RCC is spread with over height to 120 mm at the steel section and compacted first by plate compactor against the channel section and then by 2.7 ton roller to 70 mm finally as shown in Figures 9-10. The big roller then compacts the RCC layer in a direction perpendicular to the steel section form overlapping with the compaction of the small roller, to make sound, compacted foot of RCC. This method was used rather than, the time consuming and quality questionable method of rolling RCC to a tapered end, a feathered edge, at the joint with the previous layer and having to chip it off by hand.

Other construction detail associated with SLM that needed to be addressed carefully during the construction, to achieve the best quality includes:

- Mix workability: Due to the high placing rate of sloped layers (typically 4 to 6 layers placed per day), the set retarding admixture was reduced as much, since it makes the RCC mix very sensitive due to any moisture variation and causes deterioration of fresh properties of the RCC originally it has such as waving, lack of density and exposure of coarse aggregates on the concrete surface after compaction.
- Formwork system: Again, due to the rapid placing, the formwork stability was tested. Extra supports and anchors were required at times to ensure the stability of forms.
- RCC Layer Thickness: Although laser guidance to the bulldozer blade was applied to control the layer thickness, extra monitoring using total station surveying instruments was required.

4.4 *Safety procedure in regard to RCC placing*

As concrete placing was proceeded with the higher elevation, the placing width became narrow to accommodate machines and workers on it. Therefore the following measures were taken to secure the safety by keeping the high speed placing rate. The working area was clearly divided into each work such as spreading, compacting, Grout Enriched RCC (GE-RCC) injecting, and so on by colored cones with tape, poles and sign boards. A guide and a supervisor were assigned in the placing area and persons non-related to placing works were strictly kept out from the working area. Machine drivers, the guide and the supervisor were obligated to carry wireless phone for communication each other and when they found foreigners in the area, the works necessitated to be suspended as shown in Figures 11-12. It took time for practice to be soaked into all persons concerned as a sense and for them to behave naturally through repeated drills. Whenever the placing width varied, size, number of machines were rearranged in advance to meet with placing capacity by monitoring the batching capacity, time for dumping and hauling of dump tracks.

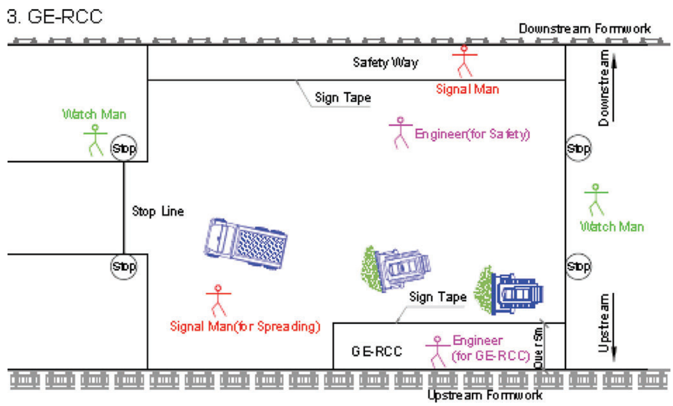

Figure 11. Safety procedure in regard to RCC placing (GE-RCC)

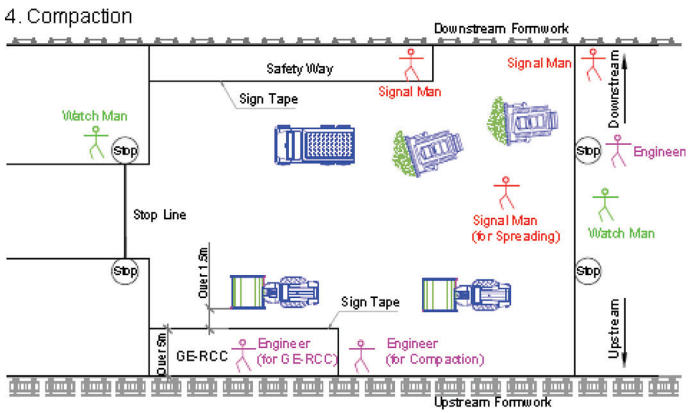

Figure 12. Safety procedure in regard to RCC placing (Compaction)

4.5 *System for placing concrete with dam zoning*

NNP1 originally had a plan of dam zoning separated in low and higher elevations, however NNP1 has studied more dedicate zoning to apply poor mix proportion at the higher elevation and inner portion for cost saving. With starting a rich mix proportion of cement of 80 kg and fly ash of 120 kg (C80F120) instead of C80F90 and stone powder of 30 kg, where production of stone powder was not controlled at the initial stage, total 14 mix proportions including the poorest mix proportions of C60F60 were applied (Aosaka et al. 2017, Nakamura et al. 2016). While the higher strength of the concrete is required at the upstream portion where tensile stress works, the lower strength of the concrete is available at the downstream portion where compressive stress is dominant. On the other hand, this trial may create the additional risk in placing two mix concrete on the same layer simultaneously such as mistake of mix proportion, wrong mixing, etc., and finally speed-down of concrete placing. For avoidance of these mistakes the system described below was established by discussion between the owner and the contractor and executed with reinforced supervision. The rich concrete is placed from upstream towards downstream, and when it reaches 20 m far from the upstream face the supervisor announces it to the supervisor at the batching plant. After 5 minutes suspension the mix proportion is replaced with the poor concrete and placing of the poor concrete starts at the downstream area. After arrival at the downstream, the mix proportion is replaced with the rich one again and this procedure is repeated layer by layer as shown in Figure 13.

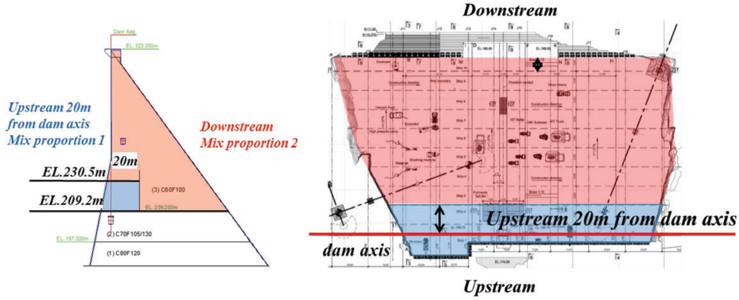

Figure 13. Dam zoning and procedure

Procedure of every layer (Owner and Contractor already conducted discussion)

Step 1: Calculation of each RCC volume of 20 m area from dam axis and downstream area. The RCC plant engineer and RCC site engineer understand above RCC volume.
Step 2: The RCC placing of mix proportion 1 (rich mixture) start from dam axis.
Step 3: When the RCC Placing of step 2 reached 20 m from dam axis, the RCC site engineer call the concerned information to RCC plant engineer.
Step 4: The RCC plant engineer change the mix proportion from 1 to 2 (lean mixture) after 5 min (Suspension time). After that RCC plant engineer inform to site RCC engineer.
Step 5: Mix proportion 2 (lean mixture) apply downstream area.

The important points of the management of construction of changing mix proportion have the contact between RCC site engineer and plant engineer, communication and observance of above procedure.

5 HUMAN RESOURCES

The system for human control including training and information control is described as below.

5.1 *Owner*

The system for human control including training and information control is described as below.

The principal is to share a same policy on quality, cost, delivery and safety for all the works among all persons related to dam construction in the owner, the contractor, subcontractor including workers and it leads to overcome difficulties encountered during construction. The system for controlling, information sharing and training was improved with the process of trial and error, and it focused on mutual understanding among all the staff of the owner, because they have variety of nationalities. To discuss problems and their causes and measures, the meetings were held periodically or on ad hoc basis internally and with the contractor and the subcontractor, sometimes with RCC expert and the third party such as Lenders Technical Advisor and Dam Safety Panel as described in the organization of the owner. The trainings were held to young and local staff through on-the-job training, and know-how and tips for especially RCC were brought from RCC expert and the third parties and shared with the contractor.

5.2 *Contractor*

The start of dam construction by the contractor was to select a capable and reliable subcontractor. The contractor went around a lot of countries such as China, Thailand and Vietnam for seeking "candidate" through hearing their intensions, after that the contractor narrowed down candidates on construction experience, number of engineers, machinery and facilities, construction planning, cost estimate and so on. After contracting with a sub-contractor, the contractor requested the sub-contractor to show the organization chart by assigning the key engineers at the important positions with clear scope of works. And three shifts per day was introduced to enhance the work efficiency. The training for the subcontractors were held on making work procedure in English properly. Trail embankment for RCC was implemented three times at the stockyard, upstream cofferdam and both abutments of the re-regulation dam for RCC placing test and training of workers, which much contributed to establish the system for concrete placing with high technology and good communication. Documents with detailed working procedure and checklist with sketches or photos and numbers worked well to instruct and train workers.

6 QUALITY

The quality of RCC in NNP1 is achieved the high productivity and efficiency while retaining the best quality as below and refer to (Aosaka et al. 2018b).

- It is found through concrete strength test that all the sampled specimens have the required density and strengths of concrete; compressive and direct tensile strength and their fluctuations were quite small; standard deviation of density, compressive, direct tensile strengths and splitting tensile strength are 0.44 %, 3.8 %, 0.18 % and 0.41 % respectively.
- More than 100 concrete specimens were sampled for visual observation and it was confirmed that there were on no pockmarks, aggregates were uniformly distributed, and boundaries between RCC and GE-RCC, foundation bedrock were tightly adhered.
- The in-situ permeability test of RCC was conducted by using vertical drain holes along the gallery and well water tightness of concrete having permeability coefficient of 10 to 8 was secured and no leakage through vertical drain holes even after initial impounding.

7 PRODUCTION RATES AND PRODUCTION EFFICENCY

The RCC dam placing started on 19 April 2016 and finished on 29 April 2018. With a total RCC volume of 2.360,000 m^3, transported to the dam by a 2.6 km long elevated high-speed conveyor system, the final average monthly placing rate of RCC was achieved at about 97,500 m^3/month, peaking at 188,110 m^3 during the month of February 2017, and daily peaking at 9,141 m^3 in the same month as shown in Figures 14-15. NNP1 dam recorded the fastest dam

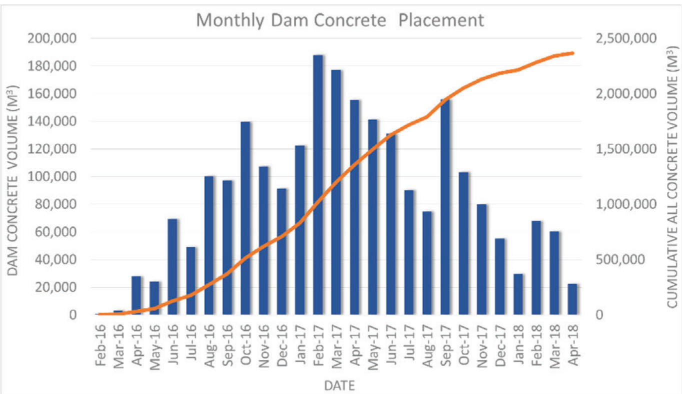

Figure 14. RCC placing progress

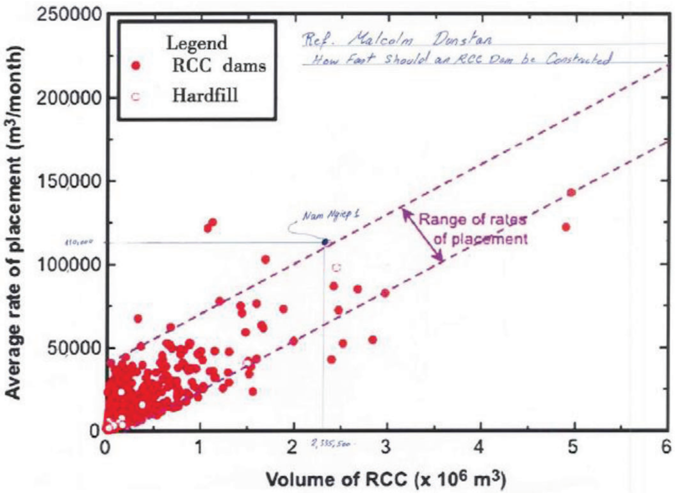

Figure 15. RCC placing speed

ever constructed using the SLM, ranking ninth in the all-time list of RCC dams constructed (Dunstan 2015a).

For most projects, additional time is additional cost and there is a 'need for speed' if construction expenditure is to be minimized. The high RCC placing rates at NNP1 dam were achieved by using relatively smaller production and delivery equipment than those used on many similar sized projects. Dr. Malcolm Dunstan creates a plant utilization efficiency factor simply by dividing the average monthly placement in cubic meter per month by the nominal capacity of production equipment in cubic meter per hour (Dunstan 2015b). According to Dr. Dunstan's records, the average efficiency factor for all RCC dams completed up to 2016 was 94.0 hours per month with a range from 13.5 hours per month being the worst to 195.8 hours per month being the best. By applying the same concept, the efficiency factor for the RCC dam at NNP1 RCC dam reaches about 250 hours per month, some 27.8 % better than any RCC dam ever constructed. And the production efficiency is 33.8 % which is top class in the world.

It is also noted that these high production rates and high efficiency were achieved despite a number of interruptions that suspended RCC placing completely for periods of time as below.

– Loss of 3 weeks to remedy problems related to consolidation works at the bottom of RCC in July 2016.
– Loss of 3 weeks as a result of stoppage of fly ash supply.
– Loss of 3 weeks in July to August 2017 due to serious accident that occurred on site.

8 CONCLUSIONS

When we suffered a big issue of emergence of weak layers in the riverbed during dam foundation excavation, we had to overcome it to minimize additional cost and recover the delay due to additional dam foundation excavation and RCC placing as measures. Especially in southeast Asia where it is clearly divided into two seasons, dry and wet seasons, even in a couple of month delay, it much affects the commencement of hydropower projects since we need a certain time for initial impounding of the reservoir after completion of the dam before start of the wet season and the commencement date of operation delays on one year basis.

For solving this issue, the owner and the contractor sit across the table from each other and racked our empty brains by getting support from RCC expert the owner employed and Dam Safety Panel as follows.

- Each material was procured and stockpiled at the site with appropriate measures to realize constant delivery.
- It much contribute to introduce the Slope Layer Method for controlling the timing of concrete placing during the wet season by changing contraction joints of hot joint and cold joint, actually it totally reduced the percent of the cold joints and for parallel conducting the series of works such as final excavation, consolidation grouting, treatment of cold joint and shift of formwork and so on during concrete placing with one lift in five to seven days.
- The method of feather edge was modified to improve the quality of concrete and so far no leakage was found through vertical drain holes along the gallery after initial impounding.
- The poor cementitious mix proportions were applied to at the higher elevation and inner portion, which much contributed the cost reduction. The dam zoning with 14 mix proportion including poorest mix proportion of C60F60 was applied to considerably tall RCC of 167 m in the world.
- In order to materialize the above three rather complex works at the same time, the systematical method was established to executes works smoothly and the workers were well educated and functioned by the leadership of the subcontractor and main contractor, which it also much achieve high quality of the concrete and the safety.
- The reliability of high quality concrete placing was verified through concrete strength tests and core observation.
- The sophisticated arrangement of all the facilities and machinery presented the high RCC production efficiency of 33.8 % ranked in top of the world.
- The slope layer method much demonstrated its advantage on high concrete placing speed achieving the 7th ranking in the world.

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