NAM THEUN 1, NEW ACHIEVEMENTS FOR RCC DAMS

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ABSTRACT: The Nam Theun 1 Hydropower Project in Laos PDR includes a 187.00 m high curved RCC gravity dam, constructed between January 2019 and February 2022, mostly under restrictions caused by the COVID-19 pandemic. Despite this, peak volumes of 16,462 m^3 and 361,333 m^3 of RCC were placed in one day and one month respectively by the Contractor, and more than 200,000 m^3 of RCC was placed in six consecutive months. Furthermore, over 300,000 m^3/ month of RCC was placed twice. A total of 20 different RCC mix designs were used in the dam, including cement and fly ash provided by three different suppliers for each material, and from three different countries (Laos PDR, Vietnam and Thailand). On some occasions, two cements and two fly ashes were stored at the RCC batching plant and their use was synchronised to prevent two types of either product being used in the same cubic metre of RCC. The slope layer method of construction was adopted with the successful use of lift heights of 3m, 6m and 9m, and with a minimum slope of ten percent and a maximum slope of twenty five percent. GERCC was used on the upstream face and the stepped downstream face. Floods were safely passed through the construction site and over the placed RCC during three rainy seasons, with the flows during the 2021 rainy season being managed by a 123.30 m high stepped overflow spillway for temporary use, which was constructed entirely of RCC and built on the right toe of the dam simultaneously with the main dam RCC. Local quarried sandstone of variable hardness was used almost entirely in the RCC mix, with relatively small quantities of imported limestone also being used together with the sandstone for the achievement of the extremely high RCC production rates.

Keywords: RCC, Record, Slope, Laos, Dam, Placement

1 INTRODUCTION

The Nam Theun 1 Hydropower Project has been developed by the Nam Theun 1 Power Co. Ltd (NT1PC) on the Nam Kading River in central Laos PDR (Bolikhamxay Province) approximately 33 km upstream of its confluence with the Mekong River and almost 220 km from the capital city of Vientiane (see Figure 1).

Key Project features include a roller compacted concrete (RCC) curved gravity dam, with a maximum height of 187 m above the deepest foundation elevation (El 110 masl), supporting a six bay radial gated crest spillway, with chutes on the downstream face of the dam discharging flood flows into a plunge pool, two separate shaft powerhouses downstream of the dam on the left bank of the river, with one equipped with two 260 MW Francis turbine/generator groups, and the other with a single 130 MW Francis turbine/generator. All units are fed by a single power waterway system (low pressure tunnel, pressure shaft and high pressure tunnel, in a single line) connected to a free standing outdoor power intake structure at the upstream end, and three separate tailrace tunnels and structures downstream that return the water to the Nam Kading River. A 500 kV double circuit transmission line (154 km long) between the powerhouse and an existing 230/500 kV substation, and 115 kV single and double circuit transmission lines connected to the Laos National Grid, have all been provided to dispatch the power generated by the Project.

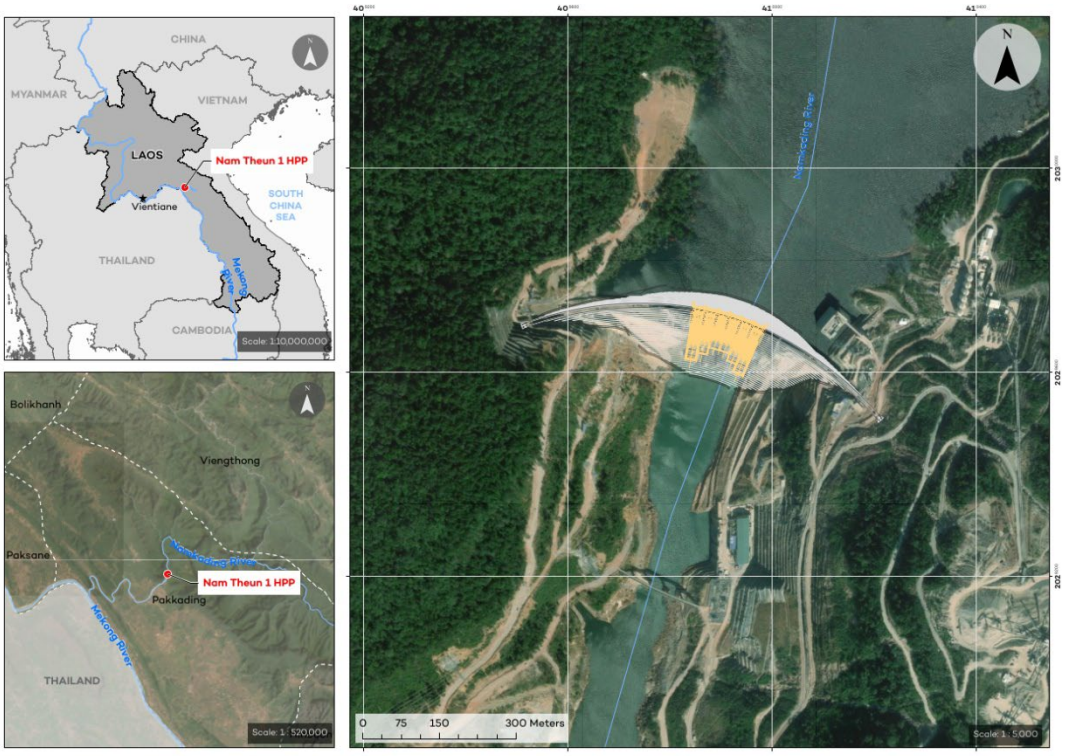


Figure 1: Location of the Nam Theun 1 Hydropower Project

2 CHARACTERISTICS OF THE RCC DAM

As well as being a curved gravity RCC dam with a maximum height of 187 m above its lowest foundation level, the RCC dam has the other characteristic provided in Table 1.

Table 1: RCC dam characteristics

Description	Characteristic
Type	Curved Gravity RCC Dam
Crest Elevation	297.0 masl
Maximum Height	187.0 m
Deepest Foundation Elevation	110.0 masl
Crest Length	771.0 m
Crest Width	8.0 m
Excavation Volume	1,840,000 m^3
RCC Volume	4,141,213 m^3
Structural Concrete Volume	272,000 m^3
Upstream Slope	1V/0.20H
Downstream Slope	1V/0.75H
Spillway Capacity (PMF)	30,200 m^3/s
Spillway Radial Gate Dimension	20.0 m x 17.3 m (6 nr.)

An aerial photograph taken of the completed dam is shown in Figure 2.

Figure 2: Nam Theun 1 RCC dam

The dam incorporates the gated ogee crested spillway located on the Nam Kading River axis and has a centrally located bottom outlet. To form the curved RCC dam, 31 blocks with a width of 25 m have been constructed, with the spillway occupying the 7 central blocks.

The spillway occupies a significant length of the dam and had to be curved to enable the discharge from the flip buckets to land in the plunge pool excavated below the existing riverbed.

A radius of 500 m was selected as the most appropriate curvature for the central part of the dam, after considering the hydraulics of the spillway.

In addition to the influence the spillway has on the longitudinal profile of the dam, its crest layout also had to be considered when the cross-sectional geometry of a stable dam in this location was determined. If the width of the dam had been narrowed in the spillway location, a large upstream crest cantilever would have been required to accommodate the geometry of the ogee weir crest, the required gates, and the weir transition into the spillway chute.

A curved gravity dam section was chosen, to resolve the above and a stable cross section satisfying the required design criteria (with the necessary height of 187 m) was determined with an upstream slope from the crest to the heel of 1.0:0.2 (V:H) and a downstream slope (measured from the upstream face at full supply level) of 1.0:0.75 (V:H).

Such a curved gravity design for the dam also has the added benefit of minimising risks that may relate to any less than ideal foundation conditions encountered.

To complete the design of a stable dam, its profile between the spillway and the abutments continued the curvature of dam on both sides of the spillway with a radius of 700 m after giving due attention to the abutment topography.

In the riverbed section below the spillway, the dam was extended downstream as required to support the six spillway chute flip buckets, which each have a radius of 25 m.

3 RCC INGREDIENTS AND MIX DESIGNS

A total of 20 different RCC mixes were required during the construction of the dam. The need to change the mix designs was based on the ongoing routine laboratory test results, but also the availability of cement and fly-ash during the COVID-19 pandemic that affected the works on site (to differing extents) from March 2020 (the month of closure of international and provincial borders in Laos PDR) until February 2022 (the month of RCC dam completion).

A summary of the cements and fly-ashes used in the RCC dam, including their country of origin, are given in Table 2.

Table 2: Cements and fly ashes used in the RCC dam

Description	Country of Origin
Cement:	
SCG Thai	Thailand
SCG Laos	Laos PDR
LCI Golden Lion	Laos PDR
Fly Ash:	
Pha Lai	Vietnam
Vung Ang	Vietnam
Hongsa	Laos PDR

All RCC mixes used Sikament TM28 as a retarder in differing percentages depending on the mix design, location in the dam and the season of the year. In addition to the quarried sandstone, imported limestone aggregate was used, when RCC placement rates were extremely high and there were insufficient materials available in the crushing plant stockpiles. The imported limestone aggregate was used in 6 of the 20 RCC mixes, and at various times in all aggregate fractions larger than the sand fraction (4.75 to 12.5 mm, 12.5 mm to 25.0 mm and 25.0 mm to 50 mm), although not in all fractions at the same time. In two RCC mixes, imported limestone aggregate and quarried sandstone were mixed in the same aggregate fraction (12.5 to 25.0 mm).

Cementitious contents of the mixes used in the RCC dam were (cement/ fly ash) 100 kg/120 kg, 120 kg/ 80 kg, 100 kg/ 130 kg, 75 kg/ 100 kg, 130 kg/ 110 kg, 120 kg/ 120 kg and 130 kg/ 120 kg, depending on the cement and fly ash products being used and the results of laboratory tests.

To avoid critical delays to the Nam Theun 1 Project, RCC was commenced in the dam with 90 day compressive and tensile strength results, and the results of accelerated curing tests.

4 RCC DAM CONSTRUCTION

Placement of RCC commenced with the former contractor on 15 January 2019 and a total quantity of 881,364 m^3 of RCC was placed in the period to 20 November 2019.

Sinohydro Corporation took over the Project and the construction of the dam on 6 December 2019 and placed a total volume of 3,259,849 m^3 of RCC during the period from 24 December 2019 to 22 February 2022.

During the period of placement of RCC by Sinohydro Corporation, several international records were beaten in relation to the placement of RCC, most noticeably in a period of 24 hours, and in a period of 1 month.

The maximum daily amount reached was 16,462 m^3 on 19 January 2021, and the maximum monthly placement was 361,333 m^3 achieved in January 2021. Of key importance was the maximum monthly placement which showed consistency throughout the month and broke the world record for a single contractor working on an RCC dam, with a single conveyor line.

Other significant monthly placement volumes are shown in Table 3, which shows that in excess of 200,000 m^3/ month was achieved over a period of 6 months in a row (October 2020 to March 2021), and over 300,000 m^3/ month of RCC was place twice (in January 2021 and March 2021).

Table 3: Significant monthly RCC placement quantities

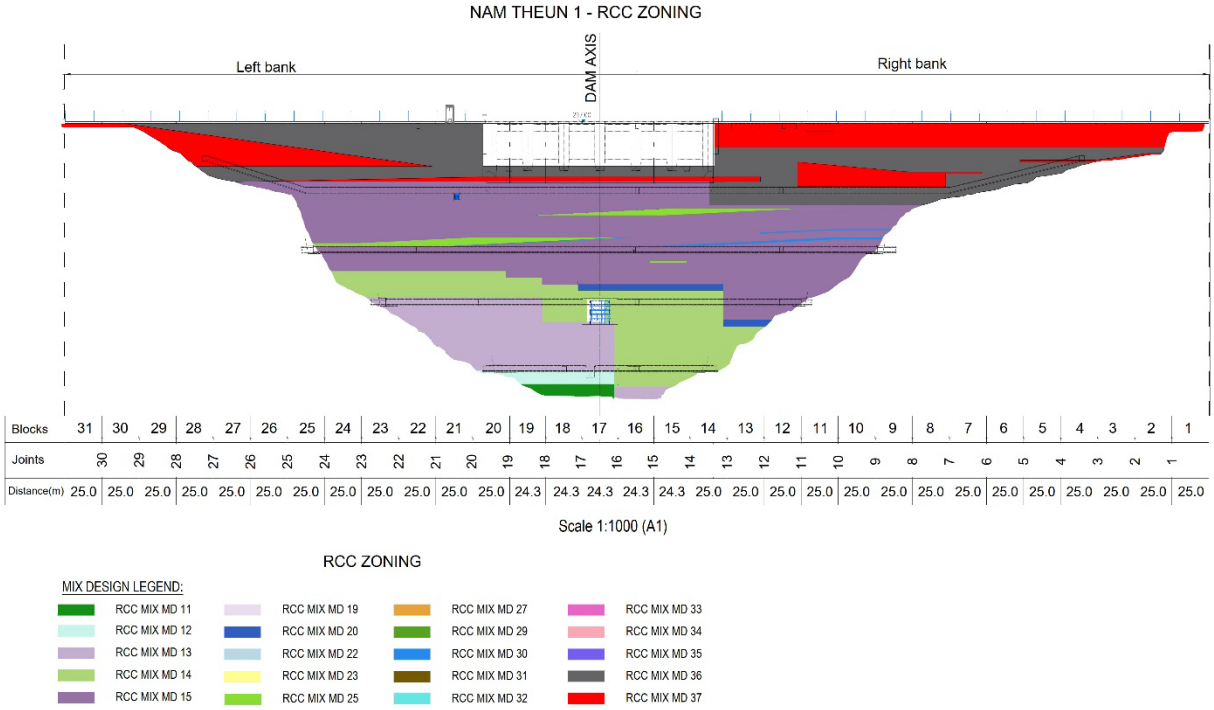
Month/ Year	Monthly Volume (m^3/ month)
October 2020	251,934
November 2020	216,591
December 2020	209,227
January 2021	361,333
February 2021	260,216
March 2021	310,946

The RCC was placed in layers of 300 mm using the slope layer method when the placement area was large enough to accommodate this approach. Whilst using the slope layer method, lift heights of 3.0 m, 6.0 m and 9.0 m were used, which is also unprecedented in previous RCC dams. The use of the slope layer method took place in slopes from downstream to upstream, as well as longitudinally. In January 2021, February 2021 and March 2021 lift heights of 6 m and 9 m were used, which was fundamental to the high monthly volumes achieved.

To control the floods passing over the right side of the dam in the 2021 rainy season, through the flood gap left in the RCC, a stepped spillway was constructed also in RCC, for temporary use (with GERCC facing), along the toe of the dam on the right side. Research of literature has shown that this spillway is the highest structure of its type for temporary use ever constructed (it has a height of 123.30 m).

5 RCC ZONING

For as-built records, zoning drawings were prepared to show the locations where each of the 20 RCC mixes were placed in the dam, both on dam longitudinal sections and cross sections at relevant construction joints. The as-built zoning on a longitudinal section and cross section at Block Joint No. 19 are shown in Figure 3.



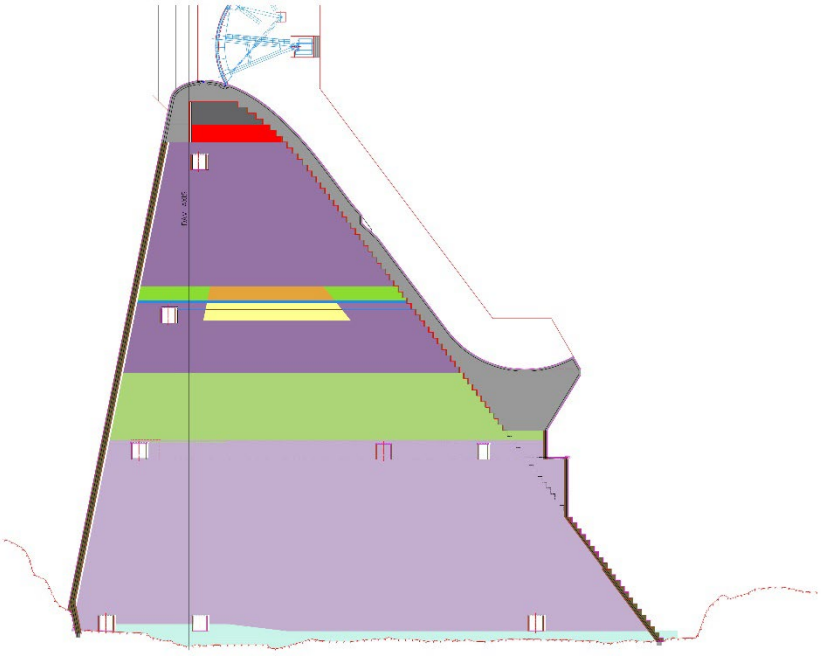


Figure 3: As-Built zoning of RCC dam

The most commonly used mix (RCC-MD-15) had a total cementitious content of 230 kg/m^3 (100 kg/m^3 of LCI Golden Lion cement, and 130 kg/m^3 of Pha Lai fly ash).

Other characteristics of this mix are given in Table 4.

Table 4: Characteristic of most commonly used mix (RCC-MD-15)

Cementitious Materials		Aggregate			Admixture (Sikament TM 28)
Cement	Fly Ash	Size (mm)	Quantity (kg/m^3)	Source	
100 kg/ m^3 LCI Golden Lion	130 kg/m^3 Pha Lai	Sand	435	NT1 Quarry	0.5%/ cement weight (1.15 kg/m^3)
		4.75 - 12.5	361	NT1 Quarry	
		12.5 – 25.0	604	NT1 Quarry	
		25.0 – 50.0	606	NT1 Quarry	

Mix RCC-MD-15 was used for 1,460,261 m^3 (equivalent to 35.26%) of the entire dam volume of 4,141,213 m^3.

The required (maximum) RCC compressive and tensile strengths for the RCC mixes were 16 MPa and 1.2 MPa respectively (at 365 days). All required strengths were satisfactorily met in the RCC with the compressive and tensile strengths reaching 19.7 MPa and 1.47 MPa with respective coefficients of variation being between 11.3 and 21.8 (compressive strengths at 365 days) and 7.9 to 16.6 (tensile strength at 365 days).

Although the original intention was to zone the dam with a lower cementitious content/ strength mix in the central/ core area of the dam, this was not done for construction convenience.

6 RCC CORING

During and after the construction of the RCC dam, a total of 12 cores were extracted from the RCC at various locations with drilling undertaken from the dam crest and downstream face.

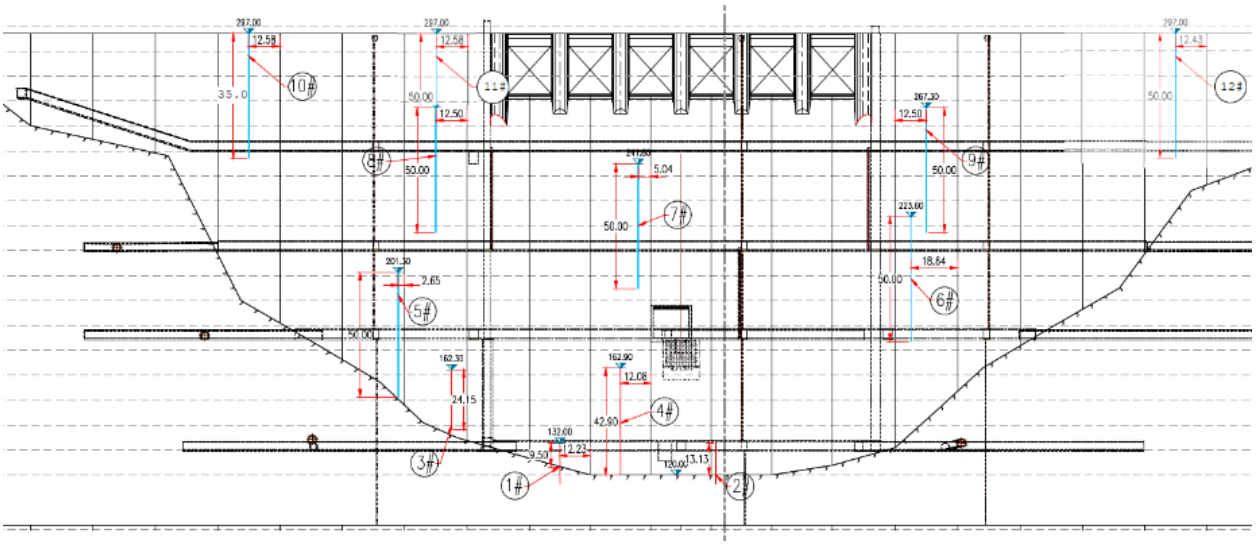


Figure 4: RCC dam core locations

For the drilling, sampling and testing, the following was strictly adhered to for cores that were considered acceptable:

- The diameter of the cores to be recovered was 150 mm minimum.
- In general, the cores had a length of 3 m to 12 m, and the cores were removed from the holes immediately if blocking of the bit or grinding of the core was indicated by the drill behaviour, regardless of the length of the run which had been made.
- Only samples not altered or damaged by the drilling process were considered acceptable.
- Cores drilled down to the rock foundation were extended to at least 0.6 m into sound rock.
- Drilling was stopped, and the core removed from the barrel as often as necessary to secure the recovery of the drilled core. Thereafter, the contractor took corrective action to ensure complete long lengths of core were recovered from that point onwards.

- Upon completion of coring, and prior to each hole being filled with thick grout, the hole was filled with water and the rate of fall of the water level with time for approximately 1 hour was recorded.

The block number and depth of cores are given in Table 5.

Table 5: RCC dam core location and depth

Core Number	Location	Depth
1	El 132.00 masl, Block 19	8.92 m
2	El 132.00 masl, Block 16	12.30 m
3	El 162.30 masl, Block 21	24.84 m
4	El 162.30 masl, Block 18	42.49 m
5	El 201.00 masl, Block 22	49.86 m
6	El 223.60 masl, Block 13	49.65 m
7	El 241.80 masl, Block 18	49.35 m
8	El 267.30 masl, Block 21	50.29 m
9	El 267.30 masl, Block 12	50.09 m
10	El 295.80 masl, Block 26	34.60 m
11	El 295.00 masl, Block 22	49.81 m
12	El 295.80 masl, Block 09	49.53 m

7 RCC OVERTOPPING

Overtopping of the upstream RCC cofferdam (and downstream RCC cofferdam) and the RCC in the main dam occurred for short periods during three rainy seasons (2019, 2020 and 2021) with the elevation of the RCC in the dam at various levels. Discharges from the upstream Hydropower Project occasionally added to the flows reaching the Nam Theun 1 Project Site.

In the 2019 rainy season, overtopping commenced on 16 August 2019 and lasted until 18 August 2019, resulting in the expected stoppage of RCC placement in two blocks on the right hand side (Blocks 17 and 18).

In the 2020 rainy season, overtopping occurred from 02 to 04 August 2020, 05 to 07 August 2020 and 16 to 18 August 2020. The RCC in the main dam on the right side was stopped at El 159.30 masl to manage overtopping without flooding the ongoing RCC placement on the left side.

The maximum reservoir level during the 2020 rainy season was El 176.65 masl, with a maximum of 1,360 m^3/s passing through the diversion tunnel and approximately 750 m^3/s passing over the dam.

Final overtopping of the RCC cofferdam and the main dam occurred during the 2021 rainy season, with flood water passing over a flood gap on the right-hand side of the RCC dam at El 255.30 masl and passing down the overflow stepped spillway constructed on the right side along the dam toe.

The flood gap had a length of 125 m (5 dam blocks), and the height of the temporary stepped spillway was 123.30 m.

Overtopping occurred from 11 to 21 August 2021 and from 24 to 25 August 2021, with a discharge of 1,600 m^3/s passing through the diversion tunnel, 573 m^3/s through the open bottom outlet, and 1,705 m^3/s passing through the flood gap and down the temporary stepped spillway (see the photograph in Figure 5)

Figure 5: Overtopping during the 2021 rainy season.

The maximum reservoir level during the 2021 rainy season reached El 259.30 masl (4 m depth through the flood gap).

It is noted that the upstream RCC cofferdam also overtopped in the 2018 rainy season, however, the placement of RCC in the main dam had not yet commenced.

8 RCC COFERDAMS

Both the upstream and downstream cofferdams were constructed with RCC, with the upstream RCC cofferdam being built in less than 3 months to a height of 51 m and a total volume (GERCC and RCC) of 109,490 m^3. The downstream RCC cofferdam was built in less than 1.5 months with a height of 27 m and a total volume of 40,099 m^3.

The upstream and the downstream RCC cofferdams were founded on GERCC premixed at the RCC batching plant and transported by trucks. To accelerate construction, formwork with GERCC was only used on the upstream face of the upstream cofferdam, with the unformed RCC downstream face having slopes of 1V/0.8H, 1V/0.7H and 1V/0.4H.

For the downstream RCC cofferdam, no formwork was used on either face which had upstream slopes of 1V/0.7H and 1V/0.4H, and a downstream slope of 1V/0.7H.

Vibrating plate compactors mounted on an excavator were used on the unformed faces of both RCC cofferdams.

9 CONCLUSION

The Nam Theun 1 Hydropower Project was continued with noticeable restrictions under the COVID-19 pandemic in Laos PDR. Despite this, the Project team consisting of the Owner (NT1PC), the Owner's Engineer (AFRY Switzerland Ltd) and the civil contractor (Sinohydro Corporation), as well as the other major contractors, endeavoured to complete the Project on time. With regard to the RCC dam, new records for RCC dam building were set including an RCC monthly placement volume of 361,333 m^3/ month, placement of in excess of 200,000 m^3/ month for six consecutive months, and more than 300,000 m^3/ month twice, whilst at times using the slope layer method with lift heights of up to 9m, and with slopes of up to twenty five percent.

During three rainy seasons, the RCC was overtopped by the floods encountered, and without damage (other than a near perfect "green cut"), and with discharges being successfully managed during the 2021 rainy season by a temporary overflow spillway with a height of 123.30 m.

These achievements and successful innovations enabled the Project to be completed on time, despite all the challenges encountered.

10 ACKNOWLEDGEMENT

AFRY Switzerland Ltd are thankful to the Nam Theun 1 Power Company for the opportunity to work on such a milestone project as their Owner's Engineer, and for their continuous support during the many years that we were guests in the country of Laos PDR. We also acknowledge our collaboration during the mix design and execution phase of the RCC dam construction with Mr Brian Forbes, and with Mr John Potts during the initial stages.