Nam Ngum 2 Hydroelectric Power Project Encountered Technical and Economical Challenges

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Abstract: The 182 m high CFRD is under construction on the Nam Ngum River one of major tributaries of the Mekong River in Lao PDR. The project site is at the rim of the Nam Ngum 1 reservoir and 35 km from the Nam Ngum 1 dam, the current largest dam in Lao since 1970s. The objective of the project is to produce electricity for sale to Thailand for the concession period of 25 years. The project cost is US $780 million. The construction had began since the end of 2006 and is scheduled to start impounding and commissioning in March 2010 and December 2010, respectively.

The dam was designed to be different rockfill zones using filter design criterion. The rockfill sections generally require the sound rock, well graded and free draining. The upstream zones were designed to be more impervious than the downstream zones, a better material quality is required for the upstream zones whilst a poorer quality can be adopted in the downstream zones. The rockfill is mainly derived from rock mass fractured by blasting from the quarry in the vicinity area where the geological formations consist of medium bedded to massive cliff forming sandstone inter bedded with siltstone layers.

According to the rock properties from a large mold triaxial test, siltstone was prohibited to mix with the downstream rockfill zone, namely 3C zone. To use only sandstone for embankment, quantity of rock excavation from the quarry have increased from 8.9 million m$^3$ to somewhat 13 million m$^3$. The project encountered the difficulty in quarry exploitation planning and keeping the completion target. Planning of quarry have to be in such a way that feeding of sandstone rockfill shall be done without interruption. The quarry area has been extended into 3 quarries and each of them has at least 3 faces in operation at the same time, almost double amount of machines and equipment have been also increased for the quarry development, exploitation and removal of siltstone layers. This have happened since early 2008 when the oil price and steel price hit the highest prices in the mankind history.

The EPC Contractor suffered with the overrunning cost and seeking for the claims related to unforeseen geological condition and force majeure related to the hike of construction material prices. With the good collaboration of all parties and the fairness treatment, the claims were settled on the right time and the project was then able to move on.

Key words: embankment, rockfill, quarry

1 Introduction

The Nam Ngum 2 Hydroelectric Power Project is developed by the Nam Ngum 2 Power Company and is one of the large hydropower projects in Lao PDR. The project is located on the Nam Ngum River, a 354 km long river of Lao PDR, which originates from the Northern mountainous region and flows south through Vientiane Province joining the Mekong at the Vientiane Capital. The project site is 90 km north of Vientiane Capital and is 35 km from the Nam Ngum 1 dam, the current largest dam in Lao which was constructed in 1970s. The objective of the project is to produce electricity for sale to Thailand for the concession period of 25 years.

The project is under construction by the EPC Contractor. It involves with construction of a
182 m high concrete faced rockfill dam, 3 large spillway gates with a total capacity of 8,900 m$^3$/s, a 530 m long power waterway and a 615 MW surface powerplant. The impound reservoir will cover the area of 107 km$^2$ and store approximately 4,886 million m$^3$ of water at maximum operation level of 375 m asl. The dam has a crest length about 480 m and contains approximately 9.5 million m$^3$ of rockfill. The project cost is US $ 780 million. The construction had begun since the end of 2006 and is scheduled to start impounding and operating in March 2010 and December 2010, respectively.

This paper will focus on the difficulty of the particular works that associated with the unforeseen conditions arisen during construction period that are e.g. challenges caused from unforeseen geology and impact of oil and construction materials prices increased. Geology, general conceptual design of the CFRD, sequence of dam embankment as well as quarry exploitation are also explained in this paper.

2 Geology

Nam Ngum 2 dam is located in a narrow site with steep slopes of the valley where geology is rather complex with foldings of sedimentary rocks. The CFRD was found to be the most suitable for the site as foundation conditions are not stringent as for concrete dam.

2.1 Lithology

The geological formations consist of a sequence of medium bedded to massive cliff-forming sandstone, interbedded with thin to thick bedded mudstone, silty sandstone, and siltstone of Jurassic - Cretaceous age and Quaternary age deposits.

The quartz-rich sandstone forms prominent vertical cliffs throughout the dam site area. It is typically light brown to light greenish grey, fine to medium grained, hard to very hard, particularly when cemented with silica. Near the base of the formation, the sandstone grades into a well-cemented conglomeratic sandstone. They commonly exhibit cross-bedding.

The interbedded silty sandstone, sandstone, mudstone, siltstone units are moderately hard to very hard (except the mudstone), closely to moderately jointed, slightly weathered to completely weathered where exposed. The sandstone interbedded with mudstone and siltstone is less resistant to weathering than the rather hard silty sandstone and hard sandstone within the interbedded units and forms gentler slopes in the dam site area. Slaking is a prominence phenomena in the siltstone and mudstone layers.

2.2 Structural geology

Geological structure at the dam site is characterized by three easterly trending anticline folds whose axes are nearly perpendicular to the Nam Ngum River channel. The dam site is situated between the limbs of two local anticlines that strike nearly East - West across the Nam Ngum River. Throughout the dam foundation area, the dip of bedding ranges from horizontal (0°) at the anticline axes to 65° on the limbs of the anticlines. The strike of bedding ranges East - West to N 60° W.

The cliff-forming sandstone is a thick bedded massive bed, with the thickness up to 25 m. The bedding planes are typically clean or iron oxide stained, tight, rather rough and slightly undulating. The interbedded formations are typically medium to thick bed. Prominent slickenside are often developed on the bedding plane surface of the weaker, mudstone and siltstone beds, and indicates shear movement during folding. The bedrock units exposed at the dam site contain three vertical joint sets, N 30° E, North - South and East - West directions.

3 CFRD

3.1 Conceptual design

3.1.1 Rockfill zoning

The embankment of the CFRD has slope inclination of 1V : 1.4H on both upstream and downstream sides and was designed to be different rockfill zones to restrain the water load with minimum deformation and against flow in the events of leakages through concrete face or foundation. The rockfill sections generally require the sound rock, well graded and free draining. The upstream zones were designed to be more impervious than the downstream zones, a better material quality is required for the upstream zones whilst a poorer quality can be adopted in the downstream zones. The rockfill is mainly derived from rock mass fractured by blasting from the quarry in the vicinity area where the geological formations consist of a sequence of medium bedded to massive cliff forming sandstone interbedded with siltstone layers. The dam has a typical zoning as shown in Figure 2.
Zone 2A is a perimeter zone filter that will act as a filter in preventing the movement of silt sized particles through the zone in the event of disruption of the water stops at the perimeter joint. This material is from a processed good quality of sandstone from crushing plant to have well graded with maximum size of 19 mm.

Zone 2B, a dam face bedding layer is designed to place under the upstream face slab to provide support to the face slab. To avoid cracking during deformation, this zone should be non-cohesive in order and is derived from crushing of unweathered sandstone with the maximum size of 76 mm.

Zone 3A, a transition to the bedding Zone 2B and rockfill in Zone 3B is produced from sound or slightly weathered selected sanstone rockfill from quarry, having a maximum size of 400 mm.

Zone 2A, 2B and 3A should be processed to meet the requirements with regard to gradation to satisfy filter criteria.

Zone 3B, the best quality rockfill placed in the upstream section of the dam that will transmit the load from the reservoir down to the founda-
tion. The material will be slightly weathered to fresh sandstone hauling directly from quarry – run process produced to meet the specified sizes and gradation.

Zone 3C is corresponding to the downstream supporting portion of the dam. Rockfills for this zone vary from good to poor rock. It was intended to use the rock from quarry run to have proportion of sandstone to siltstone of 70:30. However, the usage of siltstone is later omitted due to the unsuitable quality of the siltstone.

Zone 3D is the drainage zone placed at the bottom layer over the riverbed at downstream side to enhance the overall draining ability of the dam. This material is carefully selected from quarry – run process to meet the quality requirements for Zone 3B and also contain minimal amount of fines.

Permeability of Zone 3B. 3C and 3D must be sufficiently permeable to avoid the built – up of pore pressure.

Zone 3E is a of large boulder size of 300 – 1,000 mm for downstream slope protection. The rocks are from the hard rock fragments selected from stockpile or quarry.

Besides the above mentioned zones ther are other materials that have to place at the upstream of the concrete face that are Zones 1A, 1AA and 1B. 1AA is a pocket of non – cohesive silt placed at the top of the perimeter joint. 1A material will cover the plinth and lower part of face slab to serve as a source of material that can migrate into and heal cracks in the face slab. While 1B zone is a random material placed to support the weaker Zone 1A material.

In order to produce the rockfill material to have the desired rock gradation sizes from quarry – run process, thrial blasting was performed by adjusting blast hole patterns, type and amount of explosive and delayed blast timing for each rockmass classification.

Design study of dam embankment was performed by means of the 3 Dimensional Finite Element Study. And to satisfy the required density an experimental placement operation on those rockfill materials or so-called test fill embankment was performed to determine the required passes, quantity of sluicing water and placing equipments.

3.1.2 Plinth

The principal objective of the plinth which is part of toe slab is to provide a water tightness connection between the concrete face and the dam foundation. The placement of plinth concrete was therefore done only on the non – erodible sound rock. The width of the plinth was designed based on the foundation conditions and hydraulic gradient relative to the reservoir head. The plinth is divided into internal and external plinth, the external plinth width is fixed to be 10 m at the lowest point and decreased further up to 8 m above the elevation 230 m and to 6 m from elevation 290 m to the dam crest.

The plinth is also served as the grout cap and designed thickness of the external plinth is 0.60 m for its entire length and it is reinforced to resist the forces generated during grouting.

3.1.3 Face slab

The concrete face slab is a watertight and durable component of the dam connected from the plinth to up to the reinforce concrete parapet wall provided at the upstream edge of the dam crest at elevation 377.21 m. The concrete face slab is designed to have the thickness of 0.90 m at the bottom and further decreased linearly to 0.30 m near the crest.

Concrete slab is divided into panels by vertical and horizontal joints. The width of panel is commonly at 15 m at the compressive zone and further reduced to 7.5 m at the tension zone on the abutments. The face slab construction is designed in two stages, horizontal construction joint with watertight hypalon membrane and copper water stop is formed between the two stages at elevation 280 m. To maintain watertightness between each panel, a rearguard copper waterstop and upper barrier of mastic sealant is installed along the full length of the joint.

Watertightness along the perimeter joint between plinth and face slab are by 3 – barrier system comprising a plastico – elastic joint sealant with fabric reinforced rubber, a PVC water stop and a W – shaped waterstop.

On the upstream of embankment, the 400 mm thick of low strength concrete extruded curves form as a hard shell preventing damages of Zone 2B during construction.

Construction of face slab is performed by continuous casting method when concrete is placed on the concrete extruded curves using slip forms that moved up along the slope by elecric winches.
3.2 Dam embankment sequences

In order to meet the requirement for early impounding by providing concrete face to be constructed in 2 stages, the placement was designed to carry out as traditional placement in CFRD with the mode of upstream high and downstream low and the embankment sequences was divided into 5 stages. Negative impacts to the dam body deformation and slab stress deformation was thoroughly studied in numerical analysis, and the satisfied final construction sequences are shown in Figure 3.

![Figure 3 Dam embankment sequences](image)

Stage 1 was started from a downstream lower access road on the right bank to the dam area to fill the dam from the upstream side. In order to allow the plinth concreting for both internal and external plinth as well as filling of Zone 2A, 2B and 3A to be performed without hampering, the working area in this stage was kept distance of 25 m away from the plinth reference plane.

Stage 2, upon completion of plinth concreting, was then followed and raised to reach elevation 315 m so that the concrete face stage 1 could be started. The embankment was carried out in the way that the upstream portion is slightly higher than the downstream portion to provide a gentle slope for hauling material from down stream side.

Stage 3 was filled up in the downstream side when the concrete face was casting up to elevation 285 m in the upstream side using the access from downstream at two different elevations on the right abutment.

Stage 4 was continued at the downstream portion until it reached El. 335 m. The placing area was again kept distance of 25 m away from the extruded curves to avoid obstruction of face slab concreting activity. Meanwhile placing of Zone 1A and 1B was carried out at the upstream of the dam when the 1st stage face slab concreting was finished.

Stage 5, material for filling from El. 335 m to 377.21 m was hauled via the higher elevation access across the spillway to the embankment area. This step, upstream portion was again higher than downstream and some portion adjacent to the abutment was rose up to El. 377.20 m in order that the 2nd stage concrete facing can be prepared earliest. After the whole area is thoroughly filled up to El. 377.21 m and completion of the 2nd stage concrete facing, wave wall shall be constructed and the remaining rockfill will be carried out thereafter until reach the dam crest at El. 381 m.

4 Quarry

4.1 Location

The cliff-forming sandstone layers above the Nam Phom Stream, with the distance of 1.5–2 km from the dam site have been quarried to have the desired sizes for rockfill materials or to be crushed to produce concrete aggregates and filter materials. The sandstone layers have the thicknesses vary from 25 to 55 m approximately and between the four sandstone layers, there are interbedded with siltstone of various thickness of 20 m, 15 m and 10 m.

4.2 Rock requirement

Large quantity of rockfill are needed for CFRD as a huge demand of rockfill is for construction of
embankment and some for concrete aggregates. Estimated quantity of the filling materials for CFRD is 9.4 million m$^3$. This amount of rockfill materials will be derived from the quarry. According to the “Rock Balance” shown in Table 1, hereunder the volume of total sandstone to be quarried is approximately 9.864 million m$^3$ of solid rock or equivalent to 25.15 million tons.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Rock balance</th>
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<tbody>
<tr>
<td>Rock requirement: (Solid rock)</td>
<td>Original design</td>
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<tr>
<td>Description</td>
<td>Unit</td>
</tr>
<tr>
<td>(1) Coarse aggregate for concrete</td>
<td>t</td>
</tr>
<tr>
<td>(2) Coarse aggregate for shotcrete</td>
<td>t</td>
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<tr>
<td>(3) Rockfill:</td>
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<tr>
<td>2A - 2B</td>
<td>m$^3$</td>
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<tr>
<td>Wastage 20%</td>
<td>m$^3$</td>
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<tr>
<td>3A</td>
<td>m$^3$</td>
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<tr>
<td>3B</td>
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<td>3D</td>
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<tr>
<td>3E</td>
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<tr>
<td>Total quantity (3A + 3B + 3C + 3D + 3E)</td>
<td>m$^3$</td>
</tr>
<tr>
<td>Wastage 5%</td>
<td>m$^3$</td>
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<tr>
<td>Total rockfill (compacted 2.1t/m$^3$)</td>
<td>m$^3$</td>
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<tr>
<td></td>
<td>m$^3$</td>
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The assessment of the above required volume has been done in accordance to the following assumptions:

1. The quantities required for concrete aggregate have been increased by 40% for wastage at crusher, plus 30% for over break and batching plant wastage. The quantities required for shotcrete aggregate have been increased by 40% for wastage at crusher plus 50% for batching plant wastage and rebound.

2. For dam embankment the quantity required for filter Zone 2A - 2B have been increased by 20% for wastage. For the rockfill it was considered only 5% wastage.

3. According to reality circumstance, no rock coming from underground excavation or either open excavation has been considered on the evaluation of the “Rock Balance”.

4. To calculate the quantities, a specific gravity of 2.55 t/m$^3$ for solid rock and a compacted dry density of 2.15 t/m$^3$ for rockfill are assumed.

4.3 Sandstone availability

East Quarry – the sandstone available after less 20% caused by operational waste is 3.922 million m$^3$.

West Quarry – the sandstone available after less 20% operational waste is 3.75 million m$^3$.

The total rock available from the two quarries is 7,682,000 m$^3$ as shown in Table 2. This amount is not sufficient for the required quantity according to the Triaxial test result. Far West Quarry was then put into consideration.

Far West Quarry – the extension of the West Quarry for another 60 m to the west will gain more 2.786 million m$^3$ of sandstone.

The total sandstone available from the three quarries is 10,458,000 m$^3$ which is quite marginal sufficiency quantity compared with the total requirement of 9,863,918 m$^3$. However extension or deepening of the Far East Quarry to extract more sandstone is feasible.
5 Technical challenges

5.1 Unforseen geological structure

The information from exploratory bore holes at the proposed quarry revealed that simple structural geology of thick bedded sandstones interbedded with siltstones can be expected in the quarry area. However during removal of the overburden on top of the hill and the highly weathered rock layer in the upper part of the quarry, local landslides had occurred many times. Complex geological structures, folds, faults, potential of mass movement and local slide were recognised. These became restrictions in the design and planning of the quarry exploitation. Back slope design has to take into account of these finding. The back slopes were therefore designed to end at certain places where high angle dipping outward of slopes as well as the fault zone are avoidable. This resulted in insufficient of the sandstone quantity from the proposed quarry. To meet the quantity requirement, the proposed quarry area has to be extended further to the west direction. The investigation and rock balance had to be restudied again and came up with the extension areas so-called Quarry West and Quarry Far West. Design of final slopes were also adapted for each quarry.

At the Quarry East where most of the areas are not much influenced by the NE-SW fold, most of the rock layers lay more or less horizontally, then slope can be cut deeper into the hill (Figure 4). However the area toward east direction where the bed rocks tend to dip out of the excavation face, to avoid the high angle dipping bedrocks, the quarry is limited to end at a certain place. In the Quarry West and Far West where the areas are influenced by rather high dip angle rock layer formed by limbs of anticline and also 2 reversed faults, back slopes were limited at the place where good stability and in the meantime more quantity of sandstone can be achieved (Figure 5).
5.2 Design change due to the poor quality siltstone

From the definite design and particular technical specification, 30% of siltstone would be allowed to mix with sandstone for Zone 3C. However, in the beginning the quality of siltstone was doubtful as it is susceptible to slake or deteriorate after exposure to the atmosphere.

After the rock properties from a large mold triaxial test were adopted for the 3D FEM analysis it turned out that the 30% of siltstone for Zone 3C rockfill material is not possible as it will cause too much deformation and settlement and also will not permit enough draining of the embankment. The analysis also revealed that rockfill material for Zone 3C shall compose of 100% sandstone. The 30% of siltstone that expected to be used from the beginning was then eliminated. In order to get more sandstone to replace 30% of siltstone for Zone 3C, around 942,000 m³ of solid sandstone will have to be quarried.

To quarry such amount of sandstone and to feed the rockfill material to be consistent with the requirement of embankment plan, it was necessary to extend the Quarry West to the west side and it is so-called Far West Quarry. It is imperative that quantity of siltstone and overburden to be removed will definitely increase and this would directly affect to the work schedule and cost.

5.3 Planning of quarry exploitation

The materials used in this type of dam are rock fragments without a very defined particle size distribution, with maximum size limitation and eventual limitation of a small size content (rockfill) and granular material from crushing rock with a defined particle size distribution (filters and drains). Dam rockfill is therefore mainly sourced from rock masses fractured by blasting. While filter is produced from crushing plant.

Initially the quarry was located at a place named “Quarry East” where the rock quantity was expected to meet the project’s demand. Unfortunately, quality of the uppermost layer of rock which is called sandstone—top layer does not meet the requirement and also the unforeseen geological conditions e.g. geological structure and siltstone quality, the quarry has to be extended to “Quarry West” and “Quarry Farwest” as aforementioned.

The planning for good quarry exploitation is another technical challenge of the project as it has to take into account of the requirement of the embankment plan by feeding the rock without hampering. And also the quarry exploitation in this project is not a straightforward task because of the interbedded of siltstone layers that has to remove out to provide sufficient sandstone face to meet
the required production at each embankment stages. To get the required particle size distribution from the variation of the rock mass quality, rock-mass classification and a tailor-made rock blasting design to determine optimum burden and spacing of drill holes and powder factors is also another technique that has to be employed.

Quarry has to be managed in the manner that direct hauling of rockfill material is achieved. However, some stockpiles have been provided for smooth operation of the dam filling. The total quantity required for construction of the dam is around 8.5 million m$^3$. Given the duration of quarrying for the dam embankment being 25 months, an average quarrying rate of between 320,000 to 350,000 m$^3$/month is required. During the peak period of the second stage of dam embankment, a rate of quarrying of up to 450,000 m$^3$ per month have to be reached.

With the estimated total volume of 9.86 million m$^3$ of solid sandstone to be extracted from the quarry, the corresponding target production/month of quarry rock operation period as planned, of maximum 450,000 m$^3$/month would require 6 units of the Hydraulic Crawler Drill HCR - 125 together with 3 units of Pneumatic Crawler Drill PCR - 200, for the required production. The trucking requirement to allow transportation of the embankment material was estimated to be in combination of twenty units of the off-road 35 t trucks - CAT 769D, working in conjunction with five units of the wheel based front end loaders capacity of 5 m$^3$ - CAT980. An allowance has been included for truck maintenance and repairs. By using 20 trucks for 20 hours per day, haul distance of 2.5 km, and total cycle time of 17.5 min, so as a maximum of 450,000 m$^3$/month of material could be moved. This estimation is only for transportation of the embankment material. Unlike the quarry with a homogeneous rock type, there are other machines and equipment that have to be invested or hired from subcontractor for removal of siltstone and working at the embankment which depends on the required production of each stages.

6 Economical challenge

The omission of using 30% of siltstone for Zone 3C has impacted to quantity of rock by increasing from 9.6 million to somewhat 13 million m$^3$. This excludes a huge quantity of overburden and landslide that occurred in the beginning of the quarry development. The occurrences of landslides and increase in quantity of rock directly impacted to the project schedule.

To keep the completion target, planning of quarry have to be in such a way that feeding of sandstone rockfill shall be done without interruption. The extension of the first quarry to another two quarries and to provide at least 3 production faces for each quarry in operation at the same time, a huge amount of siltstone have to be excavated and hauled to the disposal area. The EPC Contractor has to invest almost double amount of machines and equipment for quarry development and dam embanking and this resulted in the increase of diesel oil and blasting material consumption. As the heavy equipment and machine play important roles in the project cost, the worst of it is that this occurrence happened in the time when the oil price had increased and hit the highest prices in the mankind history in July 2008 (Figures 6 and 7), the EPC Contractor has suffered with the cost overrun. To move the project forward, the EPC Contractor had to seek for claims related to unforeseen geological condition and force majeure related to the hike of construction material prices.

![Figure 6 Oil price history](image_url)
7 Conclusions

Unlike other projects that belong to the government, for the project which is invested by the private company, delay in delivery of the electricity to the Power Off-taker means disaster of the project. Good collaboration of all parties on achieving the same target is a must in the project management. Notwithstanding, the EPC Contractor had suffered from the cost-over due to the unexpected geology and the adverse impact of higher oil price, the project has passed such crisis period because of the good collaboration of all main parties, encouraging, adopting some changes and quick decision making for settle the claims based on the fairness. Although there is some consequent delay in the progress, it is expected to be caught up and will not affect to the Initial Operating Date (IOD) (Figure 8).

Acknowledgement

We would like to express our gratitude to all those who gave us the possibility to complete this paper, the NN2 Power Company Limited the owner of the project for giving us permission to present this paper, the Client (SEAN), the IE (Poyry), and the EPC Contractor [Ch. Karnchang Company (Lao)] for the support information.

Reference