DESIGN, CONSTRUCTION AND PERFORMANCE OF NAM NGUM 2 CFRD

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1. INTRODUCTION

The Nam Ngum River is one of the major tributaries of the Mekong River which forms the border between Laos and Thailand in this area. The Nam Ngum River originates on the Tran Ninh Plateau, north of Xeong Khuang, and after flowing past both dam sites, joins the Nam Lik River and flows into the Mekong River about 100km downstream of Vientiane. The Nam Ngum 2 Hydroelectric Power Project (NN2 HPP) is located approximately 90km north of Vientiane in central Laos and approximately 35km upstream of existing Nam Ngum 1 reservoir.

Nam Ngum 2 Power Company Limited (NN2PC), the client, agreed to make a contract with Ch. Karnchang (Lao) Company Limited as the EPC contractor to design, engineer, manufacture, supply, install, procure, construct, test and commission a 615MW (3 Nos. of 205MW turbines) hydroelectric power plant.

The NN2 Concrete Face Rockfill Dam (CFRD) has the lowest foundation level at 199.0masl and the crest elevation at 381.0masl, which corresponds to the dam height of 182.0m. The NN2 CFRD will be the second highest of CFRD in SouthEast Asia.

The face slab is the primary water barrier of the NN2 CFRD, which consists of concrete face slab poured on underlying extruded curb laid above support zones of the rockfill body of the dam. Thus, the design and construction of face slabs has to concentrate on watertightness and durability. Attention has been paid to identification and control of crack development in the face slabs.

Construction of NN2 CFRD has mainly divided into 5 stages for embankment in order to corporate with face slab construction, which has divided into two stages. The total volume of rockfill is approximately 10 million m^3, whereas the total area of concrete face slab is approximately 88,000 m^2.

The extensive instrumentations have been installed within rockfill embankment and concrete face slab to assess the performance of NN2 CFRD.

2. DESIGN OF NN2 CFRD

The design of the CFRD has evolved empirically over 40 years. As successful and unsuccessful experiences of previous CFRD projects, understood and thoroughly discussed with the experts, so that the design of NN2 CFRD can be assured.

The configuration of NN2 CFRD is illustrated in Fig. 1. The NN2 CFRD is consisting of compacted rockfill found on a rock foundation, plinth, face slab and wave wall. Outer slopes for upstream and downstream are defined as 1V:1.4H to suit with available rockfill material. The rockfill materials are generally classified into three designated zones as follows:

(1) Zone 1 (1A and 1B) is concrete face slab protection zone in the upstream of face slab,

(2) Zone 2 (2A and 2B) is concrete face slab supporting zone in the downstream of face slab, and

(3) Zone 3 (3A, 3B, 3C, 3D and 3E) is the rockfill zone, which is the major part of the rockfill material.

The plinth is usually made of reinforced concrete, which connects the foundation with face slab. The face slab is the primary water barrier of the CFRD, which is poured on underlying supporting zone of the rockfill body of the dam.

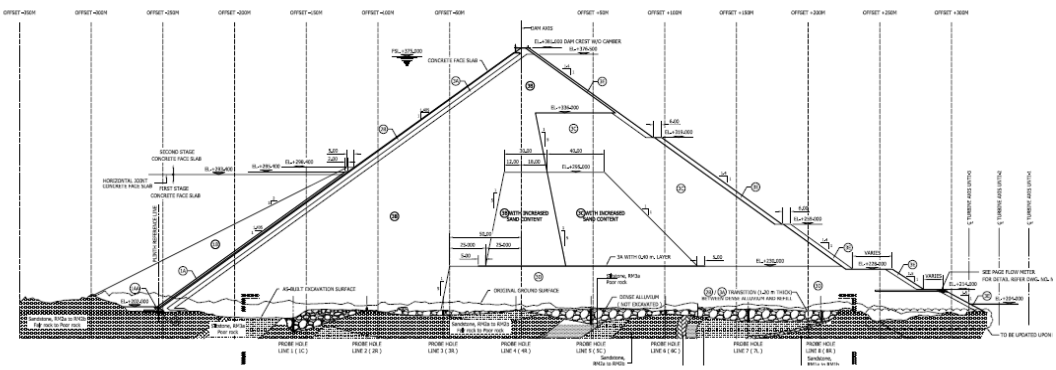


Fig. 1 NN2 CFRD Dam zoning

The joints of face slabs are of importance for CFRD. The perimeter joint is the most importance, since it connects between plinth and face slab. The vertical and horizontal joints of the face slabs have to provide with sufficient deformation in order not to cause disruption of the face slab.

2.1 DAM ZONING

The designation of the rockfill zones of NN2 CFRD, as shown in Fig. 1, are adopted as suggested by ICOLD (2004). The NN2 CFRD dam zoning is further validated by FEM. 2D and 3D FEM have been carried out to assess the rockfill material properties in order to make use of available rockfill material at potential quarry (IWHR, 2008). The non-linear properties employed in the 2D and 3D FEM is determined based on large triaxial test (IWHR, 2007). The analyses results revealed that the material properties for Zone 3C is of importance to deformation of upper part of the face slab. Therefore, material property for this zone has to be improved.

From 3D FEM analysis results, it is recommended to construct the rockfill layer from upstream to downstream horizontally. The purpose is to eliminate the possible impacts of differential deformation of rockfill on the concrete face slab. For retaining the first year's flood, the priority section is necessary. However, the height difference from the top of the priority section to the downstream rockfill should be limited. Normally, this height difference should not more than 40m. The stage of dam embankment is finalized based on experiences and 3D FEM as shown in Fig. 2.

2.2 DESIGN OF FACE SLAB

Design of NN2 CFRD face slabs begins with the selection of face slab thickness, width and location of vertical and horizontal joints. Selection of face

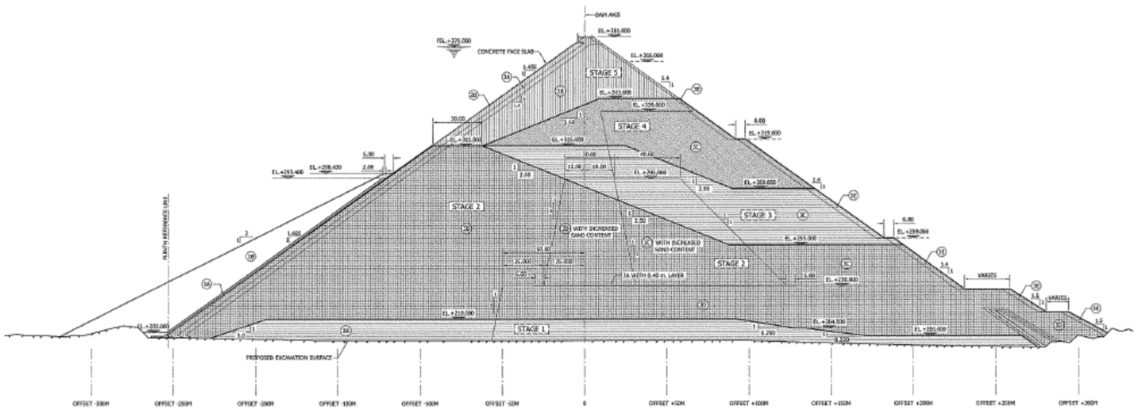


Fig. 2 NN2 CFRD Embankment construction stages

slab thickness is based on past experiences. Face slab widths are controlled with respect to dam abutments as well as valley shape. Current guidelines used for determining the thickness of face slabs for NN2 CFRD is reservoir head dependent.

The minimum design thickness of the face slab is usually on the order of 0.3m with thickness varying with reservoir head, H, in accordance with the following:

Face Slab Thickness, T (m) = 0.3 + 0.003H

From the practices of recent high CFRDs in the world, it is noticed that the face slabs in the riverbed section may be subjected to high compressive stress if the deformation of rockfill dam is not strictly controlled. To avoid the rupture of concrete face slabs in the riverbed section, it is proposed to increase thickness of the face slabs in the riverbed section. Considering the fact that the ruptures of face slabs are happened in upper part of face slab, the increase of the slab thickness could only be applied for the second stage face slabs. The thickness of the first stage face slab is remain unchanged. The suggested starting thickness at the top of face slab is 40cm. Thus, thickness of the face slab for second stage face slab at riverbed section can be determined from

Face Slab Thickness, T (m) = 0.4 + 0.00178H

Panel widths for the face slabs are typically classified into two categories. Narrower panel widths (7.5m wide) are used where vertical joints are desired as tension joints, which are located on the abutments. Wider panel widths (15.0m wide) are used where vertical joints are treated as compression joints, which are mostly located in the riverbed area.

For improving the performance of concrete face slab, double layers of reinforcement is recommended with 0.4% of the gross area of the concrete face slab for each way. The reinforcement is increased up to 0.5% in the area close to the dam plinth.

2.3 PREVENTIVE MEASURES

Measures adopted to prevent rupture of face slab during design stage for NN2 CFRD include following:

(1) Increase the thickness of the 10 central panels in second staged face slab.

(2) The reinforcement is separated into two layers, top and bottom, in both directions as opposed to the usual location in the center of the slab. The

stirrups against reinforcement buckling are also provided at the high compression area.

(3) The additional reinforcements are employed for anti-spalling and bending stress resistant at the face slab rims.

(4) Increase the face slab protection zone, Zones 1A and 1B to EL +298.4 masl, which is about 50% of the dam height.

(5) The copper waterstops and mortar pad is outside the theoretical thickness of face slab at compression joints.

(6) The height of the central loop of the copper waterstop is reduced to keep the theoretical slab thickness at compression joints.

(7) Increase the compressible filler thickness from 10mm to 20mm at compression joints.

(8) The conventional V-notch at the top of the face slab is eliminated at compression joints.

3. CONSTRUCTION OF NN2 CFRD

3.1 EMBANKMENT CONSTRUCTION

Prior to commencement of embankment work, the river bed cleaning and foundation improvement is required to achieve the competent foundation. The main dam embankment has mainly divided into 5 stages to corporate with face slab construction sequences, as shown in Fig. 2.

Stage 1: Constructed the rockfill embankment of 10m height from downstream and left the area of 30m at upstream in order to construct the plinth at river bed section.

Stage 2: Constructed the main dam embankment to accommodate the construction of first stage face slab upto elevation 315 masl, which corresponds to 115m in height.

Stage 3: This stage had to construct parallel with the construction of the first stage first slab. Partial construction of the embankment at downstream portion has been carried out by controlling the different height of embankment between upstream portion and downstream portion of not more than 40m. This is to control the differential settlement and stress in rockfill for upstream and downstream.

Stage 4: After completion of the first stage face slab concrete, the upstream portion has been embanked upto the wave wall foundation. Whenever complete this stage, the second stage face slab started commencement. In parallel the face slab protection zone, Zone 1A and 1B, have also been started in this stage.

Stage 5: After completion of the second stage face slab and the wave wall, the last portion of embankment above the wave wall foundation will be constructed.

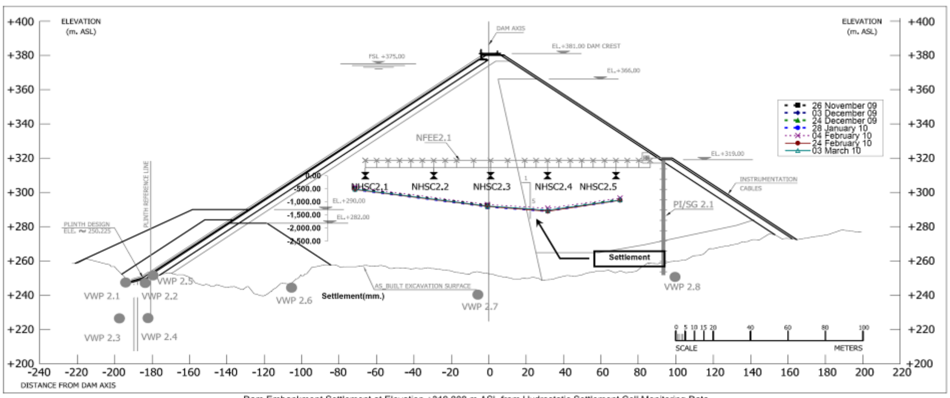
The total volume of rockfill is approximately 10 million m^3, which have been completed within 20 months. The peak production of rockfill is 700,000 m^3 per month, which have been transported by 25 units of 35 tons-off high way trucks and 50 units of 15 tons trucks. The compacted rockfill has been controlled to achieve the dry unit weight of more than 21.5 kN/m^3. The 15 tons vibrating rollers with 8 passes and with 150-200 liters/m^3 of rockfill for water sluicing have been conducted to achieve the requirement. The 0.80m lift thickness of 3B and 3C material has been employed depending on the maximum size of rockfill material.

3.2 FACE SLAB CONSTRUCTION

The total area of concrete face slab is approximately 88,000 m^2. The concrete mix design of C25/38 has been developed for concrete face slab, which is suitable for 2.0m long slip form. The concrete has been delivered by transit mixer trucks and distributed into 4 chutes, which the pouring controlled speed is 2.0m per hour. The construction of face slab is divided into two stages, first and second stage concrete face slab.

4. PERFORMANCE OF NN2 CFRD

The extensive instrumentations were installed within rockfill embankment and concrete face slab. Instrumented data are reading and analyzed continuously to assess the performance of NN2 CFRD during construction, during reservoir impounding and in-service of the dam. The instrumentations installed for NN2 CFRD within rockfill embankment and concrete face slab are summarized in Table 1.



Dam Embankment Settlement at Elevation +319.000 m.ASL from Hydrostatic Settlement Cell Monitoring Data

Fig. 3 Settlement in rockfill on left abutment

Table 1 Summary of instrumentations installed at NN2 CFRD

Location	Instrumentation	Quantity
Rockfill	Vibrating Wire Piezometer	35
	Total Earth Pressure Cell	3
	Probe inclinometer & Magnetic Settlement Gauge	3 sets
	Distributed Fiber Optic Temperature (DFOT)	900 m.
	Weather Station	1 set
	Hydrostatic Settlement Cell	22
	Fixed Embankment Extensometer	111
	V-notch Measuring Weir	1
	Strong Motion Accelerometer	1
	Gauge House	5
	Open Standpipe Piezometer	7
Face slab	Probe Inclinometer on Faceslab	1
	1 Dimensional Joint Meter	4
	2 Dimensional Joint Meter	10
	3 Dimensional Joint Meter	13
	Electro Level (Tilt Meter)	23
	3D Concrete Strain Gauge	27
	Rebar Strain Gauge	27
	Non Stress Strain Meter	7

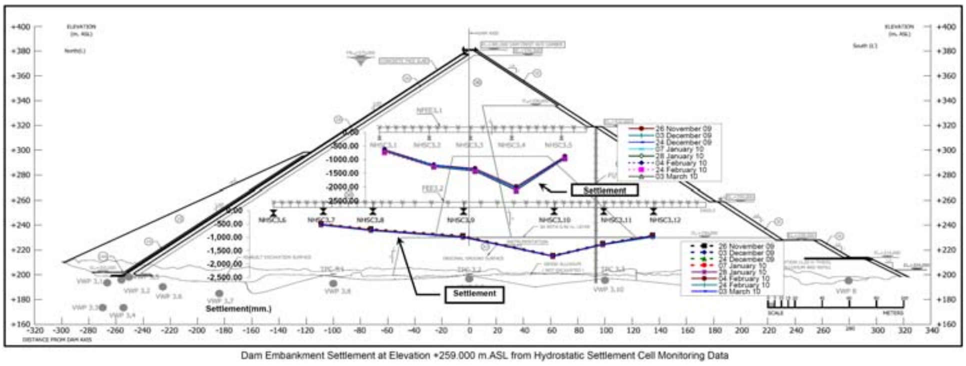


Fig. 4 Settlement in rockfill on riverbed section

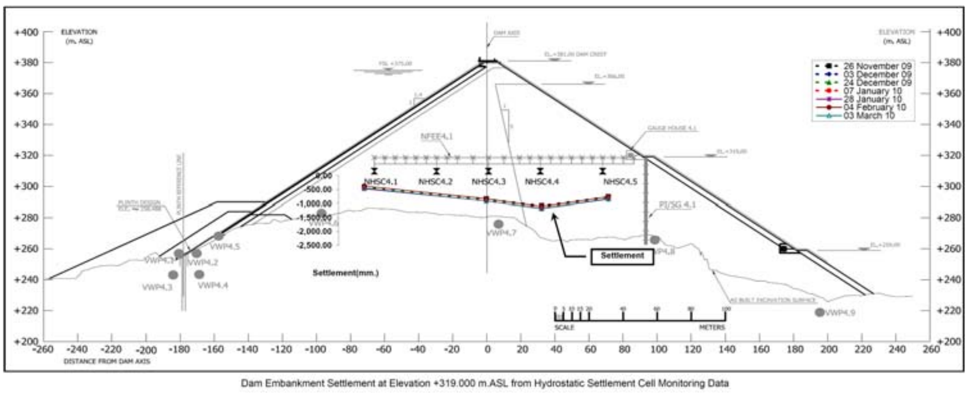


Fig. 5 Settlement in rockfill on right abutment

At the present stage, during construction, some instrumented data are reading and analyzed continuously to assess the performance of NN2 CFRD. An example of the performance derived from the monitoring results of hydrostatic settlement cells, which are installed in the cross-section at left abutment, center and right abutment, are illustrated as shown in Fig. 3 to 5 respectively. The maximum settlement observed in the rockfill is 2.13m, approximately 1.15% of the dam height, which appeared at central part of the dam towards downstream. This performance is considered as normal, which is similar to previous high CFRDs. According to the observed performance of NN2 CFRD during construction, additional measure is adopted to prevent rupture of the concrete face slab. The thickness of compressible filler material at compression joint is adopted to increase to 30mm for five panels of second staged face slab in the riverbed section.

5. CONCLUDING REMARKS

The design of NN2 CFRD is taken into consideration of recent experiences of high CFRDs with comparative considerations of the numerical analysis results. Some CFRD phenomenon can be explained by the numerical analysis results.

The dam zoning, face slab and joints are initially based on experiences from recent high CFRDs. 2D and 3D FEM are employed to assess the NN2 CFRD behavior with some modifications of initial design. According to analysis results, preventive measures are applied to prevent rupture of the concrete face slab. The actual behavior of NN2 CFRD during construction is observed by extensive instrumentations. During construction, modification of the design is required according to the observed performance.

The project is expected to be completed by March 2011 and the impounding is scheduled on March 18, 2010.

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