Deformation Characteristics after Impounding of Nam Ngum 2 Concrete Face Rock Filled Dam (CFRD) in Laos PDR

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Abstract

Nam Ngum 2 is one of the world class concrete face rock fill dam in Lao PDR. It is 182 meter high with the dam volume close to 10 million cu.m. Monitoring of dam behavior was done by 390 sensors and data acquisition system. The deformation of dam body and face slab ware measured by embankment extensometers, hydrostatic settlement cells, electro-level, joint meters, concrete and rebar strain meters and survey stations. The maximum settlement of dam crest during 2 years of reservoir operation was 24.6 cm. or 0.15 % of dam height. The settlement creep rate after the last impounding was α=0.10%/cycle time. During first impounding, the maximum deflection of face slab was 486 mm. as comparing to the anticipated deflection from the design analysis is of 457 mm. Face slab joint movements indicated the local maximum settlement of 80 mm some on the left abutment. This joint settlement was still in the allowance of copper water stop and joint sealing.

Keywords: NN2 Dam, CFRD, Deformation, Dam Monitoring

1. Introduction

Nam Ngum 2 Hydroelectric Power Project (NN2PP) is constructed on upstream of existing Nam Ngum 1 reservoir, Lao PDR. The dam is located 90 km. north of capital city of Vientiane or approximately 160 km via route No 13N. The construction was started in 2006 and finished in 2010 with dam volume of 9.7 million cu.m. The project has the capacity to generate the power of 615 MW or about 2220 GWh a year, mostly for Electricity Generating Authority of Thailand (EGAT). The dam is concrete faced rock filled dam (CFRD) of 182 m high and crest length of 485 m.

The site is located in a narrow valley with rather steep slopes and complex geology as shown in **Fig. 1**. Reservoir impounding started middle of March 2010 and by November 2010 the reservoir had reached 97 % of the full supply level (FSL).

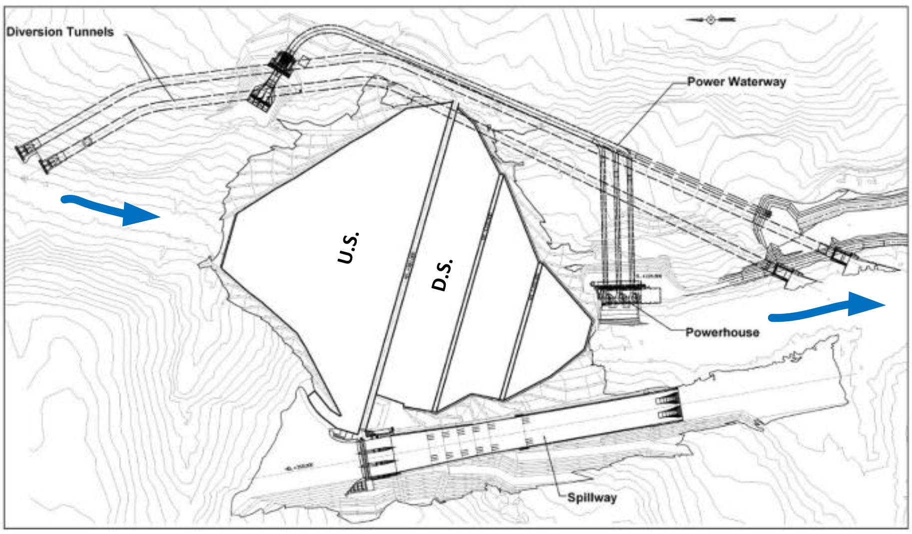

Fig. 1 NN2 dam project layout

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NN2 dam is consisting of compacted rockfill found on a rock foundation, plinth, face slab and wave wall as shown in **Figure 2** Dam slopes for upstream and downstream are defined as 1V:1.4H to suit with available rockfill material. The dam zoning was classified into three designated zones as follows: Zone 1 (1A and 1B) is concrete face slab protection zone in the upstream of face slab, Zone 2 (2A and 2B) is concrete face slab supporting zone in the downstream of face slab, and Zone 3 (3A, 3B, 3C and 3D) is the rockfill zone, which is the major part of the rockfill material.

The rock filled materials of dam body consists mainly sandstone and siltstone of Jurasic-Cretaceous periods. Compacted densities and strength properties of dam materials as shown on Table 1.

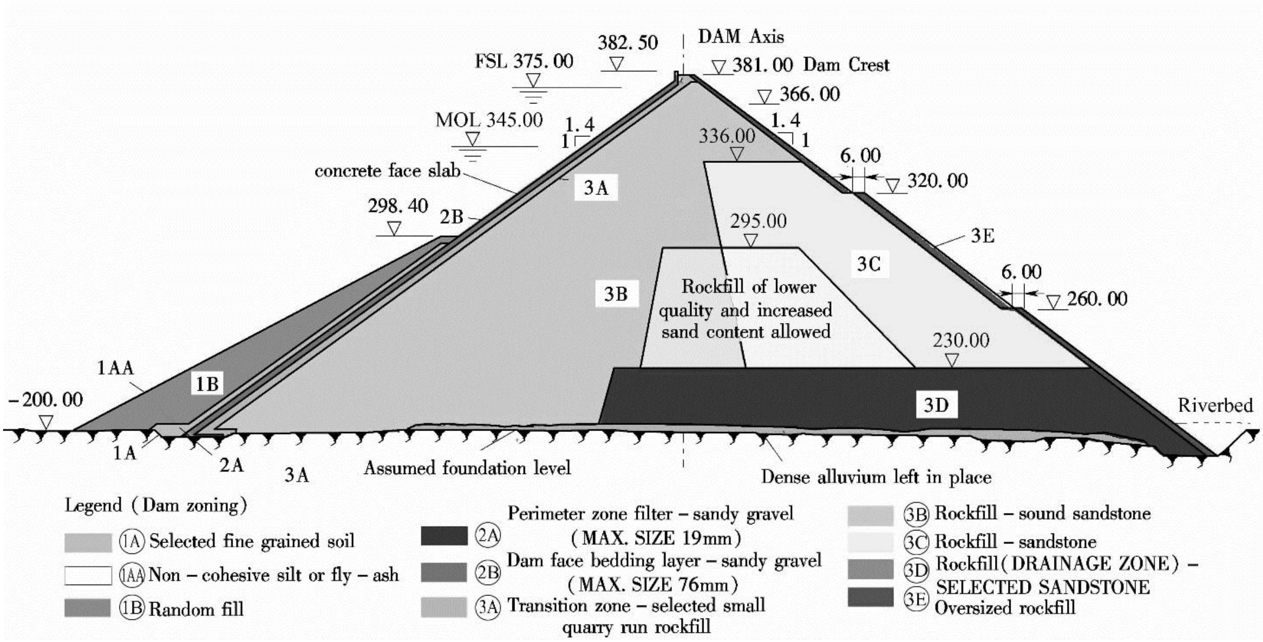


Fig. 2 Zoning of NN2 dam cross section.

Table 1 Strength and densities of rock filled materials

Materials	Density (kN/m^3)	Non-Linear Strength Parameter		Linear Strength Parameter	
		ϕ_0 (°)	$\Delta\phi_0$ (°)	c (Mpa)	ϕ (°)
2B	21.50	44.10	4.20	-	-
3A	21.50	45.90	5.70	-	-
3B	21.50	46.50	6.20	-	-
3C	21.50	45.10	5.40	-	-
3D	21.50	46.50	6.20	-	-
Alluvium	20.00	-	-	0.10	35.00
RM2a to RM1b	26.00	-	-	0.27	56.06
RM2b	26.00	-	-	0.13	47.68
RM3a	26.00	-	-	0.06	32.45
RM4a or Decomposed Sand Stone	26.00	-	-	0.06	26.00

NN2 Dam was installed more than 390 sensors, and data acquisition system to monitoring the dam behavior during the construction and operation. The deformation of dam body and face slab ware measured by 7 groups of dam instrument such as embankment extensometers, hydrostatic settlement cells, electro-level, joint meters, concrete and rebar strain meters and survey stations. After 2 years of dam operation more than 85 % of the sensors were still working.

Figure 3 and 4 shows the general layout of the NN2 dam and instrument sections. Automatic data acquisition system is applied for the instrument reading into the database system at the control room in the power house.

2. Backgrounds on Deformation of CFRD

The CFRD had gained the popularity since 1960 when the machine compacted rockfill was replaced the dumped rockfill in dam construction (Cooke, 1984). Sherard, J.L. and J.B.,Cooke (1987) mentioned that increased of CFRD due to : (1) The modern CFRD is a very good dam type from all technical standpoints; and (2) the CFRD is often the lowest-cost dam. The CFRD usually has significant less cost than the earth core rockfill dam (ECRD). This is mainly because of the more flexibility of construction method and less cost of filter and transition zones. The cost of the CFRD foundation treatment is generally significantly less, both because the work can be done independently of the embankment construction, and because the treated rock surface area is smaller.

Lau C. C., (2004) stated that CFRD has a broad base and imposes lower stresses on the ground compare to concrete dams for similar in height. Their rockfill is plastic and can accommodate deformations without cracking, such as large settlement during construction. CFRD structures are considered safer compare with concrete dam, especially in seismic area.

Yang Z., Zhou J., and Wang F. (2011) summarized CFRD dam heights had been increased from 50-100 m. in the early stage and with dumped rockfill materials. Progression from 1965 onward, the construction technique was changed to compacted rockfill dam with the maximum height of 233 m. for Shuibuya Dam in China. The future CFRD dam is planned for more than 250 m. by 2020.

The deformation of CFRD body and face slab results from the deformation of rockfill of dam body. The dam deformation should be strictly controlled on design cross section of dam body construction and impoundment procedure (CFRD International Society, 2007).

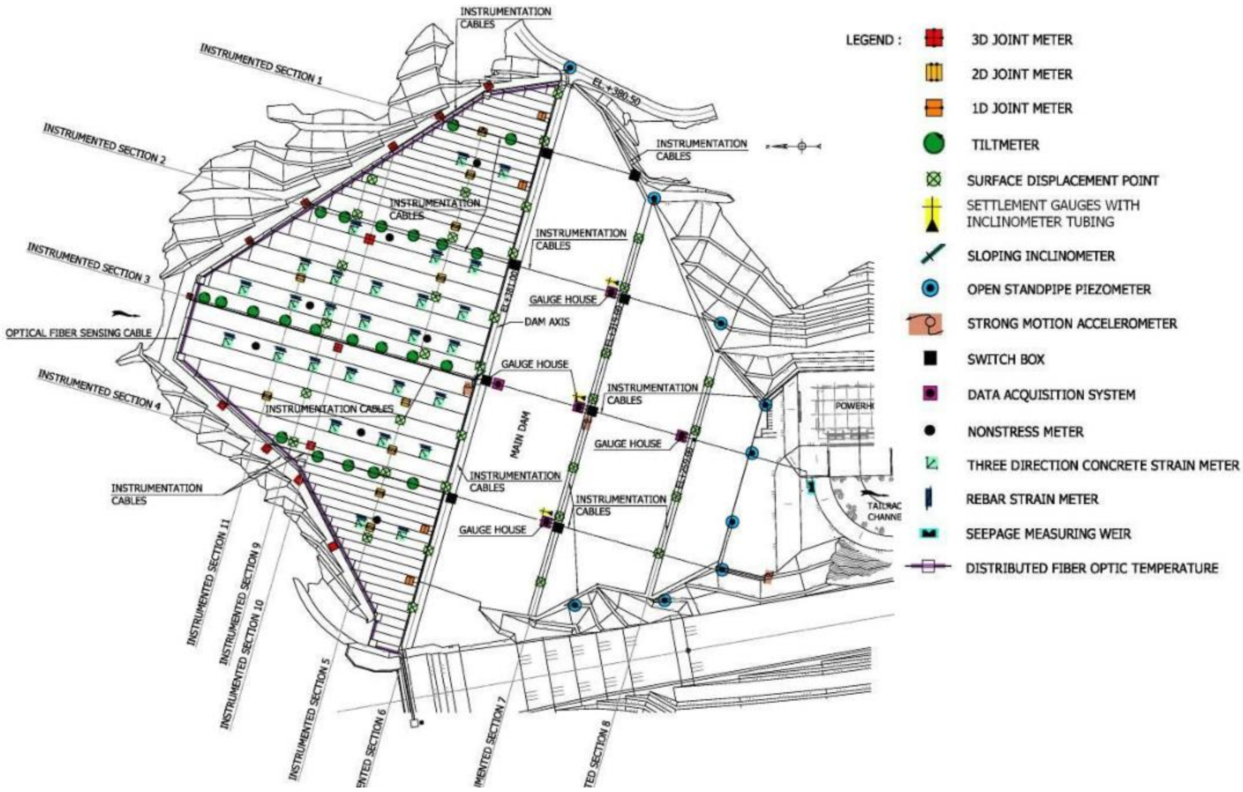


Fig. 3 Layout of NN2 dam and dam instrument sections.

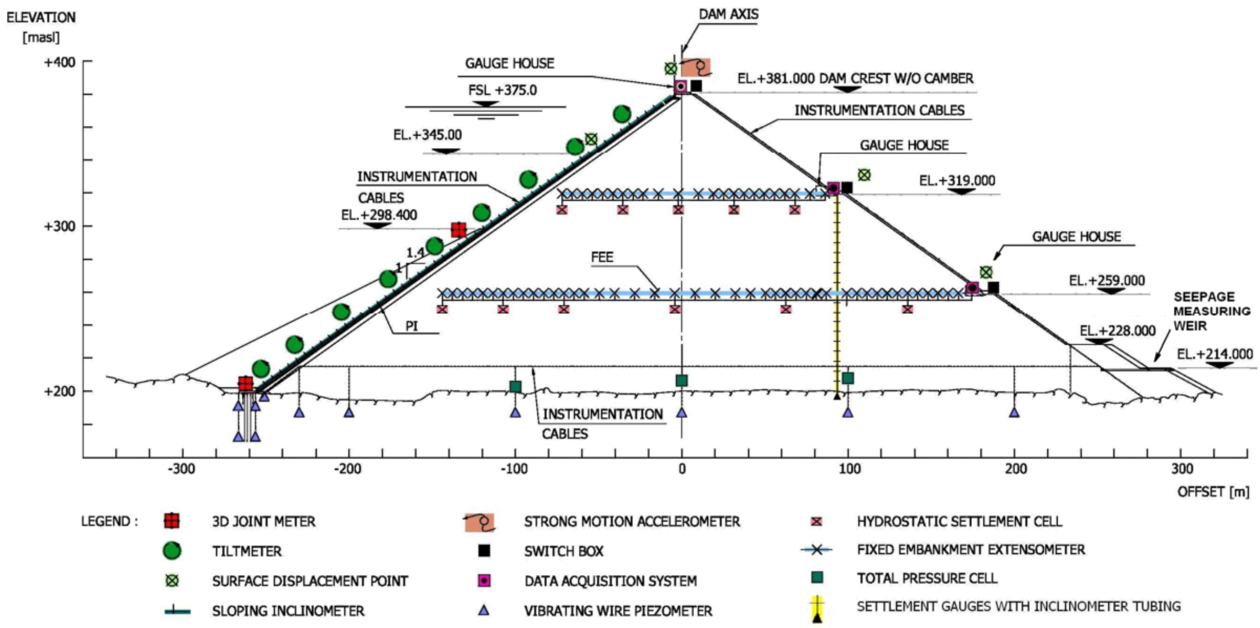


Fig. 4 Arrangement of Instruments on Depth Section (Section C)

The deformation of high CFRD compacted rockfill dam is very important and related to the following dam performances [Xu Zeping, 2011].

- The general long-term deformation of CFRD.
- The stresses and deformation levels of concrete face slab.
- The displacement of joint system on the face slab.

The dam deformation during construction is directly related with rock type, gradation, compaction density, dam height and valley shape factor. For the high CFRD, due to the high stress level of rockfill, particle breakage and re-arrangement will produce a significant post construction rockfill deformation. Xu Zeping (2011) also suggested that the maximum settlement during construction should be between 0.8 to 1.2% of dam height and compacted porosity should be 18 – 20%.

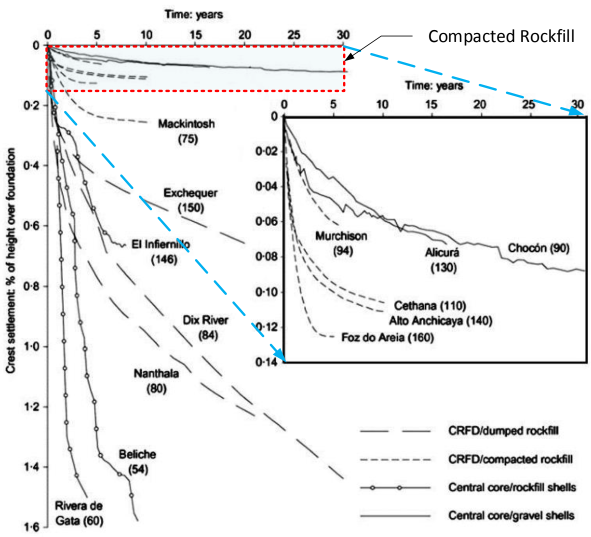


Fig. 5 Long-term settlement records in crest for different types of rockfill dams. Modified from Oldecop and Alonso (2007).

Leakage on CFRD mostly occur when the face slab and its joints are damaged caused by the excessive deformation of the dam body. Statistical data shows that the large long-term crest settlement is related to the likelihood of leakage as illustrated on Fig. 6 (GERD, 2010).

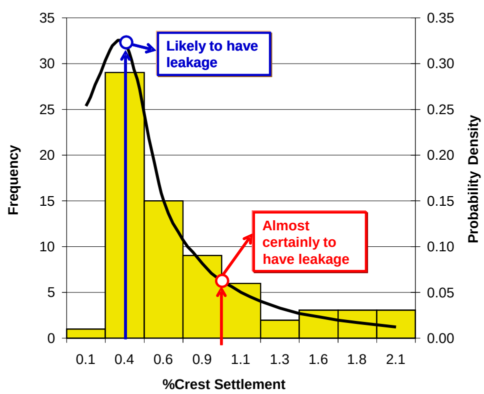


Fig. 6 Leakage on CFRD related to crest settlement. (GERD,2010)

3. Deformation of NN2 Dam

3.1 *Settlements of Dam Crest and Downstream Slope*

Settlements of dam crest and dam surface were measured by surface displacement points on dam crest and dam slope. Fig. 7and 8 indicated the settlement after the reservoir impounding until December 2012. The larger settlement occurred on the upper part of the dam and on the central zone of the valley. The maximum settlement was 246 mm. on SDP 6.5. This value is equivalent to 0.15% of the dam height. However from statistical records this value is still well below the critical deformation (0.4 to 1.0%) that can possibly causes the crack in the slab. The directions of movement are quite normal as they tend to move toward the depth section of the valley. There is no significant abrupt change of surface movement at any area which leading to the sliding or cracking phenomena.

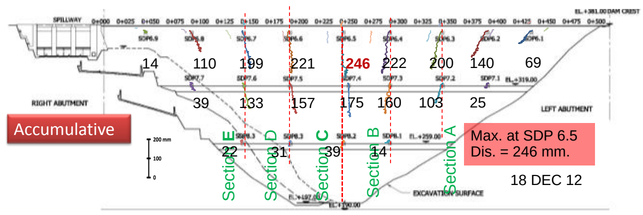


Fig. 7 Settlement of dam crest and downstream after impounding.

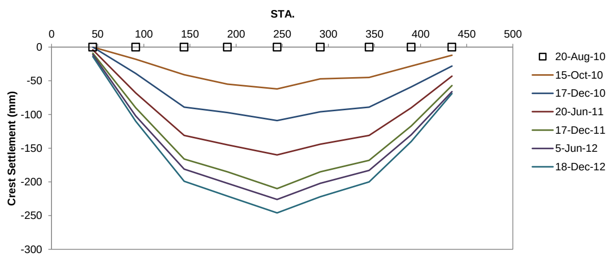


Fig. 8 Settlement distribution along dam crest.

The rates of settlement of all points are related to the reservoir impounding as shown on Fig. 9. Settlement rate started to pick up when the water level of higher than 50% of the storage level and reached to the maximum as the level up to 97% of maximum storage on October 2011. On the first filling, the average of maximum settlement rate was 42 mm/month in October 2010. Then it decreased to 4 mm/month in March 2011. On the second filling, the pattern was repeated as the settlement increasing to 15 mm/month in October 2011 and then slowing down to 2 mm/month in March 2012. On the third filling, the rate of the settlement was decreased to 4.8 and 2 mm/month in October and December 2012 respectively.

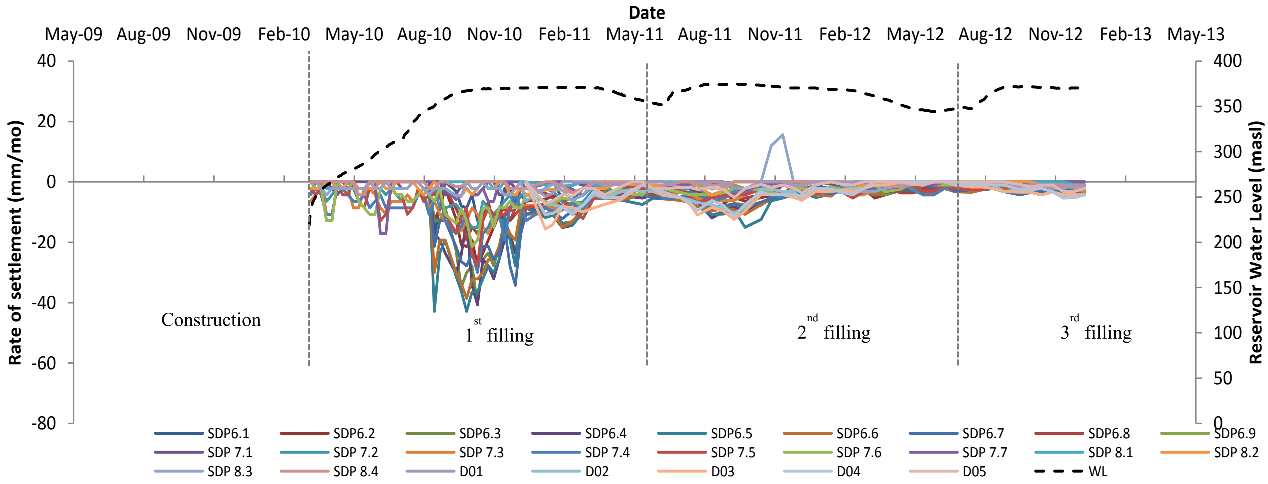


Fig. 9 Rate of dam settlement affected by the reservoir impounding

The maximum crest settlement on the deepest section observed at SDP6.5 was about 0.09% of dam height at end of June 2011. Comparatively, it was within the normal range of 0.06 and 0.13% for the compacted medium to high strength rockfill dams (Hunter, 2003) as shown in Table 2. After the end of first filling, the settlement appeared to continue with dam load time-dependent creep only at the slower rate.

Table 2 Relative crest settlement during the first filling.

Rockfill type	No. of cases	Elapsed Time(y)	Embankment height (m)	% of crest settlement
Dumped rockfill	6	Up to 1 > 1	43 to 100	0.15 to 0.48 0.23 to 0.34
Compacted gravels	2	1.13 to 1.2	83 and 125	0.017 to 0.024
Compacted very high strength rockfill	10	< 0.1	43 to 140	0.010 to 0.014
		0.1 to 0.5	75 to 110 > 110	0.020 to 0.027 0.053 to 0.20
		> 0.5	90 and 166	0.030 to 0.13
Compacted medium to high strength rockfill	**7**	< 0.5	25	0.008
		> 1	38 to 53 **60 to 85**	0.058 to 0.096 **0.058 to 0.129**

Source: Hunter (2003).

Thus creep settlement is also the important characteristic of CFRD caused by yielding of rock contact area, rock particle movement or deterioration of rock material itself. The creep rate, α , which is the % strain per log time needed to evaluated for long-term prediction.

When $$\%\ Vertical\ Strain = \alpha\,(\log T_2 - \log T_1) \qquad (1)$$

The observed data shows the creep rate of post construction till initial impounding in average of (α_1) = 0.17%/cycle. This value is corresponding with well compacted rockfill with medium to high strength material proposed by Hunter el al (2003). Based on last impounding the average α = 0.10%/cycle, then estimated creep settlements on this dam for the next 10 years will be around 0.12% to 0.16%. This amount of settlement is far less than the precaution value that causes the leakage through face slab shown on Figure 6.

3.2 Displacement of Dam Crest and Downstream Slope

Lateral movements on dam surface indicate the possibility of sliding or instability of the dam slope. Generally the interpretation of lateral movement should be considered together with settlement and dam body movement. The displacement along dam axis from abutments to riverbed also is a key indicator for evaluation of tension and compression zones on the face slab. The movements on Campos Novos dam in Brazil (Xavier et al, 2008) is a critical case of dam movement causing cracking on face slab.

Fig.10 shows the plan view of horizontal displacement on downstream slope after 2 years of impounding. The slope has moved to downstream ranging from the maximum of 150 mm. (SDP6.5) on the central of the river channel to about 40-80 mm on the abutments (SDPs 6.1 and 6.8). The displacements toward the valley have been measured only 60 mm as comparing to 100 mm in case of Campos Novos dam.

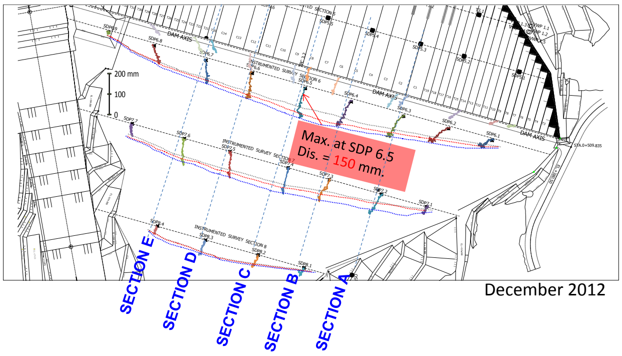


Fig. 10 Lateral movement of dam slope after 2 years of impounding.

The effect of reservoir water pressure on the displacement of downstream surface can be seen from Fig.11. The maximum rate of displacement along the slope is 4 mm/month at the end of 2012. Until present, no sign of possible sliding or excessive movement was detected as instability of the dam slope.

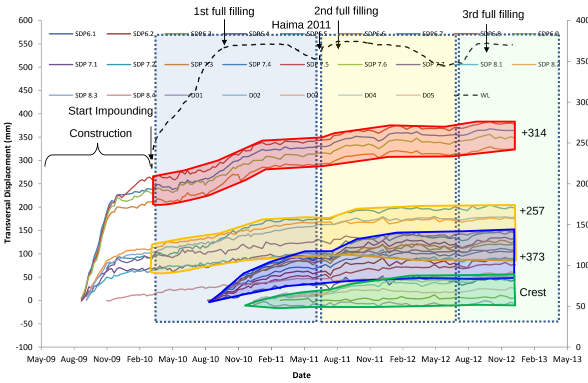


Fig. 11 Rate of displacement affected by reservoir impoundings.

3.3 Settlement in the Dam Body

Settlement within the dam body was monitored by Hydrostatic Settlement Cell (HSC) and Magnetic Settlement Ring installed during the construction. HSC in the maximum section indicated the maximum settlement of 1.89 m. or 1.04% of dam height to the end of construction. The maximum settlement is concentrated on the top of Zone 3B and 3C of special zone that allowance for increasing of sand content.

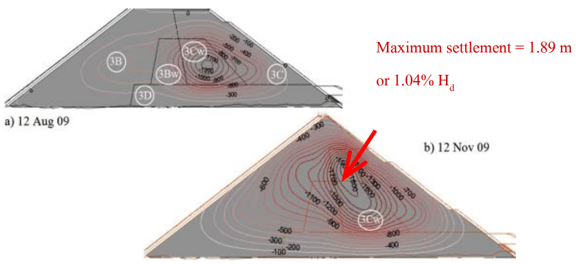


Fig. 12 Settlement in Dam Body During Construction

The settlement continued at the slow rate with additional of 0.25 m. or 0.138% on waiting period from November 2009 to March 2010 before first impounding started. During first year of impounding form March 2010 to June 2011, the maximum additional settlement of 0.54 m. or 0.29% of dam height is recorded. The distribution of settlement can be illustrated by the settlement contour as shown on Fig. 13 on June 2011. Notice that the maximum settlement zone was shifted to the top of the dam.

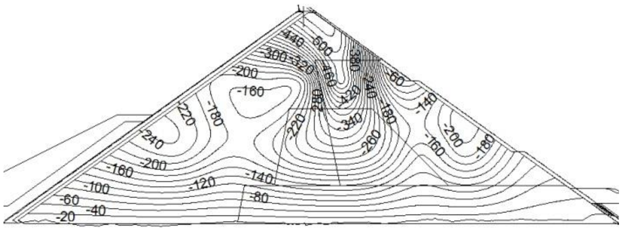


Fig. 13 Additional Settlement in Dam Body after Construction until June 2011

The maximum total settlement in dam body at beginning of the third impounding was 2.88 m. or 1.58%of dam height.

3.4 Deflection of Face Slab

Electro-levels along the axis of slabs were used for monitoring changes in angle of rotation and deflection of face slab. The results need to be interpreted with the related 3D joint meters. The face slab deflections were interpreted at 4 sections as show in Fig 14.

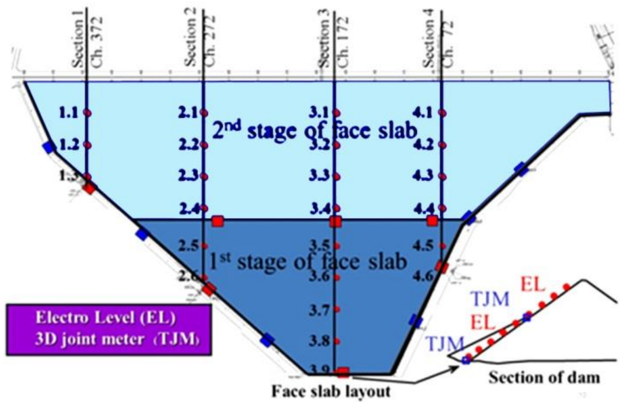


Fig. 14 Measuring Instruments on Dam Face Slab.

Reservoir water pressure caused the deflection of the face slab. Electro-levels on the face slab detected this change of curvatures just after impounding. Fig. 15 shows deflection of the face slab at various times on deep section. At the end of first impounding, the maximum deflection was 485 mm or 1/620 of the length (304m) at elevation +310 m.asl or mid length of the slab. Comparing to the anticipated deflection from the design analysis is of 457 mm. So the actual slab deflected slightly more than the design analysis.

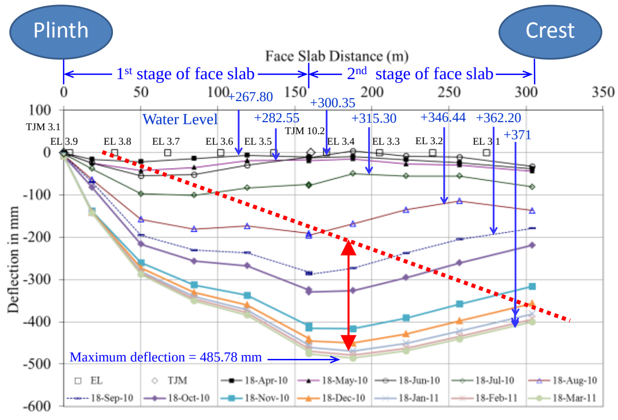


Fig. 15 Deflection of the face slab at deepest section on dam.

The movement at lower end was started at zero on the first impounding at 18th March 2010. The deflected shape of the concrete face slab on first impounding is highly dependent on the water level. As the water level reach to +371 m asl on March 2011, the maximum deflection was 486 mm. Considering the movements at the toe of 9 mm and at the crest of 400 mm, the effective deflection at mid height is only 230 mm or 1/1,320 of the slab length. The contours of the slab deformation can be plotted from 4 observed sections and the boundary condition on the plinth.

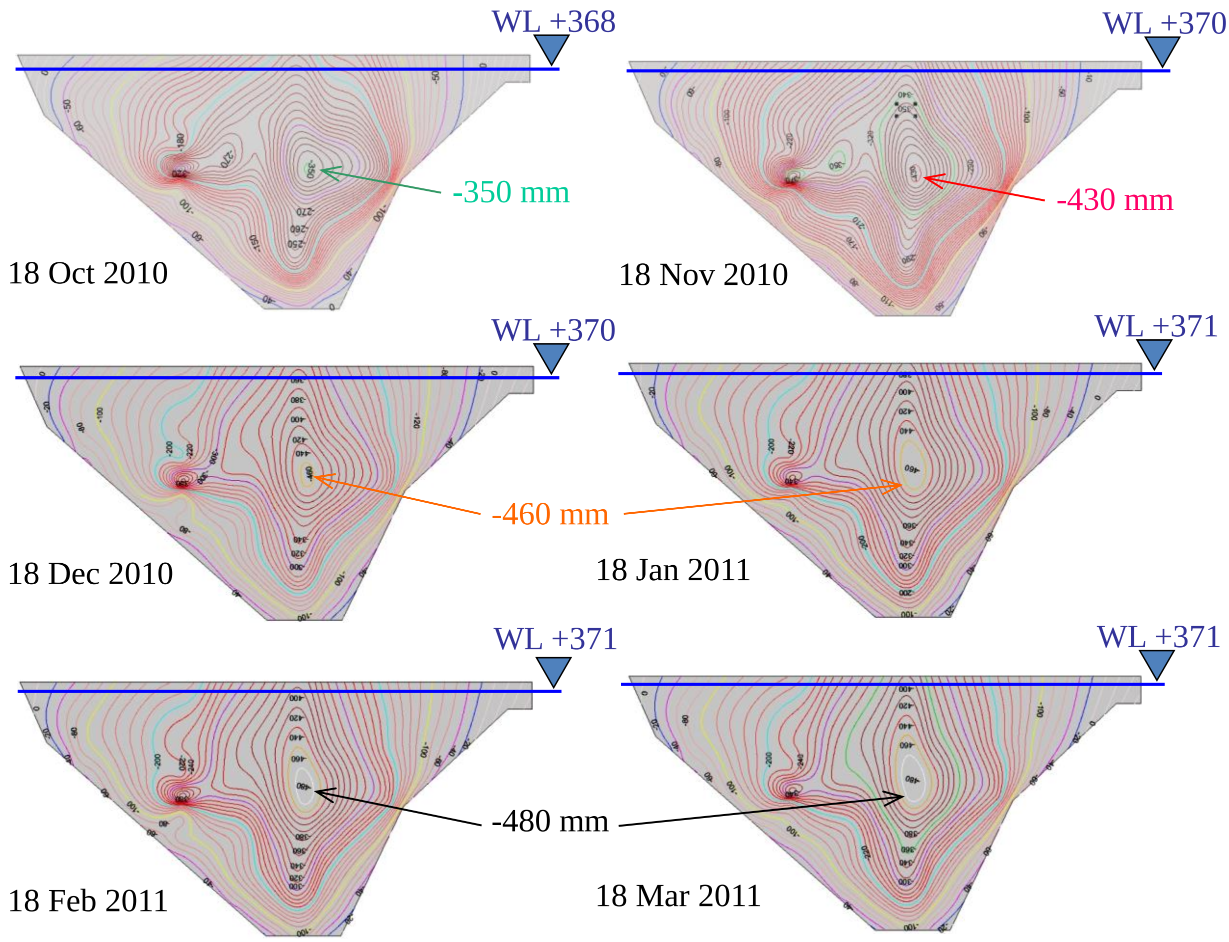
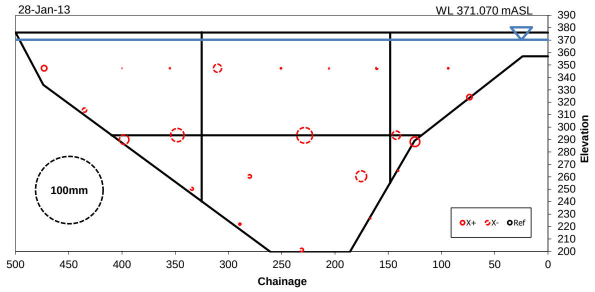


Fig. 16 Contours of face slab deflection on first impounding.

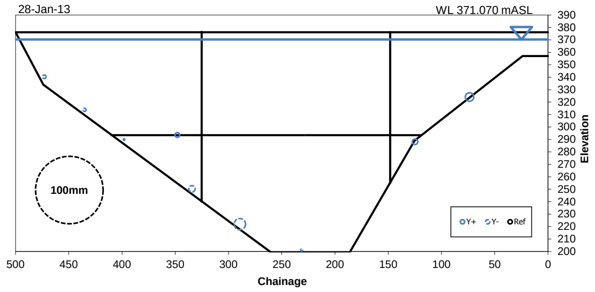
3.5 Face Slab Joint Movements

Excessive movements of joints on impervious upstream face slab can indicate the serious leakage into the dam body. Although the copper water stop and rubber joint sealing were provided in the design. But the relative movement of more than 20 cm. may start the leakage through the slab. The series of 3-D, 2-D and 1-D Joint Meters with total of 63 sensors was installed between the face slab joints. The relative movements among the face slab panels and plinth wall can be monitored.

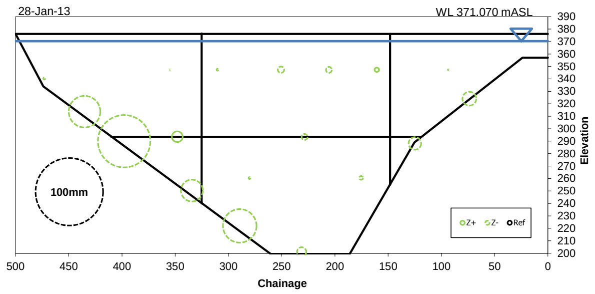
At the end of construction, the perimetric joint movements were small in the range of 0.2 and10 mm. On the early state of impounding, displacement of the joints were increased ±2 mm after the construction. However the reservoir water pressure started to induce the significant joint settlement at some location on the left abutment. The maximum of settlement was about 80 mm near the horizontal joint at elevation 290 m asl. as shown on Fig.17. The rate of the movement was at peak of 38 mm/month on August 2010 and slow down to a constant on November 2010 as shown on Fig. 18. The behavior of joint on this location was carefully monitored and it was normal and stable without any sign of leakage.



a) Openning



b) Shearing



c) Settlement

Fig. 17 Face Slab Joint Movements

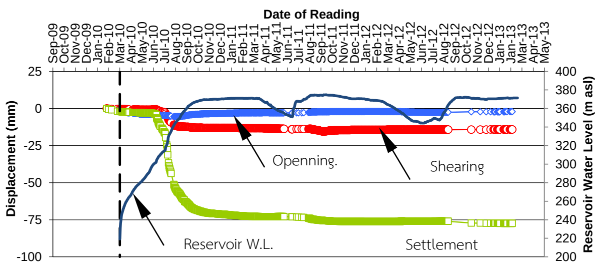


Fig. 18 Joint Movement vs. Time at TJM 2.2

4. Conclusion

4.1 Nam Ngum 2 Hydroelectric Power Project (NN2PP) is constructed on upstream of existing Nam Ngum 1 reservoir, Lao PDR. The dam is concrete faced rock filled dam (CFRD) of 182 m high and crest length of 485 m. The deformation of dam body and face slab ware measured by embankment extensometers, hydrostatic settlement cells, electro-level, joint meters, concrete and rebar strain meters and survey stations.

4.2 The deformation of CFRD during construction and initial stage of impounding is related to the leakage through dam. The integrity and water tightness of the face slab can also evaluate by the monitoring of face slab deflection and joint movements.

4.3 The maximum settlement of dam crest during 2 years of reservoir operation was 24.6 cm. or 0.15 % of dam height. This dam crest settlement is well below the critical deformation of 0.4 to 1.0% of dam height that can cause some crack on the face slab.

4.4 The creep settlement indicated by creep rate from the last impounding was α=0.10%/cycle time.

4.5 The deformation of downstream slope was 4 mm/month at the 3rd impounding and showed no sign of possible sliding or excessive movement of the dam slope.

4.6 During first impounding, the water level reach to +371 m asl, the maximum deflection was 486 mm. as comparing to the anticipated deflection from the design analysis is of 457 mm. The contour of slab deflection indicated the maximum deflection occurring at mid height of the deepest section.

4.7 Face slab joint movements indicated some local large settlement at perimeter joint on the left abutment. The maximum settlement of 80 mm. was recorded at the beginning of the 3rd impounding. This rate was slowed down after the first impounding and the settlement was still in the allowance of copper water stop and joint sealing.

Acknowledgement

Thank for the owner "Nam Ngum2 Power Company Vientiane, Lao PDR", the EPC contractor " C. Karnchang Lao PDR and Geotechnical Engineering Research and Develop-ment Center, Kasetsart University for kindly supporting of technical and management of this project.

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