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Monitoring of Leakage through Face Slab of Nam Ngum 2 CFRD

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ABSTRACT:
Nam Ngum 2 dam is 182 m concrete face rockfill dam completed in 2010 and operated since 2011. Several dam instruments were installed to indicate seepage. One of them is Distributed Fibre Optic for Temperature (DFOT) which is new technology for leakage detection in dam engineering. Two loops of the DFOT under the perimetric joint were used for measuring temperature of the surrounding area. If water leaks through the joint, then the lower temperature of reservoir water could be identified. One loop has been heated up to detect the leakage even the temperatures in the reservoir and in rockfill are not different. When DFOT was coupled with other types of instrument, the possible leakage shall be confirmed. After the first filling in 2010, the temperature measured by DFOT changed following temperature of reservoir water. The differential temperature between heated and unheated loops was relative constant. Seepage measured at downstream toe was constant of 200 l/sec. The jointmeters and strainmeters did not display any opening and crack in the concrete face slab. These instruments confirmed the leakage through the joints and cracks has not been detected.

Keywords: CFRD, Dam instrument, DFOT

1. INTRODUCTIONS

Nam Ngum 2 dam (after here may be called as NN2) is a storage dam for hydropower project which is located 140 km northeast from Vientiane in Lao PDR. The developer of the project is a group of Thai and Laos companies named South East Asian Energy and also government of Lao. The dam was designed as concrete faced rockfill dam (CFRD) by Electrowatt. Between 2007 and 2010, the dam was constructed by Ch. Karnchang (Lao) under supervision of Pöyry. Now the dam is operated by Nam Ngum 2 Power Company.

The height of the dam is 182 m with crest length of 485 m. The dam site is located in a narrow valley with rather steep slopes as shown in Fig. 1. Reservoir impounding started in middle of March 2010 and it had reached 97% of the full supply level (FSL) by November 2010. Full commercial operation of the plant was started at the end of December 2010. The dam consists of compacted rockfill found on rock foundation, plinth, face slab and wave wall as shown in Fig. 2. Dam 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: Zone 1 (1A and 1B) is concrete face slab protection zone on upstream side of face slab, Zone 2 (2A and 2B) is concrete face slab supporting zone on downstream side of face slab, and Zone 3 (3A, 3B, 3C and 3D) is the rockfill zone. To prevent seepage through the joints, GB® - waterstop system consisting of rubber sealing material and EPDM-GB® cover were applied.

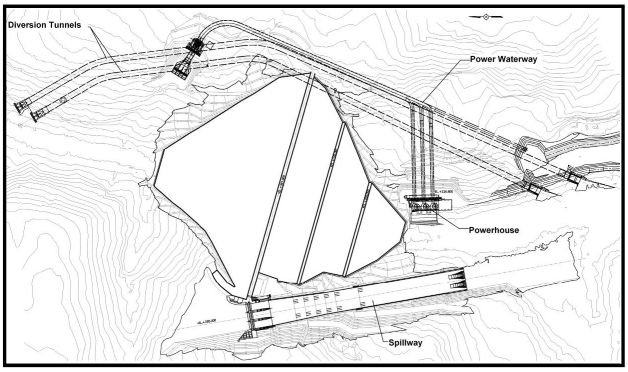

Figure 1. General Project Layout

Not only the leakage directly affects the total energy product but it also harms the dam to breach. Fell et al (2005) described the failure path of CFRDs which can be initiated by water flow through the impervious element and it then creates concentrated leak. The possible flow is caused by the different ways such as crack on face slab, opening of the joints or seepage through plinth foundation. The damage of the leakage can be developed continuously to the downstream rockfill, when the grain size distribution of the series of materials is not a filter for another. If fine particles cannot resist the leakage force, a pipe will be formed and large leakage is consequently developed. The large leakage induces high pressure on downstream rockfill slope. The settlement due to instability of the slope or extreme crest settlement causes overtopping. And finally the dam will be breached. The monitoring leakage through the dam and foundation therefore is very significant. Several geotechnical and structural instruments were installed to indicate source of leakage and amount of discharge at downstream toe of the dam. One relevant instrument for leakage detection of NN2 is DFOT which stands for Distributed Fiber Optic for Temperature. The configuration of DFOT will be presented in the further section.

2. INSTRUMENTATION FOR LEAKAGE DETECTION

Several types of dam instrument were selected and installed to detect the possible seepage path from the face slab to the downstream toe of the dam as shown in Fig. 3. Along perimetric joint and other joints, two cables of DFOT were fixed with the plinth to monitor the temperature, and the large leakage can hopefully be detected.

2.1. Geotechnical and Structural Instruments

Along the perimetric, vertical and horizontal joints where the water can seep through, 27 jointmeters were installed to measure the displacement of these joints. The joints in compression zone are allowed to close for 40 mm. The W-shape copper waterstop let to displace more than 200 mm and it can also be elongated more than 100%.

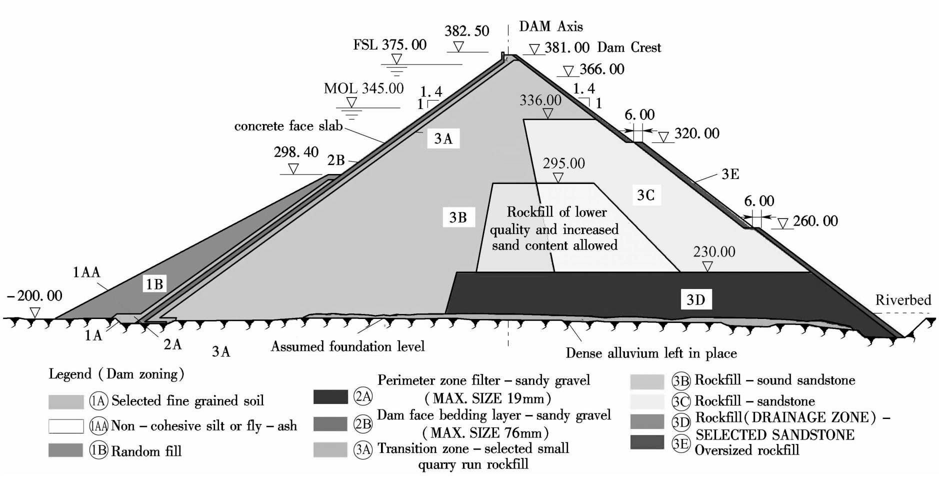

Figure 2. Dam zoning of NN2

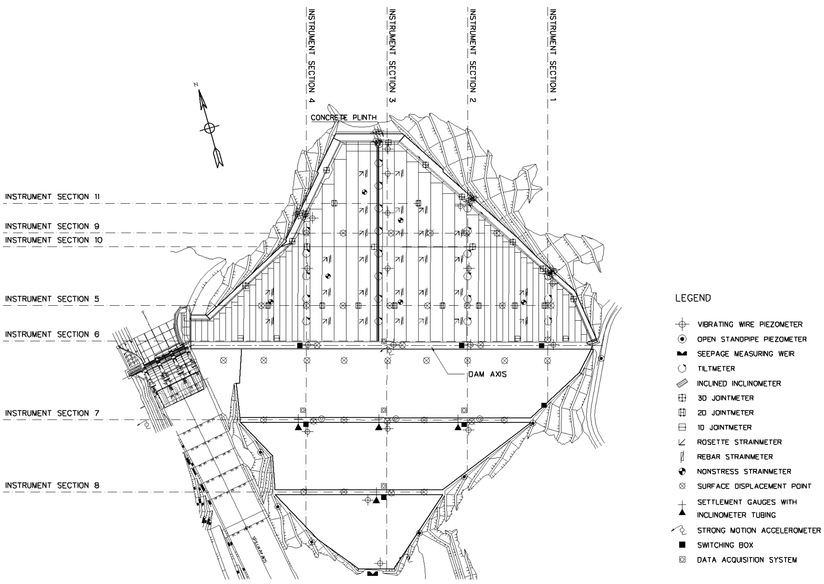

Figure 3. Location of instruments for leakage detection

Twenty seven sets of rosette strainmeters with a rebar stressmeter were embedded within concrete face slabs so the stress on the plane of the face slab and the flexural moment can be estimated. The compressive strength of the face slab is allowable of 25MPa and the tensile strength of the rebar is 400MPa. Fig. 3 shows there is also a seepage weir at downstream toe. The seepage water from the upstream is blocked by the concrete wall at the downstream toe, and then it flows through two HDPE pipes and the weir.

2.2. Configuration of DFOT

When an optical impulse is sent to the fiber opitic cable by a powerful laser, the signal will be backscattered with low intensity at every fiber position. Not only Rayleigh light, the main part of the backscattered light, but also Raman and Brilloiun lights, the additional peaks of low intensities will be observed. The frequency shift and in a certain amount the intensity of the Brillouin light is dependent on both temperature and strain at the scattering point. The widely used Raman–systems use the fact that the intensity of the so called Anti-Stokes part in the Raman light depends on the temperature at the scattering point (Fig. 4). Hereby no strain in the fiber is allowed. The distance from the measured point to the laser can be determined by the runtime or by the frequency of the light pulse. The cycle time for one distributed temperature measurement ranges from seconds to minutes. (Aufleger et al, 2007)

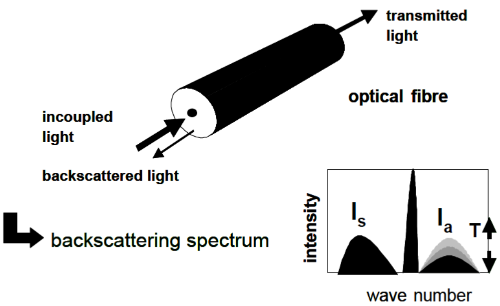

Figure 4. Measuring Principle of DFOT

For NN2, there are 2 loops of DFOT cable were installed along the plinth from P1 on right abutment to P7 on left abutment as shown in Fig. 5. The DFOT cables were fixed on the plinth with 10 cm spacing. The temperature surround the sensor has been measured every 12 minutes and each reading is taken for 6 minutes. The first reading of each loop starts at about midnight. This reading configuration gives resolution of measuring is 0.005 ^{o}C of 2 m length. Because the distance between DFOT cables is too closed, the gradient (passive) method cannot be applied but heating up a cable is needed instead. Therefore the stainless steel wire of one cable (Loop2) has been heated up while another cable (Loop1) still measures temperature without any heating. The electrical heating has been processed for 1 hour every 2 hours interval.

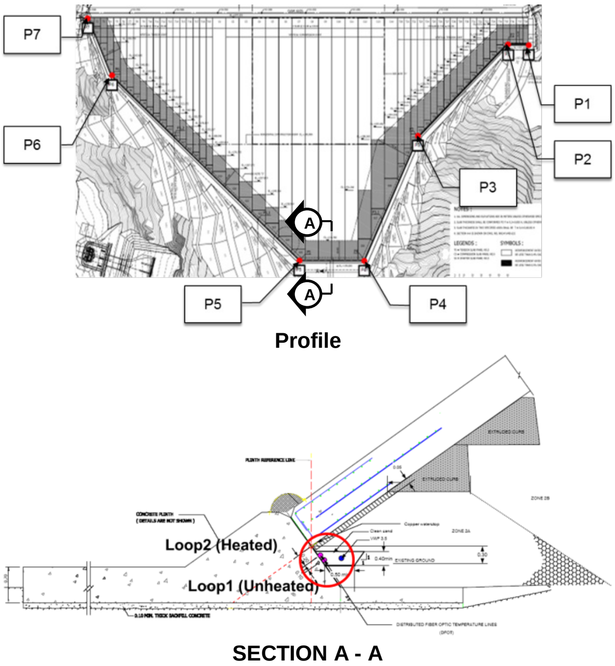

Figure 5. Configuration of DFOT of NN2 dam

3. RESULTS OF MONITORING

3.1. Jointmeters

When the reservoir water level reached to +371.39 masl as FSL, the perimetric joint on left abutment closed about 13.2 mm but on right abutment it opened for 11.0 mm. While the analysis in design stage by IWHR (2008) expected the joint closing of about 10 mm. The vertical joints in compression zone closed for 14.7 mm. This closing is smaller than the compressible filler thickness of 20 mm for all compression joints. However, the largest movement of 72.9 mm occurred on settlement direction at the left abutment as shown in Fig. 6. Shearing of the perimetric joint shows the face slab moving to the valley.

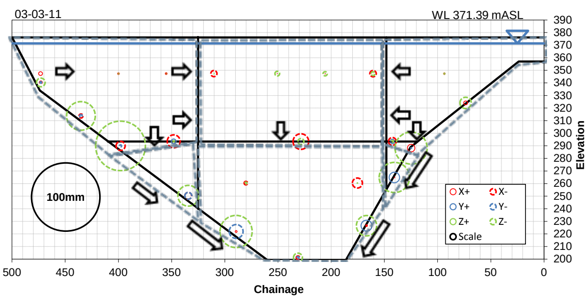

Figure 6. Joint movement at +371.39 masl water level

3.2. Strainmeters

The stress within face slab is one indicator for crack in concrete slab. The principle stresses have been computed by 2D strain transformation and Hook's law and their direction and size are presented by crosses and bubbles as shown in Fig. 7. The major principle stress is compressive aligning along the slope. The values of the stresses decreased from the bottom and the top of the slab. These shows the stresses within face slab were remarkably induced by the self-weight of concrete slab. The maximum stress of 14.4 MPa has taken place at the deepest section. Rebar is also under compressive stress with the maximum of 154.4 MPa at the toe as shown in Fig. 8. And the stress in rebar decrease from the plinth to the crest. There is no tensile stress taken place in the face slab.

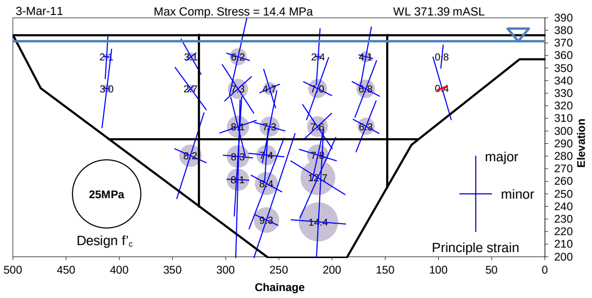

Figure 7. Stress within face slab at +371.39 masl water level

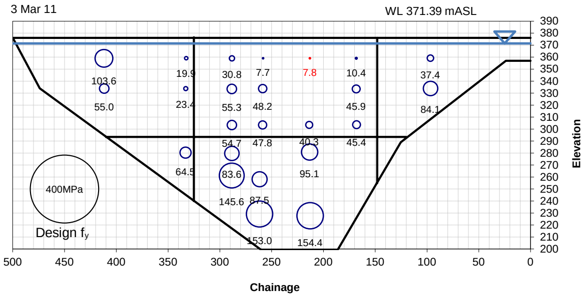

Figure 8. Stress in rebar at +371.39 masl water level

3.3. Piezometers

Anomaly seepage through grouting curtain could be detected by piezometers located upstream and downstream of the grouting curtain. Head loss efficiency is an appropriated indicator for NN2 dam because of the complicated rock foundation. For the deepest section of NN2, the head efficiency has been about 70%. For other sections on abutments, the effects of side flow from the mountain area causes piezometric head behind the curtain higher than expected.

4. READING FROM DFOT AND SEEPAGE WEIR

4.1. DFOT

The temperature measured from Loop1, Loop2 and the difference between 2 loops have been depicted as contours as shown in Figs. 9, 10 and 11 respectively. These contours show how the temperature changed with time from the right abutment (P1) on the top and the left abutment (P7) on the bottom. From the Figs. 9 and 10, it can be seen that the temperature measured from heated and unheated loops have the same distribution. On both abutments over +340 masl have higher temperature than the lower elevation. At deepest section (between P4 and P5) have also relatively high temperature. The difference temperature from heated (Loop2) and unheated (Loop1) loops has changed within 1^{o}C as shown in Fig. 11. Due to the temperature of reservoir water is generally lower than of inside the dam, if there is some leakage through the perimetric joint, the temperature at that point should drop and the gradient of the temperature both from heated and unheated loops should be observed. From the presented contours, there is no gradient of temperature with time. Or other word, there is no the large leakage taken place.

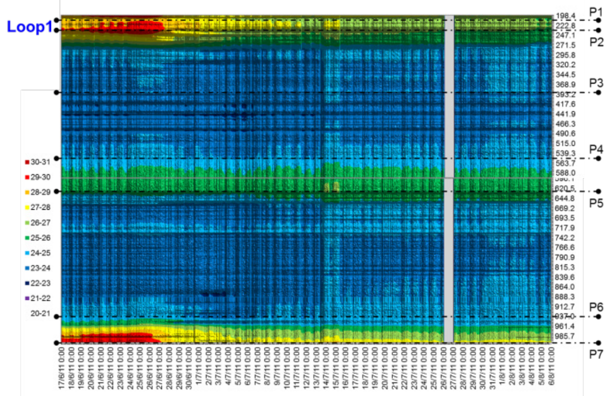

Figure 9. Contour of temperature from heated loop

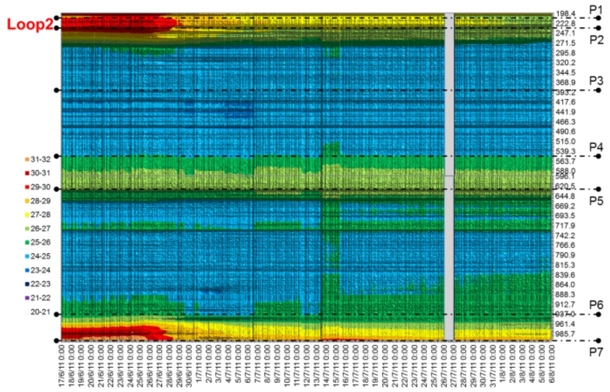

Figure 10. Contour of temperature from unheated loop

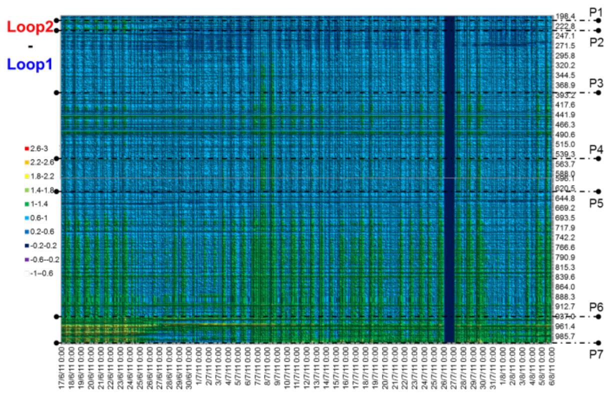

Figure 11. Contour of differential temperature

4.2. Seepage Measuring Weir

Fig. 12 shows the discharge has been quite constant at 210 liter/sec. Some peaks have been observed after daily rainfall intensity reached to 100 mm. It is believable this amount is enough to induce the side flow from both abutments. This shows most of the discharge is caused by seepage through rock foundation and abutments not the face slab. Several monsoons conducted the water level rose rapidly. And then in August of 2011, water was spilled through the spillway chute and it made the tailrace water rose up and disturbed the seepage weir.

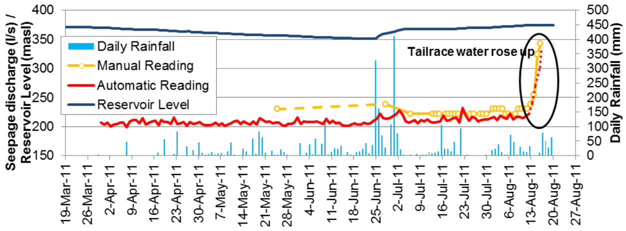

Figure 12. Discharge at downstream weir

5. FACTORS AFFECT TEMPERATURE MEASURED BY DFOT

After comparing the temperature of reservoir water and temperature inside the dam measured by DFOT, it was found the temperature inside the dam is higher than about 2 degrees Celsius from reservoir water especially for the portion below the water level as shown in Figs. 13 and 14. But the temperature measured by DFOT above the water level is slightly related to the ambient temperature as shown in Fig. 15. The temperature of reservoir water definitely is strongly related to temperature of dam body measured by DFOT, although the leakage has not been detected at downstream. The temperature measured from heated and unheated cables have a difference of less than 1 degree Celsius for whole distance of cables.

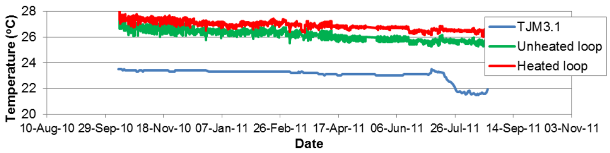

Figure 13. Temperature of reservoir water and of inside the dam at riverbed

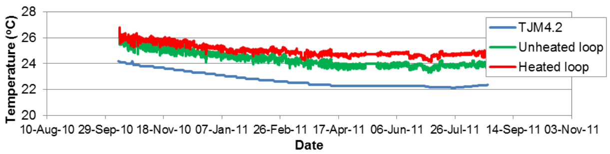

Figure 14. Temperature of reservoir water and of inside the dam at mid-height of dam

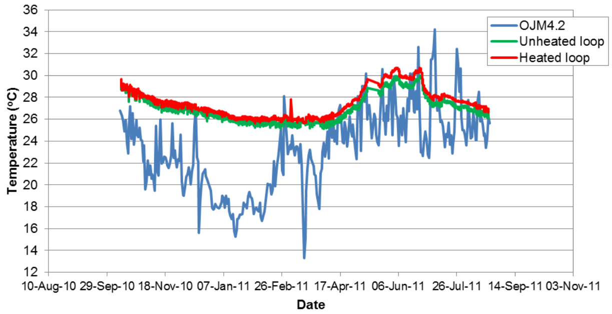

Figure 15. Temperature of reservoir water and of inside the dam above reservoir level

To consider effect of stored water level, the temperatures inside dam measured from unheated and heated cables and of reservoir water have been depicted as profile in Figs. 16, 17 and 18 respectively. The profiles of temperature inside the dam look like the profile of temperature of reservoir water. Above the elevation of +320 masl, the temperature inside the dam is varied with the storage water level because of degree of solar radiation. But below the elevation of +320 masl, the temperature is unchanged along the depth. These profiles show even thermal conductivity of concrete face slab is relatively low; the conduction through the face slab cannot be ignored. If the leakage taken place, the low temperature of reservoir water will induce the advection and the temperature measured from DFOT cables will decrease following the difference between temperature inside the dam and reservoir water. The relationship between decrease of the temperature and amount of leakage discharge can be estimated by numerical model.

One dimensional energy balance equation in Eq. 1 can be used to describe the couple thermal model (Cunat et al, 2009, Zhu et al, 2007). The left hand side of the equation is the time rate of change of the internal energy of the medium per unit volume. It depends on the change of temperature, T within time, t and volumetric heat capacity of the bulk medium, C. The heat flux for conduction is related to thermal conductivity of medium, λ and the heat loss for advection is related to flow velocity, v and volumetric heat capacity of the water, C_f. The flux due to heating cable is represented by boundary flux, Q.

$$C\frac{\delta T}{\delta t} = \lambda \frac{\delta^2 T}{\delta x^2} - vC_f \frac{\delta T}{\delta x} + Q \qquad (1)$$

The predicted temperature will be estimated based on the mentioned numerical model. In order to indicate the leakage, sum square error (SSE) will be calculated by Eq. 2. The difference between the measured temperature by DFOT, y_i at time i and expected temperature, $\hat{y}_i$ is residual. If there is no leakage, SEE should be less than accuracy of DFOT system. The large SSE implies the large leakage.

$$SSE = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \qquad (2)$$

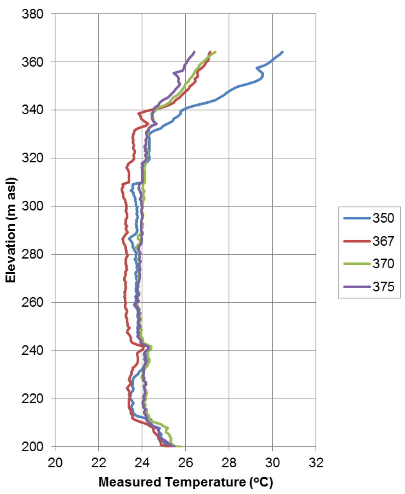

Figure 16. Profile of temperature inside the dam measured from unheated cable

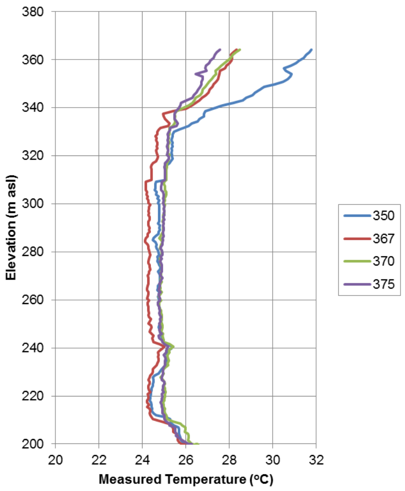

Figure 17. Profile of temperature inside the dam measured from heated cable

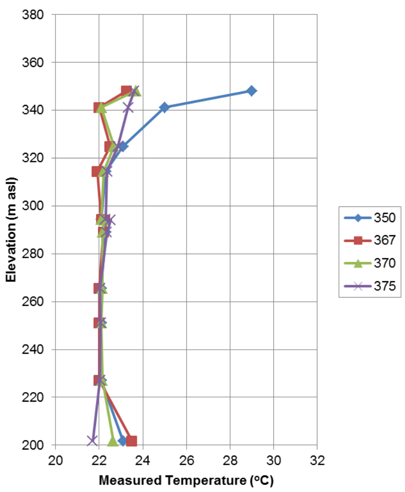

Figure 18. Profile of reservoir water temperature

6. CONCLUSION AND DISCUSSION

The sources of leakage such as the opening of the joint, overstress induced cracks on face slab, and seepage through foundation have not been detected. The perimetric joint opened about 11 mm. The vertical joint closed about 15 mm less than the provided filler thickness of 20 mm and compressive stress within face slab has been less than the compressive strength of concrete. The DFOT along the perimetric joint also confirms no leakage through the joint detected and the seepage measuring weir at downstream toe has presented the constant base flow of 200 l/s.

A numerical model of couple seepage and thermal analysis should be done to estimate temperature under any amount of leakage discharge. The developing model can be verified with the monitored temperature.

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