Dam foundation design for the main dam at Nam Ngiep1 hydropower project in Laos

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ABSTRACT

A roller compacted concrete (RCC) gravity dam of 167 m height is under construction in Laos. Due to a folded zone in the geology of the right abutment, several weak horizontal layers are distributed below the river bed and these were considered to have potential to seriously impact the dam stability. In order to evaluate the mechanical properties and the distribution and formation of these weak layers, detailed geological investigations were instigated by conducting core drilling, rock property tests, X-ray diffraction (XRD) analysis and computed tomography (CT) scanning. Through a multiple-wedge stability analysis and finite element analysis (FEA), a shear key was designed to penetrate part of the weak layers and be incorporated into the dam body to improve the dam stability against sliding.

1. OUTLINE OF PROJECT

The Nam Ngiep I Hydropower Project (NNP1) is a hydropower IPP (Independent Power Producer) invested in by the Kansai Electric Power Co., Inc. of Japan, the Electricity Generating Authority of Thailand and the Lao Holding State Enterprise of Lao PDR. It will be operated under a BOT scheme with assets being transferred to the Lao PDR after 27 years of operation. The project is located at the middle reaches of the Nam Ngiep River, a tributary of the Mekong River approximately 130 km northeast of Vientiane, the capital city, and will construct there two dams and two powerhouses. There will be a dam (height of 167 m) with a main powerhouse (273 MW) and a re-regulation dam (height of 17.7 m) with a re-regulation powerhouse (17 MW). The plan is to sell electricity from the main powerhouse to Thailand and that from the re-regulation powerhouse to the territory of the Lao PDR. Civil works are undertaken by Obayashi Corporation. The main dam is a gravity concrete (RCC) dam of a height of 167 m. Excavation of the dam foundation was completed in March 2016 and concrete placing work is now ongoing. This report will describe the design of the foundation of the main dam. Figure 1 shows the location of Nam Ngiep 1 and excavation works at the site.

Figure 1. Location Map of Nam Ngiep 1 and Current Status of Excavation

2. GEOLOGICAL CONDITION

2.1 Geological formation

Figure 2 shows a geological cross-section of the river bed 25 m downstream of the dam axis. The geological features of the location of the dam are formed by alternating mudstone and sandstone layers that incline gradually downstream. The syncline is around 8˚. On the right bank, there is a remarkable folded zone where a part of the layer shows a nearly vertical inclination. It was found during excavation near the river bed that there were a lot of clay-mediated, small angle weak layers inclined toward the downstream that might affect stability of the dam. The construction work, therefore, had to be suspended to assess physical properties, design changes to the dam foundation and additional excavation. Consequently, the excavation works took approximately three months longer than scheduled. It was decided to excavate 19 m deeper than originally planned and to increase the height of the dam from 148 m to 167 m. Additional excavation (mainly a shear key arranged at the lower part of the main dam) amounted to approximately 45,000 m^3.

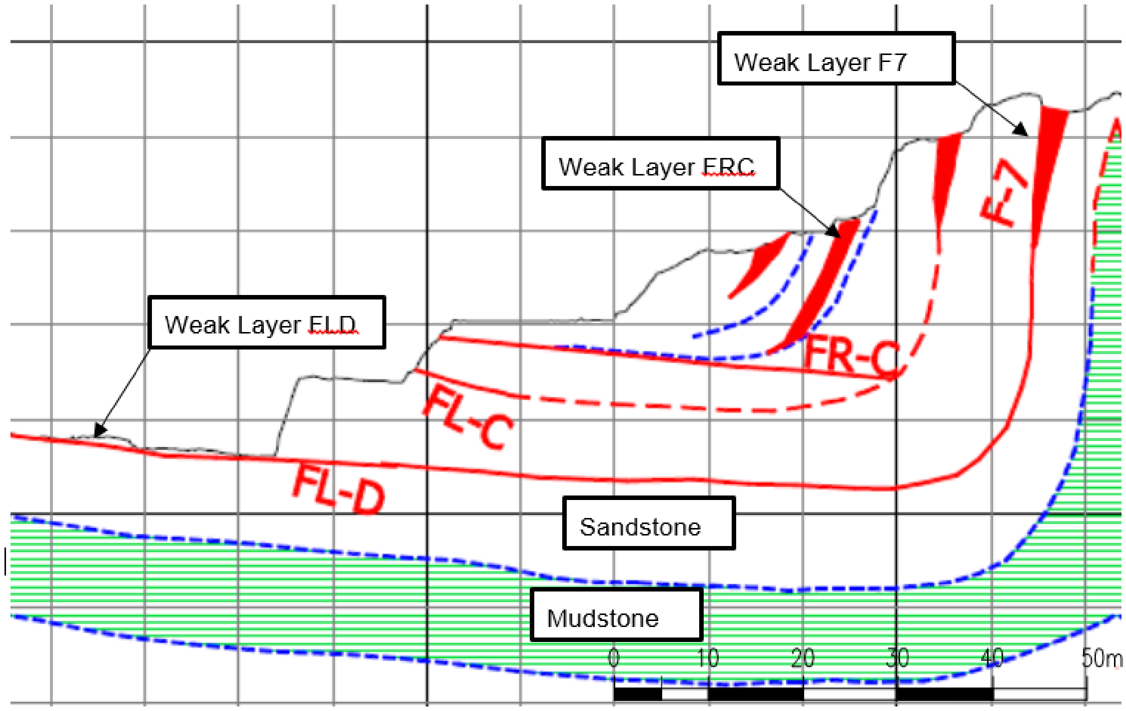

Figure 2. Geological Cross-Section

2.2 Geological survey

Hybrid drilling and observation of outcroppings were carried out as additional surveys and laboratory tests of samples taken from the surface layer and drilling cores were carried out in order to evaluate the formation process and physical properties of these weak layers. Figure 3 shows the locations of drilling for the additional surveys and preliminary surveys. For the disturbed samples taken from the weak layers, box shear tests were carried out under the condition of consolidated drainage with constant pressure. The box shear tests were carried out at a maximum restraint pressure of 2 MPa and shearing speed of 0.05 mm/min, and the physical properties of the weak layers themselves were determined based on the residual strength obtained from the tests. These conditions are considered sufficiently conservative for representing the long-term strength of the weak layers consolidated after reservoir impounding. Fine particle fractions are not distributed evenly in the weak layers and there are some parts that have no fine particle fractions and show good engagement of bedrocks. Drawings of the excavated surface layer were made, and the ratio of the fine particle fractions to the weak layer and the good engagement of bedrocks were assumed to estimate the strength of the whole layer. Figure 4 shows photographs of weak layers. Weak layers are distributed continuously along the stratum boundary.

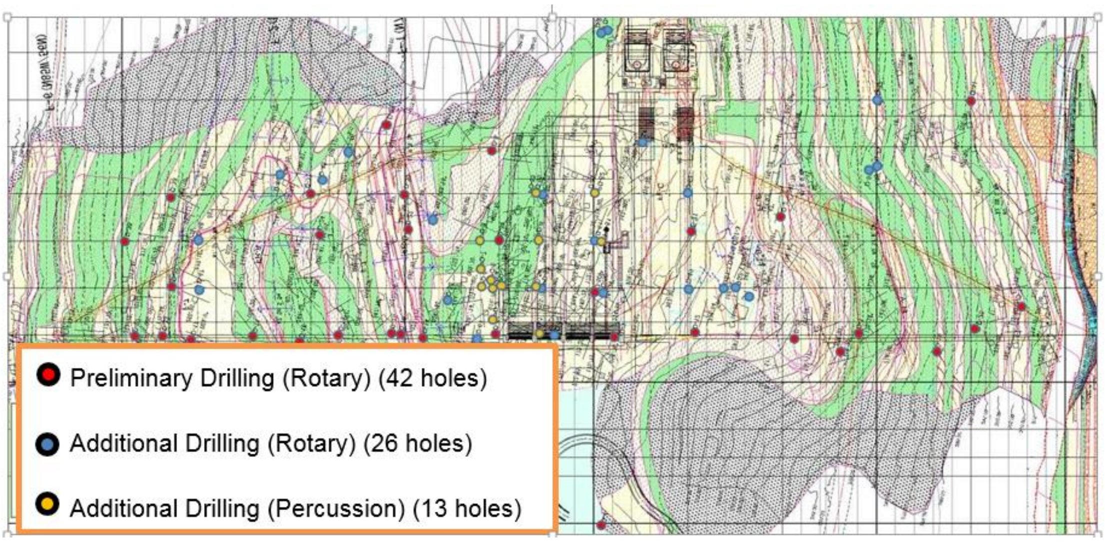

Figure 3. Number and Location of Drilled Holes

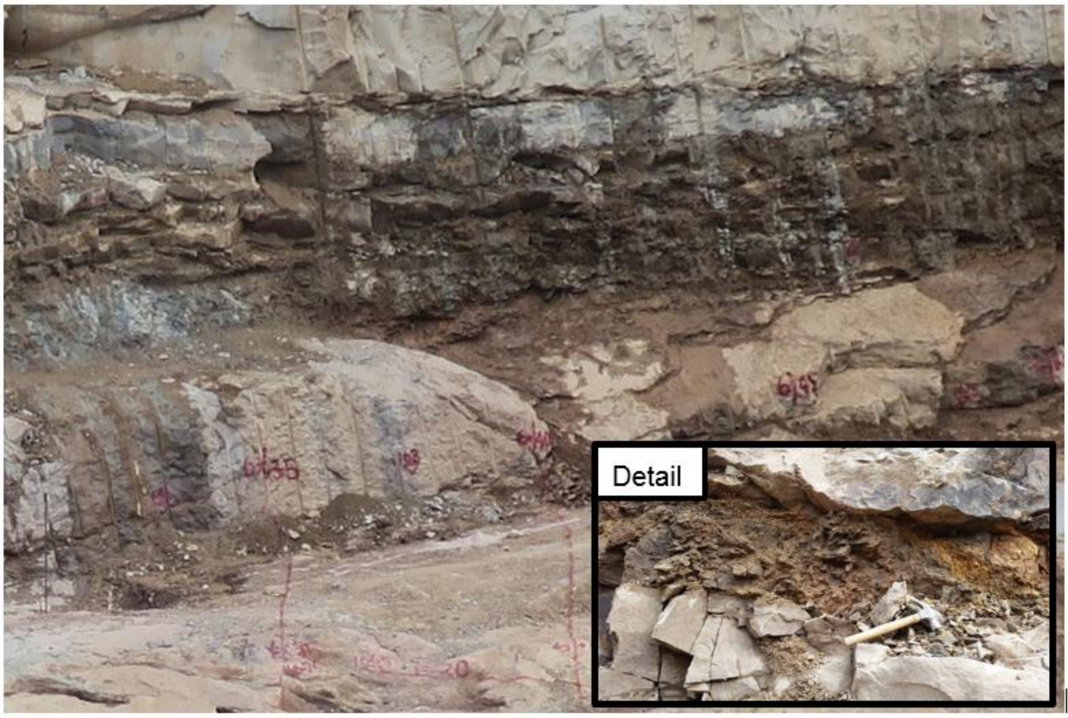

Figure 4. Photograph of Weak Layer

X-ray diffraction (XRD) analysis of samples was carried out in order to verify that these fine particle fractions in the weak layers did not include any swelling clay (for example, smectite) that might significantly degrade physical properties. It was quantitatively verified that swelling clay minerals such as smectite clay were not included (Figure 5). Detailed observation by means of CT scanning was carried out (Figure 6) in order to examine fractured parts. It is considered that the weak layers in relevant locations were formed by progressive weathering of the part that had been fractured by flexural-slipping in association with folding activity at the boundary of the hard sandstone and the soft mudstone due to pressure and the change in groundwater level. Since the fractured part existing under such FLD was not associated with fine particle fraction or the rearrangement of particles, it was verified that they were cracks, not continuous weak layers. For the hard rock parts, physical properties were determined from the results of the in-situ block shear test in the test pit and were verified using Hoek-Brown failure criterion (Table 1). Stability analysis of the dam was carried out using these physical properties.

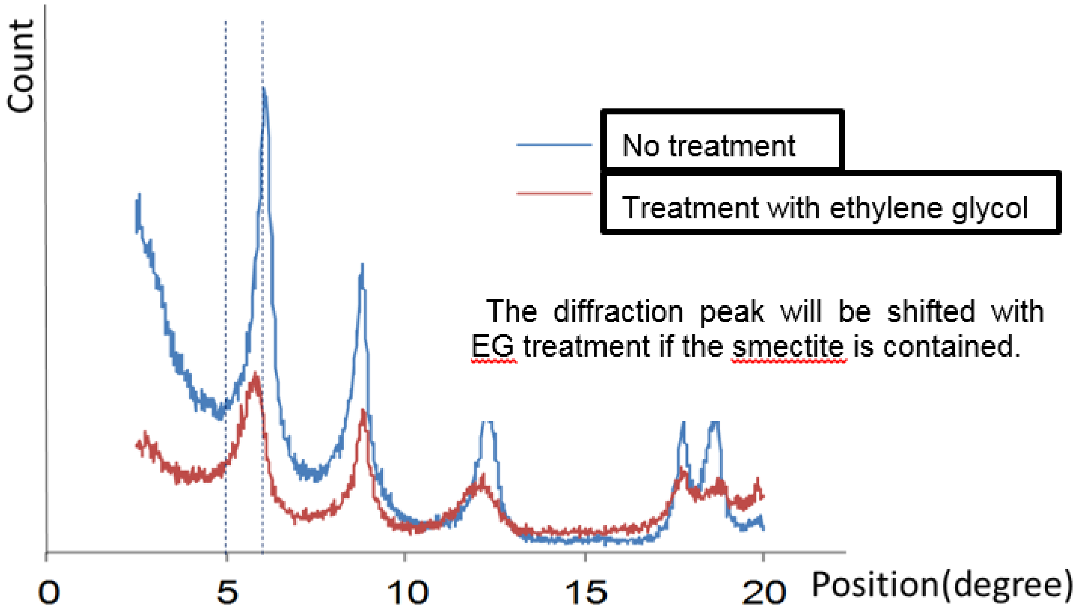

Figure 5. Results of XRD Analysis

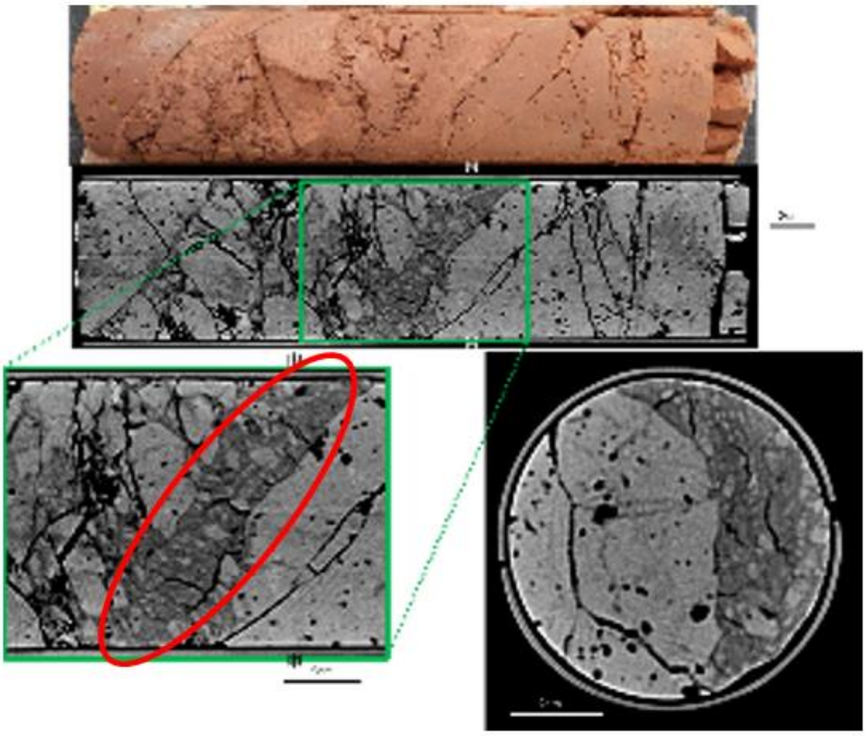

Figure 6. Image of CT Scanning

Table 1. Physical Properties (CH,CM,CL are based on DENKEN classification.)

Item	CH	CM	CL	Weak Layer	Remarks
Density[kN/m3]	25.5	24.4	20.9	20.9	Test results
Elastic modulus [MPa]	26,830	11,112	318	-	CH: Test results

					CM: General
Cohesion [MPa]	2.75	2.01	0.68	0.0	Test results
Internal Friction Angle [degree]	47.5	42.5	40	25	Test results
Compressive Strength [kN/m2]	95.5	65.7	-	-	Test results

3. STABILITY ANALYSIS

3.1 Study contents

Stability analysis on sliding, turning and bearing capacity was carried out. Study cases that might be critical were in the event of flooding or earthquake. The water level condition was determined from hydrological data. As for seismic motion, the design horizontal seismic coefficient was determined by taking the characteristics of the region into consideration and was treated as static load. Stability analysis of sliding on a small-angle weak layer was crucial for this project.

3.2 Wedge analysis

Wedge analysis was adopted to examine sliding force and resistance force of a small-angle weak layer by dividing it into multiple blocks along slip lines. Analytical conditions, necessary safety factors, etc. conformed to the United States Army Corps of Engineers (USACE) 1). The section (F+00) around the riverbed upstream of the powerhouse is shown as a model section. Since, in this section, the foundation rock around the toe of the dam was excavated in order to build a powerhouse downstream, the safety factor of sliding was the lowest. As external forces were considered the hydrostatic pressure upstream, hydrostatic pressure downstream, mud pressure, dynamic water pressure upstream, dynamic water pressure downstream, inertial force and uplift pressure. As for the uplift pressure, the decrease in uplift pressure by 66% due to a drain hole provided at a gallery downstream of the dam axis was assumed. Figure 7 shows a model of wedge analysis and Fig. 8 shows the external forces. Since the dam did not satisfy the necessary safety factor in planned excavation, additional excavation that would provide a shear key was required to remove weak layers and make use of shearing resistance force of robust rocks at deeper parts. While preparing the shear key required excavation into the bedrock, it was difficult to provide the shear key on the steep slope because it required a large amount of slope cutting, which takes time and cost. As shown in Fig. 7, therefore, multiple measures were adopted for dam stability such as a counter-weight by providing backfill concrete downstream, increasing the shearing length by expanding the fillet, adding weight by hydraulic pressure upstream and providing additional drainage holes in the gallery.

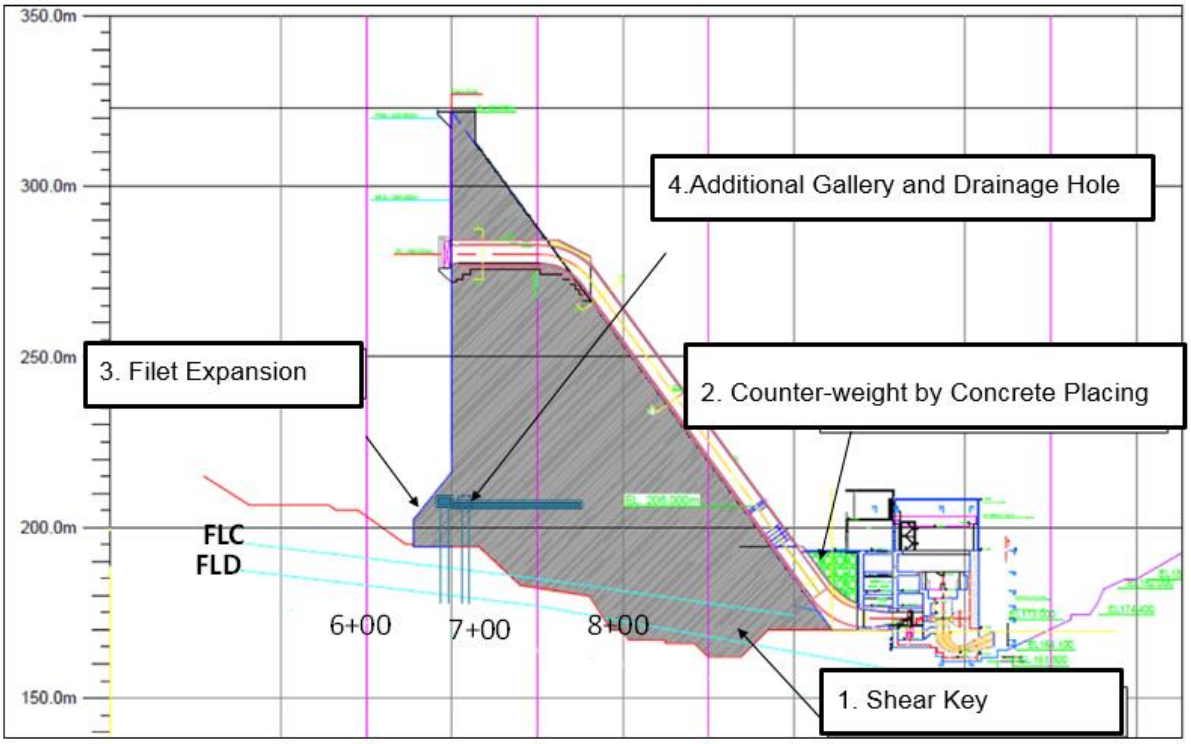

Figure 7. Outline of Wedge Analysis Model and Measures for Stability

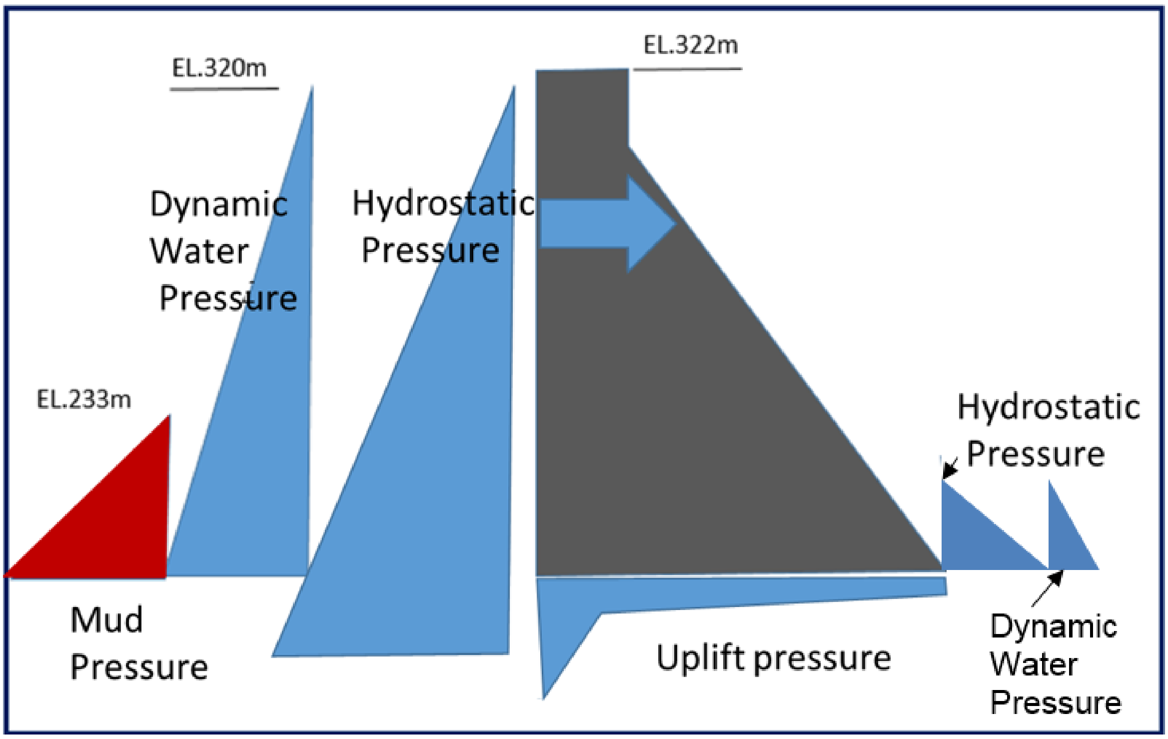

Figure 8. External Forces

3.3 Finite Element Analysis (FEA)

Finite Element Analysis (FEA) was carried out to check stress conditions. The geology immediately beneath the dam body was modelled in 1 m meshes and the weak layers were assumed as joint elements. The distribution of compressive stress, tensile stress, shearing stress, sliding safety factor, deformation, etc. were studied. Figures 9 through 12 show the distribution of compressive stress, distribution of tensile stress, and displacement of the weak layers in the case of an earthquake, which is critical for design, and a photo of re-bar installation. The largest points of compressive stress of the dam body and the foundation rock, which were acceptable considering the strength of the dam concrete and the foundation rock, were located around the toe of the dam. As for the tensile stress, it was found that the tensile stress was generated locally in the area around the boundary of the shear key and the weak layer, therefore it was decided to provide sufficient reinforcement in the part where large tensile stress was generated. Re-bar was installed to defend against crack propagation in the dam concrete, as a countermeasure to the large tensile stress. Since displacement of the weak layer was only 11 mm at a maximum, it can be evaluated that the displacement was well controlled by the shear key.

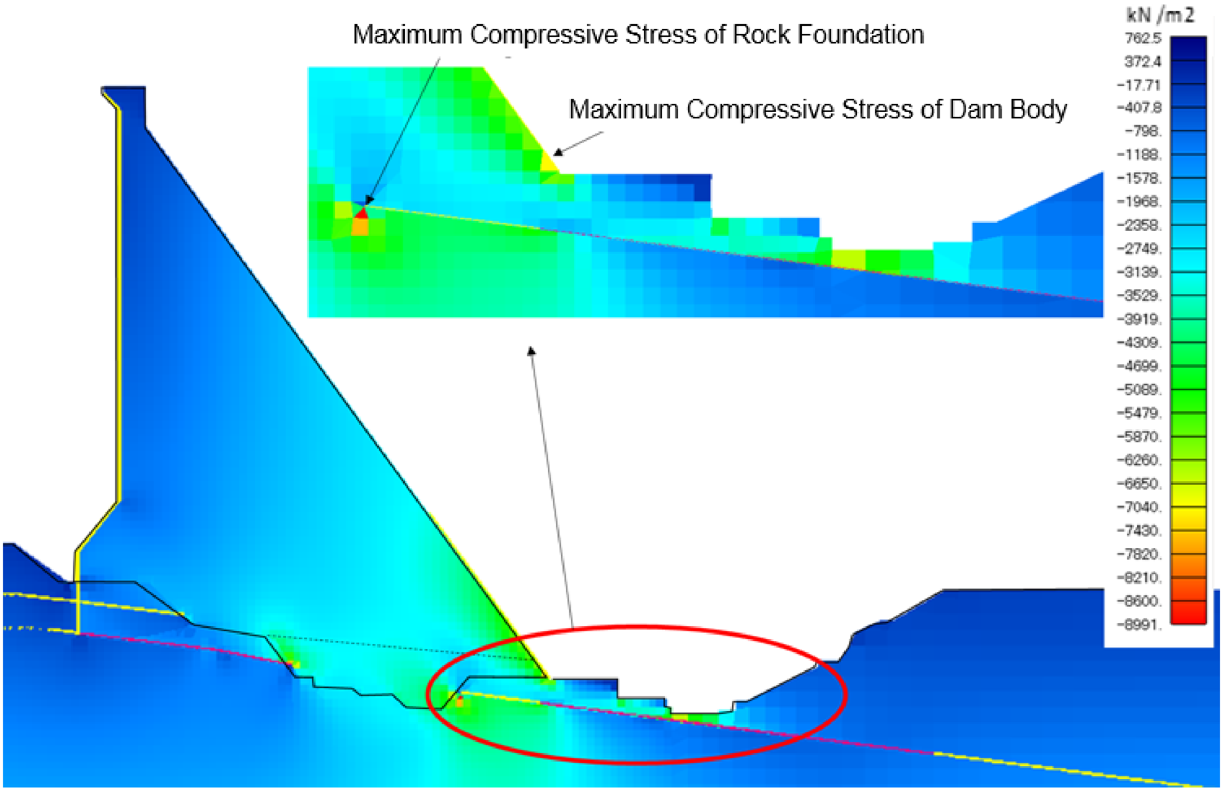

Figure 9. Distribution of Compressive Stress

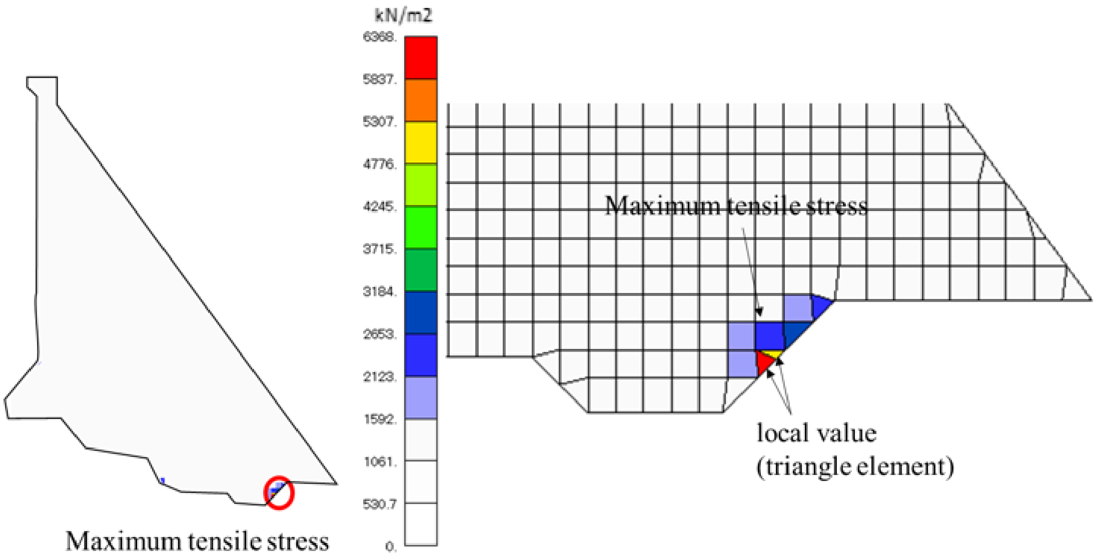

Figure 10. Distribution of Tensile Stress

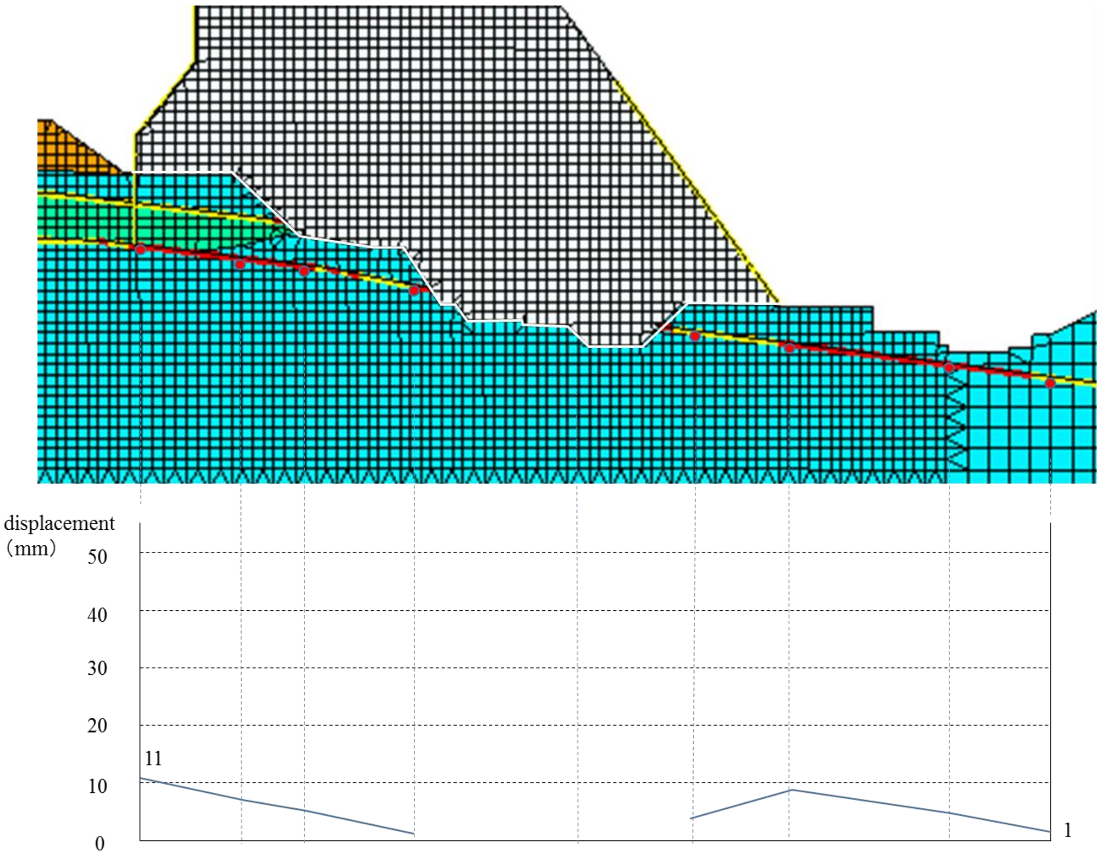

Figure 11. Displacement of Weak Layer

Figure 12. Photo of Re-Bar Installation

4. CONCLUSION

During the basic design of the dam for the Nam Ngiep I Hydro Project, the following was learned.

- The distribution of weak layers existing in alternating sandstone and mudstone was examined and physical properties were determined based on boundary tests of the samples taken from the site.
- A shear key was effective as a countermeasure against weak layers in the riverbed. It was also possible to perform economical designs by taking multiple measures, such as partially expanding the dam section and providing additional drainage holes upstream.
- The original design of the dam layout was appropriate but, taking into account the additional provision of a shear key, the final design was confirmed based on wedge analysis, finite element analysis and site investigation.
- Detailed observation by means of CT scanning and XRD analysis were effective for evaluating the continuity of weak layers and existence of swelling clay.

Finally, excavation of the foundation was completed in March 2016 and RCC placing was commenced in May 2016. As of the end of December 2016, approximately 690,000 m^3 (29%) of concrete had been placed for the main dam and the overall progress rate of the project was 59%. Figure 13 shows the state of concrete placing for the dam in December 2016. Utmost efforts are being made for a scheduled commencement of operation in January 2019.

Figure 13 State of Concrete Placing at Dam (December 2016)

5. ACKNOWLEDGEMENTS

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