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Cases of adverse geological and geotechnical conditions in Dam Construction in Khorat Rock Group

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ABSTRACT: Lessons learnt from difficulties and problems experienced in construction and operation of two recent hydropower projects sited in Khorat Rock Group of Northeast Thailand and neighboring Loa PDR are described. Predominant rock types are sandstone, siltstone and mudstone. At the first site, rock formations were of near horizontal bedded formation which was generally expected in most areas of the rock group existing in the region. However, problems associated with weak rock properties of the siltstone and mudstone, i.e., slaking, creep, low strength and high compressibility, led to difficulties during the construction and operation of the projects structures. In the second project, the site is situated in mountainous area in Lao PDR in the vicinity of the Khorat Plateau where the rock beds have been folded and faulted from past tectonic movement. However, the intensity of the folds and faults were under–interpreted during the investigation and design development phase which resulted in difficulties during the construction stage. Exposure of bed rocks following site clearing and removal of overburden revealed that the rock beds had been heavily thrusted and are full of thrust faults and bedding shears that pose difficulties in stability of rock excavation. Moreover, the pronounced slaking behavior of the siltstones led to abandonment of their use as rockfill for dam construction.

1. INTRODUCTION

Sedimentary rocks of Khorat Group cover vastly the entire Northeast Thailand and neighbouring Lao PDR and Cambodia. A number of civil infrastructure development projects have been constructed or planned in the rocks group region. Recently, a number of hydropower dam or irrigation dam projects were constructed. The hydropower development projects have been increased in number in Loa PDR owing to its abundant water resources and suitable sites in mountainous regions of the country. Lessons on rock mechanics practice learnt from the construction of recent projects sited in Khorat Rock Group regions are worth mentioning. Two projects are described in this paper. The first one is Lam Ta Khong Pumped Storage project which is situated in the Khorat Plateau of Northeast Thailand where the rock beds are gently dipping. The second one of Nam Ngum2 Hydropower project located in mountainous region in Lao to the east of Vientiene plain. The rock beds at the site are folded and faults. Construction of both projects experienced difficulties related to adverse engineering properties of the rock substance and of the rock structures (discontinuities).

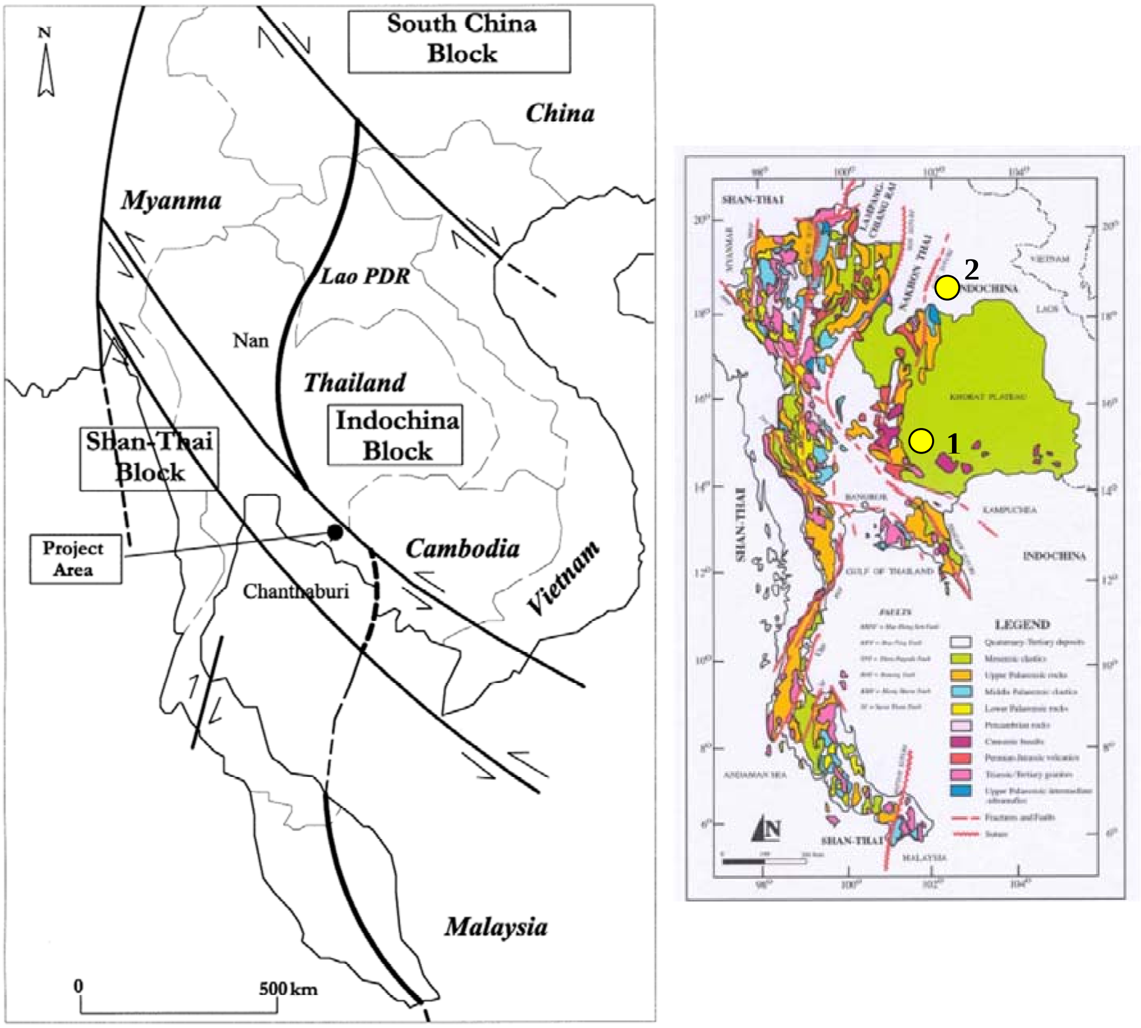

Fig. 1 Map of Khorat Plateau and major tectonic structures in SE Asia

2. GEOLOGY

Khorat Rock Group is the basement of Khorat Plateau extending over the entire region of Northeast Thailand and neighbouring countries (Fig. 1). Rocks range in age from the Lower Jurassic to the Upper Cretaceous or Lower Tertiary, generally comprising slightly deformed sedimentary beds of conglomerate, sandstone, siltstone, claystone and shale. It is relatively flat, generally dipping centripetally from the plateau perimeter, but locally are warped into narrow anticlines and synclines. The rock group comprises six formations that are from Phu Kadung Formation at the base to Phra Wihan, Sao Khoau, Phu Pharn, Khok Kruad and Maha Sarakham Formations. The greater part of Khorat Group is underlain by non-marine sediments viz. sandstone and siltstone of Phra Wihan and Phu Kaduang Formations. Phu Kadung Formation consists of sequence of brown, reddish-brown and purplish red micaceous shale and brown and gray micaceous, cross-bedded siltstone, with some conglomerate containing limestone clasts. Phra Wihan Formation lies conformably on Phu Kadung Formation and it consists of sub-arkosic sandstone with inter-bedded siltstone that caps the boundary escarpment of the Khorat Plateau. The sandstones are well cemented to friable, very fine to medium grained, thick bedded and cross-bedded.

Characteristically these sandstones are quartzose, conglomeratic with small pebbles of quartz and gray chert. The siltstones are grayish red. Many beds of sandstone are lenticular throughout Khorat Group but some are persistent for long distance before they pinch out.

2. LAM TA KHONG PUMPED STORAGE

The site is located at the southwestern rim of the Khorat Plateau in Nakorn Ratsima Province (Location 1 in Fig. 1). It is the first underground powerhouse project in Thailand. Siltstone and sandstone of Phukadung and Phra Winhan formations are the predominant rock beds at the site. The sandstones are well cemented, fine to coarse grained and thick bedded. The siltstones are medium strong to weak rock, laminated and micaceous to calcareous. On the basis of color, three types of siltstone were observed, namely greenish gray siltstone, green mottled reddish brown siltstone and reddish brown siltstone. Greenish gray siltstone consists of higher chlorite and less hematite, while in the reddish brown siltstone, the composition was just opposite. On the basis of texture they were divided into (muddy) siltstone and sandy siltstone. The

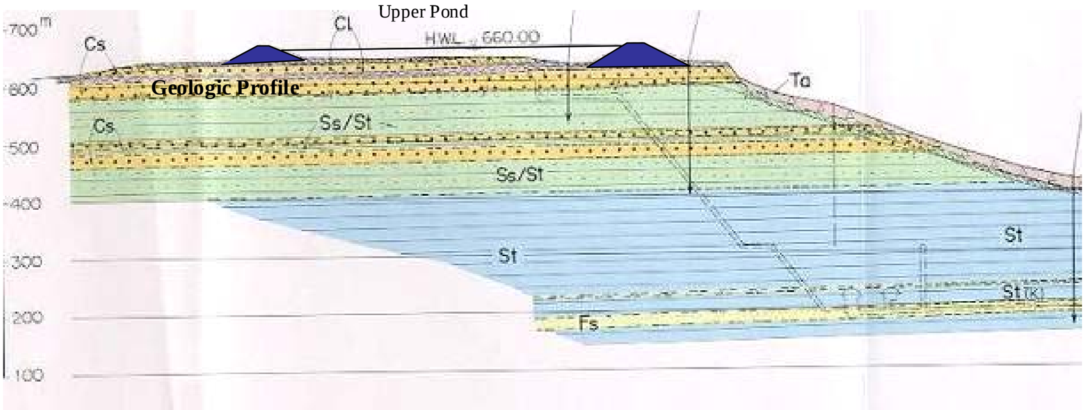

Fig. 2 Upper Pond and geologic section at Lam Ta Khong Pumped Storage site

site was free of major fault. Laboratory tests showed that sandstones varied from fine to coarse grained with uniaxial compressive strength of 51-115 MPa. The muddy siltstone was generally fissured and had uniaxial compressive strength of 22-38 MPa and water content of 3.3-4.2%. The strength of the sandy siltstone was 25-57 MPa. X-ray diffraction analysis showed smectite and chlorite present in the rock. Claystones found in the upper pond area had water content 10-13%, liquid limit 30-40% and plasticity index 10-20. The residual friction angle was in the order of 20-22°. During the detailed design stage much attention was paid to slaking behavior of muddy siltstone and claystone as it appeared more pronounced than originally perceived. Extensive investigation was made to investigate this adverse property (Phienwej et al, 1995). High degree of fissure and fractures of the rock promoted the pronounced slaking potential. Slaking of the rocks also caused difficulties and confusion in determination of mechanical properties. Unpreserved rock samples and delay in laboratory and field tests led to deterioration prior to testing. It also created difficulty in early stage of the excavation of the underground powerhouse cavern in which uncontrolled use of water in hole drilling and drainage led to induced slaking of siltstone in the roof upon contact to infiltration water to the rock mass and a collapse of the cavern roof. The subsequent control of water use and drainage refrained rock from slaking the opening could be safely excavated Rock mechanics difficulties resulted from the adverse properties of the weak rocks at the project site are described below. Only those that are related to the Upper Pond are included.

The Upper Pond

The Upper Pond was constructed on the mountain top next to a hill slope (Fig. 2). It had a crest length of 2170 m and the storage capacity of 10.3 million cu m. The cut & fill method was adopted for the construction so that rocks from the foundation

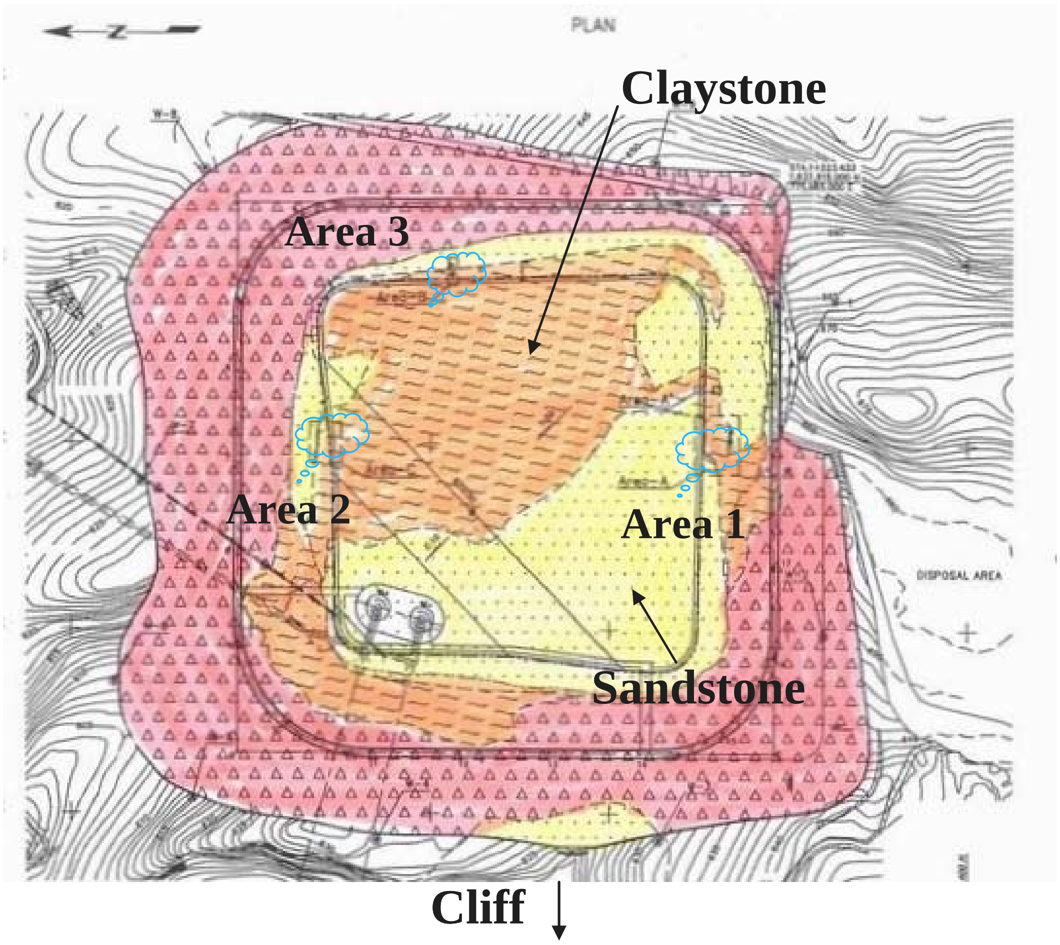

Fig. 3 Layout plan, geology and areas of asphalt face rupture of Upper Pond

excavation could be used for the construction of the fill embankment. The pond was bounded on three sides by the rock fill embankment (Fig. 3). The maximum height of the embankment was 50 m. The design concept of impervious face zoned rockfill dam was adopted for the design of the embankment, for which good quality sandstone was used in the upstream zone 3A (Fig. 4). In order to make use of most rock materials coming out from the excavation, poorer quality rocks (siltstone and mudstone) were allowed in the downstream zone of the embankment (Zone 3C) by adopting a gentle embankment slope (1:2.5 V:H). The design slope was much gentler than the slopes of typical rockfill dams (1:1.3-1.15).

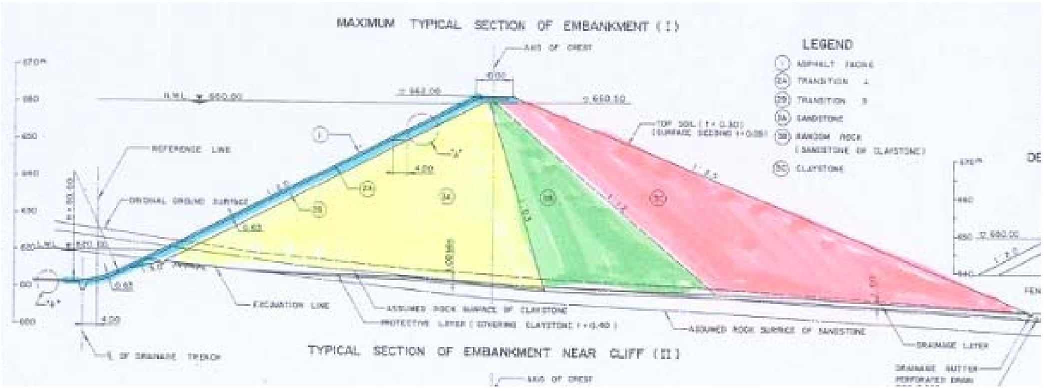

Fig. 4 Zoned rockfill embankment of Upper Pond

Asphalt face was adopted as the impervious lining of the pond. for reason of higher flexibility and ductility and more durability. The entire pond was lined including the upstream face of the rockfill embankment, the cut slope face and the excavated pond floor. A system of drainage trenches and tunnels was furnished below the bottom of the pond to handle leakage water and ground water movement in the pond foundation.

Cases of Unsatisfactory Performance

The design of the pond was checked by the world renounced expert on impervious face rockfill dams. The construction went smoothly without major difficulty despite the fact that the asphalt face lining was adopted for the first time for dam construction in the country. A series of problems were experienced during the first impoundment of the pond and also in the subsequent periods. These problems are,

- Cracks and bulge of asphalt lining on the pond slope due to slippage of lining layer over weak rock.
- Rupture of asphalt lining in the pond floor due to piping of bedding materials.
- Excessive and continuing settlement and lateral displacement of rock fill embankment resulting in pronounced cracks on dam crest.

The problems were investigated and had been remedied to a certain extent to permit the use of the pond. Lessons learnt from these incidents are described below.

(1) Cracks and Bulges of Asphalt Lining on Pond Slope

Pronounced leakage was detected during the first trial pond filling while the water level reached about a half height of the full supply level. The inspection revealed cracks, bulges and heaves of asphalt face near the toe of the pond slope in three areas, all of which were in rock cut areas where asphalt face was laid on prepared cut slope face in zones of claystone (Fig. 3). A a special treatment by means of geotextile sheet cover was adopted underneath the facing layer with the intention to avoid potential problems of deterioration and piping of the claystone when it was in contact with water. Investigation trenching revealed that the problem was induced by the low friction along geotextile/claystone interfacet that led to failure of the asphalt facing system (Fig. 5).

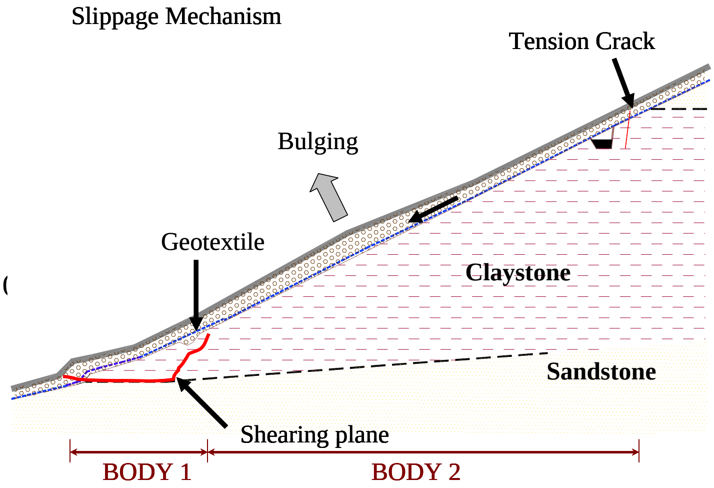

Fig. 5 Slippage mechanism of asphalt face lining over claystone face

Laboratory strength test results on samples of claystone, asphalt facing material and contact between geotextile and claystone were used in the stability analysis which confirmed the inadequate stability of the asphalt facing under that circumstance. The friction angle between the geotextile/claystone contact was as low as 16°.

The remedial measures included

- Thickening asphalt lining in toe areas of the slopes in the damaged zones to serve as buttress and improved shear resistance.
- Omitting geotextile sheet as the separator over claystone (Geotextile sheet created planar sliding surface between claystone and transition layer).

(2) Rupture of Asphalt Lining in Pond Floor

Severe leakage through the drainage tunnel at the pond base was detected during the trial pond filling almost to the full supply level. It was the result of severe cracking in the asphalt floor lining near the penstock inlet. Leaking water caused piping and voids in bedding materials below the asphalt lining leading to severe subsidence and ruptures in the asphalt lining from high water weight over it (Fig. 6). The damaged area was mainly in the area of claystone, whose excavated surface was not protected from slaking. Leveling layer made with mixture of sandstone and weathered materials over claystone bed had low resistance to piping from leakage water underneath the asphalt lining.

The damage also extended to the zone underlain by a jointed sandstone bed. Stepped sandstone face left after excavation required a dental levelling (Fig. 7). The leveling using fine materials over the jagged rock face resulted in difficulty in compaction and unstable zones below the pond floor against piping. It was judged that the condition and extent of the problem was so severe beyond repair. Similar piping could occur in any areas below the pond floor owing to false design of the under-drainage system that did not match with the foundation rock conditions. It was then decided to adopt

Fig.6 Rupture of asphalt lining on pond floor due to piping of leveling material underneath

the relining of the entire pond floor and slope face with a layer of high strength (HDPE) geomembrane sheet, which was expected to give a functional life time of 10-15 years before replacement. The measures prove satisfactory to date (5 year after operation).

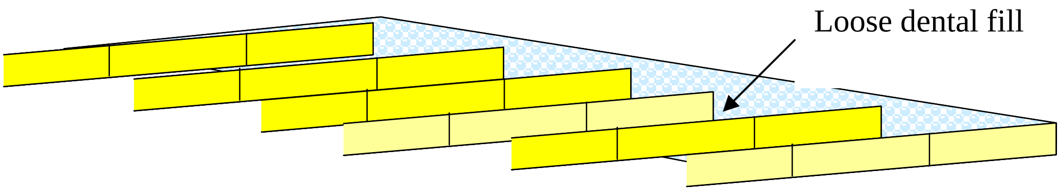

Fig. 7 Smoothening of closely stepped sandstone cut face with dental fill

(3) Settlement and Cracks of Embankment Crest

The third problematic performance of the pond was the large and continuing deformation of the sections of the rockfill embankment that led to significant cracks and settlement of the dam crest. Post construction settlement reached 1.6% of the dam height in seven years and the present rate of increase is still high. The lateral displacement is also high. The amount of settlement is on the high side compared with those of other rockfill dams (Hunter and Fell, 2003). The problem was more pronounced in the cliff side of the pond. The cause of the displacement which continued to increase with time is being investigated. The possible causes as identified include high time-dependent compressibility behavior of the Zone 3C materials consisting of unstable claystone, siltstone and weathered sandstone, and sliding toward the cliff face along the near horizontal claystone bed left underneath the dam base (Fig. 8). Creep behavior of the claystone may also have created the pronounced time-dependent lateral movement of the rockfill embankment toward the steep cliff face, located just a short distance from the toe of the dam. Up to present the exact cause has not been clearly identified. However, it is mostly likely that the problem is attributed to the progressive deterioration of the compressibility and strength of the claystone, siltstone and weathered sandstone used in Zone 3C of the

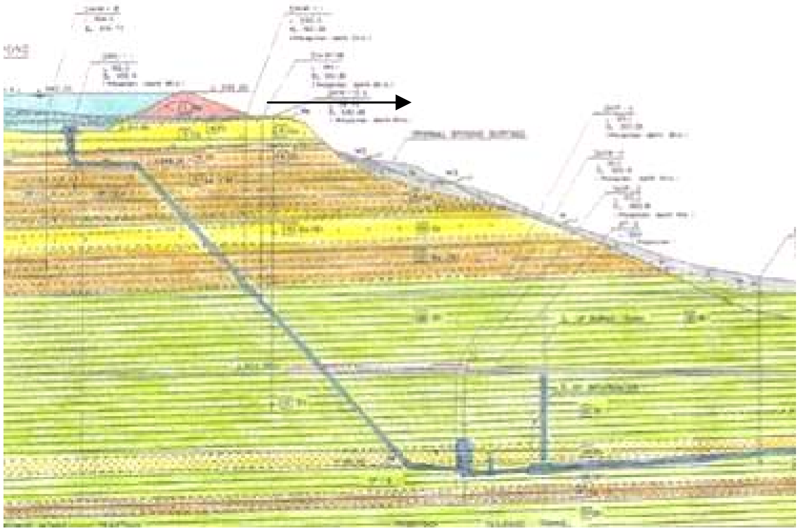

Fig. 8 Possible lateral sliding of embankment over claystone bed toward cliff face

embankment. The construction recorded showed that Zone 3C was not required to be heavily compacted (density of only 19-20 kN/m3) because a gentle slope was adopted in the design of the rockfill embankment of the pond.

3. NAM NGUM2 HYDROPOWER PROJECT

The Nam Ngum 2 (NN2) Hydroelectric Power Project is located approximately 90 km north of Vientiane in central Lao PDR, upstream of Nam Ngum 1 reservoir. The project will install a 630 MW powerhouse at the downstream of 181 m high concrete faced rock fill dam. The civil work of the project also consists of double 11.5m diameter diversion tunnels (1.1 km in length each), a head race tunnel and 3 steel lined penstocks, a high spillway, quarry excavation and production and high cuts for construction and permanent roads. The bird-eye view of the project under-construction is shown in Fig. 9. The project is now well under construction and the commission date will be in mid 2009 as planned. However, many design and construction problems related to adverse geological and rock mechanics arose during the project implementation.

The site is located near the east boundary of the Khorat Rock group where mountainous terrain dominates the area (Location 2 in Fig. 1). At the dam site, Nam Ngum River channel is very narrow and bounded by steep cliffs made of thick sandstone beds alternating with siltstone beds and interbedded layer of sandstone and siltstone. Due to the sheer cliff appearance of sandstones that outcrop many places along the river channel, the sandstone beds were called cliff-forming sandstones in the investigation report. At many places the beds were of near horizontal lying. Although folding of the rock beds as well as faults and shears were observed at places, the initial investigation report did not suggest significant existence of complex and adverse geologic structures and rock mass and rock material properties. The interpretation on the geological model at the dam site was made on the basis of prior knowledge of characteristics of Khorat Rock Group built up from studies and construction experiences in past projects mostly in Northeast Thailand. After the start of the excavation works, the actual geologic structure of the rock formations was unconcealed which turned out to be much complicated than what initially interpreted. The geology of the site is quite complex. The structure of rock beds exposed along valley wall after clearing is shown in Fig. 10. Tectonically, it was subjected to a strong compression forces acting by the collision of tectonic plates. The area may be a suture zone, where two continental plates were collided. Due to the nature of interbedded layers of competent and incompetent rocks the strong compression created folded, and reverse and thrust faults within the formations. With the sliding of incompetent layers over a low angle competent base created This area is called a frontal thrust and folding zone. The zone is normally bounded the tectonic uplifting compression crustal core. The compression was so intense that shear failure would be also accommodated by large-scaled movement of strike-slip faults. Strongly sheared

Fig. 9 Nam Ngum 2 HP Project Site under construction

rock would generally have a low strength, as the rock was already been sheared to the residual strength. Drag folds along the faults associated with this complex geology would also crushed the rock. Between the beds, the contact boundary would also be sheared dramatically. As the fold of a particular thick formation was locked into a tight position as a Chevron folds, the upper part of the fold hinge would collapse and the lower part of the fold would develop the formation of the limb thrust. The rock in this tight folding zone would be crushed into small fragments. Incompetent beds of siltstones and mudstones are heavily sheared and fractures. The competent beds of sandstone are also highly fractures at places especially near the fold hinges. Bedding shears in the incompetent beds of siltstones and mudstones are of very low strength against sliding. During excavation of quarry development in areas behind cliff faces of near horizontally lying sandstone beds, major landslide repeatedly occurred. After removal of the very thick overburden of soil and highly jointed and weathered rock beds, the concealed existence of steeply inclined bed of tight folding was unearthed in the rear part of the quarry area. Shearing along weak bedding shear in siltstone in the presence of seeping groundwater caused the reactivation of this old massive landslide. The depth the slide was more than 100 m (Fig. 11). That was just one of the samples of a number of landslide problems experienced at the project. In the initial geological investigation report, landslide was not foreseen as a significant geological hazard at the project site.

The result of this type of geology can produce adverse conditions to the rock foundation and the rock mass quality. This type of geology has never before been reported in an area of the so called “Khorat Group”, Without former knowledge of the

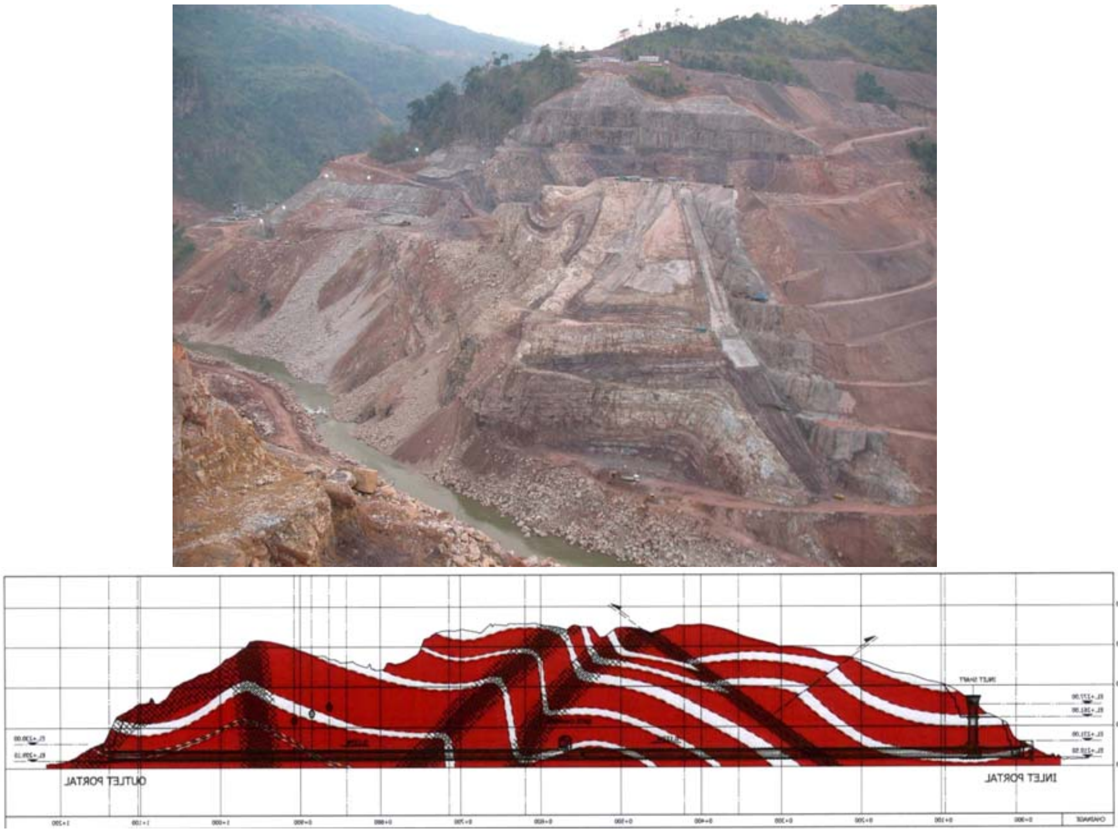

Fig. 10 Geologic structures along NN2 dam abutment

existence of such geological conditions, it would be very difficult to make a correct interpretation of the geology, regardless of the number of drillholes made. This was the situation of geological and geotechnical interpretations made at NN2.
The paradigm of the “Khorat Group” of the northeastern of Thailand and Southern Laos, where broad folding of opened anticlines and synclines is the major structure, is dominated the interpretation realm of any geologists who see with his owned eyes, the ‘Cliff forming” - near horizontal strata of Mesozoic Sedimentary rocks. The need for a large excavation and many more drilling and mapping and monitoring may be one way of exposing the geologic conditions. Actually the complete excavation of the area is the best way in obtaining the real geologic data and this is the case here at NN2.

Fig. 11 Major landslide in quarry development excavation due to concealed tight fold and thrust fault behind horizontally bedded cliff face

CONCLUSIONS

- Unsatisfactory performance of the asphalt faced rock fill embankment and cut slopes of the Lam Ta Khong Pumped storage project was attributed to the adverse properties of weak sedimentary rocks (claystone and siltstone) at project site which were underestimated during the design and construction. Lessons learnt from the project were valuable to the dam and rock engineers but it was too unfortunate to the owner.

- The lessons learnt from Nam Ngum 2 HP project proved that in the areas along the perimeter of Khorat Rock Group, the geologic structure of the rock formation can be very complex and they are easy to identify by any geological investigation program made prior to construction. The nature of weak sedimentary rocks in the rock formations make the rock mass in these zone to be of problematic conditions and behaviors in response to excavation and construction works.

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