Rock engineering service for unlined hydropower tunnels in Vietnam

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Abstract

In the last few decades, many hydropower projects have been built in Vietnam. Mostof the hydropower projects have tunnels with different length and width, constructed in different geological conditions, ranging from excellent rock mass quality in hard granitic rock environmenttopoor quality sedimentary rock formations, fracture/weakness zones, and etc. With thick vegetation and weathering cover, the amount of geological information during pre-construction phase is normally limited, so the tunnel design may involve lot of uncertainties, such as rock mass quality, groundwater, weakness zones, and rock stress. The uncertainties may require special competence and experience in rock engineering to deal with.

With a unique profile, SINTEF Building and Infrastructure (SINTEF) utilises its vast competence and experience in both hydropower and rock mechanics to effectively assist several hydropower project owners in dealing with the uncertainties, and SINTEF holds a good reputation within the hydropower industry in the country. The SINTEF services so far in Vietnam can be categorised in several groups:

1. Geological mapping for rock mass evaluation and recommendation of rock support;
2. Rock stress measurement;
3. Due diligence;
4. Working as advisor on special rock engineering issues;

Limited information in pre-construction phase means that estimation of the rock support is often preliminary based on different constructed projects with similar rock mass conditions. During construction, geological conditions are well exposed, and the rock mass can be evaluated in great details. In this situation, it is wise to carry out a detailed rock engineering evaluation in the tunnel in order to obtain the most appropriate rock support measures. SINTEF has successfully carried out such rock engineering services for several hydropower tunnels in Vietnam, and recommended appropriate rock support solutions. In two hydropower project, we proposed to change a tunnel from full concrete lining to an unlined tunnel.

As mentioned in the welcome message of the conference that "*The goal of Workshop is to promote the exchange, transfer of knowledge and experience on Rock Mechanics and Rock Engineering for sustainable development of this field in Vietnam*", in this paper, we present our experience in carrying out our services for different hydropower tunnels. Rock engineering challenges, technical and economical values added to the projects as well as benefits bringing to the project owners are also presented. This paper is an updated version of a publication in 2013 (Trinh and Grøv, 2013).

Keywords: Rock Mechanics, Rock Engineering, Unlined Tunnel, Hydropower in Vietnam, Norwegian Tunnelling Technology.

1. Introduction

Vietnam, a country with a population of approximately 90 million has 1,110 hydropower projects in operation with a total installed capacity of approximately 25 GW. The installed capacity of these operating hydropower projects varies significantly and ranges from just a few kW up to 2400 MW, the latter being the Son-La HPP which entered into operation on the 23rd of December 2012. Some existing large and medium scale (>100 MW) hydropower plants are presented in Table 1.

The geology of Vietnam is in short divided into five structural blocks: Northeast, Northwest, Truongson, Kontum and Nambo. The NE block consists of igneous rocks which have been found dating from the Early Paleozoic to the Quaternary. The NW and Truongson blocks are regarded as NW-SE trending Paleozoic folded systems filled with Paleozoic formations of thickness >12000 m. Precambrian strata are widespread in the Red River fault zone and Fansipan range in the NW block, and in the Kontum block. Archean rocks are found only in the Kontum block, which is regarded as a stable massif without Paleozoic sedimentary rocks. The Nambo block is covered with a very thick (>6000 m) sequence of Cenozoic formations deposited in a continental drift (Tran Ngoc Nam, 1995). As a tropical country, the rock in Vietnam is normally covered with in-situ weathered (soil) material.

Except the in-situ weathered soil and young sedimentary rock types, the natural circumstances described in very brief terms above are that areas with hard and stable rock mass do exist in Vietnam. Thus, they are well fit for the development of hydropower projects, and government of Vietnam has set out a master plan for developing hydropower potential. The master plan is updated from time to time. The most updated plan has been approved by the Prime Minister of Vietnam and dates back to as recently as 21st of July 2011. According to this plan, there are about 70 large, 38 medium, and a large number of small hydropower projects are planned to be developed during the period of 2011 to 2030, as shown in Fig. 1.Locations of existing large hydropower (>100 MW) in Vietnam are shown in Fig.2.

The design concept of hydropower projects in Vietnam is mainly based on a number of Vietnamese standards and sub-standards. In addition, some foreign guidelines are also available and can be used in situations where the local Vietnamese standards are not fully appropriate or in cases where new technologies are considered being required. A typical set of the design standards for a medium hydropower can consist of more than 20 standards covering many aspects of a hydropower project.

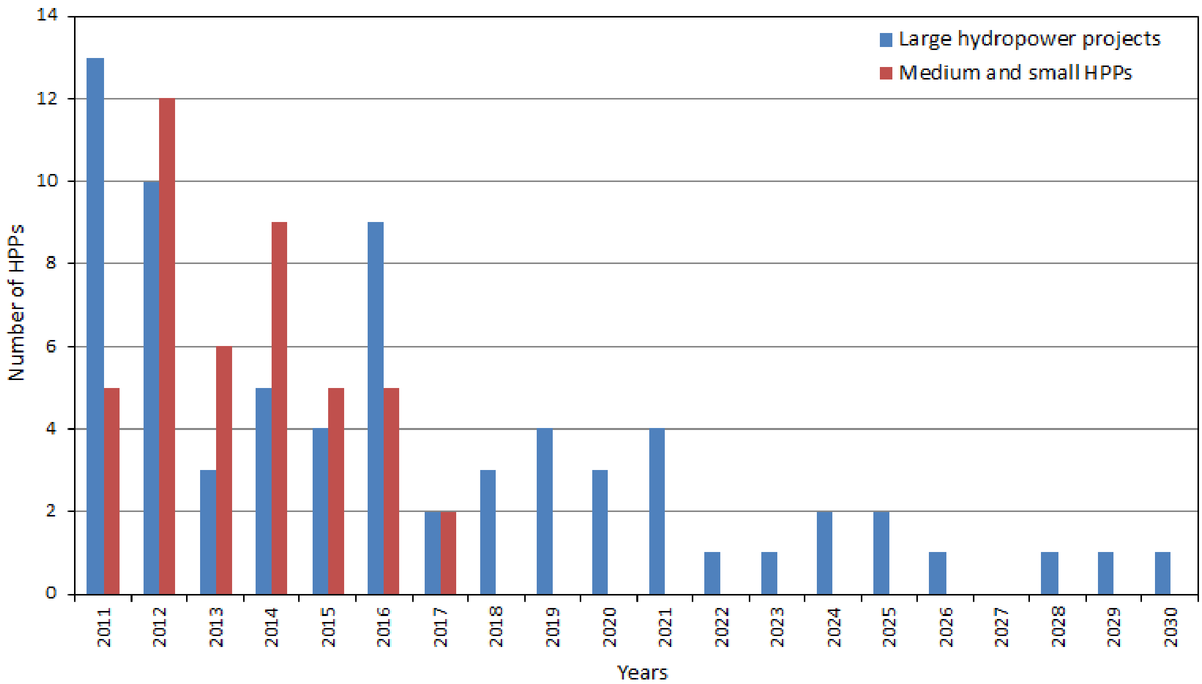

Fig.1.Planned number of large, medium and small hydropower projects that will enter into operation during the period from 2011 to 2030 in the "National Plan of Energy No.7".

Table 1Existing large and medium scale (>100 MW) hydropower plants in Vietnam.

No.	Name	Inst. P (MW)	Year of compl.	No.	Name	Inst. P (MW)	Year of compl.
1	Da Nhim	160	1964	13	Plei Krong	110	2009
2	Thac Ba	108	1971	14	Sesan 4	330	2009
3	Tri An	400	1991	15	Buon Kuop	280	2009
4	Hoa Binh	1920	1994	16	Ban Ve	300	2010
5	Thac Mo	150	1994	17	Kanak-An Khe	173	2010
6	Ham Thuan	300	2001	18	Song Tranh 2	190	2010
7	Da Mi	175	2001	19	Srepok 3	220	2010
8	Yali	720	2003	20	Dong Nai 3	240	2011
9	Sesan 3	260	2006	21	Son La	2400	2012
10	A Vuong	210	2008	22	Dong Nai 4	270	2012
11	Dai Ninh	300	2008	23	A-Luoi	170	2012
12	Song Ba Hạ	220	2009	24	Ban Chat	220	2013

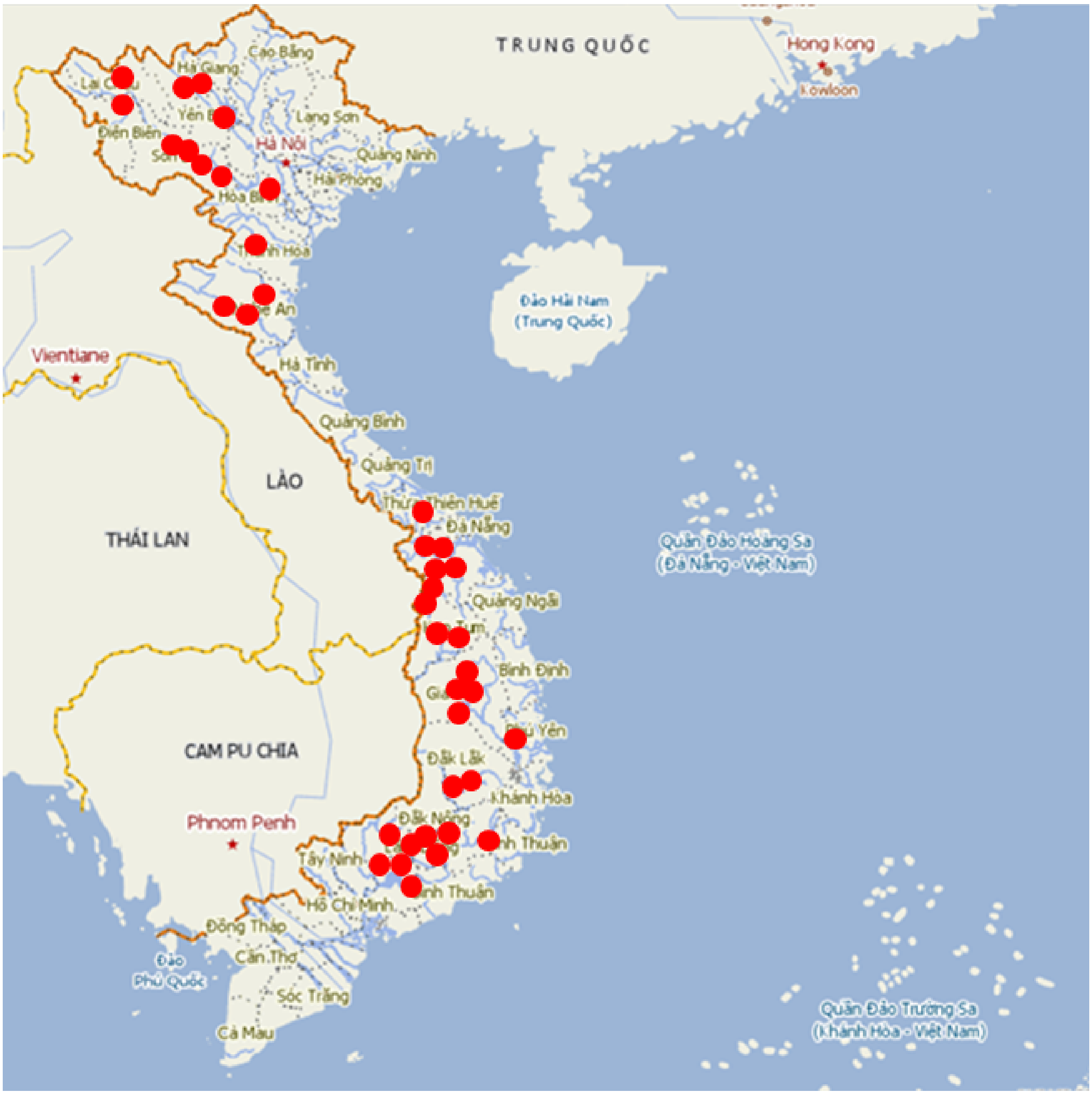

Fig.2. Locations of large and medium scale hydropower projects in Vietnam, i.e. projects with installed capacity larger than 100 MW.

2. Introduction of the Norwegian concept for hydropower projects in Vietnam

Norway is known for favourable conditions for developing hydropower with relatively high topography located near to the sea, and high annual rainfall. During the 50's to 70's of the 20th century, the hydropower was extensively developed in Norway to exploit its great potential. Today, in Norway more than 99% of a total annual production of 125 TWh of electric energy is generated from hydropower. Some significant achievements in hydropower tunnelling in Norway are summarised below (Broch, 2005):

- Approximately 4000 km of hydropower tunnels have been excavated, since early 20th century;
- Of the World's 500-600 underground powerhouses one-third (200), are located in Norway;
- Unlined pressure tunnels and air-cushion surge chambers;

During a period of several decades following the 2nd World War a continuous development in tunnelling in Norway took place, Norwegian experience has since been extensively collected and systemised. Norwegian tunnelling technology can be characterised by cost effectiveness, flexibility to adapt to changing ground conditions, safe internal environment for the users, and preservation of the external environment (Broch and Odegaard, 1982).

The Norwegian hydropower concept was first introduced systematically to selected Vietnamese hydropower engineers who participated in the Hydropower Development Programme at the Norwegian University of Science and Technology (NTNU). This programme is tailored to fit the need of young international engineers within the field of hydropower development.

According to the introductory description, the MSc.-course in Hydropower Development at NTNU, known as the HPD programme, is a two-year long international Master's programme in hydropower planning. The first year consists of a series of 6 basic courses and a desk study of a relevant project where the students work in groups applying knowledge from the courses and conducting a pre-feasibility study of the development alternatives in a Norwegian water catchment. This involves learning how to combine techniques, environment and economy to secure success. The final year consists of four compulsory advanced courses in the autumn, while the entire spring semester is dedicated to the master thesis.

Since 1996 a total of 12 Vietnamese engineers have graduated from this HPD Programme. The students are given scholarships from NORAD (Norwegian governmental aid programme) to enhance development in some selected countries, and one of these is Vietnam. A part of the agreement is that these professionals shall perform their skills in their country of origin following graduation to MSc. As a direct result from this programme the Norwegian hydropower concept is gradually being acknowledged and applied in Vietnam. Through this programme Norwegian hydropower tunnelling technology has been introduced to young engineers. They again bring confidence in this technology to Vietnam to motivate it to be applied in the Vietnamese hydropower industry.

Norwegian experience in rock tunnelling has been brought to Vietnam through the knowledge obtained by the students from the HDP-programme described above. However, so far the knowledge of Norwegian concepts has been materialised in just a limited way in just three or four hydropower projects. The application has typically been limited to:

- Plan, design, and construct the headrace tunnels as unlined tunnels;
- Change tunnel design from concrete lined tunnels to unlined tunnels to reduce the cost implications and construction time;

Water conveyance in a high head hydropower project in Vietnam normally consists of 3 main components: low water pressure tunnel (up to e.g. 150 m head), a surge chamber/shaft and high pressure shaft (vertical or inclined) upstream a tunnel leading to open air power station. Construction of vertical or inclined pressure shafts appears to be the most challenging task and currently this is the main obstacle in improving the layout of hydropower projects in Vietnam.

Whilst in Norway, construction of shafts was earlier carried out with the use of the Alimak system (drilling and blasting platform climbing upward on a rail system). The Alimak system is today considered to be out of date in construction of hydropower shafts (and shafts in general) due to the inherent safety risk associated with the method. Implementing today's technology the construction of shafts can be carried out in a safe manner with the use of raise boring technique. Thus there are two particular challenges to be dealt with when implementing this technology in Vietnam:

- The available capacity of contractors in Vietnam in excavating vertical shafts is at present shorter than a length of 170 m;

- Shafts higher than 170 m will require international contractors. Such contractors are difficult to hire in this region of the world.
- The difficulty in finding a reliable contractor with a reasonable price level affects heavily the cost aspect of the shaft alternative. Thus, under such circumstances unlined pressure shafts become less competitive, the longer these shafts are the less competitive.
- One of the solutions that have been introduced is to divide the shafts into several sections of less than 170 m, but this solution requires additional access tunnels to these sections and thus increasing the total cost.

Another solution would be to apply TBMs or drill and blast tunnel with an even and steady inclination from the intake to an underground powerhouse with the use of air-cushion surge chamber. Such a solution may imply that the tunnel inclination becomes steep and thus requiring specialist contractors employing dedicated construction equipment. Such special requirements would affect the construction cost and time.

The application of Norwegian tunnelling technology will be described in more details in the following chapters. The chapter will discuss both technical challenges as well as economical brought to the project owners after applying Norwegian tunnelling technology.

3. Geological engineering and rock support for tunnels

As mentioned above, Norwegian tunnelling technology has been introduced to some hydropower projects in Vietnam, and probably the potential exists for increased influence in the Vietnamesetunnelling industry. It would be way too comprehensive for an article like this to enter into all the relevant details from these projects. Therefore, we have chosen to describe some typical examples herein and present some details from three projectson how and where Norwegian experience has successfully been applied.

3.1 Zahung HPP, 30 MW, H= 66 m, unlined tunnel L= 1.5 km

Zahung hydropower project is located in the central part of Vietnam, with an installed capacity of 30 MW. Its location is about 100 km west of Da Nang city, along the A-Vuong river. The headrace tunnel is a normal horseshoe shaped tunnel of 6 m width and about 1.4 km length. The tunnel is placed in a granitic rock formation with generally excellent rock mass quality. The tunnel had been designed as unlined tunnel following the Norwegian experience in hydropower tunnel. The design team for the project was headed by a professional who achieved his MSc-degree at the mentioned HPD-programme. An optimum cross section, rock cover and rock mass quality as well as rock support were designed accordingly.

The major part of the tunnel has been classified as "Good" to "Extremely Good" rock mass quality, according to the Q-system - see Fig.3. In this part of the tunnel, only scaling and spot bolting was needed for supporting the tunnel. In one particular section of the tunnel a weaknesszone was encountered. The weaknesszone was mapped and classified as having "Poor" rock mass quality and required rock support consistingsystematic bolting and 10 cm thick sprayed concrete reinforced with steel mesh. The construction was completed and put into operation in 2009. The remaining of the tunnel held typically good rock mass and was supported with occasional installation of sprayed concrete and rock bolts. Since the commissioning of the Zahung hydropower project it has been operating successfully without any problems or interruptions in operation. One year after operation, the tunnel was dewatered for inspection in 2010, and observation in the tunnel showed that the tunnel is in excellent condition, as shown in Fig. 4. The amount of rock fall in the 1.5 km tunnel was less than 1 cubic meter.

The Zahung hydropower owner recently constructed another hydropower project (Nam-Pong HPP, 30 MW) with a headrace tunnel of 4.5 km. With successful cooperation earlier, SINTEF was once again asked to provide similar service as for the Zahung hydropower project. In this project, not only a longer tunnel, but also geological conditions along the headrace tunnel are much more complicated. The rock mass along the tunnel is varying from "Extremely Poor" to "Excellent" quality. The "Extremely Poor" rock mass quality required heavy rock support during construction (SINTEF, 2012). A case of tunnel cave-in happened during construction. Despite of the geological challenges, the service was done successfully and the project was commissioned in November 2013. It has been in operation without any problem. The first inspection of the tunnel was done in 2014, and the tunnel showed no stability problem.

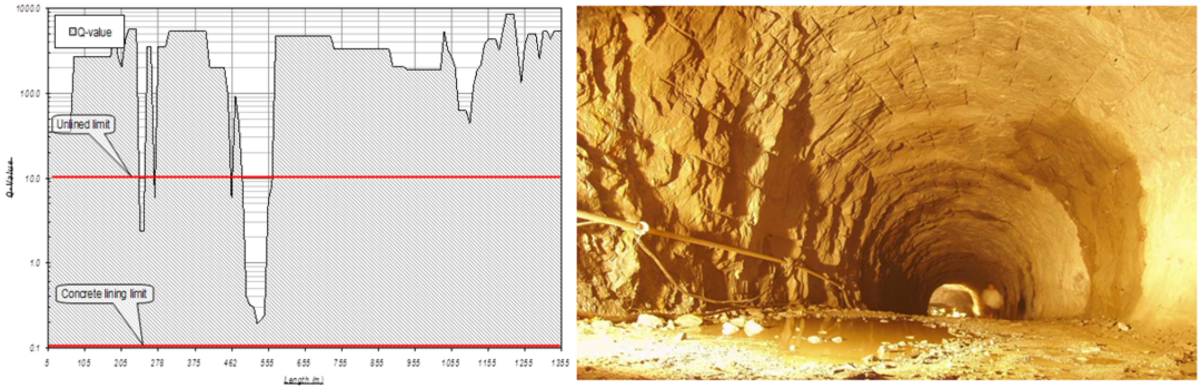

Fig.3. Q-value distribution along the Zahung headrace tunnel and a typical tunnel section with "Extremely Good" rock mass quality (SINTEF, 2008).

Fig.4.Excellent stable condition in the tunnel after one year in operation at Zahung HPP.

3.2 A-Luoi HPP, 170 MW, H=456 m, lined/unlined tunnel L= 12 km

This hydropower project is located in the Hue province in central Vietnam. The project has an installed capacity of 170 MW with average static water head of about 456 m. The head race tunnel is approximately 12 km long. The longitudinal section of the tunnel is presented in Fig.5. The project is designed to use Pelton turbines.

In the design stage, a section of 4 km tunnel (between adit 2 and adit 3) was designed as unlined tunnel in accordance with the Norwegian tunnelling concept. The remaining part of the tunnel was designed with concrete lining. During construction, it was found that the rock mass at major part of the tunnel was better than anticipated, thus SINTEF was invited to carry out tunnel mapping and rock mass evaluation. After a careful mapping program followed up by a detailed analysis and evaluation, a large part of the concrete lining was removed from the design.The Norwegian philosophy of unlined tunnel was adopted. Summary of the evaluation is presented in the next paragraphs.

It is noteworthy to study the last portion of the headrace tunnel which was excavated from two adits and holds a series of shorter vertical and inclined tunnel sections. This is indeed not a modern solution. A Norwegian design approach would have an even inclination from one end to the other end of the headrace tunnel with the possibility of avoiding several adits, or alternatively an inclined/vertical shaft with a full length being placed deeper into the rock mass to withstand the inner pressure without steel lining, associated with air-cushion surge chamber and an underground powerhouse complex.

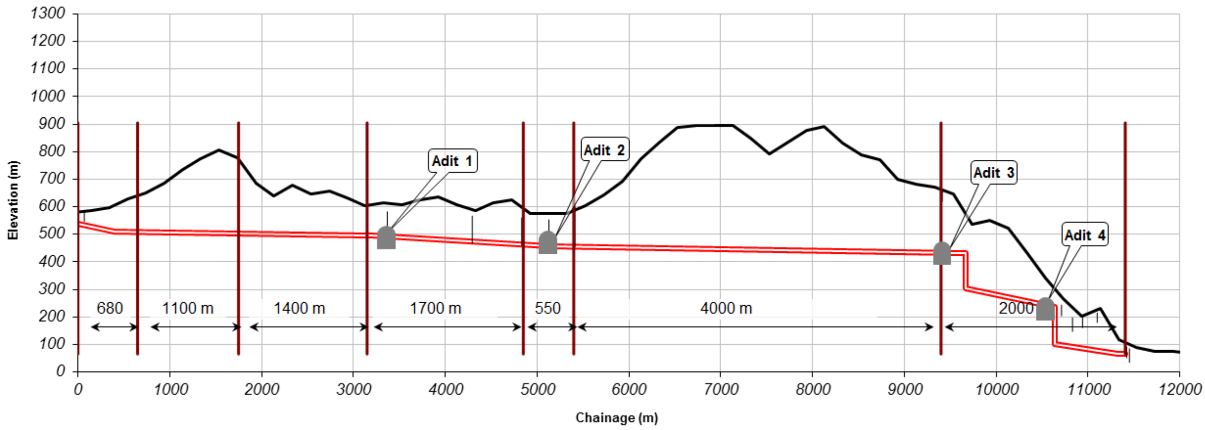

Fig.5. Longitudinal section of the A-Luoi HPP (SINTEF, 2011).

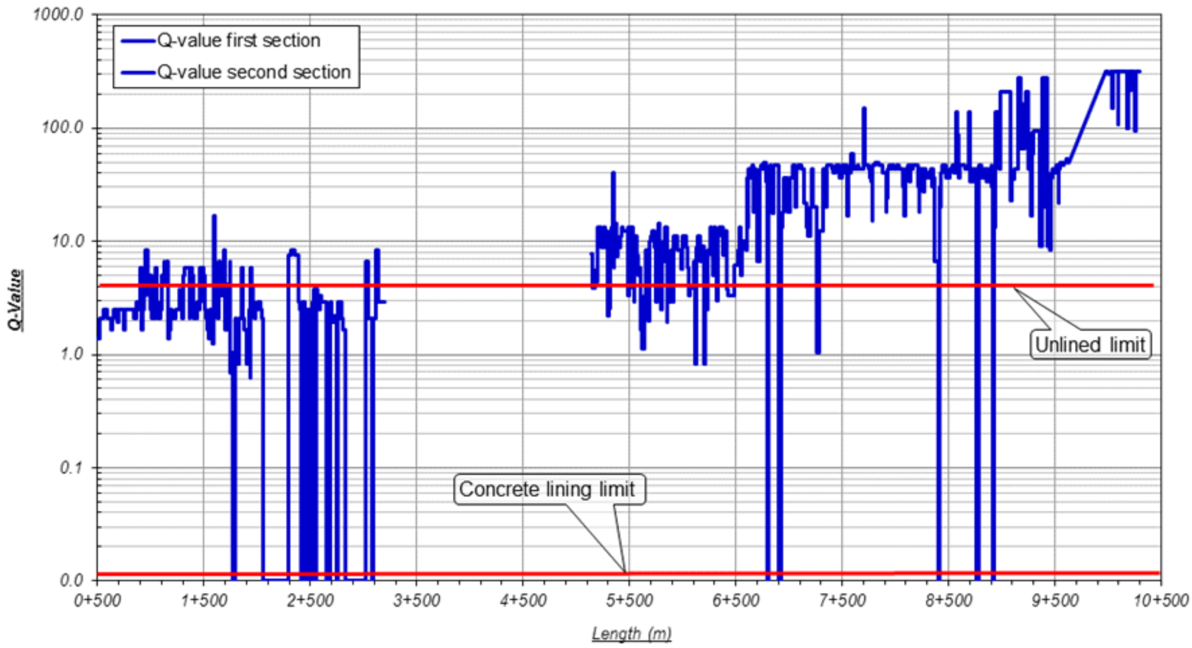

Fig.6. Q-value distribution along the headrace tunnel of the A-Luoi HPP (SINTEF, 2011).

The geological conditions along the tunnel are considered as complicated. The upstream half of the tunnel is located in sedimentary rock, and the second half of the tunnel (from about chainage 5000) is located in granitic rock. The geology in the tunnel was mapped and the Q-values are found in Fig.6. The rock mass quality in the sedimentary section varies from "Extremely Poor" to "Fair", whilst "Poor" rock mass quality was observed to be crushed and weathered rock. In combination with groundwater, this rock mass becomes very unstable. During construction spiling bolts and steel ribs embedded in shotcrete were used as temporary rock support in many locations to enable safe construction in these zones. The zones were permanently supported with concrete lining. In the "Fair" rock mass quality the temporary rock support consisted of scaling and spot bolting. The permanent rock support in the "Poor" to "Fair" rock quality was a combination of rock bolts and shotcrete. Typical conditions of the rock mass in this section are presented in Fig.7.

The second half of the tunnel is located in granite. The rock mass varies from "Fair" to "Extremely Good" quality. Preliminary and permanent rock support in such areas consisted of scaling and spot bolting. Several crushed and sheared zones were encountered with thickness varied from less than a meter to a few meters. Typical filling material in such zones was weathered rock and clay. The presence of groundwater was sometime associated with these crushed and sheared zones and caused considerablechallenges during the excavation phase. Spiling bolts and steel ribs embedded in shotcrete were normally used as temporary support in these zones whilst permanent rock support consisted of systematic bolting with steel mesh and 10 cm thick shotcrete were normally used. Concrete lining for permanent rock support was used to a limited extent in one single large weakness zone which yielded "Extremely Poor" rock mass conditions. Mapped Q-value along the tunnel is as shown in Fig.6. Typical conditions of the rock mass along the tunnel are presented in Fig.7 and 8.

By applying the Norwegian tunnelling philosophy, it was possible to reduce the construction costs, and the construction of the hydropower project was completed before schedule. The project was commissioned in 2012.

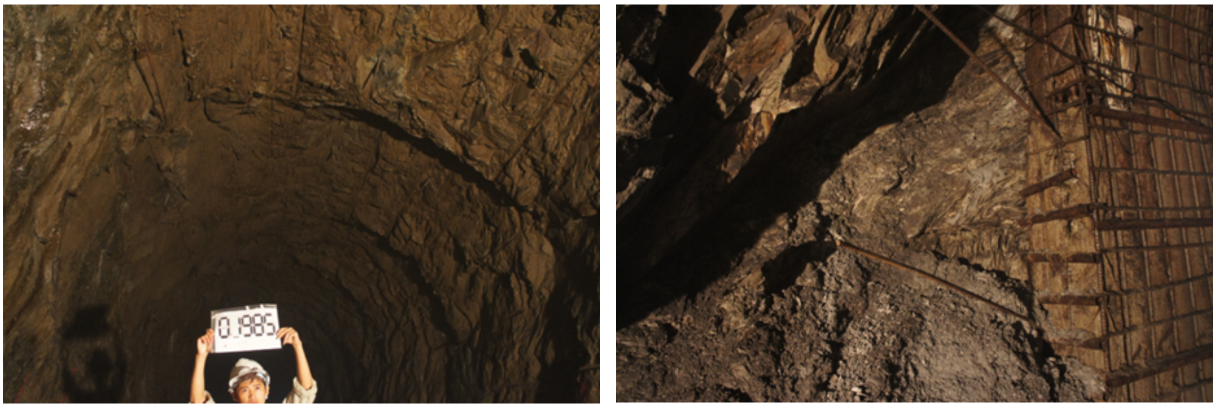

Fig.7. Typical "Fair" (left hand side) and "Extremely Poor" (right hand side) rock mass conditions (SINTEF, 2011).

Fig.8. Typical "Crushed zone" (left hand side) and "Extremely Good" (right hand side) rock mass conditions (SINTEF, 2011).

4. Special services

Recently, SINTEF has been invited to provide several special services for a large hydropower project. The project is under-construction with a complicated situation between project Owner and Contractor. Thus the name of the project cannot be mentioned. The provided services from SINTEF are briefly summarised below:

- Review the technical design for several underground works (headrace tunnel, vertical shaft, and underground powerhouse complex) made by the Contractor: using extensive Norwegian experience in hydropower tunnelling, SINTEF reviewed the design and provided necessary recommendations for improvement;

- Several trips for following up during construction with special assignment upon request from the project Owner: SINTEF's experts were called-inseveral times during the construction with special assignments for each field trip. The assignment was including dealing with averse geological conditions, performance of the construction equipment, and construction organisation;
- Stress measurements to identify full picture of the in-situ stress (magnitudes and orientations of the three principal stresses) at a key location: during the construction of this hydropower project, it was a claim from the contractor that the in-situ rock stress is low and leading to extraordinary rock support. The claim was up to about 100 million USD additional budget and 5 years of additional construction time. SINTEF was asked to carry out an independent rock stress measurement by using in-house developed technique and field equipment. The resultsfrom the rock stress measurementsindicated that the in-situ rock stress is sufficient, and based on this result the project owner decided to reject the claim;
- Performing a due diligence for a potential investor to the project;

5. Conclusions

With a unique profile, SINTEF has utilised a vast competence and experience in both hydropower and rock mechanics to effectively assist several hydropower project owners in dealing with different uncertainties, such as geological challenges, optimisation of the design work, obtaining important geological information and so on. Cooperation between SINTEF and different hydropower owners in Vietnam has been fruitful bringing convincing benefit to all involved parties, especially the project owners. By presenting this paper, we hope that the Norwegian experiences in tunnelling as well as underground technology in general can be promoted in Vietnam. Hopefully more project owners and contractors can get familiar with the Norwegian tunnelling technology and applied it to bring more benefit to them as well as to the Vietnamese society.

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