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Overcoming extreme tunneling conditions on Vietnam's longest tunnel

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ABSTRACT: Vietnam's Thuong Kon Tum Hydroelectric project is a 17.4 km headrace tunnel that will be the country's longest once complete. A section of the tunnel was excavated by a 4.5 m diameter Main Beam TBM in granitic rock up to 250 MPa UCS. Started in 2012, the project's original contractor left due to non-satisfactory performance. In 2016, the contract to refurbish the TBM and excavate the remaining 10.45 km of tunnel was awarded to a joint venture of Robbins and a local contractor. Robbins was fully responsible for the TBM operation, including supplying operational crews. The crew overcame massive granitic rock, fault zones gushing water at 600 l/s, and difficult conditions. In under two years, the TBM advanced from a standstill at 15 percent project completion to 85 percent complete. This paper will address the refurbishment of the TBM in the tunnel, the work to streamline operation, and challenges faced.

1 INTRODUCTION

The Thuong Kon Tum Hydroelectric Power Project is a 220 MW hydroelectric project located in the Kon Tum State, in central Vietnam. The power project consists, among other works of construction, of a 17.4 km headrace tunnel that will be the longest tunnel in Vietnam once completed. The project is located in the highlands of Vietnam, with very limited infrastructure and industrialization (see Figures 1–2).

The tunnel excavation started in 2012 with a section bored by a 4.5 m diameter Robbins Main Beam TBM designed for the granitic rock types expected (see Table 1). The remainder of the tunnel is being excavated conventionally.

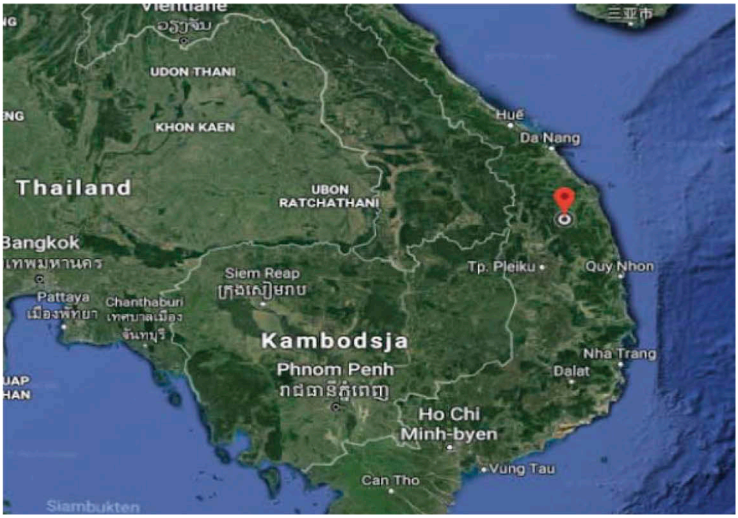

Figure 1. Location of Thuong Kon Tum project.

Figure 2. The Thuong Kon Tum job site.

Table 1. TBM specifications.

Machine Diameter	4,530 mm with new cutters
Cutters	17”
Number of Disc Cutters	30 (To be 30)
Maximum Recommended Individual Cutter Load	267 kN
Average Cutter Spacing	75.5 mm
Recommended Operating Cutterhead Thrust	8010 kN
Maximum Operating Cutterhead Thrust	13345 kN.
Cutterhead Drive	VFD Electric motors/safe sets, gear reducers
Cutterhead Power	1980 kW (6X 330 kW)
Cutterhead Speed	0 to 9.6 RPM

The geology of the project was described as a granitic rock type with strengths up to 120 MPa, however, the available geology of the project was very limited, due to the mountainous jungle above the tunnel which made pre-investigations complicated and expensive.

2 BACKGROUND

The tunnel excavation started in 2012, but after slow progress and non-satisfactory performance, the contract with the project’s original contractor was cancelled in 2014. The TBM had then excavated 2636 m in two years in the hard and massive granitic rock, with some zones having significant stability problems.

In late 2014, Robbins was invited to the site to inspect the condition of the TBM and auxiliary equipment that had been left in the damp and warm tunnel for months after the original contractor left the project. After the initial inspection it was obvious that the equipment was not maintained in a proper fashion during operation, nor had any protective measures of the machine been taken before it was left in the tunnel in a tropical climate, with the temperatures in the tunnel being above 30℃ and with a humidity above 90 percent. The combination of the previously stated conditions resulted in the TBM and its equipment needing considerable refurbishment before any boring could be restarted (Willis, 2018).

In addition, there was a severe lack of appropriate rock support in the already excavated tunnel, which needed to be properly supported (see Figure 3).

The condition of the tunnel and the TBM was summarized well in the inspection report written by Robbins Field Service Personnel in December 2014 (McNally, 2014):

> “As reported during our two (2) previous visits on the 9th August & 16th September 2014. There needs to be improvements with the facilities at site/camp.

Figure 3. Example of inappropriate rock support.

- Conditions in the tunnel were substandard & unsafe
- Visual inspection of the TBM/Back-up showed total lack of maintenance
- No preventative actions were taken in the protection of the major components before closure of operations

> Therefore, I must stress our concern to the likely possibility of major/catastrophic problems we may encounter during the repair/refit of the TBM & associated equipment."

In 2016, more than two years after the original contractor left the site, a joint venture between The Robbins Company and the Vietnamese contractor, Construction Joint Stock Company No. 47 (VH47) was awarded a contract to refurbish the TBM and auxiliary equipment and excavate the remaining tunnel. Robbins was fully responsible for the refurbishment and TBM operation, including supplying operational crews and eventually rock support in the tunnel as well. Construction Joint Stock Company No. 47 was responsible for the site operation, logistics, and rock support in L3.

3 THE REFURBISHMENT OF THE TBM

The refurbishment of the equipment started in mid to late March 2016 and included, among other works, the following:

- Inspect all machine components
- Overhaul hydraulic system
- Repair/replace all electrical systems, including VFDs
- Repair tunnel conveyor and tunnel conveyor E-Stop
- Inspect and repair motors
- Repair and commission rock support system
- Recommission guidance system
- Recommission all systems, including VFDs

In addition, VH47 had to overhaul the tunnel logistic system, ventilation system, and install appropriate rock support in the already excavated tunnel, as the installed rock support was not appropriate. VH47 also made significant efforts to improve the living quarters and facilities at site.

The original proposed refurbishment plan called for four months of refurbishments; however, the owner's production plan insisted on shortening this significantly by instead starting excavation with some work left to be done during TBM operations. The works of the refurbishment followed a strict schedule, which allowed for about two months of refurbishment work before the start of boring. The work was being performed simultaneously with the overhaul of the rest of the tunnel, and this made the logistics and planning important. As an example, the ventilation system and emergency systems were being repaired in the same period as the TBM, resulting in downtime during the TBM refurbishment. The TBM started boring in June 2016 after two months of intense repair work.

4 COMMENCING BORING AND OPTIMIZATION OF OPERATION

The boring commenced in mid-June 2016. In addition to the general follow-up on the machine and the continuous refurbishment efforts, a thorough review of the operation conditions and what could be done to improve the performance and safety at site was implemented. Some of the topics that were identified include:

- Improvement of the structure and organization at site, especially between the different stakeholders
- The rock support already installed in the tunnel was not appropriate and needed to be improved to allow for efficient operation in the tunnel
- Inefficient rock support scheme and rock support methods required by the owner and consultants hampered the production and needed to be revised
- The process of geological mapping and decision on rock support needed to be improved
- Hot and damp working environment on the TBM and Back-up hampered production
- Inappropriate processes for Health, Safety & Environment (HSE)

Some of the measures implemented were purely physical, such as installing water curtains, installing air coolers, running the ventilation through the night to reduce temperatures, etc., but there was also a big focus on aspects of operational processes. A detailed methods statement for the remaining refurbishment and the machine operation was developed. This included, among other aspects, a clear distribution of the responsibilities down to the lowest levels of the project, principle machine operation instructions in different rock conditions, new rock support methodology, new HSE plan according to Robbins international procedures, clear procedures for any operations with safety concerns, and employing a JV geologist team to work with the owner's geologists to make decisions and install rock support as efficiently as possible.

One of the most important features employed was a detailed analysis of the rock support methodology on site. The rock support methodology was defined in the initial contract and was based on a conservative approach to the Q-system (NGI, 2015). This included systematical bolting and shotcrete in all rock classes. Upon evaluation of rock support classes an agreement of a new support methodology was agreed upon. This included quick conclusions on temporary rock support installed in the tunnel by a team of geologists and a revised support scheme based on a less conservative approach to the Q-System. The rock support developed is a guideline for rock support in the tunnel. It is important to mention that the installed support was decided in the tunnel by a team of geologists (see Table 2).

When employing the Q-system with rock support classes in a TBM tunnel it is imperative to consider that the system itself is based on empirical data from Drill and Blast tunnels. As it is very likely that some of the support installed in a D&B tunnel in hard rock is there to compensate for blasting damage, a direct use of the Q-system itself for TBM tunnels is, by nature, conservative. This is important to consider with great caution to avoid misuse of the system and an inappropriate support being installed. (NGI, 2015)

Table 2. Rock support scheme for Thuong Kon Tum.

Rock Class (Q-System)	Q-Values	Rock Bolt (Qty/m)	Mesh (m^2/ meter)	Ring Beam/m	Shotcrete thickness (cm)	NOTE
A	>100	0	0	0	0	Spot bolting very occasionally
B	>4	0 – 4	0	0	0	Spot bolting as needed
C	>0.1	3 – 6	6	Strap if necessary With McNally	2 to 6 if required	Rock Support needed (quantities might deviate)
D	>0.01	0 – 14	10	Ring Beam with McNally System	6 – 12 (crown portion)	Evaluated case by case
E	>0.001	0 – 14	As required	Ring Beam with McNally system	12 – 15 (crown portion)	Evaluated case by case

Note: McNally System will be adopted to increase safety in the Tunnel

5 GEOLOGY AND ROCK SUPPORT

The geological baseline of the project indicated the vast majority of the tunnel being bored in a granite biotite which was described as relatively fresh and massive, although, with a limited rock strength. In total, the initial geological report described the occurrence of three geological classes (see Table 3, Geological Baseline Report – Kon Tum).

The encountered geology in the tunnel is a combination of granitic rock with a varying degree of gneiss features. The rock is generally massive with limited fractures, resulting in a high Q value and limited rock support needed. There are several stretches with practically no fissures and fractures. The rock is generally experienced as hard, but brittle (see Figure 4).

During operation, UCS testing of the rock was performed at representative locations in the tunnel. This was sent to an internationally recognized laboratory and the results can be seen in Figure 5 (Dahl, 2016).

The results from the testing show a very high rock strength in the majority of the rock mass with strengths of up to 260 MPa. The average rock strength is 194 MPa.

Systematical mapping of the tunnel was also performed according to the Q-system, which confirmed the massive rock conditions (NGI, 2015). The homogenous and strong rock mass is illustrated in high Q value. There were several open water-leading joints in the tunnel causing

Table 3. Baseline geology.

Classification	I	II~III	IV ~ V
Percentage Estimated (%)	10~15	70~80	10~15
Engineering Geol. Description	IIB rock, monolithic. Thick overburden, mostly over 400m	IIB~IIA rock, sub-monolithic ~ massive, inlaid structure. Overburden 200~400m	IB~IA rock, block cracking~ cataclastic, and chipping. Two ends of the tunnel and the places with faults 20m wide as influenced belt for Class IV faults, 10m-wide as influenced belt for Class V faults
UCS (Dry)	95.00–105.00	70.00–90.00	60.00–70.00

Figure 4. Example of typical rock conditions in the tunnel.

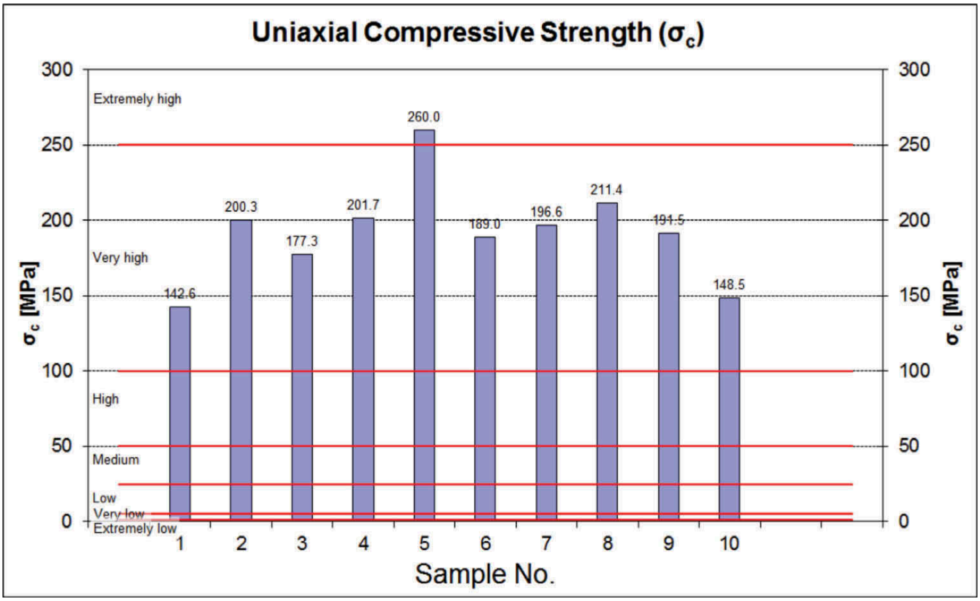

Figure 5. UCS values tested at international laboratory.

a relative massive total water ingress in the tunnel over the length. The Q classes for a representative part of the tunnel are given in Figure 6.

The above charts show that the tunnel has been excavated in a very hard and massive granitic rock type, with more than 90 percent being in rock class A and B. This also gives a clear indication that the majority of the tunnel can be unsupported or supported only by spot bolting.

It is also worth mentioning that even though there have been ground conditions that have deviated from the baseline geology, the JV and the owner have been working efficiently to find a solution on how to handle the geological conditions during the project.

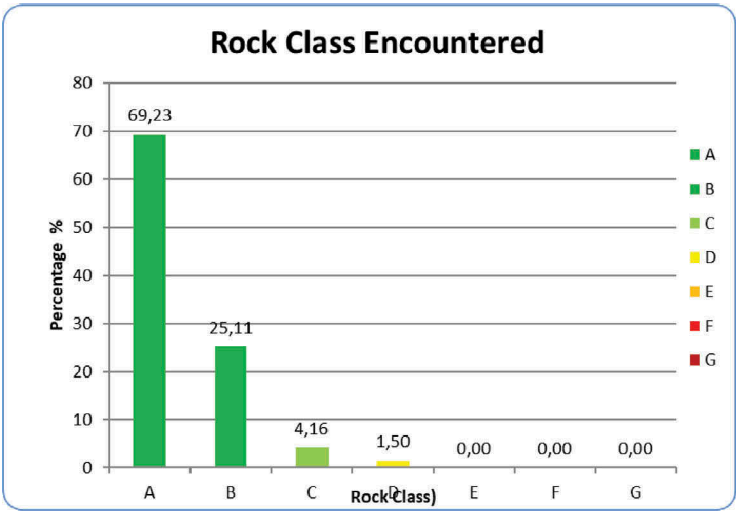

Figure 6. Rock class distribution as mapped by Robbins geologists.

This solution-driven approach has led to an absence of unsettled geological claims as the project is approaching its completion.

6 PRODUCTION AND PERFORMANCE

For the initial part of the project with the original contractor, the performance was not satisfactory with an average production rate of 120 m/month. In addition to the low production, there was a significant lack of maintenance. The lack of maintenance and the unprotected storage of the TBM and equipment in the tunnel caused damage to the machinery that limited the production on the project overall, due to more time being spent on repairs and maintenance than normal. This has especially been relevant to general maintenance, the cutters and cutterhead, and the conveyor system.

Based on the condition of the equipment and the geology, the site organization made a detailed plan for the excavation of the rest of the tunnel, with planned maintenance and down periods. This planning helped to achieve a steady production on the project, which seemed

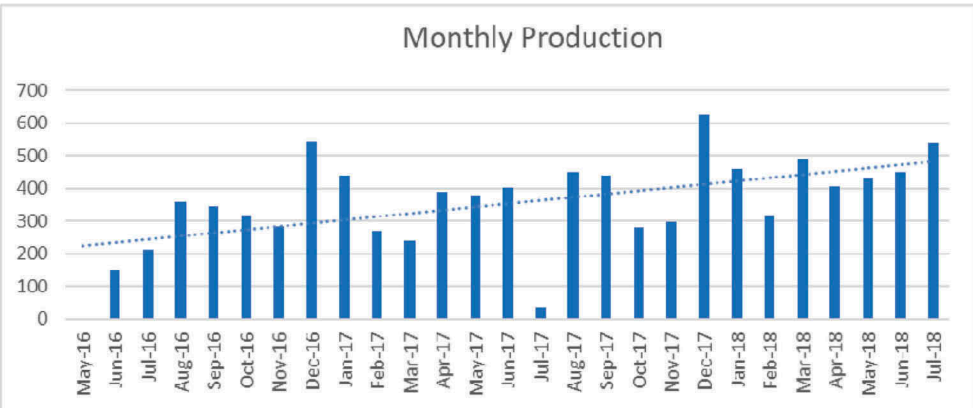

Figure 7. Monthly production.

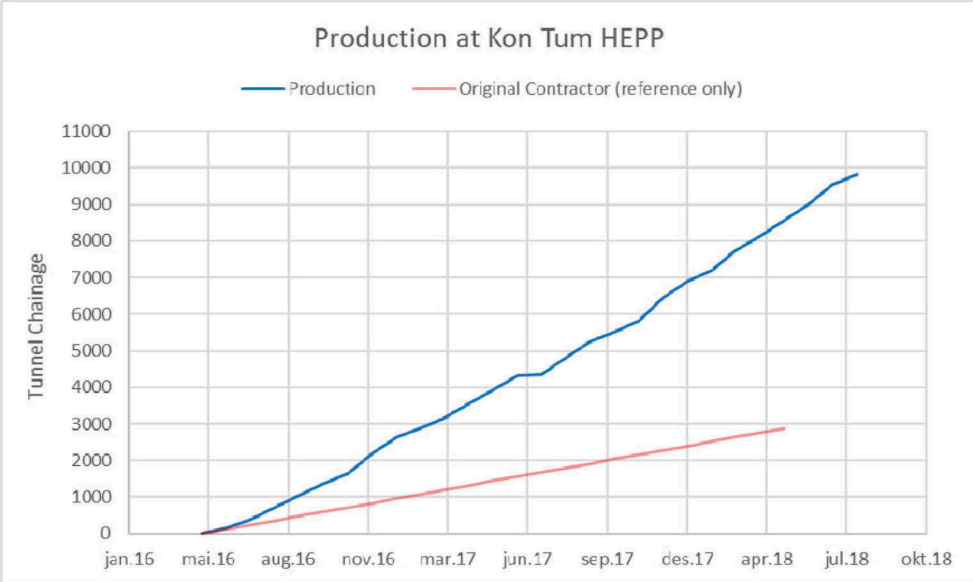

Figure 8. Production chart and comparison to production in 2012–2014.

impossible at earlier stages of the project. Planning also included the remaining refurbishment of the system, which accounts for some of the lower production in the early months and the positive trendline in the production chart (see Figure 7).

The average production of the project after May 2016 until September 2018, with less than 500 m left to bore, has been about 380 m/month. This includes significant maintenance and advancing through adverse fault zones, which has required pre-excavation grouting. The steady production and vast improvement on the project is clearly visible in the production chart given in Figure 8.

7 DISCUSSION AND LESSONS LEARNED

The excavation of the headrace tunnel for the Thuong Kon Tum Hydroelectric project has been a very interesting project experience from an operational point of view. In the time before the operational contract with Robbins was signed, there were several discussions ongoing between the project owner, international consultants, and contractors on how to finalize the project within the time frame. Among the topics of discussion was the idea to employ a second TBM, replace the current TBM, go Drill and Blast, and/or change the cutterhead to 19”/20” cutters to better cope with the hard and massive rock mass.

After thorough inspection and evaluations, the JV committed to a production rate that would finalize the project in the given time frame. This included doing a thorough review of the operations at site, refurbishing the TBM and equipment, and replacing the current cutterhead with a 19”/20”-cutter compatible cutterhead. In hindsight, the performance proves that the correct decision was made at the time. When the operation restarted in June 2016 the performance was so satisfactory that a decision was made not to take the time to replace the cutterhead, even though the new cutterhead was already in production. This decision was made in consideration of the downtime it would take to replace the cutterhead that would have had a bigger effect on the completion date than the relatively lower production with the current cutterhead.

The experience from the project is a prime example of good and bad maintenance on a TBM and the effects this has, in addition to the importance of focusing on improving processes and making the TBM operate as much as possible. Considering the condition the equipment was in when Robbins took over operation, well-planned maintenance and a focus on a steady production has been imperative for the success of this project.

The results of the project give a proper reminder that tunnel excavation with a TBM is not a "push-the-button" solution. Even though TBMs have become more advanced and automated over the years there is still a big demand for skillful and experienced personnel. Proper training of the crews and supervision from experts at an early stage is still an important part of any TBM operation and it is not wise to forego this to save money.

One of the reasons why TBM tunneling is not a "push-the-button" solution is the material the machines are operating in. Geology varies in any rock mass and it is seldom exactly as expected. On this project, the geology was harder and more massive than what was known prior to the project. In hindsight, it is apparent that use of 19"/20" cutters should have been considered thoroughly due to the geology that was encountered. Especially in projects where the available geology is limited and over-design of the TBM is a cheap "insurance" if harder conditions are encountered.

Lastly, the rock support scheme on projects needs to be appropriately designed to be efficient with the technology of excavation. On some global projects there are set rock support schemes established as early as possible in the bidding phase. This is often based on some of the internationally recognized rock classification systems. In this case, the support scheme was based on a conservative approach to the Q-system, which specified a rock support scheme that was not optimized for TBM operation and made efficient operation challenging. It is important that the rock support methodology is considered with efficient operation in mind so that it can be an integrated part of the operation. The experience at Thuong Kon Tum also highlights the need for a standardized rock support system based on operation with a Main Beam TBM, as most of the current systems in use are based on D&B tunneling.

8 CONCLUSIONS

The experience from the excavation of the headrace tunnel for the Thuong Kon Tum Hydroelectric project reminds us of some obvious truths that sometimes are forgotten:

- A skilled contractor and knowledgeable crews are essential in any tunneling project
- Focus on planned activities and integration of maintenance in the planning stage is the best way to a steady production
- Rock support needs to be designed and customized to the excavation method and the specific TBM in cooperation with the contractor
- Improved processes and a clear focus on HSE has a clearly positive effect on production
- Even though the TBM is often blamed for low production on a project with sub-optimal performance, the TBM itself is rarely the cause

The project also shows us a few not so obvious reminders:

- Even TBM- related equipment that has been suffering from lack of maintenance and left in a damp tunnel in a tropical climate for two years can be put into operational shape
- It is possible to get a steady production from TBMs in very remote job sites with sufficient planning of activities

By September 2018 the tunneling machine had less than 500 m left before breakthrough. The vast improvement in performance has allowed the project to finish on time, which seemed like an impossible milestone less than 30 months ago.

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