

Tunnelling Journal

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Going like lightning

IN LAOS

In July, SELI Overseas set a new double shield excavation record of 1,005m in a single month at the Xe-Pian Xe-Namnoy Hydroelectric Project, in the Laos People's Democratic Republic. Amanda Foley visited the project during this record-breaking production period to find out how SELI Overseas and TBM manufacturer Terratec worked together to overcome challenges at this remote location



**Top: Hexagonal segments are cast at the on-site segment factory using Fama moulds
Above: The moving tripper conveyor efficiently loads the muck wagons**

AT THE END OF JULY, SELI Overseas passed the halfway mark on its 11.5km long low-pressure headrace tunnel for the Xe-Pian Xe-Namnoy Hydroelectric Project, in southern Laos, having completed 6,442m of the drive. Using a 5.74m diameter Terratec Double Shield machine, the contractor also smashed its previous single month production record – 816m at the Kishanganga Hydro Project, in India – achieving an impressive advance of 1,005m.

Having commenced TBM excavation in March 2015, the machine has faced a number of unique challenges while boring through the

region's mudstones, sandstones and siltstones, which have required the contractor and TBM supplier to collaborate closely over the course of the design, commissioning and operation of the machine.

Project background

The Xe-Pian Xe-Namnoy Power Company's (PNPC) US\$1.02 billion Xe-Pian Xe-Namnoy Hydroelectric Power Project is located in an isolated area of national park on the Bolaven Plateau, in the south of the Laos People's Democratic Republic (PDR), approximately 35km northwest of the provincial town of Attapeu and 80km east of the larger Mekong



Muck wagons are tipped directly into a holding area near the edge of the plateau for removal by main contractor SK E&C

River town of Pakse.

Formed in October 2012, PNPC is a consortium consisting of Korea's SK Engineering and Construction (SK E&C), Korea Western Power (KOWEPO), Thailand's Ratchaburi Electricity Generating Holding (Ratch), and Lao Holding State Enterprise (LHSE). SK E&C was awarded the engineering, procurement and construction (EPC) contract for the project, while KOWEPO was awarded the operations and maintenance contract for a period of 27 years. Ratch is responsible for the construction supervision.

The main components of the 410MW scheme include a large reservoir that is in the process of being formed via the construction of a number of dams and buried transfer conduits – combining the runoff from two neighbouring watersheds (see Figure 1).

From the new reservoir, an intake will draw water into a 13.7km long concrete-lined low-pressure tunnel (11.5km of which is being driven by TBM) to a vertical drop shaft and high-pressure tunnel; developing a head of some 650m that will be harnessed by four turbines at an open-air powerhouse at the base of the plateau, and released via a 6km long open cut tailrace channel that connects with the Xe Kong River (see Figure 2 on p18).

When commercial operations begin, currently anticipated in 2019, about 90% of the power generated will be sold to the

Electricity Generating Authority of Thailand (EGAT) under a 27-year power purchase agreement, signed in February 2013, with the balance going to Electricite Du Laos (EDL).

In January 2014, SK E&C awarded Italian tunnelling specialist SELI Overseas the subcontract to excavate the 11.5km TBM driven section of the low-pressure headrace tunnel, along with the construction and operation of the project's pre-cast tunnel segment manufacturing facility. SELI Overseas in turn placed an order with Australian TBM manufacturer Terratec for a 5.74m Hard Rock

Double Shield TBM – a first, as despite both companies being very active in Asia, they have not collaborated on a project before now.

TBM design

Being an experienced tunnel contractor, SELI Overseas had a lot of input into the TBM's design and configuration. This, combined with Terratec's expertise, has resulted in a robust machine with some unique features. "We had a lot of requests, in terms of adapting the equipment to fit our needs and what we wanted," says Dario Vizzino, Project Director for SELI Overseas. "There was a lot of back and forth during the design and manufacturing phases and during this process we developed a very positive working relationship."

The machine's cutterhead is dressed with 39 x 17in back loading disc cutters and features four large bucket openings. A 2000kW electric VFD main drive provides maximum speeds of 7rpm in harder rock zones, while delivering a torque of 8,000kNm to cope with a number of fractured fault zones anticipated along the alignment. In order to mitigate potentially difficult ground conditions within these fault zones, a high-power probe drill is also installed within the TBM, to conduct any drilling or grouting deemed necessary (see Figure 3).

Having selected the use of rolling stock rather than a continuous conveyor, for spoil removal, a key feature of the machine is the use of a tripper conveyor to fill the muck

Figure 1: Location and configuration of the project



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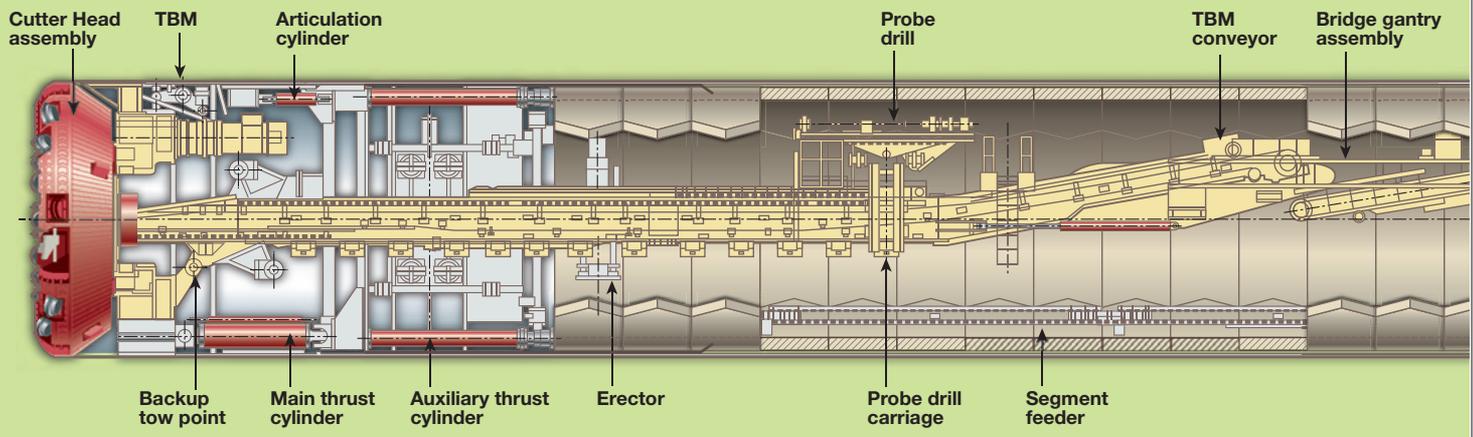


Figure 2: Configuration of the 5.74m diameter Hard Rock Terratec Double-Shield TBM

wagons. "The TBM conveyor empties onto the back-up conveyor, which then loads the [moving] tripper conveyor," explains Bill Brundan, Terratec's Site Operations Manager. "So the train can come into the tunnel and park, and the conveyor moves rather than the train. Actually it's a very good system, it makes the 60-minute process to fill the muck skips about 10 minutes faster, and so it just fine-tunes the production."

The use of pea-gravel to backfill the annulus behind the project's hexagonal segment rings also prompted some interesting design features, including a hydraulic lift within the pea-gravel bays on the back-up to lift and empty the gravel cars; and a double capacity pea-gravel pumping system to facilitate the anticipated advance rates of the machine.

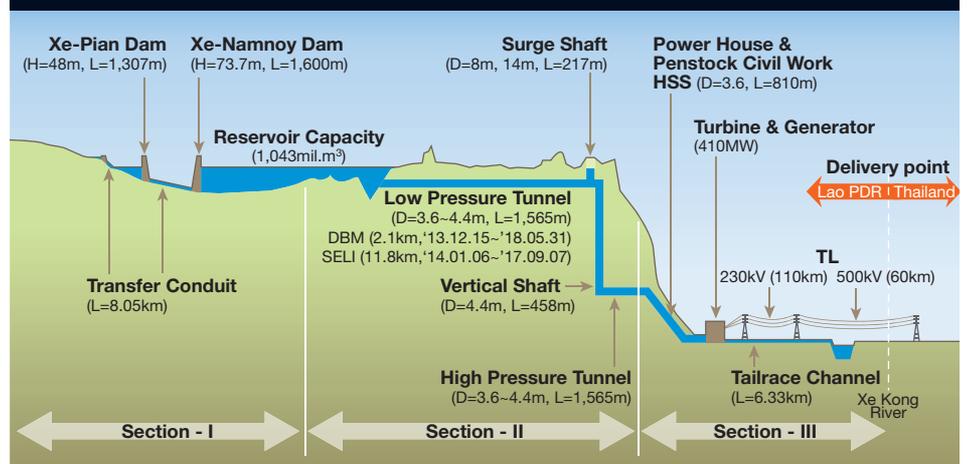
Among many other refinements, also included were a number of design modifications to accommodate the width of the segments, as well as a custom fabricated narrow gauge MineARC refuge chamber.

Project mobilisation

While key parts of the TBM were being produced in Australia and Japan, SELI Overseas mobilised on site in the summer of 2014 and began clearing and landscaping an area for the project's segment factory, as well as its site offices, workshops and accommodation buildings. The actual tunnel portal area is located a further 5km on from the main site, very close to the 650m cliff-edge of the plateau (see photo on p22). "There was only jungle here in the beginning," says Vizzino. "There was the [hard packed dirt] road, which was built by SK E&C four years ago, but that was it. We had to prepare everything you see here and we didn't have that long to do it."

Considering the highly isolated nature of the site, and frequent monsoons during the rainy season that often wash out the road, preparing the site in just under six months was no mean feat. With the nearest major hospital located five hours away on the other side of the Thai border, safety is also a concern for the project. There is no helicopter support

Figure 3: Main components of the Xe-Pian Xe-Namnoy Hydroelectric Project



available and, in addition to the standard risk of construction and road accidents, there are also a number of highly venomous snake species prevalent in this area.

After a tight assembly period at Terratec's facilities in China, the TBM arrived in Bangkok's seaport in the last week of January 2015. "From there it took about two days to transport the machine by road to the Laos border and then we started sending all the components up to site using five trucks a day," says Brundan. "As the cutterhead is formed of two pieces [to facilitate disassembly at the end of the drive], the largest component was the cutterhead support at about 60 tonnes."

By mid-March the TBM was assembled on the edge of the plateau and ready to commence excavation. Originally, the machine was to be advanced through a 500m long drill and blast adit to the launch chamber on a 500m radius curve. However, a last minute realignment reduced that radius to 300m. "We had to keep a specific distance from the drop shaft, so SK E&C had to change the angle of the entry point," explains Vizzino. "But the TBM was already in production when that decision was made."

Rather than redesign the backup, it was agreed that SELI Overseas and Terratec would

find a way to make the machine fit around the curve somehow. "And we did it," says Brundan, "but it did cause some problems, particularly in terms of the TBM conveyors."

Another issue at the beginning of the drive was the challenge posed by fluctuations in the power supply to the TBM, which was having a significant impact on the machine's progress. "It was initially suggested that the TBM's transformers were the issue, but we had good support from our component suppliers and we were sure that wasn't the case," says Bruce Matheson, Terratec's Sales and Marketing Director.

SELI Overseas and Terratec therefore spent a lot of time working together to find a solution to the issue and Electricité du Laos (EDL) offered a window of time that provided the least amount of draw on the electrical grid, between 1am and 5am, when they could provide the best power supply possible. "It still wasn't good," says Brundan. "We were going up to specification on the voltage drops, and it wasn't really resolved."

"By this stage we were pretty sure the problem was coming from the main power grid," says Matheson. "So we brought in some pretty high-tech datalogging equipment to monitor the supply coming in and all its qualities." Terratec eventually proved its case

and an order was placed for five Cummins 800kv generators, which arrived on site in July 2015. "Things immediately got much better with the more constant power supply and we started to get some good production rates," says Vizzino. "The generators have worked really very well for us ever since then."

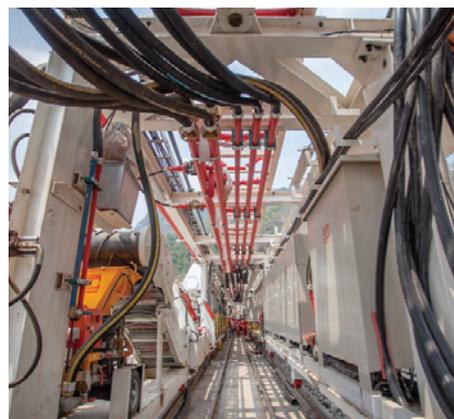
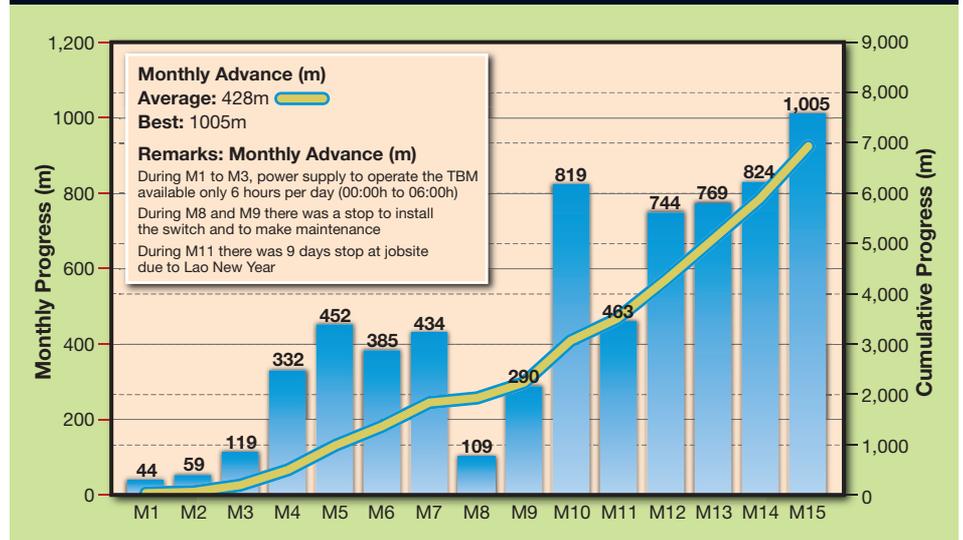
As a result of the delays caused by the power issues, SELI Overseas made the decision to add an extra shift and now works three eight-hour shifts during the week, with two 12-hour shifts at the weekends. "So when we finally started getting good production, we found we were suddenly getting very good production," says Vizzino. "In the last three months alone we have done 2.5km. Recently we have been averaging about 33m per day and we hope to reach 1,000m of production this month. Our best day so far is 50m with a best shift of 21m." (See Figure 4)

With a scheduled completion date of June 2017, the team is currently running about three months ahead of schedule. "At the moment production is very high. I don't want to assume we will carry on doing 900m or 1000m per month, but as we only have 5km left to go, it's safe to assume that 600m or 700m per month will be fairly easy to achieve," says Vizzino.

Segment production

As the TBM progresses it installs hexagonal lining rings that consist of four 250mm thick and 1.5m wide steel reinforced segments with concave and converse longitudinal joints that, along with the tunnel, were designed by Italy's Ingegneria Geotecnica (IG). These are produced at the onsite segment factory located next to SELI Overseas' main site complex. Following the six-month site mobilisation period, the first ring cast for the project was in December 2014, "but we

Figure 4: Monthly progress rates ending with July's record-breaking 1,005m



Italian tunnel precast lining and gasket specialist Fama, with two hours of prep time before curing. All materials are provided by SK E&C, including the cement, additives, and steel rebar, which is welded into cages at the factory. By the time TJ visited the site, this July, SELI Overseas had produced 7,500m worth of segments to date, with 1,000m of segments kept in stock. In addition to storage at the factory, there are also two different segment areas at the portal site, one close to the portal for loading onto the trains and one behind the portal area. This means SELI Overseas is continually moving the segments.

didn't go into full production until February 2015," says Vizzino. "Now we are producing 24 rings per day."

The segments are steam cured for four hours, using four sets of moulds supplied by

"Initially, we were worried about all this transportation and movement, from the production to the stock areas, but the segment quality is very good and we aren't seeing any fractures or cracks at all," says Vizzino. "The portal area is 5km away, so we

have to truck them down a steep slope, which is about 5-7% grade. The segments are big, with each ring weighing 15 tonnes, and we have had some issues, especially during the rainy season when the road can get pretty bad. But we have enough trucks, and plenty of storage, so now we keep to one ring per truck for safety."

Above: The backup during TBM assembly on the plateau with the pea-gravel pumps on the left hand side

Left: Segment installation within the rear of the TBM



Tunnel construction

For such a long tunnel, it may be surprising to some that SELI Overseas decided to use rolling stock rather than a continuous conveyor to remove muck from the heading on this drive. However, as Vizzino explains, there are benefits to both approaches: "It depends on the situation. It's true that the investment cost is lower for rolling stock, but the delivery and assembly time is also much faster. In this case we did a comparison between the two and

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the result was much the same, so we went with trains." The other benefit is that you end up with quite a flexible solution, as you can always add another train to increase capacity. "With a conveyor system, when that conveyor is going as fast as possible, you can't change that. So if the TBM is flying, you're still limited by your maximum conveyor speed, but there is some flexibility with the rolling stock."

At the time of *TJ's* visit, SELI Overseas was using three sets of Schöma locos, each pulling a heavy train consisting of 18 cars – one car for personnel, two pea gravel cars, four cars that carry two rings of segments (weighing 30 tonnes), and 11 muck wagons. The rolling stock is primarily manufactured by Palmieri, with design input from SELI Technologies, but also includes the custom-made pea gravel cars, which were fabricated by Italian manufacturer ELEA.

An innovative set-up at the portal area sees the muck cars unloaded with a hydraulic tipper directly into a muck bin. "Our scope of work ends when we unload the cars, it's in the contract that SK E&C takes away and disposes the muck," says Vizzino. "Initially, they used the material to extend the portal area. But now it's only used to maintain the access roads, which is good for us, because the roads need a lot of upkeep, especially during the rainy season."

As far as excavation goes, the rock encountered so far has primarily been limestone, mudstone, siltstones and sandstones with an average Unconfined Compressive Strength (UCS) of somewhere between 70MPa and 130MPa; and, despite an area of hard limestone (200MPa) at the beginning of the drive, cutter wear has been good and much less than expected. "The most recent data says we are excavating about 480m³ of rock per cutter," says Vizzino. "At the beginning [in the limestone] there was a period where we broke a lot of cutters, but now the rate is very consistent."

Mining through the fault zones has also gone better than anticipated. "Of course, the rock has been weak, Class 4 and sometimes Class 5, and we have had some water. But that hasn't been an issue for the TBM," says Vizzino. "The only real problem we had was large boulders in the fractured ground. We had to slightly modify the openings of the cutterhead by welding in some grizzly bars to prevent the boulders falling down onto the front conveyor and breaking the belt." Despite this, progress remained high, with 800m achieved this June whilst passing through the largest of the anticipated fault zones.

Following segment erection, SELI Overseas



TBM assembly at the portal area, close to the edge of the Bolaven Plateau



also saves a lot of time. The cost of the clogged pipes is one thing, but it's the time that you waste changing the pipe that is terrible."

Completing the drive

Looking forward to the remainder of the drive, logistics will likely be the main challenge ahead. SELI Overseas already has another Schöma loco and rolling stock set on order, which is due to arrive in October, to cope with the ever-increasing travel times to the heading. In July, the journey

was approximately 30 minutes, but this will more than double towards the end of the drive. "We will also need a new switch. We already have a mobile California switch behind the backup," says Vizzino. "But we decided it was better to separate out the activities in the end. However, at the moment we are still only at the first kilometer and it's taking a lot of time, due to the people. It's difficult to manage the locals in this activity, so moving forward we need to increase the number of expatriates we have working on this."

There were also some quality issues with the backfilling at the beginning of the drive. At present, pea-gravel is pumped into the annulus at 10 and 3 o'clock, and if required – depending on the ground conditions – topped up at the invert and sometimes the crown. From the outset, SELI Overseas specified a high-capacity pumping system for the backfill – including twin sets of Aliva compressed air pumps and compressors – knowing from experience that the doubled system would be required if progress rates were high.

However, crushed aggregate was being supplied to SELI Overseas as the backfill material rather than smooth river gravel. "We had problems with the pumps, problems with the pipes. It wasn't washed, so the fines were clogging everything, and it just wasn't working," explains Vizzino.

So the switch was eventually made to river gravel. "Using real pea-gravel is so much better. You pay a lot when you buy it, but it

At present, Vizzino estimates the drive will likely be complete in March 2017. "That is very possible, if you consider 600m per month. The Terratec TBM is very powerful and it is performing very well. I think it is proof of the quality of the TBM, the team, and also all the systems that we chose for this project. Of course, you can always improve production, so I think we can even do more than 1,000m in a month, I think we could reach 1,200m if rock conditions continue this way, it's possible."

The tunnel drive is due to finish under the plateau, 2km short of the new reservoir intake, in a TBM disassembly chamber that has already been excavated by SK E&C's Thai drill and blast subcontractor. Following breakthrough, the machine will be dismantled there and the components will be brought all the way back through the tunnel. "Logistically, it will not be easy and we will have to plan it very carefully," says Vizzino.