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Picking up the pace

How two open TBMs are tackling Mumbai's weathered rock to help improve the city's water infrastructure.

Picking up the pace

Overcoming geological and pandemic-related challenges, two open TBMs are tackling Mumbai's weathered rock to help improve the city's water infrastructure. Here Nicole Robinson spoke with Patel Engineering this summer about the first part of its drive on the Amar Mahal II project

Like many cities worldwide, the infrastructure providing water to Mumbai is as much as 100 years old, and hasn't managed to keep pace with the city's growth, and it certainly has grown. In fact, there are few places in the world as populous or dense as India's largest city and as can be imagined this makes for complications when constructing new infrastructure. In parts of central Mumbai and its suburbs, utilities are managed by Brihanmumbai Municipal Corporation (BMC) and it faces issues with leakages as well as the potential for contamination due to the area's outdated water pipes.

Among the BMC's many solutions is the Amar Mahal I and II project, comprising two water supply tunnels totalling 14.8km.

Contractor Soma Enterprise Limited is doing Amar I project (9,452m of boring) and Patel Engineering Limited has the contract for Amar II (5,350m of boring). Both contracts are using new 3.2m-diameter Terratec open TBMs.

Rocky circumstances

There were initial concerns about the project's geology that came from an earlier tunnel on the BMC's wider scheme. In this instance a different TBM faced issues with the rock turning to more of a clay and settlement occurred. Fortunately, the boreholes along the Amar Mahal tunnel alignments have shown the project team this is unlikely to happen again.

"As it's an open TBM, we were concerned about the contractor having to spend a lot of time on rock support," says Bill Brundan, Terratec operations manager. "We planned for rock support equipment, but actually the geology has been better than hoped for, so less rock support than expected has had to be applied."

Ground supporting equipment includes a fixed probe drilling unit, two rock bolting drills and a steel arch erector. The contractor is carrying out probing every 50m as a contract requirement and so is by now very familiar with the probing protocols.

There are a few areas where the geology changes from a harder basalt to one that's more weathered. "The cutterhead buckets start choking with material, this dries and hardens and requires intervention at times to keep the buckets clean and the machine mucking optimally," Brundan explains.

The team made steady progress regardless. Throughout the drive there were small, 1m to 2m changes in the rock, which were comfortably managed by the TBM operator. "Every metre of the tunnel is different ," says Mehul Parekh, project manager for Patel engineering. "There are always geological surprises in tunnelling."

This proved very true with a cave in of very fractured, hard rock in late 2021. The incident happened approximately 2,300m into the drive when rock started falling onto the TBM, creating a cavity of around 15 to 20m in diameter and around 100m in length.

"Suddenly there was this rock fall on the machine, putting the men in the tunnel at risk. The fractured rock came in from the sides of the machine too," Parekh explains.

"It's very difficult. Geological investigations can't give you 100% of the conditions you will encounter. And while we have probe drilling arrangements to predict the rock, that can only help

The finished 2.5m i.d tunnel will connect Parel to Hedgewar Udyan, through the Amar Mahal I contract. The second contract continues the tunnel to the Trombay Low-Level Reservoir and connects further on to the Trombay High-Level Reservoir (Figure 1). The client required open TBMs for the two tunnels, because at depths of 80 to 90m, the tunnel alignment stays mainly in competent basalt rock.

up to some percentage."

The Patel team spent around a month cleaning out the TBM and preparing the site to ensure no workers would get injured. The rock kept falling as the team started grout injections, and along with concern for workers' safety Parekh started to worry about settlement, too. "It's a very hard rock. It's not a sludge or a mud and it's very difficult to handle."

They used steel ribs, manually erected, to help safeguard the soffit.

With an eye on the schedule the team wanted to get the TBM moving as soon as it was feasible. However, with a cavity at least 5m in diameter and a 3.2m-diameter TBM, the machine's grippers couldn't be used to thrust the machine forward. "We made some manual arrangements like concreting on the sides and wooden planks for the grippers to use to move ahead," Parekh explains.

"Otherwise we would have had to wait at least a week to do the full concreting of the cavity so that the gripper could take the load. It was very time consuming and very difficult to do because we didn't have enough space to do all of this work."

In the end the contractor used around 800kg/m^3 of foam concrete grouting to fill the cavity left by the overbreak. Though the tunnel's small diameter continued to prove challenging. Parekh adds, "with a larger diameter TBM you have more space to do rib erection, rock bolting or other measures."

By January the team was back to normal boring, still manually erecting the ribs. "We have the rock bolting and rib system installed on the machine but unfortunately we can't use it because both features are below the shield and rock keeps falling behind there."

He explains doing rib erection when in the normal conditions is five times faster, and also easier on the crews. Despite this, the team has been making solid progress.

This January the TBM did a record boring of 653m in one month, a big accomplishment in such a small diameter tunnel. "We're proud of that," Parekh says. "We have completed the tunnel boring within our contractual obligation despite having two months of delays due to the geological issues, as well as the second COVID-19 lockdown."

The Terrratec TBM in the factory

Shaft rotation

The contractor completed its first drive of 3.5km in early May, breaking into an 11m-diameter circular shaft. In just a month's time they dismantled, rotated, reassembled and restarted the TBM for its next drive. Considering the weight and length of the machine's main components – the cutterhead, the bridge area and the conveyor system – to lift and rotate the TBM in the shaft Patel would need at least a 500t crane at shaft top with a minimum 110m boom. Beyond the space constraints of deploying such a large crane in a crowded city environment, in Mumbai – much like other cities worldwide – there is a shortage of availability for specialised lifting services. Patel decided to design its own turntable that can accommodate the TBM components, with a minimum of 70t, the weight of the cutterhead. Using external jacks, they were then able to rotate the TBM 108 degrees to relaunch the machine. The contractor has used

The cutterhead being lowered down the start shaft

Work progresses along the rock tunnel

this turntable method on other tunnelling projects in India, but never with such a heavy TBM, nor such a small diameter shaft. Other measures to prepare for the rotation included welding wheels on the machine and cutterhead, and creating a temporary support system for the bridge area. The team knew there was a risk of the welded plate breaking but worked slowly to ensure the process was safe and successful.

"We took everything one by one to rotate the three main components and that was the most difficult part," Parekh explains. "It took us close to 10 days. Then we need to do the reassembly. We were working in a shaft 100m deep and only 11m in diameter and there are many space constraints. This team has achieved a very difficult task in just 40 days."

While they performed this rotation in the shaft, the contractor and Terratec staff also undertook maintenance on the TBM to prepare for the second drive and the final 2km of the Amar II tunnel.

The Patel team has implemented several lessons learned to maintain their progress on this next drive. On the first drive they were losing time to cutter changes and worked with Terratec to start changing the entire cutter unit rather than getting accessories delivered in and doing it in house. Facing issues with temperatures, they've also added a chiller plant to the site, and by increasing the RPM of the cutterhead, TBM progress improved.

"The learning curve at the beginning of a project with a machine like this can be longer than with a shielded machine because of the unknowns of the geology," Brundan says.

"It's a case of everyone learning the machine and once you get to grips with the machine, you get results. That's been proven here doing 30m per week at the beginning and then doing 653m in a month. That shows the learning curve really well."

Patel started its second drive in late May.

Mental health challenges and support

Of course COVID-19 created myriad challenges for the project over the last two years. The machine assembly started in lockdown in 2020, requiring a swift transition to online communications for Terratec and Patel as they started up the TBM. It also reduced the availability for specialised consumables the team is used to buying in the local market.

"The government diverted all the oxygen cylinders to the hospitals, and for the welding work we needed to do this slowed progress," Parekh explains. "We were able to get electric welding machines that were available, but rates are three or four times more expensive and work speed is very slow and not as required."

They also struggled to get workers onto the project while the government conveyed its message to stay home to stay safe. "Everyone was frightened," he says. "We had to help people with their mental health. We also had a medical centre testing people, as well as providing food so no one needed to go out. There were many other arrangements we had to make to run the project, other than the normal tunnelling activities."

Along with taking care of the workforce, Patel is also taking care of its neighbours alongside the project as well. "When you're in a dense city like Mumbai, you don't get all the space you need for a project. There is a limited capacity for how much muck can

Teams celebrate the breakthrough

be stored on site and there are traffic restrictions on when we can remove it."

Everything needs to be synchronised or TBM mining has to stop and wait for the muck to leave the site before starting again. Most of the muck removal happens during the night shift when there is less traffic and fewer restrictions, and there is a designated team that only works on this part of the project looking after the dump trucks.

There were similar challenges when the crews started to excavate the shafts, which included blasting when the excavation reached rock after about 5 to 6m of fill. There were many buildings within 15 to 30m of the blasting area. "We did controlled blasting and used the minimum loads we could to get the desired results, but people still feel like it was an earthquake."

Parekh and his team did a lot of community outreach to help the local residents understand why they were blasting and how minimal the impact actually was. "The vibrations we measured were less than a heavy bus going past the buildings," he says. "We were allowed to be in the normal range, which is 2.5mm/s, and we were maintaining rates of less than 1."

With the TBM making good progress on the second drive the team will also start work this summer for the tunnel's in situ lining. Patel is using a 30m, hydraulicly actuated tunnel gantry system to line the 3.2m-diameter tunnel for its 2.5m finished diameter. With the project's straight alignment the gantry and lining process is expected to move easily through the tunnels.

When Patel is finished with the tunnel drive it's most likely the TBM will be reversed back through the final section of the tunnel, and the cutterhead has been fabricated in two pieces, specifically to aid this process.

	Amar Mahal I	Amar Mahal II
Contractor	Soma	Patel Engineering
Drive 1	4,213m	3,252m
Drive 2	5,239m	1,768m
Normal day	10 to 30m	10 to 30m per day
Best week	166m	166m
Best month	593m	639m

India's booming market

At any given time Mumbai has more than a dozen TBMs at work. The team jokes for every kilometre of the city there's a TBM. In addition to the Amar Mahal tunnels the city is nearly completed with its Metro Line 3, a highway tunnel and several other sewage and water supply tunnels.

It's a similar story across the country. The Pune Metro Rail Project celebrated its final TBM breakthrough last summer, followed by a TBM breakthrough in Dehli last December for its newest metro line. There are 7km of tunnel being mined by an EPBM in Surat for phase one of its metro system. Meanwhile Terratec has recently delivered the first of six TBMS to expand Chennai's metro system.