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Tunnels AND TUNNELLING

British tunnelling

Delhi Metro

Sprayed concrete

CERN CALLS

The scientists at CERN need ever larger tunnels

FINAL STAGES

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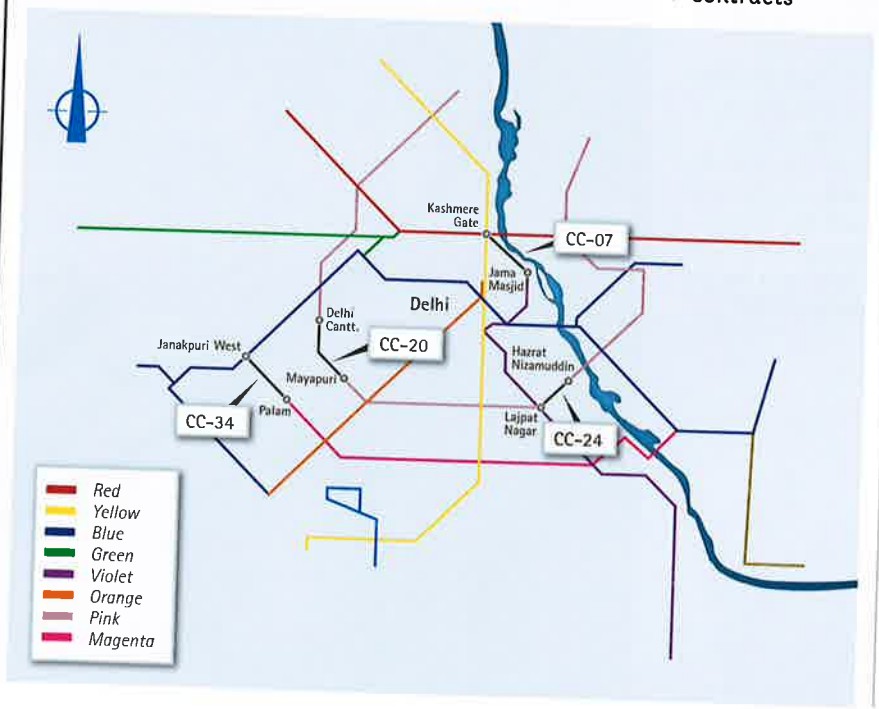
With 12km of tunnelling completed on phase three of India's most advanced metro project, *Terratec* gives an update from worksites it supplied machines to, as tunnel work enters the final stages

FROM FULL FACES OF QUARTZITE to mixed conditions of soil and hard rock, and the need to avoid the foundations of newly built elevated metro stations, there have been plenty of challenges for the tunnellers working to deliver phase III of Delhi's metro system for the Delhi Metro Railway Company. TBM supplier Terratec has been supporting contractors on four major contract packages and despite the challenging ground, advance rates have been good with breakthroughs being achieved throughout 2014 and 2015.

Contract CC-07 has perhaps been the most challenging for the team led by the main contractor joint venture of Russia's Metrostroy with local firm ERA Infrastructure. The first twin drive between Kashmiri Gate and Lal Quila began in December 2014 and breakthrough was celebrated the following August. "The varied geological profile was the biggest technical challenge," explains Bruce Matheson, regional manager for Terratec. Along this 1.35km drive the mixture of soil and hard rock meant that that the advance rates were variable averaging 20m/d in soil whereas in the rock it was 6m/d. Fortunately the 900kW VFD electric drive mixed ground cutter head for the 6.61m o.d. EPB shield machine was more than capable of handling the quartzite which at one point was dominating the bore. "The full face of hard rock wasn't expected but the machine was perfectly capable of cutting through the rock. It did mean that the contractors ended up eating a lot more cutter discs though," says Matheson. Creating the tunnel took 967 rings, each consisting of five segments plus key.

The second drive to complete the down line which runs from Jama Masjid back to Lal Quila is set for completion in January 2016. Between them the two TBMs will create two critical tunnel sections located to the north of the Violet Line (Line 6) which was built as part of the second phase of Delhi's metro. The existing 20km section began operations in October 2010. Further extensions to this line are also underway as part of phase III.



***Below:** Delhi Metro map showing relevant contracts*

Further south Terratec machines have also completed several important bores on the new 58.6km Pink Line which takes a U shaped loop through the city starting at Majlis Park in the northwest, heading south through Mayapuri and Delhi Cantt before heading east through INA to Lajpat Nagar where it then heads north again back up as far as Shiv Vihar. Within this, contract CC-24 has seen Indian contractor J. Kumar & Associates working with China Railway Tunnel Group (CRTG) to deliver 6.9km of new metro tunnels running between Lajpat Nagar and Nizzamudin. Completed in three drives the last 966m section between Vinobapuri and Ashram is set for completion in March 2016. "This was in mixed ground and the ground was as expected so we were advancing at 70mm/min. We were regularly placing 15 to 20 rings per day and it went really well," says Matheson.

Heading west from Lajpat Nagar contract CC-20 will deliver 2.2km of new line between Mayapuri and Delhi Cantt. Very hard rock along the full face of the alignment was expected within this section so advance rates were steady at 12m per day. The low water table allowed the contractor, which was again the J. Kumar & Associates/CRTG joint venture, to change the 17 inch cutters quickly. The final breakthrough on this contract at Mayapuri is scheduled for this February.

The final contract CC-34 to deliver 3.6km of new tunnels is the first to be completed in full. The three drives will enable construction of the Magenta Line (Line 8) which runs east-west across the south of Delhi. Delivered by a joint venture of Hindustan Construction Company (HCC) with South Korea's Samsung Engineering and Construction

All: ***Contract CC-20 (right) and CC-07 (above) both had to deal with very hard rock but cutter change was aided by a low water table***

Group, the completed section forms part of the most westerly section of the new line between Janakpuri and Palam Station.

Initial boring started in August 2014 from Vikaspuri Shaft and broke through 219m later near Kerala school. From there both TBMs were dragged 110m through the cross-over area to start boring a second drive of 354m to Janakpuri Station. The stretch between Vikaspuri and Janakpuri stations was carried out under moderate water pressure up to 2 bars. Beneath the existing Janakpuri elevated metro station the distance between the tunnel wall and foundation piles of the existing metro station was only 3m. "We had to go carefully and gently and this was really the balancing part of the EBP operation. This was soil and there was no rock in this alignment," says Matheson explaining that overall progress on this

Table 1. Delhi Metro Phase III - Lines with Underground Sections

Line	Colour	Underground running length (km)	Overground/ elevated (km)	Total (km)
Line 7	Pink	19.1	39.5	58.6
Line 8	Magenta	23.8	10.5	34.3
Line 6	Violet	9.4	0	9.4
Line 3	Blue	1.5	2.8	4.3
Other overground			52.7	52.7
Total		53.8	105.5	159.3

Source: DMRC

section was excellent.

The geology in this area was composed of very wet silty clay and sandy soil typical of Delhi. Both TBMs passed underneath residential areas for what a very accurate settlement control was implanted, keeping the settlement within less than one centimetre on those critical zones.

During construction of the final section from Dashrathpuri to Palam Station the twin 1,224m long drives passed through very dry soil, and the foam injection system on the TBM cutterhead was used for conditioning of the muck. On this stretch the contractor kept steady advances of up to 120m per week.

The contract drives were completed in August with the second machine S36 finishing a month after its twin S37. The lack of rock meant that these TBMs had a spoke type cutter head with a 57 per cent opening ratio. The good progress was recognised at the breakthrough ceremony. "We are thankful to all our sub-contractors and equipment suppliers, especially Terratec, as these TBMs have excavated very smoothly and this has helped to complete the works ahead the planned schedule" said Mr. Raman Kapil, project director of the joint venture. By early 2016 Terratec's eight machines will all have finished work making their valuable contribution to the 58km of new underground lines that are part of phase III. A further 105km of overground lines are being built too taking the total phase III network to 159km - adding to the 189km of lines already in place. "It was, and is, a very aggressive and ambitious programme which has been carried out very well." summarises Matheson.

DELHI METRO TAKES THE LEAD

Delhi metro has been a pioneering project for India and it is thanks to the drive of the Delhi Metro Railway Corporation (DMRC) that light rail systems are now being constructed in cities throughout the country. The organisation embarked upon the metro in the late 1990s with phase one planned to deliver a 65km system with 13km of this built below ground. Costing USD 1.6bn at today's rate) the system opened in phases with the Red Line, line one being the first to begin some services in December 2002. Other sections of the line opened in 2003 and 2004 and operations on lines two and three followed between 2004 and 2006.

Phase two required a lot more tunnelling with almost 30 percent of the 124km expansion being carried out underground. The simultaneous use of 14 TBMs during 2008 was a high point for the project which saw TBM manufacturer Herrenknecht supply 20 machines over 11 different contracts. Unexpected rock became a feature of the underground work and in one case Herrenknecht explained that it had to deliver a new cutting wheel to the contractor to fit to its machine in order to make it through the rock. Tunnelling was completed in October 2009 in order to ensure that the new lines were open in time for the Commonwealth Games the following year. The cost of this phase was USD 2.8bn.

Today phase three is underway which is set to add almost 160km to the network, almost doubling the 189km that is now operational. Not surprisingly then the cost too is much higher with a budget of USD 6.2bn.

In March this year DMRC announced that there were 19 TBMs working beneath the streets of Delhi constructing the 53km of new tunnels needed to expand the network. At the project peak there were 26

Below: ***Break through on contract CC-34***