DELHI'S BELLY

Supplying eight of the 25 TBMs required for Delhi Metro's Phase III, manufacturer Terratec is heavily invested in the project. In a series of vignettes, *Tunnels* checks out how the different worksites are being handled in a city crowded beyond capacity

IT'S A hot day – by European standards – in Delhi in late October. The driver has just leant on his horn as another Hero Honda motorcycle scythes across six lanes of traffic on a four-lane arterial road. The sound is lost in the orchestra of honking all around us, as the drivers use a kind of group sonar to keep track of other vehicles.

"It's gotten a lot worse," says Bill Brundan, site operations manager for TBM manufacturer Terratec.

"Since I was last working here, about half a decade ago, I think the traffic might have doubled."

The imperious struts of a section of Delhi Metro elevated rail divide the traffic flowing in different directions. These enormous concrete pillars are at regular intervals in perfect alignment until they are lost from sight in the haze of pollution.

Everywhere one looks there are signs that Delhi has a serious infrastructure challenge squarely facing it, and that an MRT project on the scale of the Delhi Metro is only just keeping pace is incredible.

The cyan hoardings of the Delhi Metro Rail Corporation (DMRC) are everywhere; the project has an incredible presence in the city as tunnelling begins on its third phase. Some 45km of underground line is needed for Phase III, with 31 underground stations. With the 'easier' routes being constructed largely above ground already, a greater and greater proportion of subsequent phases will be underground. Phase III has almost as much tunnelling as the previous two combined.

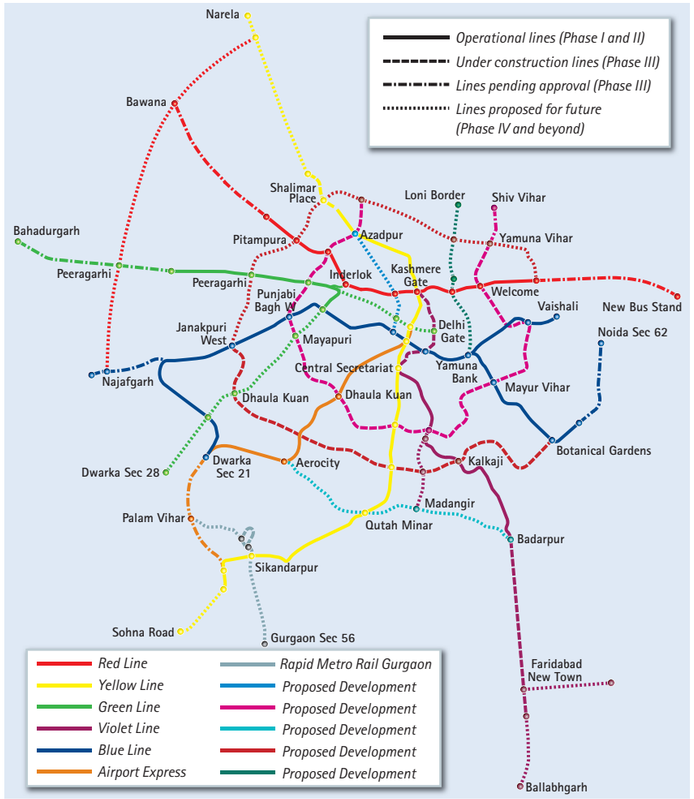


Table 1. Machine and drive attributes

DMRC Contract	CC-07	CC-20	CC-24	CC-34
Contractor:	METROSTROY-ERA JV	J.KUMAR-CRTG JV	J.KUMAR-CRTG JV	HCC-SAMSUNG JV
Number of TBM's:	2	2	2	2
TBM Serial Number:	S23, S24	S26, S27	S25, S28	S36, S37
Design & Manufacture:	TERRATEC	TERRATEC	TERRATEC	TERRATEC
TBM Type:	EPB Shield Machine	EPB Shield Machine	EPB Shield Machine	EPB Shield Machine
Expected geology:	Mixed Soil/Rock	Mixed Soil/Rock	Mixed Soil/Rock	Soil
Shield Diameter:	6,610mm	6,610mm	6,610mm	6,520mm
Segment Ring Dimensions:	ID6350mm/OD5800mm/ L1400mm	ID6350mm/OD5800mm/ L1400mm	ID6350mm/OD5800mm/ L1400mm	ID6350mm/OD5800mm/ L1400mm
Number of Segments:	5+Key	5+Key	5+Key	5+Key
Cutterhead				
- Type:	Dome	Dome	Dome	Spoke
- Opening Ratio:	37%	37%	37%	58%
- Drive Method:	VFD - Electric Motors	VFD - Electric Motors	VFD - Electric Motors	VFD - Electric Motors
- Installed Power:	900kW	960kW	900kW	550kW
- Nominal Torque:	5628kNm	5424kNm	5628kNm	5416kNm
- Max. Speed:	3rpm	5rpm	3rpm	2rpm
Max. Advancing Speed:	71mm/minute	71mm/minute	71mm/minute	71mm/minute
Max. Thrust Capacity:	40,000kN @ 350bar	40,000kN @ 350bar	40,000kN @ 350bar	40,000kN @ 350bar
Articulation Type:	Active	Active	Active	Active
Articulation Capacity:	35,000kN	35,000kN	35,000kN	35,000kN
Min Curve Radius:	250m	250m	250m	250m
Back-filling System:	2-Liquid Type	2-Liquid Type	2-Liquid Type	2-Liquid Type
Tunnel Data				
Tunnel Drives:	2 per TBM	2 per TBM	3 per TBM	2 per TBM
Drive Locations:	Jama Masjid to Lal Quila, Kashmir Gate to Lal Quila	Naraina Vihar, Mayapuri and Delhi Cantt.	Hazarat Nizamuddin Station to Ashram Station; Lajpat Nagar Station to Vinoba Puri Station to Ashram Station.	Janakpuri West to Palam, Delhi
Approximate Tunnel Length:	1,980m per TBM	1,290m per TBM	3,332m per TBM	1,795m per TBM
Geology:	Drive 1; AlluvialSandy Silt/ Clay, possibly some Moderately Weathered Rock. Drive 2; AlluvialSandy Silt/Clay	Drive 1; Weathered Quartzite Rock. Drive 2; Alluvium Deposits. Drive 3; Alluvium Deposits.	Drive 1; Sandy Silt to Gravelly Silt and Sand. Drive 2; Sandy Silt to Silty Sand with Gravel. Drive 3; Highly Fractured & Weathered Quartzite	Mixed Soil, Soft Clay, Stiff Clay, Dense Clay & Silty Sand, Dense Sand

Source: Terratec

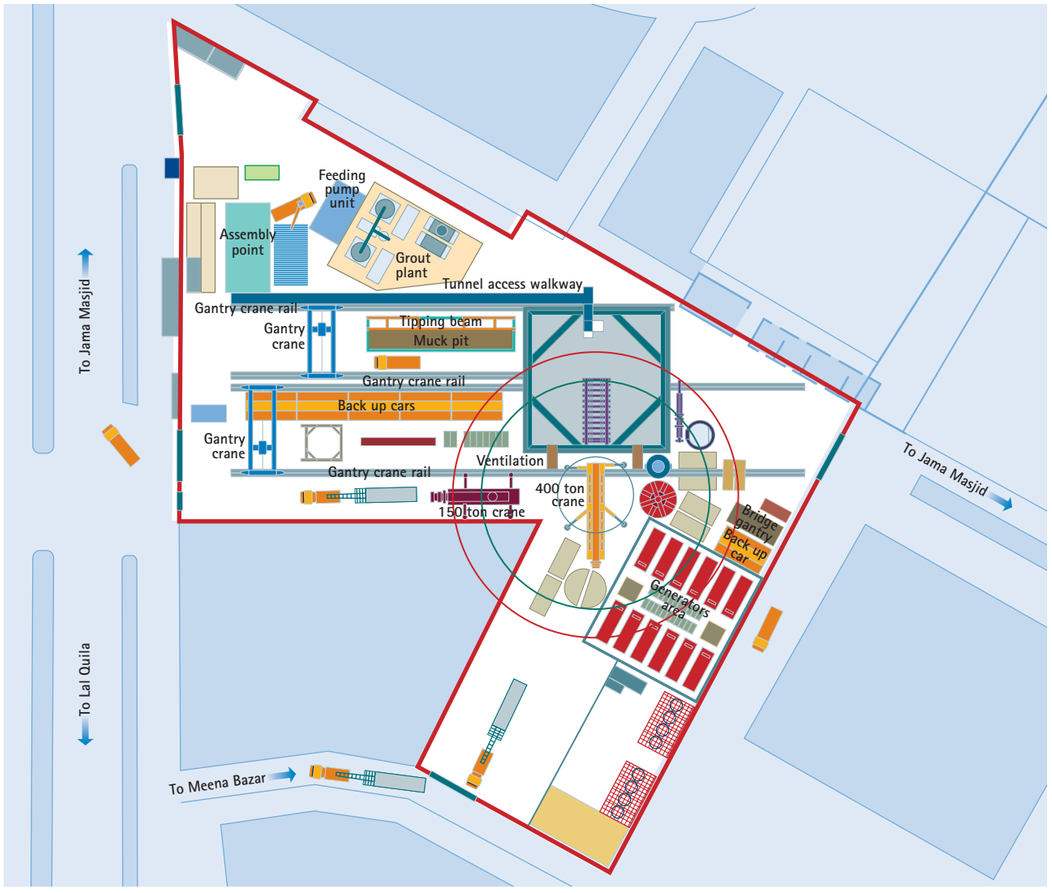
CC07

Contract CC07 is located in the heart of Delhi, running approximately along the west side the Red Fort, and spans three sites (from north to south): Kashmere Gate, Lal Quila and Jama Masjid. The contractor is a JV of Metrostroy-ERA. The Jama Masjid launch site on CC07 has a mixed demographic of staff. Metrostroy-ERA has retained responsibility for the project management and all the working labour, whilst the specialised team to carry out the operation and maintenance of the TBM has been brought from Terratec's field service personnel.

Predominantly from Thailand, they tell *Tunnels* that they have a particularly strong teamwork culture, and find it most important to stay together as a unit, from job to job. The workers are housed together in Delhi, and have brought their own cook with them. The result is an exceptionally quiet bustle on site, with an arcane system of gestures, hand and eye signals, with very few shouts. Everyone knows where to look, and who is watching what. There is more noise from the flies.

Brundan added, "We believe that supplying services is very important in markets such as India, Thailand and the Middle East and we are very active in helping to assemble, operate and service our TBMs if that is required by the

Opposite: Figure 1, Delhi's Metro with Phase III and future expansion



contractors. In Delhi we are proving 24-7 operation and maintenance services, with teams from four to 18 people per TBM, depending on the Client's needs. CC-07 is challenging because of its location and also because of the constraints of the actual site."

Above: Figure 2, Worksite layout during TBM assembly, with routes in and out of the site

Left hanging

The former managing director of DMRC, Elattuvalapil Sreedharan, is largely credited for the past successes of the Delhi Metro scheme as a whole.

Work on Indian projects is often described as 'organised chaos' by expats, with the greatest contractors excellent at 'fighting fires'.

Jama Masjid is working well – the client actually commented that the field service team had executed the best (well grouted, little ingress) initial drive on Phase III – but it is not without challening logistics. While *Tunnels* is on site, there are problems with a gantry crane contractor that has delivered its crane, but not showed up to assemble it. In the end, to speed up progress, the Terratec personnel assemble the frame, but are not certified to handle the electrics to make it operational, which still waited upon the vendor.

CC-24

Executed by a JV of local contractor J. Kumar & Associates, and CRTG, the CC-24 contract covers the sites and associated tunnels for Hazarat Station, Ashram Station, Lajpat Nagar Station and Vinoba Puri Station.

The Delhi Metro lined tunnels are OD 6,350mm, id 5,800mm with a cutting diameter of 6,650mm. The tightest curve on CC-24 is 320m, and grade lies in the range of 1-3 per cent. Geology is competent and no challenges from the scope of excavation work demanded are foreseen.

This is a first use for the Delhi Metro, and for all tunnel projects in India, of real-time monitoring. A system by Encardio-Rite Electronics of India is in use by an independent consultant to conduct the investigation works.

It's not unusual for the Delhi Metro to lead the way in Indian tunnelling in other regards. For instance, the health and safety standards are famously high on projects handled by DMRC, with swathes of work shut down on previous occasions when questions over worker safety emerged. It can be difficult to enforce at times, though.

There's no such problem on CC-24, with the contractor entirely on top of safety standards and with its own team.

All conditional risk is on the contractor – DMRC lays nearly all risk on the contractor as standard – with some progress rate risk on the machinery manufacturer.

Speaking to *Tunnels* in January 2013, Bob Moncrieff of Rona Consulting said, "In India it is usual for all financial and geotechnical risk to be placed on the contractor and away from the client. They are very one-sided contracts. The industry is getting better at site investigation though, but with a short tender time, it is a brave contractor that undertakes extra investigation. I suspect if this does not change quickly, a contractor will eventually 'catch a cold' in unexpectedly bad conditions, and this will force prices up from then onwards. The current contract culture is short sighted."

CC-20

The two sites forming this contract are Naraina Station and Delhi Cantonment, to the west of central Delhi – a military headquarters district. The area is less confined than many of the other sites in Delhi, but logistics are still a challenge. The contractor is the same as for CC-24, J. Kumar/CRTG.

The JV's work on CC-20 was delayed by land acquisition processes as *Tunnels* visited. An island of shops and residences in the middle of the Naraina worksite had yet to be cleared, but preparation works were advanced; with pile rebar stacked and ready, and ground leveling underway. Naraina Station's diaphragm wall was down despite the island of local residents.

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Below: Some contracts are advancing quicker than others due to land acquisition delays

To offset some of the impact of the delays, and following DMRC permission, the two CC-20 TBMs will be transferred to CC-24 to complete two drives, the works of which are more advanced. The J. Kumar-CRTG JV is on both jobs, making this possible.

Brundan gave an update as Tunnels went to press, "The CC-20 machines will go to CC-24 for one drive each between Lajpat Nagar Station to Vinob Puri Station. This is now confirmed, and the assembly is planned to commence middle of February. The CC-20 project has also moved forward and the land problems are resolved now with all the shafts progressing. As soon as the CC-20 machines complete their CC-24 drives, they will be moved back to CC-20 to start their original drives.

"All four machines are similar and all can manage the soil or rock conditions without any concern. At CC-20 though one of the drives is expected to be mostly rock, The CC-20 machines have slightly more power and more speed suitable for rock conditions, and you also use less torque in rock than in soft ground."

Works packages are relatively small on Delhi Metro, but this is an advantage of keeping similar works 'in the family'. The sites are streamlined in this way, and now managed together.

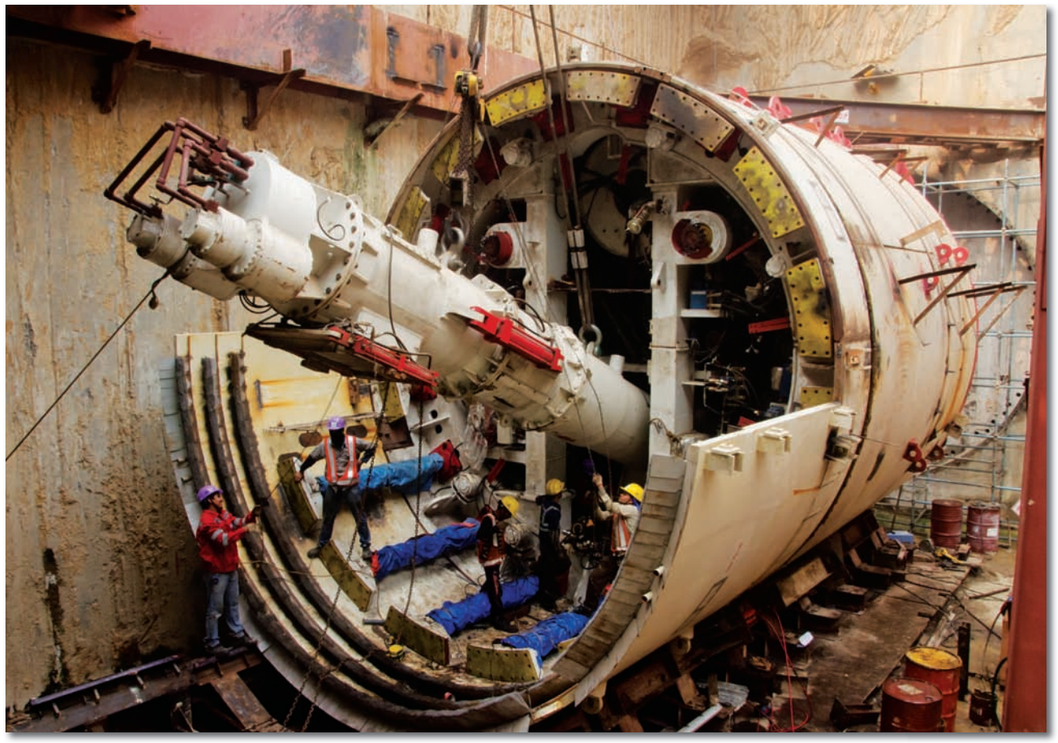
A sophisticated site office was also already set up, with offices for various engineering disciplines.

"It's the general experience with J. Kumar, they are very eager to learn and do things properly," says Brundan.

"It's their first tunnelling job, and our first time working with them. Tunnelling is very difficult to handle, and highly specialised. J. Kumar's executive director Nalin Gupta holds meetings from 6pm until midnight, eager to hammer out every last detail.

"It's personally tiring, but professionally very encouraging. This company is great to work with."

It is common in India for a great deal of help to be given to local contractors. CRTG provides the joint venture with the necessary experience in tunnelling by its engineers at site, but manufacturer



All: TBM assembly at the shaft bottom in Delhi

of the TBMs will come as close as 4.5m away while travelling between the piles. There will be stringent monitoring, and grouting if needed, but at this time it is thought no additional measures will be taken.

Other obstacles involve a flyover with piles, and the existing Dabri Mor Station, which means a passenger walkway cannot be excavated by open cut.

Making lemons

The segment factory for CC-20/24 is also doubling for J.Kumar's shield storage. The CC-20 launch site was not ready to receive the Terratec TBM's when delivered to site.

Fortunately there proved to be more than adequate space on the segment site for storage, but this presented the challenge of protective maintenance on the machine, including oiling and greasing and dust protection, but also this runs support is also key during the TBM erection, commissioning and tunnel construction.

Engineers on site hoped that the legal wrangling with site acquisitions would be concluded within the month.

CC-34

Project CC-34 was awarded to a JV of HCC-Samsung. Covering the sites of Janakpuri West Station, Palam Station, and the cut and cover Dabri Mor and Dashrath Puri stations between. A key future challenge on this project will be navigating the piles of the existing Janakpuri West Station. On its drive, one of the TBMs will come as close as 4.5m away while travelling between the piles. There will be stringent monitoring, and grouting if needed, but at this time it is thought no additional measures will be taken.

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The centre of the Red Fort in Delhi

Segment yard

In the Mundka industrial area towards the western extremity of Delhi, DMRC leases an area of land to its various companies for segment factories to be set up. The works packages are divided between a number of contractors, so there are multiple factories in the vicinity. Segment factory manager from J. Kumar-CRTG JV, Nath Poopong, shows Tunnels around his setup for contracts CC-20 and CC-24.

The contractor bought the yard from ITD, which was working on the earlier Phase II of the metro. If the setup is no longer required, the contractor will likely sell it on to groups set to work on subsequent metro phases.

Of around half a dozen factories on site, it is the only one that has a connection to the national grid, which was down to the preference of the previous occupiers. Still vulnerable to Delhi's power cuts, there is also generator power available. All TBMs on the sites visited are generator-powered.

Korea Mold supplied the moulds for CC-24, Poopong worked with their products previously in Dubai as a project manager for Obayashi. Concrete is mixed with a micro silica additive for permeability, and reinforced with cage rebar. No poly or steel fibres are called for by the specification.

The heat of summer requires a cooling water system, with temperatures easily rising into the 40°C. While Delhi's brief and relatively mild winter sees factory reliance on steam curing with a temperature of 55°C. Still, demoulding time is lengthened from the summer duration of 4/5 hours at 12.5kN strength. Buildings in the city are not typically well sealed against the cold, making this period of the year more miserable than might be expected.

The segments are a five plus key universal ring, with glued VIP gaskets from the UK. There are three types being produced to form rings in soft ground, rock and sand. The only real difference between the three is the amount of rebar.

the risk of circumstantial damage from operations such as truck movements. Cosmetic marks from the storage near a dirt track were visible on the shield, but nothing more.

FUTURE

On the state of contracts in Delhi, and future work in the country, Brundan concludes, "The current Delhi Metro work on Phase III has all now been awarded. Future phases will come up in the next few years and of course we would be very interested in being a part of this huge and impressive set of projects."

On the sites in question, tunnelling for all sections was expected to be complete by the end of 2014. CC07 and 24 are proceeding to this schedule. CC-20 has had land acquisition issues and delay of approximately 6 months, allowing J.Kumar –CRTG's use of the CC-20 machines on CC24. Accelerating CC-24. CC-20 is now back on track with TBM work expected to start in the summer. CC-34 is approximately two months behind, but tunneling is still expected to be complete in 2014