



## Special report: Middle East

T&T Asia takes a look at the enormous scope of works in the Middle East, including the Abu Dhabi super sewer, Cairo metro line three and the high speed rail tunnels in Israel

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T&T Asia visits the stage two launch site for Singapore's Downtown metro line



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## comment

# New year, new era

The speed of growth across all of Asia is offering the greatest challenges and the greatest opportunities. The seizing of these opportunities by those with the right experience and know how can overcome all of the challenges to meeting demands.

Throughout Asia growth is feeding growth. The economies are powering through the global downturn at such speed that many expect a shift in world power from west to east.

In many cases the least developed areas are seeing the fastest growth. Over the next decade, population migration within China will bring about some 170 cities with a population of more than a million. That is drastically more than Europe's 70 cities.

The population migration is coupled with a growth of the middle class, which demands higher standards of living. All of these cities will need underground infrastructure, as they develop to meet these standards. The usual utility services will need to be constructed as will transport infrastructure. Metro systems are already under construction in Xi'an, Chengdu and Chongqing – to name just a few.

This development is not limited to China of course. The special report in this month's T&T Asia focuses on the Middle East. In Abu Dhabi massive sewer developments are under construction (see page 14) to further the regions growth. In Cairo metro developments are going ahead to help alleviate congestion in the most populated parts of the city (see page 18).

But with these opportunities come challenges. Many of the regions where growth is greatest have little or no experience in underground construction. Governments and other clients keen to further boost the local economies will be looking to invest in local construction firms. Contractors with little tunnelling experience are going to need outside support from consultants or joint venture partners to bring them the expertise. They will also need to be equipped with reliable machinery and trained on how to use it.

Consultants working on some of the Himalayan tunnels have warned of the inexperience of contractors and the poor quality of equipment. Lack of experience, poor equipment or ill advice will lead to higher accident and death rates and possibly the ultimate failure of the project. So it is vital that those with the know-how seize on this opportunity and overcome the challenges.

T&T Asia is also stepping up to meet this challenge. The magazine was launched last year as a supplement to *T&T International* as a quarterly publication. From 2011 onwards *T&T Asia* will be printed bimonthly as a standalone publication to serve readers throughout Asia. If you wish to contribute to strengthening *T&T Asia* as a resource for the tunnelling industry please get in touch with technical papers, research and hopefully invites for the magazine to visit your project.

Best of luck for the New Year!

Jon Young

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# CHINA: FIRST LARGE DIAMETER YELLOW RIVER CROSSING ACCOMPLISHED.

The renowned South-North Water Diversion Project in China consists of Western, Eastern and Central routes. The Yellow River Crossing Project is the key junction of the entire Central route, with a total length of 19.3 kilometers, channeling the water from Danjiangkou Reservoir to Beijing, Tianjin and other northern China areas. Along the Central route, two 4.25 kilometer-long parallel tunnels cross under the Yellow River in order to connect the water channels of both river sides. 3.45 kilometers of each tunnel are built with maximum overburden of 36 meters beneath the river, while the rest of 800 meters Mang Mountain Tunnel is constructed with a designed gradient up to of 49.1‰.

Herrenknecht provided 2 Mixshields (Ø 9.0m), named as "Yellow River" (S-358) and "Traverser" (S-359), to construct these large-diameter crossing tunnels in the Central route. The "Traverser" reached its target shaft successfully on the 22<sup>nd</sup>, June, 2010, achieving a best weekly rate of 115.2 meters. Its sister machine, the "Yellow River", followed on September 27, 2010. Their common success will contribute significantly to the operation of the Central route in 2014.

## ZHENGZHOU | CHINA

### PROJECT DATA

**S-358, S-359**  
**2x Mixshield**  
 Diameter: 9,000mm  
 Cutterhead power: 1,100kW  
 Tunnel length: 2x 4,250m  
 Geology: Pebbly sand, medium grained, coarse clay

### CONTRACTOR

Joint Venture of China Railway 16<sup>th</sup> Group and Sinohydro Bureau 7, Joint Venture of China Railway Tunnel Group and China Gezhouba (Group) Corporation  
 Client: Construction and Administration Bureau of South-to-North Water Diversion Middle Route Project



## News in brief

Construction starts on Tuen Mun sewer  
Chun Wo Development Holdings (a Hong Kong construction company founded in 1968) has begun work on the HKD 710M (USD 91M) Western Trunk Sewerage Project in Tuen Mun, Hong Kong. A remote-controlled TBM was chosen method to bore the 4km of pipejacked drive as it has the smallest impact on residents. Some 2.5km of the pipejacked sewer will be in DN1800 concrete gravity pipe, with 1.5km as a DN1400 sleeve pipe for twin hdpe rising mains of DN900. The remaining 2km of sewer will be laid as a twin-cell box culvert. It will all be completed in 2014.

Marmaray Project gets extra funds from Japan  
The Japanese government has approved an additional loan for the Marmaray Project, which is constructing an undersea rail tunnel in Istanbul to connect both sides of the city, European and Asian. The 2005 loan has been increased from JPY 98.7M (USD 1.18M) to JPY 140.8bn (USD 1.6M).

# Kuala Lumpur names project manager for MRT

## MALAYSIA

A Gamuda-MMC joint venture will be the project development partner (PDP) for the Mass Rapid Transit (MRT) in Kuala Lumpur, Malaysia's Prime Minister Datuk Seri Najib Tun Razak announced on 18 December.

The MYR-36bn (USD-11.5bn) MRT project will build a 150km rail network in the capital city and the

surrounding area. The government expects construction to start in summer 2011 for the first line, which will run roughly 50km, mostly underground, from Sungai Buloh to Kajang, with 35 stations.

Gamuda and MMC, both Malaysia-based engineering and construction companies, have experience on major tunnelling in the region, including the SMART (Stormwater Management and Road Tunnel) and the Kaohsiung

MRT System in Kaohsiung, Taiwan. For that reason they will be allowed to compete for the MRT's tunnelling works, estimated at MYR 14bn, but none of the other contracts that will be tendered.

Local analysts suggest this exception, highlighted by Razak in his announcement, gives Gamuda-MMCM an edge over other bidders. Work packages are expected in the first half of 2011 for construction to start in July.

# Kashmir railway breakthrough

## INDIA

There has been a second tunnel breakthrough reported on the 148km Katra-Qazigund (Leg 2) section of the Kashmir railway to link Jammu with Srinagar and Baramulla on the north-western edge of the Kashmir Valley. This project is officially called the Jammu Udhampur Srinagar Baramulla Railway Link (JUSBRL) and has been declared a National Project, meaning that it will be completed 'whatever the cost'. Before this declaration in 2002, progress had been sporadic.

The second Sandalgam tunnel is 1.48km long and is located in the Ramban district. The single, horseshoe section passage was driven by drill and blast from both ends and took 28 months in 'difficult' geology.

The project is managed by the Konkan Railway Corp (KRCL) and includes 47 tunnels with a total length of 58km. The longest are 5.3km and 5.9km long. Satluj Jal Vidyut Nigam (SJVN) was appointed as consultant dealing with geotechnical engineering, geological mapping, tunnel support design if required, concrete lining, portal design,

testing the sprayed and cast concrete mixes. Work on this leg had been cancelled in 2008 by the Ministry of Railways due to suspected geological instability, followed by a reconsideration of the alignment. Work resumed in June 2009 with minor alignment changes and geological tests.

See also *Tunnels & Tunnelling International* Feb 2010 p23-26 for a description of the Pir Panjal tunnel work on the same route.

The Katra-Qazigund section opening has been rescheduled to 2017, thus completing the whole route. Leg 1 is expected to be completed in 2012.

# Jakarta MRT under land stability scrutiny

## INDONESIA

Tendering of Jakarta's mass rapid transit (MRT) contracts could be delayed if a study into land stability does not find in favour of the project. President director of mass rapid transit owner PT MRT Jakarta told local media last month that a study into land stability was needed to ensure the safe construction of the MRT line.

According to the Jakarta Industry and Energy Agency, some 60 reference points were monitored

in the Jakarta area from 2002 to 2010, revealing some alarming land subsidence in North Jakarta including Mutiara Baru, Pantai Mutiara, Pantai Indah Kapuk, and Acol. The subsidence levels varied. In Mutiara Baru, the land subsidence reached 1,160mm.

Chairman of the Association of Indonesian Soil Engineers (HATTI), Bigman Marihat Hutapea explained to Berita Jakarta, land subsidence would not continuously occur. Jakarta is indeed experiencing land subsidence, but as long as it is

taken into account in the analysis of soil structure, it does not matter he claimed.

He said, "As Jakarta MRT structure is held by pile foundations, and each underground station is reinforced with cut-off-walls, then the land subsidence does not need to be worried about," he stated.

MRT Jakarta will stretch some 110.3km, consisting of the 23.3km south-north line and the 87km east-west line.

The development of south-north

line will be carried out in two stages. Phase One will cover a 15.2km long corridor from HI traffic circle to Lebakbulus, with 13 stations, seven elevated stations and six underground stations. It is scheduled to start operating in late 2016. While Phase Two will extend from HI traffic circle to Kampungbandan. It is targeted to operate in 2018.

The west-east corridor is currently in the pre-feasibility study stage. It is targeted for completion in 2024-2027.

# EIB grants loan for Vietnam metro



Magdalena Alvarez

## VIETNAM

The European Investment Bank (EIB) has approved a EUR-150M (USD-198.4M) loan for the development of Line 2 of the Ho Chi Minh City metro, Vietnam. The deal was struck in Hanoi

on 6 December 2010.

The line runs for 11.3km through 11 stations in Ho Chi Minh City centre of which 9.6km will be underground.

The loan was made as a result of the most recent Asia and Latin America (ALA) mandate. The current fourth mandate (ALA IV) relates to the years 2007 to 2013. Under this mandate the EIB can lend up to EUR 1bn (USD 1.3bn) to Asia for the purposes of mitigating climate change or supporting the EU presence in these regions.

Magdalena Alvarez, vice president of the EIB, said, "the Bank is pleased to support this project as it will improve the quality of life of citizens by reducing congestion and daily commuting time as well as contributing to climate change mitigation by reducing traffic related emissions to the environment."

The Asian Development Bank, the EIB and KfW Bankengruppe are all now financing the city's metro project.

# Tibetan tunnel breaks through

## CHINA

Contractors last month achieved breakthrough on the 3310m Galongla mountain tunnel in remote Tibet. The final 152kg blast round was detonated on 15 December to complete the excavation.

The tunnel is part of an 117-km strategically important highway to link the last isolated county in China with the national highway system. The road will link Bome County and Metok County in Nyingtri Prefecture of Tibet.

The tunnel crosses Galongla mountain at an elevation of some 3750m to provide the 11 000 population of Metok County with

an all-weather route. Snow and rain make the mountain roads impassable for nine months of the year, and walking out of the mountains can take about 10 hours according to China news service Xinhua. Mudslides and avalanches are common on the mountain.

According to Tibetan media, China's urgency to build a highway link to the remote county could be explained due to its strategic importance.

It is located in the lower reaches of the Yarlung Tsangpo river at the eastern section of the Himalayas, close to Tibet's border with India's strategically important Arunachal Pradesh state.

## News in brief

### Developer fined for Delhi metro delays

Continued delays in the opening of the Delhi Airport Express metro service resulted in a fine on the developer recently. The 'last straw' appeared to be the failure to obtain the mandatory safety clearances from the Commissioner of Metro Rail Safety. Delhi Metro Rail corporation, as client, ordered penalties amounting to INR 11.25 crore (USD 2.53M) on the developer and contractor: Delhi Airport Metro Express

### Seven killed in Chinese rail tunnel collapse

A tunnel collapse in northern China killed seven people in mid-October during construction of a 280-km railway line. Four workers died on site while another three workers passed away at a hospital. The cause of the accident is still unidentified though an investigation has been launched. The line will connect Chifeng, Inner Mongolia to Jinzhou, Liaoning.

### Amman tunnel completed

The Greater Amman Municipality (GAM) has completed both sides of the upper tunnel, each with three lanes, of Prince Hussein bin Abdullah II Square in Amman, Jordan. Work in the 2-lane lower tunnel is more than 70 per cent complete. The project started in February 2009 at a cost of JOD 23M (USD 32.5M).

### Azerbaijan tunnel complex

A complex with multiple tunnels and underpasses will be built at the Ganjilik underground station in Baku, Azerbaijan, within two years. The complex will reportedly consist of six tunnels, two underpasses, one underground 3-storey station and two additional entrances for the Ganjilik underground station.

### China railways get big boost

The China Minister of Railways, Liu Zhijun, has (1 November) signed an agreement with Jianxi province governor Wu Xiniong to accelerate railway infrastructure development in the region. The stated objective is the guaranteed sound and fast development of the economic and social infrastructure in the region. This follows a similar agreement with Jilin Province.

### Busan-Geoje Fixed Link opens

Korea's Busan-Geoje Fixed Link officially opened to the public on 14 December, having completed the immersed tunnel portion of the project this summer. A joint venture of Danish company Cowi and Korea's Daewoo Engineering designed the 3.4km tunnel, comprising 18 elements as deep as 48m below sea level, said to be the world's deepest immersed tunnel.

### Contract awards for Malaysian hydropower project

Tenaga Nasional Berhad (TNB) has awarded contracts for the construction of the Hulu Terengganu hydropower project. The contracts, valued at around MYR 1bn (USD 319.03M), were awarded to a joint venture of Loh and Loh Construction and Sinohydro Corporation.

### Lushan tunnel suspended

Construction of the Lushan Mountain Tunnel in China, announced earlier this year, has been suspended. The National Development and Reform Commission (NDRC) has halted the project, claiming that it had not examined or approved the plans. These complications come during a public outcry against projects in the area, including a cable car system.

# tunnels & tunnelling is expanding

As *T&T Asia* approaches its 2nd, successful year, we are pleased to announce the expansion from quarterly to bimonthly publication. From 2011, the same in-depth and technical coverage you've come to expect from *T&T Asia* will now be delivered to you in a stand-alone format, bagged with your issue of *T&T International*. We look forward to this opportunity to better serve our Asian readers with a more local focus, more often.

## Editorial Schedule

- January:** The Middle East  
**March:** China  
**May:** South East Asia  
**July:** North East Asia  
**September:** Asia Subcontinent  
**November:** China



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# Riding the boom

Recent contract awards are boosting the tunnelling sector in the Middle East including Qatar's successful 2022 World Cup bid. A number of major projects are underway, Bernadette Redfern reports

**F**rom Cairo's metro to Abu Dhabi's super-sized 40-km sewer, tunnelling is enjoying a busy time in a relatively new market. The Middle East and Africa are giving the international tunnelling community a lot to be optimistic about, particularly the Gulf States such as the UAE, Qatar, Saudi Arabia and Kuwait. "Twenty to thirty years ago it was impossible to think that Gulf States would ever embark upon tunnelling or metro schemes but under the new 2030 development plans, regional governments are reclaiming the city and utilising the third dimension," says Martin Knights, immediate past-president of the International Tunnelling Association.

The most significant development in the Gulf's tunnelling sector to date has been the USD-7.6bn Dubai metro project, which has almost doubled in price from the original USD-4.5bn budget. The first 52km Red Line opened on time in September 2009 and the second, 23-km Green Line opening date has been extended from March 2011 to August 2011. A total of 7.9km of this section is underground including six stations.

The contractor consortium is led by Japan's Obayashi Corporation, with Kajima Corporation, Mitsubishi Heavy Industries and Turkey's Yapi Merkezi.

Despite the cost and time overruns the project remains a major achievement for a region with no previous experience of TBMs or light rail. Of the first 70km of light rail system, 13km were tunnelled using three 9.56m-diameter Mitsubishi EPB GBMs in 10 separate drives.

Plans for extensions of the metro are currently on hold as Dubai weathers the financial storm battering its state-owned development companies and affecting governmental infrastructure spending. However Knights expects Dubai's metro will be extended in the future. Other states, he says, are also pursuing tunnels for metros, utilities and road links. "In the future I believe we are going to see the use of strategic tunnels linking islands in the region, instead of bridges and causeways."

Most current tunnelling activity is centred on Abu Dhabi, which along with plans for its own light rail system, is also building a new sewer network. Known as the 'strategic tunnel enhancement programme' (STEP), it is designed to replace the existing pumped wastewater network with a new gravity sewer system. A total of six contracts are being awarded including three for the main 40km sewer, two for the connection pipework and one for a new pumping station. The main bore will run from Abu Dhabi Island in the north down to the new Al Wathba sewage treatment works on the mainland in the south. The first two contracts for this were awarded to Italy's Impregilo. The first was awarded in the summer of 2009 and concerns a 15km long section with a 5m internal diameter that makes up the central piece of the sewer. Another contract for the final 10km length of sewer with a 5.5m internal diameter was awarded at the end of November.

A total of eight EPB TBMs will be used on the bore. The three 5m diameter, three 6m diameter and two 6.5m diameter machines are set to remove 1.2 million cubic metres of fill. Contractors are expected to bore through the sandstone, mudstone and gypsum at rates of 100m per week. Korea's Samsung is understood to be among the bidders.

Contractors tunnelling in Abu Dhabi will need to carry out extensive ground investigation as the area is prone to large sub-surface voids. "Regional geological formations lend themselves to karstic formations. These can be discrete or sometimes widely connected. You have to carry out very, very good site investigation," says Knights. "And be mindful of your pump rates when grouting."

It is not just Knights who is confident of the region's potential for tunnelling. On 22 February 2010 Germany's Herrenknecht signed an USD-8.7M agreement to establish a joint-venture TBM manufacturing company with Abu Dhabi's Aabar Investments. "The business objective is the continuous market

development of mechanised tunnelling in the MENA region (Middle East and Northern Africa)," said a Herrenknecht spokesperson.

The German giant is already supplying a TBM to Qatar, which is increasing stormwater storage in the Qatar capital of Doha, and in Saudi Arabia it is supplying drilling equipment to Saudi Aramco for a new 3-km oil pipeline.

Along with its stormwater storage plans Qatar is also set to move ahead with a 340-km metro system, which is expected to involve a significant portion of underground construction, and a 10-km road crossing under Doha Bay. The 2 December announcement that Qatar had won a bid to host the World Cup in 2022 will give the projects a significant boost as the bid documents outlined the metro as the main mode of transport for visiting football fans. Stations will be located at the major stadia such as the planned 86 000 capacity Lusail Stadium and the first 30-km 'Red' line will run north south through the city linking New Doha International Airport with the Lusail development. The project is being managed by a joint venture of Qatari Diar Real Estate Investment Company (QDREIC) with DB International, the international consulting arm of Germany's Deutsche Bahn. According to the bid documents the network will be 70 per cent complete by 2020, serving all stadia.

Throughout the region there is no shortage of planned schemes. Damascus (Syria), Amman (Jordan), Kuwait City, Baghdad (Iraq) and Tehran (Iran) and Riyadh (Saudi Arabia) are all planning metros and are keen to learn from pioneering Dubai's experiences. Further afield in North Africa, Egypt is extending its metro by adding a third line. A Vinci Construction Grand Projects-led consortia is undertaking a 3.5km, 9.5 diameter bore under the River Nile. Construction is scheduled for completion in mid 2011.

With so many projects planned and several underway it is no wonder that the industry is excited about the regional opportunity. ▀



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“It was most enjoyable and the Summit was well attended and lively. If you are considering a further Summit next year, I'd be happy to work with you.”

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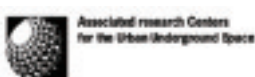
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# Israel fast link

A series of tunnels are to be excavated near Jerusalem as part of the eastern portion of the new fast rail link to Tel Aviv, reports Patrick Reynolds

**T**o improve the speed and efficiency of the rail network in Israel, a project is under development to construct a new, faster link between Tel Aviv and Jerusalem.

Works are underway at many locations between the cities and have been for the last few years with two of the three stages of the scheme already completed. The third stage includes various excavations and underground constructions for tunnels and stations and work on most sites is underway.

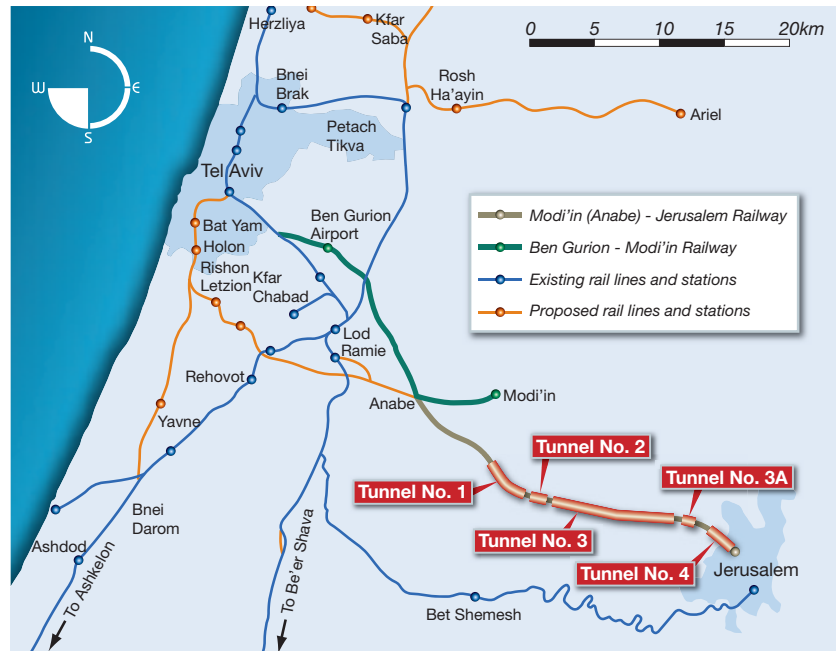
The rail link was studied for many years to be a replacement to the older, slow line between Jaffa and Jerusalem, which was built in the late 19th Century and also the first main rail route in the area.

The new line is being developed by Israel Railways and is to be an approximately 60km long, double-track route with a design speed of 160km per hour. In the western portion of the rail link the route generally follows that of the adjoining highway. It is planned that the line, which rises at a maximum grade of 2.5 per cent from Tel Aviv to reach an elevation of 740m a.s.l. in Jerusalem, will be for passenger transport only.

But in addition to some technical challenges there are also political sensitivities on parts of the route which are near some villages, some within Israel's borders and others on the West Bank demarcation line between Israel and Palestine.

## Planning and initial stages

In the first stage of the scheme, construction of the rail link began with the section from Tel Aviv inland to Ben Gurion Airport, including two tunnels. One tunnel was constructed by cut and cover and required a temporary diversion of Road No.1, the main highway between Tel Aviv and Jerusalem. The other tunnel was mined in clay using sprayed concrete lining (SCL) below the Shapirim Bridge near Beit Dagan. Both tunnels were



Above, top: Map of the fast rail link under construction in Israel  
Above, bottom: Initial groundbreaking at second tube on Tunnel 3A

designed by A. Rozen Engineering.

The second stage of the rail link construction took the line farther east, from the airport to the city of Modi'in. Five tunnels were built in this mid-section of the route, including two at Anabe and the other near Modi'in. One of the excavations was by cut and cover, on the 1.6km, longest of the tunnels. The majority of the tunnels

were mined using SCL and designed by A. Rozen Engineering.

Construction of the Anabe tunnels was performed by contractor Linom, a bridge contractor becoming more active in tunnelling. The cover to the tunnels was relatively shallow below the main road and forepoling was employed, notes Arnon Rozen of A. Rozen Engineering.



Project manager on the works – which included Israel's first, and so far only, underground station – was Hana Stern of Dana Engineering. The Mod'in Central station is constructed 30m below the surface.

However, the real weight of the tunnelling work on the rail link is in the third stage, concentrated in the eastern portion of the route closest to Jerusalem. The total length of the main running tunnels is approximately 36km.

Preliminary design work was done in 2000 by Hasson-Yerushami Engineers, as prime designer. The tunnel design work was undertaken by A. Rozen Engineering, and at that stage – a decade ago – the concept was to build three twin tubes and an underground station, with an access tunnel, in Jerusalem.

The present design of the third stage of the rail line was performed by Amy-Metom, as prime engineer. Split into four sections (A-D), the rail link has five tunnels in sections B-D. The tunnels are Nos. 1, 2, 3, 3A and 4 – the latter tube not being the longest but having the most complicated layout as it links into the new underground station being constructed in the city.

### Tunnels in the east

The tunnelling works in the third stage of the fast rail link involve a range of bores of radically varied lengths and employing different construction methods, from TBM to mining with SCL.

Most of the route underground will see trains travel through the twin tube, single-track tunnels of Tunnels 1, 2, 3 and 3A. The only single bore, double-track tunnel on the project is Tunnel 4, which is 2280m long and the farthest east of the tubes taking its approach to the new Binyanei Hauma



**Above:** Spoil removal with a Schaeff ITC 312 loader at first tube of Tunnel 3A

station, in Jerusalem.

The lengths of the tunnels are 3,544m, 1180m, 11,600m and 820m long, respectively. The only single bore, double-track tunnel on the project is No. 4 which is 2280m long, is the furthest east of the five and approaches the new Binyanei Hauma station in Jerusalem.

Excluding cross passages at approximately 250m intervals, the total length of the main running tunnels in the third stage of the link is approximately 36.5km with almost two-thirds to be driven by TBM.

Various joint ventures between Israeli and international firms have been awarded the construction contracts covering the five tunnels:

- Tunnel 1: JV of local firm Menrav and Russian contractor Mosmetrostroy.
- Tunnels 2 and 3: JV of local company Shapir and Italian firm Pizzarotti.
- Tunnels 3A and 4: JV of local contractor Hofrey Hasharon and Max Bogl.

Two companies are responsible for the principal tunnel designs – A. Koren for Tunnels 1 and 2, and A. Rozen Engineering for Tunnels 3, 3A and 4. However, the contractors on Tunnels 1 and 2 have modified the design within their design-build contracts, and the design of Tunnel 3, which will have the TBM drives, was also altered by the contractor, notes Arnon Rozen.

The project manager and site supervisor for Tunnels 1, 2 and 3 is Eldad Spivak of Spivak Engineers. For Tunnels 3A and 4, Hana Stern of Dana Engineering is providing the project management and site supervision services.

Separately, the JV of Horey Hasharon and Max Bogl is working on excavation of the two lower station, large-span caverns that are connected to Tunnel 4. The upper level excavation, elevators and ventilation shafts and the concourse cavern are being built by Israeli contractor Ramet.

### Tunnels 1, 2 and 3

The alignment of Tunnels 1 and 2 pass through mainly marly formations with chalk and soft limestone, whereas the rock to be met in the other three tunnels is harder, including limestone and dolomites, explains Spivak Engineers.

The greenlight for construction of Tunnel 1 was recently given, and the JV of Menrav and Mosmetrostroy plans to excavate the twin tubes by TBM. The contract is the last on the route to begin excavation.

For Tunnels 2 and 3, the contracting JV – operating as Shapir Pizzarotti Railways (SPR) – has a 44-month basic programme to construct the twin tubes, which are about 15m apart and will have a total of 46 cross passages.

Geology along the alignment of the tunnels comprises limestone and dolomite of the Cenomanian-Turonian era, and the

**Below:** Drill and blast work underway in Tunnel 3A





**Above, left:** Excavation and support inspection in Tunnel 3A **Above, right:** Excavation in an Anabe tunnel during an earlier stage of fast rail link construction

bedding dips generally at about 20 degrees from east to west. However, there are some karst formations expected along the route. Cover to the excavated crown will range from 7m up to 40m for Tunnel 2 and 270m for Tunnel 3.

Given the semi-arid climate it is expected that groundwater challenges will not be present except, possibly, for a few potential but relatively small perched water tables along the alignment of Tunnel 3.

Tunnel 2 is already under construction using SCL for about 900m of its length, and in the portal areas the excavation is by cut and cover. The mined bores have basically a horseshoe-shaped cross-section and advance with full-face excavation. The excavated width is approximately 9.3m with a primary lining of approximately 250mm of shotcrete, steel ribs, and mesh, as required.

In the soft broken chalk/marl of the west portal area the contractor used both hydraulic hammers and rotary heads fitted to an excavator to advance the drives. Once the drives had progressed into limestone the contractor employed advanced the face by drill and blast excavation using a Sandvik rig.

Following placement of drainage and waterproof membranes on the primary lining the tunnel will be completed with placement of insitu concrete for the secondary lining.

Once Tunnel 2 has completed it will be the conduit through which will be transported the two Herrenknecht TBMs that will be used to bore the twin tubes of Tunnel 3 – the longest tunnels on the entire rail line. This is expected to happen in early 2011.

The pair of 10.04m diameter double shield TBMs will each be used to drive up to 10km, or approximately 86 per cent, of the tunnels. The refurbished shields are to be launched at the western portals and

then be dismantled underground in chambers prepared about 1.6km from the opposite end by drill and blast drives.

But negotiating the suspected karstic voids is expected to be the biggest construction challenge on the contract, especially any that may be below or near the TBM invert areas.

The remainder of the Tunnel 3 tubes will be constructed by SCL except for the portals, which will be done by cut and cover. Overburden

Cross passages along Tunnels 2 and 3 are spaced at approximately 260m intervals, and have excavated dimensions of 5.8m wide and 5.8m into the horseshoe-shaped roof. Detailed design work is still continuing to establish the final, completed dimensions of the cross passages. The majority of the cross passages - 43 - will be built to linked the parallel tubes of Tunnel 3.

#### Tunnels 3A and 4

The contractor JV of Hofrey Hasharon and Max Bogl has a 48 month period for excavation and lining of Tunnels 3A and 4, and the schedule calls for the underground civil works to be completed by March 2014. Work on Tunnel 3A commenced in September 2010 and excavation of Tunnel 4 is due to begin in January 2011, explains project manager Dana Engineering.

All the tunnelling works are to be undertaken SCL. Geology along the alignment of Tunnel 3 comprises chalk and limestone and the overburden is up to 65m. The cross section of each tube is approximately 8.65m by 8.2m. Each of the primary and secondary linings of shotcrete are about 150mm thick.

Tunnelling plant on the project includes an Atlas Copco Rocket Boomer L2C with two booms and a Schaeff ITC 312

roadheader. The contractor is driving from the east end only of Tunnel 3 due to the tubes running below a large national park. It has, therefore, one set of equipment working across the parallel north and south drives which enables excavation to proceed in one bore while concreting works are underway in the other.

However, while the average planned advanced rate is about 35m per (6-day) week across both drives, poorer ground conditions have meant progress has been less so far. But full face excavation is being achieved.

Dana Engineering also notes that the payment approach is different for the latest tunnelling works on this fast rail link. Instead of the traditional system of payment based on quantities of materials, the new system is based on payment per metre of advance – the rate varying up and down with poorer to better ground conditions.

There are four basic support designs set under the system for ground conditions varying from fair to poor then very poor and the worst being extremely poor, based on the Barton rock classification system, notes Dana Engineering. Any debate between contractor and project manager/supervisor can call on the designer to settle the matter – in this case Arnon Rozen.

Tunnel 4, though, is both longer and a much more complex tunnelling challenge with the single tube starting on the ramp that supports Road No. 1, and therefore early works in 2011 will include a shallow passage below the highway.

The layout of the tunnel, running under Jerusalem, will also include four emergency connecting tunnels, each with its own utilities, and also a large access tunnel. With a major portal and five small tunnels the tunnelling works could see three or four faces being worked on simultaneously. Tunnel 4 will bifurcate on the approach, approximately 80m below the surface, to the caverns of the new Binyanei Hauma Station. ▀



# Abu Dhabi's super sewer

Mechanised tunnelling is underway in the Middle Eastern emirate of Abu Dhabi for the first time with a new 40km deep sewer project reports Bernadette Redfern

Construction of Abu Dhabi's new 40km gravity sewer has reached another major milestone with the award on 30 November of a USD 200M contract for the second of three contracts for the bore. The 10km section will have a 7m external diameter with a 5.5m internal diameter.

Italian firm Impregilo beat bidders such as fellow Italian firm Astaldi, Germany's Ed Zeublin, UAE based Lindenberg and French firm Bouygues Batiment

International. "In addition to the tunnel, the project involves construction of four access shafts to depths of between 60 and 80 metres, as well as the links to the main tunnel," says the Impregilo statement on the contract which is expected to take three years to build. Rates of up to 100m per week are expected. "The project presents significant technical and organisational complexities. It involves simultaneous use of two earth pressure balance tunnel boring machines for pressures up to 8 bars, to bore and simultaneously line the tunnel with prefabricated concrete elements," says the statement.

The contract is the second awarded to Impregilo, which this month is starting boring a 15km central section of the sewer worth AED 891M (USD 243M). The award was made in September 2009 and involves three 6.3m diameter EPBMs. A further three contracts are also still to be awarded for connecting tunnels and a major pumping station.

A third tunnelling contract for the remaining 17km of tunnel, with a 4m internal diameter, is still to be awarded. Korean firm Samsung is understood to be among the bidders. Contract awards have been slower than anticipated as Abu Dhabi's Executive Council has thoroughly reviewed the need for all major projects following the global economic downturn, and the financial pressures placed on the United Arab Emirates, which has had to give more than USD 10bn in support to the emirate of Dubai which has struggled to meet its financial obligations to lenders - mainly in the real estate sector.

## Coping with growth

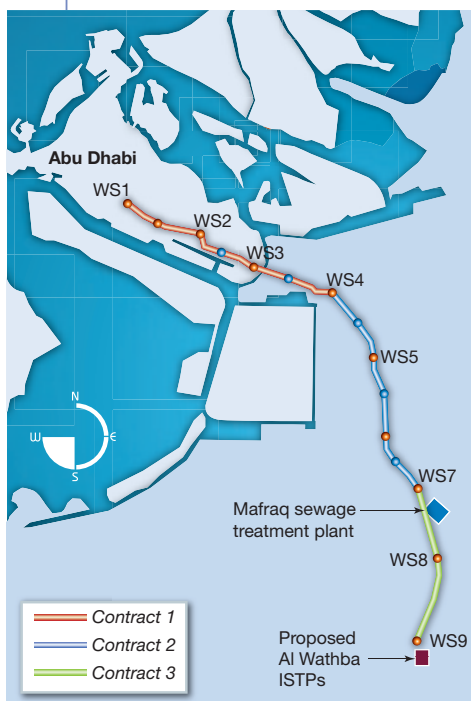
However the need for a new sewage system was never in doubt. When the government of Abu Dhabi first installed a sewage collection system back in the 1970s it could not have predicted the stratospheric growth that was to

characterise the next four decades. From a population of around 156,000 in 1975, it is today approaching 1 million and the network of 50 pumping stations and mains that collect sewage and transport it to Mafraq treatment works is under severe strain. The result has been some surcharging of the gravity mains that feed the pumping stations and not surprisingly this had led to complaints from the public.

Solving this issue will involve the construction of a new 40km sewer with 50km of connecting sewers and a new pumping station at Mafraq. Starting on Abu Dhabi Island at 30m below ground level, the tunnel will run southwest to the mainland and terminate at a depth of 100m. Each bore will be 5km in length meaning that a total of eight EPBMs will be required. "We knew that breaking it into eight contracts would be too small for international contractors, so we broke it into three contracts, roughly around AED 750M (USD 204.2M) to AED 1bn (USD 272.3M) each. These were large enough to attract international tunnelling contractors but not too large that you put all your eggs in one basket," says Robert Marshall, Strategic Tunnel Enhancement Project (STEP) programme manager from CH2MHill, who was interviewed by T&T in August.

The organisation charged with managing and upgrading the sewer network is the Abu Dhabi Sewerage Services Company (ADSSC), formed in 2005 and until 2009, a subsidiary of the Abu Dhabi Water and Environment Electricity Authority (ADWEA). and bBack in 2006 it undertook a masterplan which explored the potential issues that the emirate would face, along with proposing solutions for the network. "The original masterplan consultant GTZ Dornier called it a sewage time bomb," explains ADSSC managing director Alan Thomson. "It predicted that by 2009 Abu Dhabi would face mass sewer flooding. I am delighted to say we have managed to prevent this so far and we will continue to do so until the final solution is in place," he says.

ADSSC's masterplan envisaged that to meet projected growth of up to 3.1 million by 2030 the best solution would be a deep sewer tunnel that would collect effluent and transfer it all to a single pumping station by



**Left, top:** The 40km tunnel system was divided into three contracts

**Left, bottom:** A 50km network of sewers will feed the main sewer tunnel



gravitation. This would then move flows to a new sewage treatment works at Al Wathba. As implementing something on this scale was beyond the experience of ADSSC, it decided to bring in a project management consultant to run the scheme. The winning bidder was announced as US based CH2MHill in February 2008. The firm was fresh from project managing Singapore's impressive 48km deep sewerage tunnel (DTS) project. "We looked at the tunnel route, what length it should be, where it should go, what diameter it should be, what gradient and what depth," says Marshall.

As with many tunnelling schemes the client opted for a design and build approach and estimate that this saved 12 months on the construction programme as it allowed TBM orders to be placed at contract award, enabling detailed design and shaft sinking to be done in parallel with procurement of the boring machines. Designs were produced to approximately 30 per cent complete for the tender documents to be issued and to date all six contracts have been tendered and bid.

The EPBMs are new machines coming from Herrenknecht's main facility at Schwanau in Germany. The first was installed in the launch shaft in mid-October last year with boring getting underway in December. The other two TBMs are on a one month lag. Construction of this section is set for completion by June 2013.

Originally it was envisaged that the entire STEP programme would be completed by the end of 2012, however the Abu Dhabi government is carefully reviewing all of its growth forecasts in the light of the global financial crisis. The emirate has a reputation for conservative planning, a move that has served it well as neighbouring states have seen their growth plans plummet - along with bank lending.

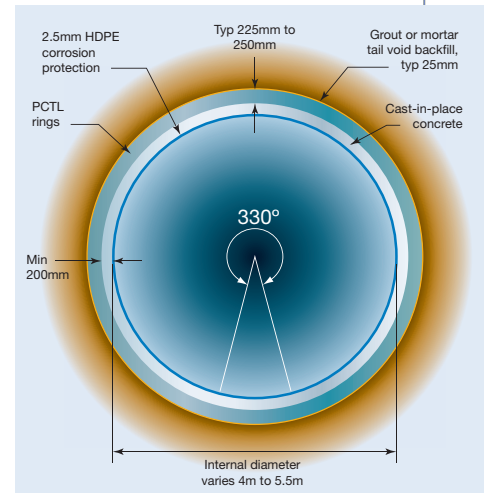
As a result although the remaining four contracts have been evaluated by ADSSC and a preferred bidder has been chosen, they are still awaiting approval from various

**Right:** A typical section through the deep sewer tunnel

**Below:** Abu Dhabi's deep sewer is needed to support population growth

government departments.

Given the current situation Thomson expects that 2014 is now a more realistic deadline for the project. "The other elements will be approved in due course. It is really just going through the bureaucratic procedures which are part and parcel of government controls," says Thomson.





The remaining tunnelling contract to be awarded is a 17km length from Abu Dhabi Island to Mussafah on the mainland and will have a 4m internal diameter.

### Cutting the sewer

The presence of gypsum presents a potential risk for the tunnellers. Its propensity to dissolve in the presence of groundwater has led to a series of underground voids and caverns on the mainland, which the team refers to as "solution features".

This risk led the contract team to specify pressurised face tunnelling for the bore to prevent any uncontrolled ground loss, and although ADSSC did not specify whether EPBMs or slurry, all contractors bid using EPBMs. "We also require the EPBMs to have the ability to forward probe and we have asked the contractors to provide forward looking radars to pick up any cavities. And we have compressed air so we can get into the cutterhead if there is a need to change tools," says Marshall.

Extensive site investigations have also been carried out with more investigation to be done prior to boring. "If a cavern was detected we would try and grout it up

**Below and opposite:** Preparatory works underway at the launch shaft

either from the tunnel or from the surface in advance of the TBM arriving. So far there is no real evidence of any solution features in the depths we are tunnelling in," says Marshall.

From a tunnelling perspective ADSSC and CH2MHill are optimistic about the ground conditions as despite large pressures at the deepest point of the tunnel – 8 bars, permeability of the ground is very low. "The biggest risk is encountering a very large cavern. The probability of this is low but the impact is high," says Marshall.

The EPBMs will place a 200mm thick concrete structural lining and once this is complete contractors will enter the tunnel with steel shuttering to place the internal lining that also acts as a dual corrosion protection system. This comprises HDPE that is in contact with the flows and a concrete backing cast in situ that is at least 200mm thick. "The structural lining is gasketed so it should be a dry tunnel. Any leakage that comes in from groundwater would find its way through the concrete and run down the back of the HDPE and run onto the tunnel invert as the bottom 30 degrees is not lined in HDPE," explains Marshall. "If it was fully lined then any water coming in would not be able to penetrate and so would bubble it until it



**Above:** Robert Marshall of CH2MHill

burst, but ingress is expected to be very minimal," he says.

The HDPE itself will be supplied in 2.5m roles which will be welded together on the surface before running it into the tunnel and wrapping it around the steel shutters. The concrete liner will then be poured. This is a similar method to that used on Singapore's DTS. "In Singapore for example we had some shutters that were 37m long," says Marshall.





### Linking in

Beyond the tunnel itself contracts are also to be awarded for two link sewer packages that will feed flows in to the new sewer tunnel. Part of the rationale behind structuring the main tunnel and connection sewers in separate contracts is to enable both local and international firms to participate in the scheme and it is envisaged that local firms will be involved in link sewer construction.

Between the the two link sewer contracts a network of 50km of connection pipes will be created. Marshall says these are not expected to be at risk of encountering solution features as the majority of them are on the island where such caverns have not been a problem.

Connection sewers range from 400mm to 3m diameter lying anywhere between 10m and 25m deep. These will be pipejacked in place from manholes at 3m centres and the biggest challenge for the team will be getting authority approvals for the detailed designs of the jacking pit locations and receiving pit locations.

The sixth contract to be awarded is for the new deep pumping station at Al Wathba sewage treatment works. "A single pumping station design was a major consideration in cutting down odour problems in the future as wherever you have a pumping station you effectively have sewage coming to the surface in one way or another and more likelihood of an odour problem," says Thomson.

ADSSC has reserved a 4.7 hectare plot of land from the Abu Dhabi Municipality for the pumping station and ground conditions are expected to consist of overburden soils followed by a weak sedimentary rock formation. Contractors will be expected to take into account expected artesian ground water conditions. According to ADSSC the construction of the pit could involve reinforced concrete diaphragm walls, secant pile wall, shotcrete and rock bolts, followed by inner structural concrete ring walls, intermediate slabs, and a base slab. However the most appropriate form of excavation support system will be left up to the contractor.

Although the government is taking its time over awarding the contracts, the consensus seems to be that this piece of infrastructure is badly needed, and it is part of wider investment in the emirate's water network. "We are building another four waste water treatment plants, two in Abu Dhabi itself and two to cover Al Ain the second city. These are well in advance and will add an extra 800,000m<sup>3</sup> per day to our treatment capabilities across the emirate," says Thomson.

The current capacity at Mafraq is 360,000m<sup>3</sup> per day but Abu Dhabi is currently averaging 500,000m<sup>3</sup> per day. Fortunately for ADSSC the heat accelerates the bacterial activity that kills pathogens so although the wastewater is not being treated for as long as it was designed to be, the effluent leaving Mafraq is still high enough quality to be used for irrigation. As an interim arrangement ADSSC has placed connection pipes between the existing Mafraq sewage treatment works and the new treatment plants which will convey some waste water down to the new plants to relieve Mafraq. "Flows have increased 8 per cent, per year. We are making temporary arrangements with overland pumping, tankering where that is practical, and a refurbishment of some of our pumping stations if only for a few years to improve efficiency to keep the wolves from the door," says Thomson.

Much work remains to be done before Abu Dhabi's sewage problems are a thing of the past but major steps have been taken and a solution is on its way. The government is taking its time making the awards but at the same time is ensuring that Abu Dhabi gets the best infrastructure available. As a result the experience gained herein terms of both expertise and knowledge about local ground conditions, will be important information for other local and regional projects in the future. ▀



# Planning ahead in Cairo

Construction on Line 3 of Cairo metro is seeing Phase One handover to Phase Two works while detailed planning is underway for the next two phases, reports Patrick Reynolds

Cairo is intensively expanding its metro network with construction currently moving ahead on Line 3 to the second phase and soon the third, while planning is being advanced for the later stages to extend both further east and west. A major addition to the existing network, Line 3 will be 40.3km long with 32 stations and still further lines have been on the drawing board for some years and are in studies – for Lines, 4, 5 and 6.

The present focus of work on Line 3 is in central Cairo, on the east bank of the River Nile, where tunnelling has been underway for approaching three years. The tunnelling works on Phase 1 have reached the closing stage on the first phase, which includes recovery of a stuck TBM through a rescue shaft using ground-freezing and the use of an additional TBM brought in to complete the workload.

Next door, to the east, early activities on Phase 2 of the line's development are progressing well with a further TBM onsite and being prepared for launched in early 2011.

Contractor for both the Phase 1 and 2 of Line 3 is the French-Egyptian consortium of Vinci Construction Grands Projets, Arab Contractors, Bouygues and Orascom Constructio Industries. The JV was awarded the contract for Phase 1 in 2007 by the National Authority for Tunnels (NAT), which is part of the Ministry of Transportation and the second phase was won in mid-2009.

French consultant Systra has undertaken a variety of services to the Line 3 works, from feasibility studies to the tender phase. The services range from design feasibility, general features and preliminary design with local subcontractors providing the basic design and technical tender documents, including the bills of quantities and specifications.

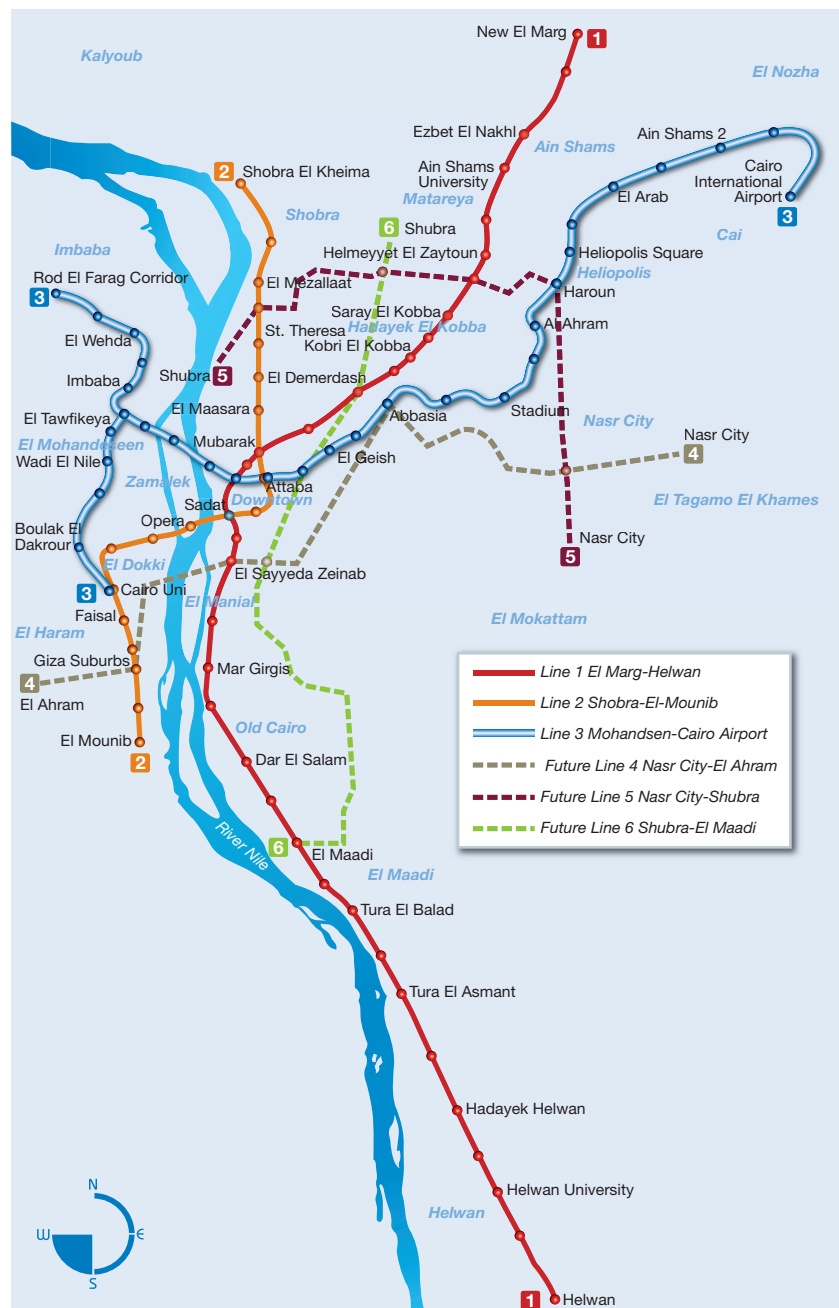
While tunnelling completes on Phase 1 and gets set to start on Phase 2, Systra is

**Right: Cairo's extensive metro strategy for six lines is currently focused on construction of Line 3**

developing the design and tender documentation of the initial stages of Phase 3 to be ready this year, and studies are underway for Phase 4.

## Line 3

In layout, Line 3 is like a giant Y-shape lying on its side across Cairo, the branches being on the west bank of the river. Once





completed, the line will run from the international airport in the east and then westwards through the city and below the Nile to the west bank, where it will split with branches north and south to Imbaba and Mohandessin, respectively.

Line 3 is a single bore, twin-track tunnel of 8.35m i.d., and the concrete rings (5 + 2 counter) have 400mm thick segments to give an outside diameter of 9.15m.

Geology along the alignment comprises sand that is medium dense to dense, with clay pockets in the upper layers. The groundwater is level is slightly below street level in the downtown area and lower further east. The tunnelling on the project will use a combination of slurry and EPB TBMs.

#### Phase 1

Phases 1 and 2 will construct much of the main stem of the Y-shape of Line 3. They have a combined length of 11.4km with a total of 10 stations, and cover the business district, or downtown Cairo, out to the edge of Heliopolis, halfway to the airport.

Phase 1 is a little over 4.2km long with five stations, which are from west to east – Attaba, Bab El Shaaria, El Geish, Abdou Pasha and Abbasia. The line will have its first interchange station, at Attaba, with Line 2. Construction involved both TBM and cut and cover works.

#### Phase 2

The second phase is 7.2km long and also has five stations – four originally planned and a fifth added for the contractor to have an exit shaft for construction reasons.

Running east from Abbasia, the original stations are Cairo Fair, Stadium, Kolyet El Banat and Al Ahran. The additional station is Haroun, originally to be part of Phase 4, but the change now means Phase 2 ends a little nearer Heliopolis.

#### Phase 3

Phase 3 is to be constructed in three stages – 3A, 3B and 3C – with a total of 15 stations over 17.7km of line, and two crossings of the Nile via the island of Zamalek.

The first stage, 3A, will be 4km long and start to extend the line to the west from Attaba (built in Phase 1), and the initial drive will cross Line 1 where an interchange station will be built at Nasser. From there, the line will pass under the Nile with a further three stations in the area (Maspero, Zamalek and Kit-Kat Square).

**Right, top:** Line 3 will be constructed in four phases, and Phase 2 tunnelling is about to start

**Right, bottom:** Construction of Phase 1 of Line 3 was completed by the end of 2010

Stage 3B is to be 6.6km long with six stations and will take the line onto its north branch after first constructing the Sudan station, which will be where Line 3 will split and so will have a stub tunnel for the south branch to be constructed. The north branch includes stations at Imbaba Airport, Monira, El Wehda, Ring Road and it terminates at Rod El Farag Corridor. A workshop area for the trains and infrastructure maintenance will be constructed between the last two stations.

With five stations over a stretch of 7.1km, stage 3C will take Line 3 onto its south branch from the previously built junction station at Sudan and then the line will terminate at an interchange to Line 2,

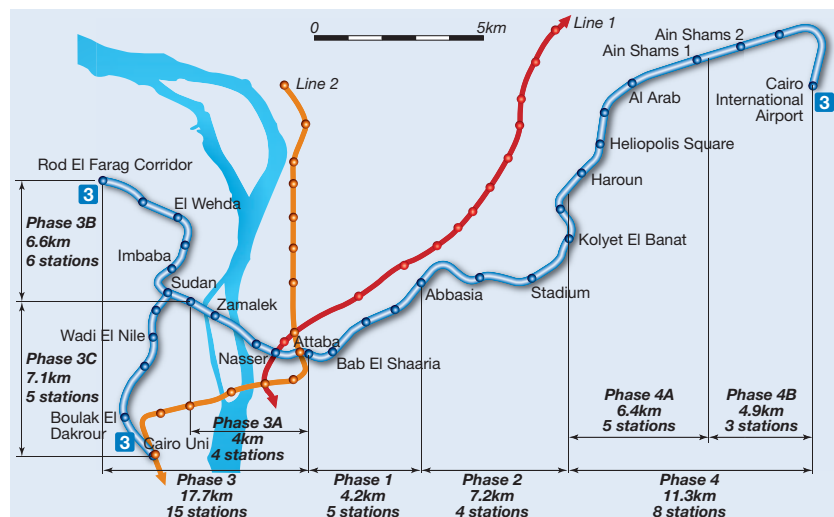
at Cairo University. There will be four intermediate stations built along the south branch, and proceeding south they are – Tawfikia, Wad El Nile, Gamat El Dowal El Arabia and Boulak El Dakroul.

An underground diversion structure is to be built that will allow the two branches to be operated with no grade intersections of the railtracks.

Design work on Phase 3 is due to be completed early in 2011, says Systra.

#### Phase 4

Phase 4 of the line's development is at the opposite end, in the east, extending out from the end of Phase 2 works towards the international airport. Prior to the adjustment with Haroun station to help the Phase 2





works complete using an exit shaft, the plan for Phase 4 specified the works would be done in two stages – 4A and 4B – with eight stations over 11.3km. The total would be adjusted to seven, depending on what may remain to be done at Haroun; the change would also see the number of stations in stage 4A down from five to four. The total distance to be constructed may also be reduced slightly.

The listed, unadjusted plan for stage 4A states that over a 6.4km length it would have five stations, and proceeding eastwards they are – Haroun, Heliopolis Square, Alf-Maskan, Al Arab and Ain Shams 1.

Stage 4B would have three stations over a distance of 4.9km, taking Line 3 via stations at Ain Shams 2 and Omar Ibn El Khatab out to the international airport, where the line terminates.



## Construction – Phase 1

Tunnelling work on Phase 1 has been undertaken using slurry TBM excavation. The groundwater level is 1m-2m below street level in the downtown area.

A 9.4m diameter, refurbished Herrenknecht slurry TBM, christened Cleopatra, was launched at Abbasia to drive westwards toward Attaba. The machine was previously used on construction of Line 2, on stages 1A and 1B of Phase 1 of that project.

Excavation began in the first quarter of 2008 and was originally expected to complete in the early part of 2010. However, in September 2009 the works suffered a major setback when a collapse buried the TBM in the stretch between El Geish and Bab El Shaaria stations (*T&T* July 2010).

The TBM had constructed the majority of the tunnel for Phase 1 when there was an inflow of water laden gravels and sands under a 20m head. The tunnelling into the tunnel did not cease until the ground disturbance reached up to the surface, creating a sinkhole at a road. The tunnel alignment in this section of the project mainly follows the roads.

Fortunately, no-one on the surface or in the tunnel works was hurt by the accident, which is suspected to have resulted from two segments of the lining being misplaced in an erected ring, and subsequently collapsing into the tunnel with the consequent inrush. A cut-off wall was built back along the tunnel and from there to the TBM the tube was flooded to help ensure stability and prevent any further problems.

A recovery operation was launched for the buried machine, and work involved sinking a shaft in front of the collapsed area with walls constructed to a depth of more than 90m to penetrate, and gain the beneficial base seal, of a clay layer. The shaft was built by Bauer. Works then proceeded to install a ground-freezing system using arrays of injection pipes and brine solution, and the recovery is close to completion.

A new Herrenknecht bentonite slurry TBM was sourced to complete the tunnelling work on Phase 1 while the recovery operation was being executed. The new machine was launched in July 2010 and bored eastward towards the rescue shaft where it will hole through and be removed, expected around the end 2010.

**Left, top:** A rescue shaft was used to recover a TBM trapped by a collapse on Phase 1 **Left, bottom:** Preparations for ground-freezing underway at the bottom to the rescue shaft



By the end of 2010 the tunnelling works had completed 3.35km of TBM excavation and 1.1km of cut and cover, says Systra. Overall, it notes, the construction programme for Phase 1 has suffered on slight delays due to the tunnel collapse.

### Construction – Phase 2

For the first 2km, or just over half, of Phase 2 – east of Abbasia and en route to Cairo Fair – the geology lies within the Nile alluvial valley. Groundwater is slightly deeper in Phase 2 than in Phase 1.

The Vinci-led JV plans to use the slurry TBM that was brought-in to complete Phase 1 on this portion of the tunnel. The TBM will break out at Cairo Fair.

The remaining 1.85km of the Phase 2 tunnelling work will be undertaken by a 9.46m diameter EPBM manufactured by NFM Technologies, which arrived on site for assembly early in the fourth quarter of 2010 and is due to start driving early in 2011. Geology along that section includes clay, sand and sandstone. The contractor requested that the machine will be capable of being adapted to slurry mode for possible later use in the project.

The EPBM will be used to construct the tunnel between Cairo Fair and Haroun (now added to the Phase 2 works, as previously noted). The extra distance to be built that will take the tube to Haroun will be used during the operational phase of the metro line as a temporary sidings area, notes Systra.

Civil works for Phase 2 are to be completed in 2012, says Systra. The plan has been for this phase of Line 3 to come into service by about late 2013.

### Preparations - Phases 3 and 4

Systra is currently focused on the basic design with tender documentation for stage 3A of Phase 3, and documents for 3B and 3C are expected around March 2011, which would complete planning for that section of the project. The early work on Phase 3, including feasibility studies and general features, began in 2002. Site investigations have been completed.

It is anticipated that the second Herrenknecht slurry TBM on the project – used to complete Phase 1 and is excavating part of Phase 2 – could be held for tunnelling works on Phase 3A of Line 3, between Attaba and Kit-Kat Square. Slurry TBM drives are also planned for the other two stages of Phase 3, to construct the north and south branches.

Civil works for Phase 3 are to be completed in 2015, says Systra.

The feasibility study for Phase 4 was



**Above:** Reaching the buried TBM from the rescue shaft;  
**Below:** The recovery works advance at the TBM



undertaken almost a decade ago, and the necessary site investigation works are being planned. The expected tunnelling method for Phase 4 is to use EPB TBMs.

Current studies for stage 4A of Phase 4 are underway, led by Systra's project manager for Phase 4, Paolo Patrizi, and are expected to be completed by the end of 2011. The detailed studies for stage 4B

have yet to begin. The completion schedule for civil works on Phase 4 has yet to be determined.

Key challenges or further works include limited areas in the dense urban environment to help station construction, which could see studies to explore possibilities for mined tunnelling being used, says Systra. ▀

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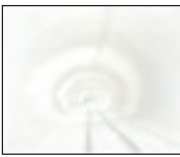


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# Future proofing Singapore

A massive push by the Singapore government to get residents out of their cars and onto the metro is driving a huge expansion plan on the city's MRT. Jon Young reports from Downtown Line stage two where tunnelling work is about to kick off

**T**he scorching equatorial sun beats down on the quiet streets of Singapore. City dwellers hurry from one air-conditioned safe haven to another, avoiding the sweltering heat wherever is possible.

The rich developments on the Marina Bay Sands sit side by side with the colonial classics such as the infamous Raffles Hotel. Brilliant glass buildings with

crazy architecture define Singapore as a modern city on the forefront of technology and thinking.

In 1983, when engineers first set to work on the city-state's mass rapid transit (MRT) metro, Singapore had a population of approximately 2.5M. The government instructed engineers to develop a network fit for a little over 3M. The city's population last year broke 5M. This

underestimate is the reason why the MRT operates six carriage trains when eight would be more appropriate.

Downtown Line stage two director Ng Kee Nam, who works for client the Land Transport Authority, says, "When LTA launched its Land Transport Master Plan it decided to make rail the backbone of the public transportation system in Singapore. The plan [launched in March 2008] is to double the network in the next 10 years from 195km to more than 300km."

The LTA is responsible for all transport in Singapore. The roads in Singapore are not congested, traffic flows with relative ease compared with major metropolises elsewhere in the world. This is because of the very powerful traffic control methods

the government has at its disposal. There are three methods employed: a more than 100 per cent tax on car purchases making it very expensive to own a car in Singapore; a permit for car ownership called a Certificate of Entitlement, which can cost thousands of dollars (Singaporean and US) and a congestion charging zone that discourages drivers from entering the city.

To continue with such a tough anti-car stance it is vital the city can offer a reliable and comprehensive public transport option and this is the main driver behind the LTMP and the extension to the twin bore Downtown Line (DTL).

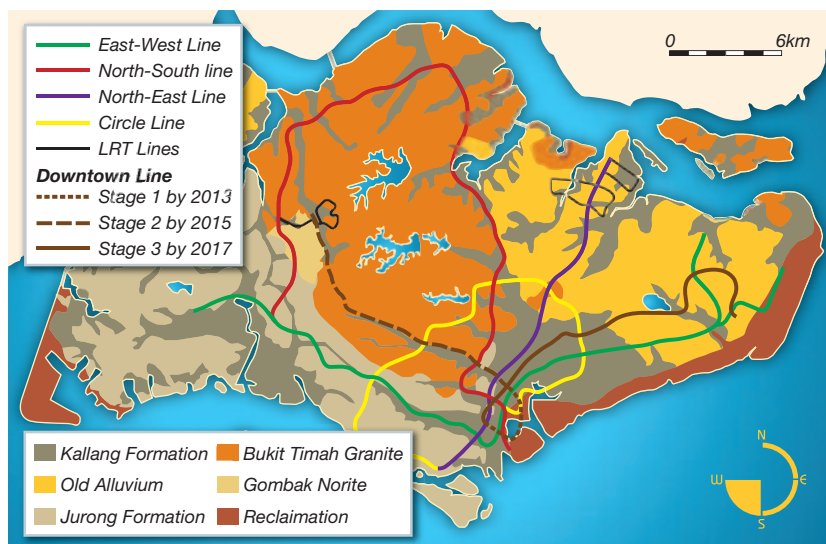
### The extension

Stage one of the DTL had only just been announced when the LTA began working on plans for its extension. DTL will be the fifth MRT line in Singapore. When fully completed, the line will be about 42km long with 34 stations. It will be a fully-automatic and driverless system similar to the North East Line and the Circle Line, and will be fully underground.

Somewhat similar to the East West Line, the line will serve the Bukit Timah area and eastern Singapore and bring commuters to the developments in the downtown area. The line is coloured brown on the rail map.

Stage one of the DTL is targeted for completion in 2013, while stage two is targeted for 2015 and stage three is targeted for 2017. When completed, the line is expected to serve some 500,000 commuters daily and reduce travelling time from Bukit Panjang to Expo to about 65 minutes.

**Below:** Map showing the geology of Singapore and the route of the underground rail system



As construction on stage one nears an end and stage three is still in planning, stage two is preparing for its peak next year. Construction started on stage two with a groundbreaking ceremony at Beauty World station in July 2009. Nam says, "Downtown Line two is 16.6km with 12 stations and one depot. The project is split into 10 main civil contracts and is fully underground."

At the northern end of the line the tunnels run under less populated areas of the city. There is ample space to run the tracks above ground. Perhaps the government has learnt a lesson from its earlier mistake of opting for six-carriage trains and is now keen to future proof the project. LTA project manager for civil construction team one, Simon Hoblyn, says, "The instructions came for the whole lot to go underground so that's what we're doing."

The Singapore government's decision not to hold public consultation on the alignment of the tunnels or the location of the stations was crucial to meeting the political promises in the LTMP. The 2015 delivery target for stage two is the single greatest driver for the project.

Hoblyn says, "The philosophy has been to put program first so that we can deliver the tunnels on time. So we have not tried to build particularly long stretches or drive through stations or have complicated interfaces. We have actually come up with more TBMs with a typical drive distance of 1km or less to try and ensure we deliver the job on time. Occasionally we do reuse the TBMs but it is normal for each TBM not to drive more than 1km in total. At the end of

the drive the machines are dismantled underground and taken away."

The TBMs will not be removed through the stations, as one LTA requirement is to separate the station and tunnel works. Hoblyn explains, "Station and tunnel programs often don't coincide. So wherever possible we have given the TBMs their own launch shafts and at the interfaces we do not guarantee the contractor access through the stations and so they will need to take the machine back through the tunnel."

The stage two alignment, which runs as deep as 35m below the city, has been broken into two sections, civils team one and civils team two. It runs relatively flat with a maximum gradient of 3 per cent. Team one cover the northern end furthest from the city and team two cover the southern end, nearest the city.

The two teams are currently enabling the tunnelling works with shafts going down. Some TBMs are under manufacture while others have been delivered and waiting to go underground. Tunnelling is set to get underway in April.

### Fit for purpose

Much of the program for this project is based on lessons learnt and one of the greatest lessons learnt on earlier lines, especially the Circle line, is just how harsh Singapore's tunnelling environment is. The Bukit Timah granite is a fiercely hard rock and in many stretches along the stage two alignment the face dips in and out of soft ground and very hard rock.

The toughest conditions are in the mixed faces - hard rock in the invert and weathered rock in the face. The rock itself can range from typically 100-250mpa, very fresh and very abrasive. Along the entire alignment the rock is dipping in and out of the face.

Team one uses nine TBMs, seven of which are slurry machines and two of which are EPBMs. Team two uses 10 TBMs, two slurries and eight EPBMs, explains Hoblyn.

Hoblyn says, "We were careful where we saw a high percentage of Bukit Timah granite. We've had experience from Circle Line and other projects here and it's strength is very hard and where it is mixed face, where the rock has become weathered beyond rock grade three and four the EPBs do not operate efficiently, they struggle to maintain face pressure and they struggle to maintain excavation volume control. So we as LTA took the decision when we put the contracts out to tender to specify slurry machines where we saw Bukit Timah granite.

"The majority of Bukit Timah granite is



coming down from the northwest that dips towards the interface [between civils team one and civils team two] so they have a few slurry machines there. Where we are tunnelling more in the soil of granite we use the EPBs.”

On DTL stage two the client has left it to the contractor to purchase the TBMs but did specify some of the details.

The first stretch to get underway will be McConnell Dowell’s two 1km drives in the central section of the project in April. The TBMs are 6.6m external diameter Herrenknecht slurry machines.

“They are really quite powerful at 1750kw drive. The power was specified by the contractor as there is a lot of rock expected and a lot of mixed ground expected, they want the assurance that the TBM is able to perform no matter what. It is part of our philosophy of wanting the job to finish on time – it is better to be looking at it than for it,” says Hoblyn.

Herrenknecht country manager Dirk Schrader adds, “It is about 30 per cent full face rock, 40 per cent mixed face and the rest will be soil... Our approach was to learn from experiences in dealing with the

Bukit Timah granite and increase the power, increase the torque. We changed the slurry circuits, improved the cutterhead design and cutter tools spacing. So a lot of improvements were made to avoid the experiences of the past.”

Once the machine is in the ground it cannot be changed but the geology will and in Singapore it is notorious for changing drastically within a metre. “I haven’t come across any other geology that is as complex and difficult as Singapore, to design a machine that can overcome all the unknowns was a challenge,” says Schrader.

To cope with the unknowns he says, “We increased the power and the torque. We changed the cutterhead design. We changed the opening ratio of the cutter face. We also narrowed the spacing between the cutters in order to treat the rock as a rock. We increased the number of cutters in the face and centre and we increased the number of cutters in the gauge area, we increased the gauge cutters on the last track and the second to last track to ensure we always have a certain over cut.

“Previously we only had one cutter on

#### Above: First TBM launch chamber for Downtown Line stage two

the final track, just one cutter to cut this over cut. If you don’t change this cutter properly the machine will get stuck and that’s what happened on earlier projects. Increasing the number of gauge cutters increases the amount wear the machine can withstand without reducing the operation skills. We had to design the machine as a hard rock machine that could cope with softer sections, which means there is a huge compromise.”

The machine is fitted with 17-inch wedge lock type disc cutters with an 18-inch tip. The cutters are pressure compensating to help cope with the mixed conditions. The face is fitted with wear detection on the cutting wheels and cutter tools and a double chamber man-lock, which is in compliance to EU regulations, to allow access to the face.

To finish the tunnel the LTA has specified it’s standard tunnel segments in a 5:1 ratio. The segments are 6350mm long and some 1380mm wide. The tunnel will be made water tight with gaskets. ▀



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# Subterranean subatomic detector

It has been nearly half a century since the last neutrino-detection experiments took place in India. Equipment was set up in cramped mines that have since been flooded and abandoned. This time, housed in its own mountain and approached by a single access tunnel, the India-based Neutrino Observatory brings scientists back for more, reports Alex Conacher



**W**hen thinking of projects that tunnels are used for, infrastructure and utility inevitably cover the balance of the industry. Such hugely expensive projects require justification in terms of the necessity of their existence. Traversing extreme geography by old routes is dangerous and inefficient – so a tunnel is built. An increasing inner city population results in large demands and limited means to provide and remove – therefore a tunnel is built. Out of sight, out

of mind and, crucially, out of the way.

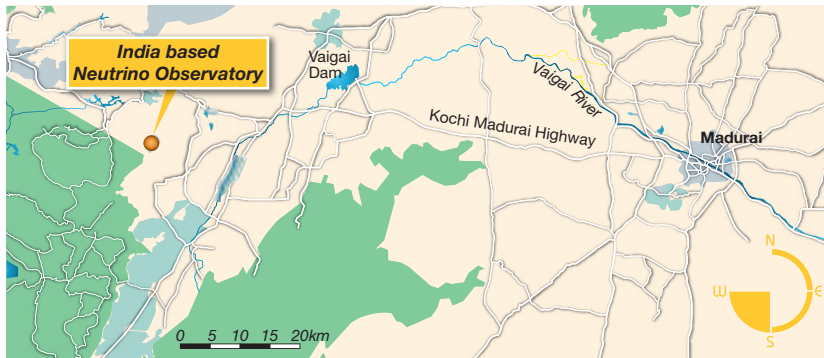
When a tunnel does not service any immediate requirements of the populace or increase the revenues of the client, the discerning tunneller knows that the project must be special.

The Tata Institute for Fundamental Research (TIFR) finally on 18 October 2010 had a site request cleared by the Indian Ministry of Environment and Forests for the pet project it has been nursing for years: the India-based Neutrino Observatory.

**Above:** The new INO site at Bodi West Hills near Madurai

## Requirements of the lab

The project, currently undergoing feasibility investigation, calls for construction of the largest cavern laboratory ever constructed in India. It must be located under a mountain of hard, dense rock with a minimum rock cover of 1000m on all sides to eliminate interference from cosmic radiation (see box, Understanding neutrinos, p29). The



**Above:** Location of the India based Neutrino Observatory relative to Madurai  
**Left:** Madurai, the nearest city to the INO in Tamil Nadu, India

There must be provision for a good quality road enabling easy access to the site as well as a supply of water to cool the massive magnetic detectors used in the neutrino experiments.

A reliable 3MW source of electricity is also required for the lab to function, though diesel generators could be activated in emergencies. Living quarters for a permanent research staff of up to 30 scientists and engineers must also be provided.

The lab will be located in the Bodi West Hills, near Madurai in the Theni District of Tamil Nadu, India. This region was chosen for the characteristics of its rock, landscape and fairly remote location.

Rock at the Bodi West Hills site, as with southern Indian mountains in general, is highly dense and compact. Gneiss and some schists can be found although the majority is hard charnockite. The geology is also stable, unlike the metamorphic, sedimentary rock of the Himalayas in the north. These factors

rock must also be stable to ensure the safety of the structure.

A 2km tunnel, with a maximum overburden of 1300m, will provide the only access to the lab. The initial reaches being excavated by cut and cover until more stable rock is reached. Blasting will be used to excavate the remainder of the tunnel and cavern. Although it is anticipated that vibration will be minimal due to the sturdy rock at the site, progress on the early sections of the tunnel will be slow due to the two blast daily limit. Once an acceptable depth has been reached, blasting will begin in earnest.

make it perfect for the INO.

The previously proposed location was Singara near Masinagudi, also in Tamil Nadu. This was the preferred site, however the project moved when the Singara area was declared a tiger sanctuary and the Ministry of Environment and Forests refused permission for the start of works.

### Engineering and environmental challenges

An environmentalist hand can be felt throughout the plan for this project. The rejection of the first site then the conditional approval of the second – trees cannot be cut and there is to be no damage to the forest cover or noise disruption of any kind – shows a clear weighting given to the environmental interest side of the project. This provides a challenge. Other environmental issues faced by the project include the lack of an electric fence to keep animals out, heavy noise restrictions and muck disposal.

The estimated total generated muck for all underground operations is around 224,000 cubic metres. Dust will be minimal, estimated at around 10 per cent of total muck, owing to the hard nature of the rock. Topsoil removed during the cut and cover phase will be reused for backfilling and greening the dump yard. Rock debris will be processed and used to produce about 80 per cent of the sand needed for the entire project. Some 20 per cent of the rock debris will be used for concrete lining and shotcreting the tunnel and cavern, as well as building construction.

Wind presents a particular obstacle to surface works at the portal. The region experiences very strong wind for six months of the year. Dry masonry walls are required to protect the muck store yard and

Scientists building INO particle detector



**Right:** The 'Super-K' detector in Japan

avoid contamination of nearby water. Metal or fabric wind sheets will also be used as protective fences.

The construction force of around 100 people will be required to undergo environmental guidelines training.

**Learning from experience**

The Tamil Nadu Electricity Board (TNEB) announced that it has been given a consultancy role for the project owing to past tunnelling experience in the region, such as work done on the Pykara Dam. For fear of putting bias on the future tendering process, the client, TIFR, refused to confirm this appointment, or indeed anything regarding the construction process.

There are four main neutrino observatories in existence today. These are: Sudbury Neutrino Observatory in Canada, Kamioka in Japan (now the larger 'Super-K'), Gran Sasso Mountains in Italy and the Nova site at the Soudan Mine in the USA.

Although this is the first purpose-built neutrino observatory in India, the nation does have a history in this field. The Kolar Gold Field mine experiments of the sixties saw the first detection of atmospheric neutrinos some 2km below the surface. This has inspired the conception of the INO and also perhaps the Aristotle quotation that is so frequently paraphrased in INO documentation: 'The search for truth is in one way hard and in another way easy, for it is evident that no one can master it fully or miss it wholly. But each adds a little to our knowledge of nature, and from all the facts assembled there arises a certain grandeur'.

**Need for the lab**

The INO hopes to determine the mass of neutrinos as well as the mass order they are ranked by. As they are the most numerous particles with mass in the universe, this is of great importance for getting a clear understanding of reality. Despite the neutrino observatories already available to scientists, this is still unknown and TIFR scientists believe that only the INO (or perhaps the Nova site in the USA) stands a chance of answering this in the next 10 years. This is because the INO can distinguish between neutrino forms (see box: Understanding neutrinos).

A neutrino observatory in India is particularly desirable as it is close to the Earth's equator, meaning that any night time observations will be of neutrinos that have passed through the Earth's core. This could reveal help with the tomography of the Earth, as no other particle can equal the neutrino's ability to penetrate matter.



Long-term goals include working in tandem with other observatories and even yet-to-be-built neutrino factories.

Unlocking the secrets of neutrinos

will hopefully lead us closer to understanding the fusion furnaces that nourish the stars. It will also shed light on the origins of the universe. ▀

**Understanding neutrinos**

- Neutrinos are elementary sub-atomic particles, which have a small (almost a million times less than the lightest known charged particle), unknown mass and possess no charge.
- They come in three types called 'flavours'. These are: electron neutrino, muon neutrino and tau neutrino.
- They are part of a group of particles called 'leptons'. This group is comprised of six particles (and their anti-particle equivalents) of which three are the neutrino flavours given above. The most famous other particle of this lepton group is the electron (not to be confused with the electron neutrino).
- Due to a quantum phenomenon, as the particles travel through space they also oscillate between flavours. This represents a complete change in entity, unimaginable in the everyday, macro world – it is the equivalent of leaving your home with two arms and two legs and arriving at work as a Christmas pudding. It also adds to the challenge of studying neutrinos. The INO is designed to overcome this.
- Neutrinos are produced by the nuclear fusion and decay process of stars as well as some left over from the start of the universe, 'relic neutrinos'.
- Aside from photons (particles of light), they are the most common particles in the universe. The Sun alone produces  $2 \times 10^{38}$  neutrinos per second while a supernova could produce 1000 times more neutrinos than the Sun could in 10 billion years. Around a trillion pass through your body every second, though only one or two will make any sort of impact in your entire lifetime.
- Neutrinos interact with other matter primarily through the weak force at a very short range. This means they can pass through it with almost unstoppable ease. They pass straight through the Earth as we pass through the air, though with less resistance.
- Due to their unobtrusive nature, efforts to detect them on the surface of the Earth are often thwarted by 'noisier' cosmic radiation. Locating detection laboratories deep underground where solar radiation will weaken itself into insignificance can solve this. The neutrinos are not affected by the rock overburden.
- Wolfgang Pauli proposed the existence of neutrinos in 1930 but evidence was not found until 1953 during the famous experiments of Reines and Cowan. The first atmospheric neutrinos (neutrinos created by a reaction of cosmic rays and atomic nuclei inside the Earth's atmosphere) were discovered in the Kolar Gold Field mines, India in 1965.



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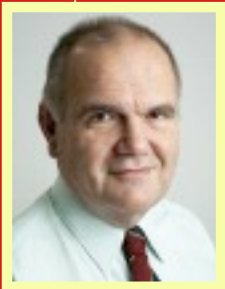
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