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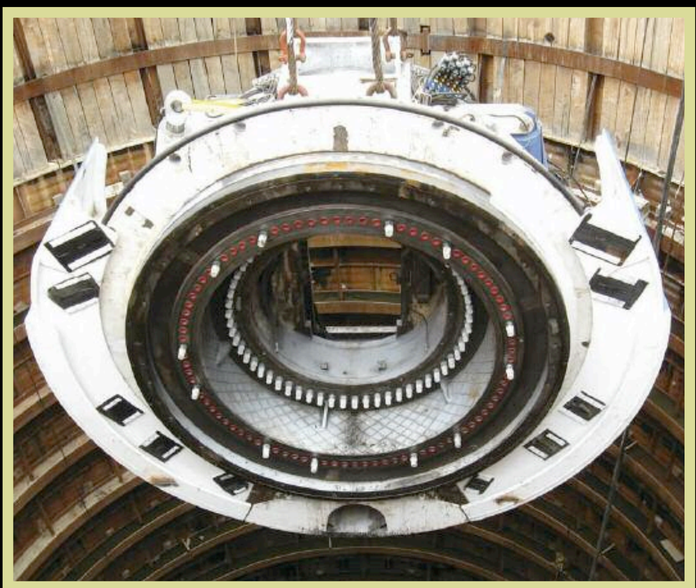

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BRISBANE: A SUPERLATIVE TUNNEL PROJECT.

Brisbane is the large city with most sun light in Australia, but car drivers also know its dark sides: slow-moving traffic and endless traffic jams. This is because the Brisbane River, which divides the city in two, can only be crossed over bridges.

A superlative project to solve this situation is under construction. The new "Clem Jones Tunnel" is to cross beneath the Brisbane River and, with a length of 6.8 kilometers, will be the longest road tunnel in Australia after completion. For the two 4-km long stretches, which will be excavated mechanically, the contractor ordered two gigantic Double Shield TBMs (Ø 12.34m each) from Herrenknecht. In order to meet the extremely tight time schedule, "Matilda" (S-375) and "Florence" (S-376) were built, shipped and assembled on the construction site in Brisbane in a record time of only one year. In the meantime, both machines have mastered their first partial section and achieved breakthrough at the intermediate station "Kangaroo Point" after 2,562 and 2,674 meters of tunnel respectively.

After completion of the construction work, which is scheduled for 2010, the tunnel will connect the city district of Woolloongabba in the south of Brisbane with Bowen Hills in the north, taking 100,000 cars per day underneath the river. This means unhindered driving fun and is great news for the city's traffic.

BRISBANE | AUSTRALIA

PROJECT DATA	CONTRACTOR
S-375, S-376 **2x Double Shield TBM** Diameter: 12,340mm Max. torque: 18,473kNm Tunnel length: 3,997m + 3,932m Geology: tuff, arenite, phylite with quartz seams, rock faults	LBB Joint Venture (Leighton Contractors Pty. Ltd., Bilfinger Berger AG, Baulderstone Hornibrook)

Herrenknecht AG
D-77963 Schwanau
Phone +49 7824 302-0
Fax +49 7824 3403
marketing@herrenknecht.com

Herrenknecht Australia Pty. Ltd.
93 Links Avenue South, Eagle Farm
AU-4009 Brisbane QLD
Phone +61 7 3291 2700
Fax +61 7 3216 4534

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Its just a bit of snow...

I am sure you'll all be aware that most of the world, especially our friends in Scandinavia and Canada, have had a good old laugh in recent weeks at the UK's wholesale inability to deal with weather of any severity. On Monday 03 February, roughly one foot of snow completely crippled London's transport network and subsequently it's workforce, and the rest of the country didn't fare much better.

The day saw 20% of the UK's employees, certainly much higher in London, unable to make it to work - that's around 6.4M people, at an estimated cost to the economy of US$1.8bn. Everybody was up in arms and even the 20% who had a day off to make snowmen pretended to be appalled. Cries rang out of "where was the grit, where was the salt?" And my personal favourite, "where were the snowploughs?"

Well, the answer to the final question is, "we don't really have any," and that's because we live in England, not Iceland. The same people would probably back a multi-million dollar flood defence system in the Sahara. The fact is, it would cost considerably more to be constantly prepared for another Monday 03 February, than to take the once in 20 year snow hit, which may, or may not even happen.

But the furore did polarise a point. Why such a fuss over this when it's becoming increasingly impossible every day, not every 20 years, to get anywhere on time in the UK purely because traffic volumes exceed the available infrastructure?

I drive almost every morning out of London, through the Blackwall Tunnel, one of the multitude of access points to the city. Almost daily, the traffic heading into London is completely gridlocked leaving up to one hour of work productivity lost per person. Multiply this urban scenario internationally and the lost production figures become obscene, and this is a daily event!

We may not be able to do much about lost productivity due to freak snow storms, but we can certainly do something about daily productivity lost due to poor infrastructure. It's time to do some serious maths and point out to decision makers that improved urban infrastructure can, and will pay for itself. Life costing is the way to promote the advantages of such large-scale projects, ultimately making cities more functional and economically productive.

Then when the snow comes again in twenty years time, we could actually afford to take the day off and build some snowmen.

Tris Thomas

COMPANIES IN THIS ISSUE

Lovat completes Moscow steep bore

Left: Looking down the inclined bore at the Lovat TBM

Disassembly of the internal equipment of the 11m diameter Lovat EPBM working on Moscow metro is underway following completion of the 30 degree downward drive for an escalator access tunnel, and contractor Mosmetrostoy plans more such works.

The skin of the TBM has been left in place to support the tunnel lining during the disassembly, and the equipment is being withdrawn back up the bore to the surface.

Key design challenges for the large diameter TBM and the construction process had to be overcome for the full system to work successfully at that slope.

In addition, the 9.4m i.d. bore had to be done in EPB mode given the geology – dolomite, limestone, clay, marl, loam and loamy sand, and there being mixed ground conditions for much of the drive. The groundwater pressure met was up to 4.5 bar.

Lovat said that stabilising the centre of gravity was a key design challenge, which it solved with modifications to the cutterhead overcut diameter to provide the mounting of the main drive to be offset vertically higher. The change kept the shield from sinking at the invert by eliminating the gap between the skin and ground.

Materials handling on the downward slope also required a mine-type hoist system to supply 7.25 tonne segments to the backup. A bespoke segment car was lowered down the bore. The rings (6+1) are 10.6m o.d.

The TBM with a two-stage screw conveyor and high density pumping system to deal with spoil removal, and Lovat said this was an important technological advancement in its offering.

Manoeuvrability in excavating the 150m long escalator access tunnels came from two articulation joints and a cyclical copy cutter (*T&TI*, January 2008, p7).

Lovat supplied the design for the lining and segment forms as well as providing technical support, guidance systems, ground conditioning and grouting equipment.

Alborz service drive breakthrough

After a series of difficult ground conditions to overcome over four and a half years, breakthrough was achieved on the Alborz road tunnel in Iran early this month.

A 5.2m diameter open gripper machine met a string of tough conditions that delayed completion of the 6.3km drive: methane, H_2S and CO_x gases: major fault zones; anhydrite with karst sections that required numerous bypasses; squeezing ground that blocked the cutterhead or shield; material and water inrush of up to 800 l/s.

Three parallel tubes are eventually to form the Alborz tunnels on the 121km long Tehran Shomal Freeway to link the capital to the Caspian Sea.

The service tube was first to be bored by the Wirth TBM with the plan for the shield to then drive the bores either side for the main tunnels, which would subsequently be widened to approximately 14m.

However, following completion of the service tunnel by contractor Jäger, the commencement of excavation of the main tunnels has not yet been determined.

The freeway is being designed and built in lots. Swiss firm Amberg Engineering has provided consultancy, design and site supervision services to the client during the TBM excavation. The TB 520E machine was delivered to site in late 2003 along with auxiliary equipment supplied by Wirth, and excavation began in the second half of the following year.

Aside from the fault zones, geology anticipated along the alignment comprised sandstone, tuff, andesite, basalt and limestone with strength up to 150MPa. Tunnel support used rockbolts, mesh and shotcrete but a ring beam lining device was fitted to the shield should poorer ground conditions be met.

Almost there … Chunnel fix finishes

Final fit-out of the replacement fixed equipment in the North tube of the Channel Tunnel, to complete the repair works, is slightly ahead of the programme set down by owner and operator Eurotunnel after the shuttle train fire on 11 September last year.

A 650m section of the tunnel required repairs, the worst damage being over a stretch of 550m. Hydrodemolition was used to helped clear the damaged concrete segmental lining and prepare it for shotcreting once exposed reinforcement was fixed.

Access to the fire-damaged tunnel, which resulted in the temporary operational loss of one third of the North tube, was only possible from mid-October. The main civils works finished ahead of schedule and the lead was kept by the electro-mechanical fit-out activities (see full article p21-23)

Asa Pictures/ABACA/PA Photos

Delhi TBM successes

The last of the 14 TBMs being used in the Phase 2 expansion of Delhi metro has just been launched on the Airport Express Link – 13 months after the first launch of a shield on another section of the fast-track tunnelling scheme.

The launch comes after a series of breakthroughs elsewhere on the scheme over recent months as excavation proceeds on the characteristic short drives of the project that involves approximately 16km of TBM drives.

In total, Phase 2 involves approximately 30km of underground works, including stations excavations.

The client, Delhi Metro Rail Corp (DMRC), said all tunnelling work is on track for completion by this December. The major expansion of the metro is strategically important to the city, not least as it is hosting the Commonwealth Games next year.

The geology facing the generally 6.2m diameter EPBMs comprises sandy silt, silty sand and gravels. Groundwater is under 2 bar or more over the invert. Cover is approximately 15m.

The 5.7m i.d. and 5.8 i.d. tunnels are lined with segmental rings (5+1) of 275mm thickness.

Four machines are now excavating the twin tubes of the Airport Express Link: a pair driving the 2.3km long section between New Delhi Railway station and Shivaji Stadium; and two TBMs – including the last to be launched on the entire project – on the 1.5km long stretch from Dwarka Sec 21 to Indira Gandhi International airport.

The contractor on the former section is a JV of Alpine, Hindustan Construction Co (HCC), Samsung. On the latter section, the contractor is a JV of Shanghai Urban Construction Group (SUCG) with Larsen & Toubro (L&T).

The majority of the tunnelling in Phase 2, however, is elsewhere - in two other corridors from Central Secretariat (CS), to Badarpur and to Qutub Minar, respectively.

The CS-Badarpur corridor has approximately 10.8km of total excavation to be executed by four TBMs.

The first breakthrough on the CS-Badarpur corridor was on 21 January, at Jawaharlal Nehru Stadium, after being launched from Jungpura last October to drive the 586m long stretch. The shield driving the parallel tube is to hole through this month.

The last pair of TBMs are currently excavating the 1,776m long Udyog Bhawan-Khan Market section and are expected to finish by August. The contractor on the CS-Badarpur corridor is a JV of Ital Thai Developments (ITD) and ITD CEM, and its contract is BC-24.

In the CS-Qutub Minar corridor there is a total of 14.3km of tunnel to be constructed using six shields. Tunnelling got underway earliest on this section of the Phase 2 works.

There are pairs of 3km and 4.16km long TBM bores to be done, respectively, in sections from Hauz Khas to Malviya Nagar and from Udyog Bhavan to Green Park (*T&TI,* July 2008, p7).

Tunnelling works on the Hauz Khas to Malviya Nagar section are being undertaken by Metro Tunnelling Group (MTG) – a European-Asian consortium led by Dywidag International with Shimizu, Ircon and L&T. The design and construct contract package is BC-18 and has a duration of 38 months.

The JV members had been together on Phase 1 of the metro construction in Delhi.

Excavations on the Udyog Bhavan to Green Park section of the corridor are being done by a JV of Taiwanese firm Continental Engineering Co (CEC) and local company Soma Enterprises. The design and construct contract is known as BC-16 and has a duration of 40 months.

The majority of shields on the project were manufacturered by Herrenknecht, either new (10) or were original builds previously used on Phase 1. Four of its shields are used on the Airport Express Link, four on BC-24, two on BC-18 and the remaining two on BC-16.

The project is also served by Robbins, which has an EPB design by Mitsubishi Heavy Industries (MHI) being used of two shields on BC-16. The TBMs were manufactured in Dalian, China.

Both firms have supplied other current major projects in India - Alimineti Madhava Reddy (two 10m diameter Robbins TBMs) and Subbaiah Veligonda (10m diameter Robbins and 7.9m diameter Herrenknecht).

AP/PA Photos

Above: **Another breakthrough celebration on Phase 2 of Delhi metro, at Jawaharlal Nehru Stadium, last month with the first of four TBMs on the Central Secretariat-Badarpur corridor**

Sir Alan Muir Wood dies

Sir Alan Muir Wood has died. A tunnelling engineer of world renown, past Chairman of the British Tunnelling Society, first President of the International Tunnelling Association and a past president of the Institution of Civil Engineers, he passed away peacefully at the start of February.

A family service was held at his home in Berkshire, England. A memorial service will be held later this spring in central London.

With passion for a broad range of engineering, Sir Alan was a Fellow of the Royal Academy of Engineering and the Royal Society, and took a proactive stance in founding the ITA to promote the tunnelling profession. He was Senior Partner of Sir William Halcrow & Partners over 1979-84, and was knighted in 1982 for his services to civil engineering.

Martin Knights, current President of ITA, said: "Sir Alan had a formidable intellect. He wrote and spoke widely about many issues in the tunnelling world.

His achievements were many. His wide circle of government and business colleagues and friends, and his family, will surely miss a man who influenced everything that he was involved in and whose legacy to the Engineering profession is well documented and acknowledged. I shall also miss a good friend and advisor."

Two NFM shields for Beijing metro Line 10

Contractor China Railway Construction (B12) has ordered two EPBMs from NFM Technologies for delivery in the third quarter to be used on excavation of twin tubes on Phase 2 of Line 10 of Beijing metro.

NFM said the scheduled delivery of the two 6.28m diameter shields is July and August, respectively. The contract was signed last month but the value was not disclosed.

The TBMs will be used to bore a total of slightly more than 8,000m on Line 10 between Caoqiao and Mengjiacun stations with Fanjiacun as an intermediate station and future interchange with Line 16.

Between Caoqiao and Fanjiacun one of the shields will drive a 3,225m long tube before being used to bore the parallel tunnel.

The second TBM is to drive the twin tunnels between Fanjiacun and Mengjiancun, each of which is 808m long.

The tunnels will be bored at depths of 9m-17m below dense urban and historic areas of the capital. Geology along the alignment comprises mainly conglomerates.

Phase 1 of Line 10 was constructed between late 2003 and mid-2008, is almost 25km long, has 22 stations, is totally underground and was completed just before the Olympics hosted by the capital. Planning started in the late 1990s.

Main works on Phase 2 works commenced recently and will extend the line initially in the north west of Beijing. In adding a further 32km eventually, Line 10 will become the city's second loop line. It is to be completed by 2012-13.

Lovat EPBM starts Terrassa dig

Excavation is getting underway on the Terrassa rail project in Spain with a 6.9m diameter EPBM, the first of two Lovat shields that will be used on the twin tube drives at the edge of Barcelona.

The first shield was delivered to the JV of FCC Construccion, Copsia and Obrascon Huarte Lain in late November last year, and assembly commencement by mid-December. Lovat received the first order for a shield just after mid-2007 and later in the year received the second call, for an identical EPBM.

Geology along the alignment comprises mainly sedimentary deposits including argillaceous, granular and cemented materials, and isolated layers of conglomerate and cemented deposits. The complete alignment is below groundwater with the head varying from 5m-24m over the tunnel invert.

The mixed face shields will drive 3.7km long twin tunnels, and an average advance rate of 10m/day is envisaged per machine. Each machine can produce 9,000kNm of torque and thrust is 65,000kN.

Launch of the first machine had been previously earmarked for around October last year. Lovat is also supplying technical assistance and parts for the RME270SE TBMs (*T&TI*, Jan 08, p5).

Ferrocarrils de la Generalitat de Catalunya (FGC), the rail company of the autonomous Government of Catalonia is developing the project which is an inland extension of the FGC network in Barcelona.

Back to burrowing in Gaza

Not long after the conflict between the Hamas forces in Gaza and the Israeli military, smuggler tunnels are being excavated again in the Palestinian territory along its border with Egypt despite ongoing risk of air attacks on the digs. Here, a tunnel is shown being excavated in Rafah early this month.


LANDOV/PA Photos

Last month, researchers in Israel announced they had developed a system of buried fibre optic cables to detect ground movement due to such excavations. The system, developed by Technion-Israel Institute of Technology's civil and environmental engineering dept, is based on strain measurements in the cables caused by ground movements.

The researchers said the system was verified to differentiate between tunnelling and other ground changes, and it may be possible to detect excavations at depths of up to 20m. However, details were not immediately available on the ranges and tolerances of the geological and groundwater conditions studied.

San Cristobal fully opened

The second tube of the San Cristobal road tunnel concession in Chile is now operation after additional non-underground works following the first bore having opened almost on schedule last year.

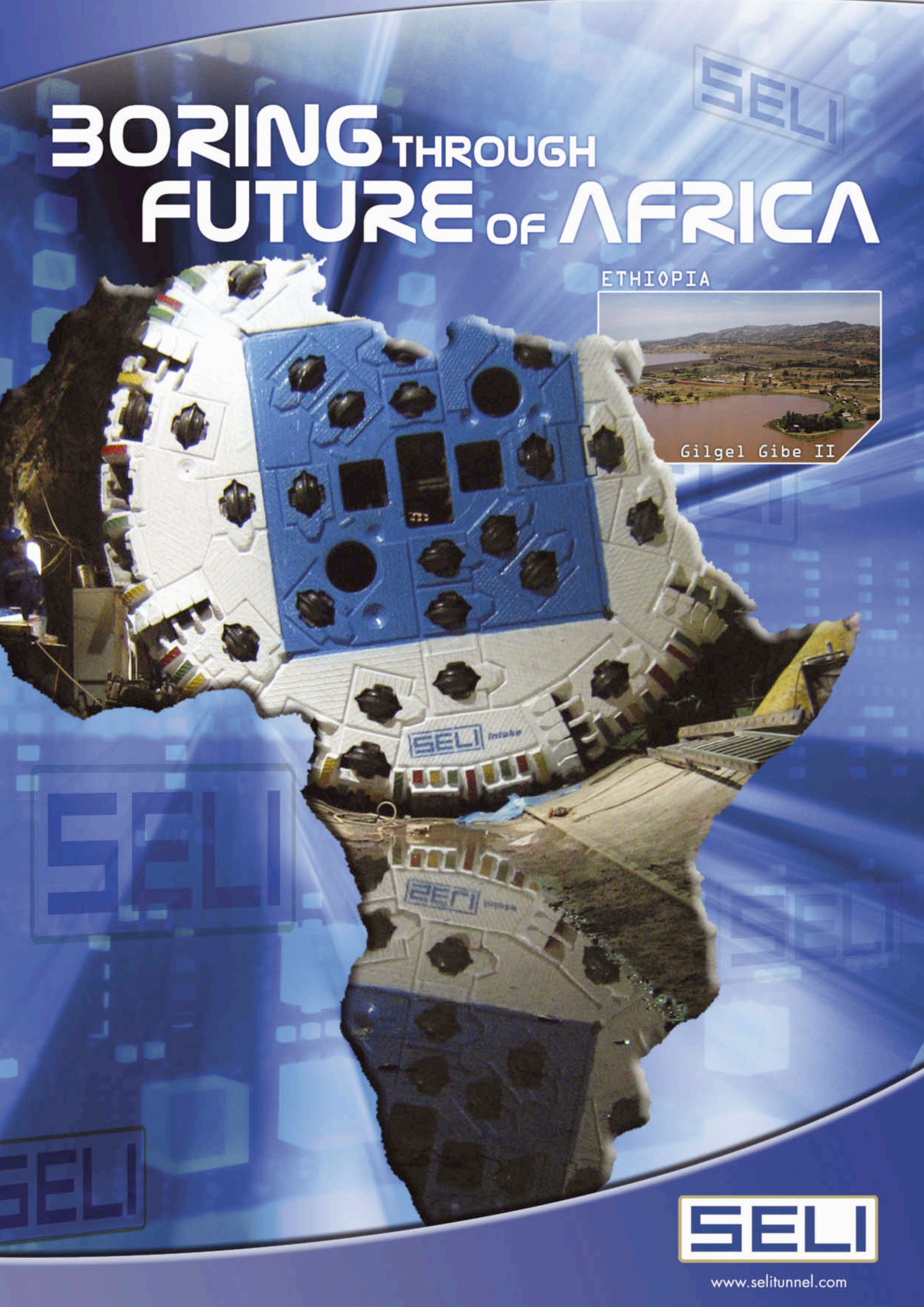
Both 1.8km long tubes on the toll link are operating as planned for the PPP concessionaire, a JV of Hochtief and ACS-Dragados. They were awarded the PPP contract in 2005, which calls for the twin tunnels to be constructed as part of a 4.1km link in north Santiago.

The tunnel consists of the two tubes linked by eight evacuation galleries, two of which are for vehicles, at 200m intervals.

Excavation started in April 2006, and the drill and blast works and mechanical excavation were finished by April 2007, and with lining underway later that year the project was on schedule to fully open in mid-2008, as planned.

However, only one two-lane tube on the link was opened in July last year, only slightly after the planned completion. The projects includes also construction of an additional 2.2km of access roads (*T&TI*, July 2007, p7).

The second tube was not opened until a series of works were done to alleviate traffic congestion. The tunnel was opened on 30 December, taking the link to full capacity. Costs recently cited are US$125M whereas previously the budget was given as US$91M.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Above, Left: **Station excavation at Sirkeci on Marmaray Crossing in Istanbul; TBM drive on Asian side while delays on European side**

Marmaray TBMs still in stop-go

Only two of the five TBMs on the Marmaray Crossing are making progress due to ongoing delays caused by archaeological discoveries in Istanbul, but the pair are making steady progress and the project can already boast completion of the immersed tube tunnel last year below the Bosphorus.

The two Hitachi-Zosen slurry TBMs on the Asian side of the rail crossing began their drives almost two years ago, and by the end of 2008 had completed 3,076m and 2,667m or the twin tubes, or almost 75% and 65%, respectively.

Upon completion of the 4,124m long drives, the leading 7.89m diameter shield is expected to dock with the 1.4km long immersed tube in 11 months. A low-strength sand-cement stretch will act as a transition zone before the shields dock, the skin sealed and innards dismantled.

Before then, the TBM is expected to hole through at Uskudar station around May. Most recently, however, it achieved breakthrough into the Asian crossover cavern on the route between Ayrilikcesme and Uskuder shoreline.

A pair of sister Hitachi-Zosen machines on the European side of the crossing have been severely held up, however, due to extensive archaeological investigations at the Yenikapi portal. They are to drive 3,130m long twin bores from there to Sirkeci shoreline, and the latest estimate is for the 7.04m i.d. drives to finally commence by mid-year for completion by late 2010.

By the end of last year the Istanbul Archaeology Museum had supervised the excavation of 125,000m^3 of material from the Yenikapi portal area.

A Lovat shield is also on site to drive both parallel tunnels between Yedikule and Yenikapi. Excavation with the 7.97m diameter mixed face EPBM has not advanced beyond 100m in late 2007 due to expropriation issues (*T&TI*, May 2008, p21-24).

Cross passages will be spaced every 200m along the running tunnels, which are constructed of 1.5m long segmental rings (6+1).

The 11th, and final, element of the immersed tube was placed in September 2008. Work is currently focused on backfilling the trench, concreting joints and casting ballast concrete.

The crossing is being developed by the General Directorate of Railways, Harbours and Airports Construction (DLH), which is part of the Transport Ministry. DLH is supported by Avrasyaconsult, a consortium led by Pacific Consultants International. Other members include Yuksel Proje, Parsons Brinckerhoff, JARTS and Oriental Consultants. The contractor is a JV of Taisei and Gama-Nurol.

Seli to drive Kishanganga

Main tunnel excavation will start in 2010 for the Kishanganga hydropower project in India following the award of the main contract to a JV led by Hindustan Construction Co (HCC), which in turn has subcontracted Seli to provide TBM equipment and execute those works.

HCC was awarded the US$560M turnkey contract by the National Hydroelectric Power Corp. The project is located in the state of Jammu & Kashmir in the north of the country, and the construction period is 84 months.

The Indian contractor has described the main civils works as requiring 23.5km of headrace tunnel, an underground powerhouse and a dam.

Seli said it has been awarded a US$47M subcontract to undertake TBM excavation and lining of 14km of headrace tunnel. The double shield is to be launched in July next year.

The Italian firm is also designing and supplying the 6.1m diameter TBM and auxiliary equipment, including back-up, rolling stock and precast segment moulds.

To deal with the difficult geology, the TBM will be fitted with equipment to treat the ground ahead of the face and also have capability to overbore and cut.

A contract period of 60 months has been agreed with HCC, including the manufacture and mobilisation of the TBM.

The main contractor is a JV between HCC, holding 98%, UK-based consultant Halcrow.

Guangzhou high speed double for Robbins

A pair of Robbins EPBMs have been launched to excavate twin tubes in part of China's first high speed rail link, which is being constructed between Guangzhou and Foshan.

Excavation with the second of the 6.3m diameter shields is just getting underway just after the launch of the first TBM, in mid-December.

The machines were launched from a 16m deep shaft and the drives will pass through stations of Jushu, Xilang and Hedong, and the bores are to be completed before the end of the year. The TBMs will each drive a total of 2.6km, driving the both tubes in two sections.

Geology along the alignments is comprised of weathered rock, coarse sand, and silt at pressures up to 4 bar. The shields are fitted with disc cutters and rippers to deal with the mixed face conditions.

The running tunnels are being lined with precast concrete rings (5+1) with 300mm thick segments.

Robbins assembled the TBMs and back-up systems in Guangzhou for the twin tubes on Lot 12 of the Guang-Fo line. The high speed link between Guangzhou to Foshan will be 33km long.

The line is part of the Government's Pearl River Delta Inter-City Rapid Rail Project, which started construction just over 18 months ago and is to completed by 2015. In total, the major project involves placing a total of approximately 32km in tunnel, and constructing 21 stations, 14 of which are to be operational in 2010.

Robbins EPBM gets underway on Guangzhou high speed rail bore

Yangtze tunnel cross passages excavated

All eight cross passages have been excavated on China's major Pudong-Changxing Island tunnel project below the Yangtze river in Shanghai.

Last month, excavation of the eighth cross passage was completed between the 7.5km long main tunnels that run below the Yangtze. The 15m long link tunnels are spaced are intervals of approximately 800m, had excavated widths of almost 4m using ground freezing and the finished openings are 2.74m wide.

The tunnelling works are being done by Shanghai Tunnel Engineering Corp (STEC) in JV with Bouygues, and breakthrough of the second 15.43m diameter Herrenknecht Mixshield (S-318) brought the landmark main bores to completion in September last year.

The TBM drives employed the biggest shields ever used in tunnel excavations.

Geology along the 7.17km long bores comprised sand, clay and rubble up to 65m below the river. Lining is segmental rings (9+1), each 2m long (*T&TI,* October 2008, p7). The main tunnels will be fitted with double-decking, roads on top and the lower level will take service and safety installations, and maybe a metro link.

The client is Shanghai Changjiang Tunnel & Bridge Construction Development, and design was by Shanghai Tunnel Engineering Design Institute (STEDI).

DLR Woolwich link opens early

The extension of the Docklands Light Railway in east London to Woolwich, which had involved twin 1,830m long bores below the river Thames, has been opened two months early.

Last month the £180M (US$267M) link was formally opened between King George V and Woolwich Arsenal stations, and providing south east London with a fast link to London City airport, also served by DLR.

The project was developed under the Private Finance Initiative (PFI) by concessionaire Woolwich Arsenal Rail Enterprises, a JV of Land Securities and the Royal Bank of Scotland. The design and build works were performed by Morgan Est (formerly Amec, prior to acquisition) and Colas Rail.

Excavation of the 5.3m i.d. tunnel was done over 15 months using a 6.05m diameter Lovat EPBM. Geology along the alignment comprises sands and gravels, and below the river there was fissured, flint-embedded chalk with pressures up to 3.5 bar.

The drives were completed in late 2006 and July 2007, respectively (*T&TI*, August 2007, p7). In mid-2005 work on the entire £180M (2005 prices; US$340M at 2005 currencies) scheme started and in the second quarter of 2006 tunnelling commenced.

Construction also involved building a box station at Woolwich and also a large intervention shaft and headhouse, 15m wide by 40m deep and sunk next to the river flood wall. It is used for power and communications.

Crossrail advances

Keeping up the pace of rapid progress of recent months, Crossrail has appointed a new chief executive, the shortlist has been made for the Project Delivery Partner and preparatory work for the US$23.3bn (£15.9bn) project have commenced in central London.

Rob Holden, presently chief executive of London & Continental Railways (LCR) has been appointed to that same role with Cross London Rail Links Ltd (CLRL) with effect from 1 April. CLRL is developing the east-west rail link through the capital, and which calls for excavation of a total of 41.5km of 6m i.d. twin tube tunnels. Services are to start from 2017.

Crossrail's executive chairman, Douglas Oakervee, becomes interim non-executive chairman when Holden joins. Oakervee has led the project in early development to Parliamentary hearings and achieved Royal Assent last July, and praised Holden's 'exceptional' experience on major projects, including High Speed One.

The new non-executive was previously announced as Terry Morgan, chief executive of Tube Lines, who is to take up the role from November. CLRL is now a wholly-owned subsidiary of Transport for London (TfL).

Last month, CLRL shortlisted four parties in the procurement of the Project Delivery Partner, which is to help the client deliver to standards, time and budget, and also provide supplementary suitable personnel to the core CLRL team.

The four parties are: Bechtel; Legacy 3 (a JV of Parsons Brinckerhoff, Balfour Beatty Management and Davis Langdon Programme Management); Laing O'Rourke Holdings; and a JV of Capita Symonds and Northcroft. The party that did not make the shortlist was Flare – a JV of Fluor, Ove Arup and EC Harris.

The deadline for tenders to be submitted by the shortlisted firms was 30 January.

The first two of the shortlisted parties have also been shortlisted for the Programme Partner contract, the other being Transcend – a JV of Aecom, CH2M Hill United Kingdom Unlimited and Nichols Group. CLRL said a decision was expected shortly.

At the close of last year a dozen consultants were awarded Design Framework Agreements to bid for design packages. The agreements last for the entire project. The 12 companies are: Aedas Group; Atkins; BDP; Capita Symonds; Halcrow; Hyder Consulting (UK); Jacobs Engineering UK; Mott MacDonald; Ove Arup; Parsons Brinckerhoff; Scott Wilson Railways; and, WSP UK.

Preparatory works for Crossrail commenced last month, at Tottenham Court Road tube station in the West End of London. Main construction activities are programmed to start next year. CLRL plans to use Optimised Contractor Involvement (OCI) in the procurement process for the main construction contracts (*T&TI*, January, p10).

DHL Excel Supply Chain has been hired to study logistics options to minimise the disruption to the capital from the string of work sites, equipment and materials movements cutting across the heart of the city.

With most of the funding for the project coming from Government, there is also a parallel procurement activity by the Department for Transport to perform project oversight.

Shortlisted parties are: Arcadis AYH; Atkins; Booz & Co with support from Aecom/Turner & Townsend; Jacobs Engineering UK with support from KPMG; Mott MacDonald with support from Ernst & Young/FirstCo; Nichols Group-Nicholas Arup JV with support from First Class Partnerships/ NTTX; Parsons Brinckerhoff with support from Davis Langdon; Parsons Group International with support from Gardiner & Theobald; and, Praxis High Integrity Systems.

Alain Balan heads France's AFTES

Alain Balan, a consultant and former head of major infrastructure projects with rail group SNCF, has been appointed as President of the French Tunnelling and Underground Space Association (AFTES). He will serve a three year term and succeeds Jean Philippe.

Balan led tunnel construction work at Fontenay, Sceaux and Villejust on the French TGV high speed rail line in the 1980s. Over 1999-2000 he was director of the Paris, Express Subway, Line E (EOLE) Project, then set up SNCF's department for major infrastructure projects. In the 1970s, his early SNCF work included tunnel rehabilitation.

With a specialist focus on geotechnical activities, he now operates as a consultant in infrastructure engineering and project management. He was elected as President by the Board of AFTES at its meeting on 16 January.

PPP Arbiter issues metro upgrade cost report

Results of an international benchmarking study into costs of metro improvements has been issued in a report* by the Arbiter of the Pubic-Private Partnerships ("PPP Arbiter") being undertaken to refurbish and upgrade the London tube network.

The PPP Arbiter, Chris Bolt, commissioned the study to help judge the costs and performance of tube upgrade concessionaires Metronet and Tube Lines, and both firms participated. He also wanted to identify lessons that could be imported.

Metro systems in eight cities agreed to help the study – Hong Kong, New York, Munich, Barcelona, Toronto, Stockholm, Boston and also parts of the UK's Network Rail.

In terms of civil structures, only global costs were examined due to variations in classifying operating and capital costs. The data could not be "normalised" for statistical meaning due to their variability. Chronic underspending in infrastructure meant low civil maintenance cost did not indicate good practice.

Also, given the complexity of civil structures it was not possible to establish an effective benchmark range. It was noted, though, that Tube Lines' civil maintenance costs were relatively low compared to the others, and Metronet.

He noted that while the findings would be used as part of negotiations with Tube Lines under its Periodic Review, interpretation of benchmarking findings depended on various factors: relevance of comparators, robustness of the methodology used, the volume and quality of underlying data.

The benchmarking analysis was based on only one year of cost and performance data, and not all asset areas had information to readily provide. It was further noted that companies working on upgrades in London face a contractual performance regime.

He said an extension to the study is being commissioned to address some issues identified in the benchmarking analysis, such as obtaining extra years of data for study and ensuring the quality is at least as good, ideally improved upon.

The study was undertaken by BSL Management Consultants. Work stated in late 2007 and finished after just over a year.

* "International Benchmarking of the Costs and Performance of Maintaining and Renewing Metro Systems".

Waterview tunnel in cost risk

The proposed 3.2km long twin bore tunnels for New Zealand's Waterview Connection scheme could be dropped after higher estimated costs led the Government to call for alternatives to tunnelling to be investigated.

New cost estimates for the tunnel project show a 46% increase to NZ$2.77bn (US$1.47bn) from NZ$1.89bn (US$1bn). The estimate, from the Treasury and Ministry of Transport, includes debt servicing. It is being developed by Transit New Zealand.

Restrictions on serving increasing demand are a further complaint against the project, which is would have two traffic lanes in each tube between Mount Roskill and portals at Hendon Park and Waterview Park. Taking the project up to three lanes in each tube would increase the cost to more than NZ$3bn (US$1.6bn), said Transport Minister, Steven Joyce.

Last year, it was envisaged that the plan then under approval by the then Labour Government would see work commence in late 2009. The tunnels would be excavated by TBM at a depth of approximately 40m and be lined with concrete segments (*T&TI*, May 2008, p8).

Joyce said: 'The last Government allowed expectations to be raised about a number of large transport projects, including Waterview, without actually allocating funding to them.'

He added: 'The Government is committed to delivering a Waterview Connection but wants to ensure the project is advanced in a cost-effective and future-proofed way.'

The Waterview link would have a total length of 5km and was planned to be finished in 2015, and so complete Auckland's 48km long Western ring route.

US venture plans deep dig hydro

Site investigation is to start shortly for a US$2bn new type of hydropower scheme in New Jersey that calls for major tunnelling, and the venture fund-backed developer aims to build four similar projects in North America. The developer, Riverbank Power Corp, plans to locate the first project at Limecrest quarry near Sparta, NJ. The company is backed by venture investor Blackrock.

If the geotechnical data prove favourable, Riverbank envisages that the approval and construction period of approximately four years to bring the huge, 1GW plant into service by 2015.

The design calls for a grid of caverns and tunnels to be excavated approximately 610m below the quarry. The tunnels would hold the powerhouse and also a lower reservoir of water that would be re-circulated with the flooded quarry, acting as an upper reservoir. Riverbank calls the "closed-loop" system Aquabank.

Local Government in Sparta backs the project for its proposed inward investment, land use and construction employment. The developer notes that the scheme would also contribute to the state's goals on renewables generation and jobs.

Riverbank said that it plans at least five Aquabank projects across North America and that Sparta was one of the most favourable sites, where it is collaborating with property owner Limecrest Quarry Developers in studies for the project.

Apart from providing valuable peak power capacity to the electricity grid, the business strategy in developing these schemes that would call for significant tunnelling works comes from the flexibility of their location. Proximity to key load centres can improve grid stability in general but also to assist in the massive introduction in wind power, which fluctuates and so its inputs needs balanced.

Cavico wins two more tunnel jobs

Cavico is to undertake more than 4,500m of tunnelling in Lao PDR and Vietnam as key parts of contracts worth a total of US$16M.

In Lao PDR, a subsidiary of the group will use a TBM to excavate a 1,000m long tunnel and a 45m deep dismantling shaft for the Theun HinBoun expansion project.

Cavico said the construction work is expected to be completed in 24 months.

The contract was awarded by Italian contractor Cooperativa Mutatori e Cemenisti – CMC di Ravenna, and is valued at US$6.2M.

The company also recently won a US$9.8M job on a hydropower project, Song Giang 2 in Vietnam, to undertake a package of tunnelling works. The entire project is valued at approximately US$50M.

The tunnelling package includes a 3,900m long headrace, two sub tunnels of 650m in total length, and a 42m high surge tank.

Construction work is to be completed within 20 months.

DSI acquires Brazil's Fosminas

Brazilian firm Fosminas Ancoragens has been bought by Dywidag-Systems International (DSI). Financial terms of the acquisition of the Latin underground support services company were not disclosed.

DSI has taken all 28 employees of Fosminas as part of the transaction, which will see the business re-branded to the new owner's title.

The expanding group said the strategic acquisition would enable it to expand in underground support services throughout South America.

The Brazilian firm was established in 2003 and has a strong research and development base, said DSI.

Alan Bate recently took over as DSI chief executive last year from Howard Poulson. The company was acquired by venture capital firm CVC Capital Partners in 2007.

Naitwar Mori deadline change

The deadline for contractors to submit prequalification submissions for the Naitwar Mori hydropower project in northern India, which calls for major underground works as part of the turnkey package, has been rescheduled to 10 February.

The client, Satluj Jal Vidyut Nigam (SJVN), had reset the deadline a number of times for the engineering, procurement and construction (EPC) contract.

Most recently, submissions to prequalify for the contract were invited by 20 January. The cutoff has been shifted by a further three weeks.

Tunnelling works on the project, to be built in the state of Uttarakhand, include excavation of a 4.3km long headrace of 5.6m width and horseshoe-shaped cross section, and a partly underground powerhouse.

There will also be a 41m deep surge tank, adits with lengths of 43m and 169m, respectively, and the tailrace may also be constructed as tunnel.

Geology along the alignment of the bore is mainly in gneisses, which are along three-quarters of the headrace.

SJVN is planning for the contract is to be completed within 36 months.

The utility is a joint venture of the Indian Government and the state of Himachal Pradesh.

BOMBELA

GAUTRAIN SITE DEMOBILIZATION

Bombela Civil Joints Venture consortium, that consists out of Bouygues Civil Works, Murray & Roberts and SPG is currently busy with site demobilization and the following equipment / plant is available:

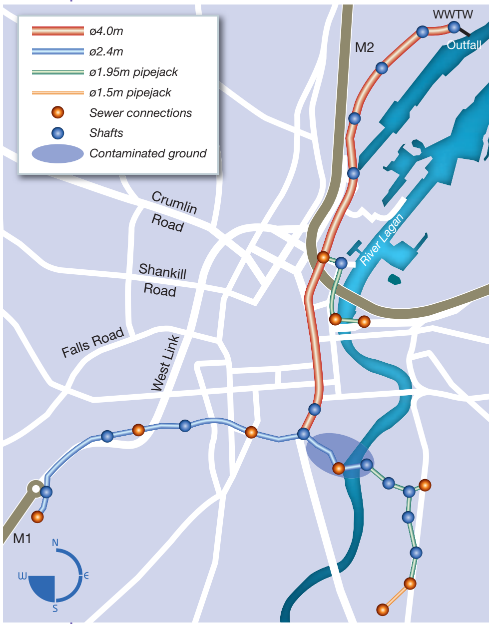
- COGEMACOUSTIC Tunnel ventilation fan: 30 to 250 kW
- Shotcrete Robot PUTZMEISTER model: PM407 - PM500
- PAUS Dumper ITC 10000 20t payload interchangeable with Concrete mixer CIFA
- Basket NORMET 9915 BA
- LHD GHH Model 6.3
- Batching Plant COUVROT and ARCEN: capacity from 40 to 60 m3/h
- Rolling Stock 900 MM
- FERMEL Utility vehicle
- BOART LONGYEAR Charging Unit
- Grout Pumps CLIVIO
- Agitator Hopper SECATOL: 7m3 - 10 m3
- Gantry Crane: 30 - 40t
- Side tipping bucket GERSTADT. Capacity (3m3 - 4m3)

For more information contact:
christophe.ollivier@bombelacjv.com
Telephone: 0027 (0)11 997 8141
Mobile: 0027 (0) 83 632 9116
Address: 22 Milky Way Avenue
Linbro Business Park
Johannesburg
P.O. Box 1177
South Africa

GAUTRAIN
FOR PEOPLE ON THE MOVE

Belfast's tunnel challenge

Contractor Morgan Est is currently meeting a multitude of challenges in extremely mixed ground conditions for the new Belfast sewer tunnels. Technical journalist Adrian Greeman reports



Left: Fig 1 - The various tunnel alignments

The ground in Belfast, Northern Ireland, is as troubled as the city's past history, if not more. Soft grey alluvial deposits named 'sleech' are up to 15m thick in the docks area and barely stiffer than toothpaste. This can give way in an instant to solid quartz dolorite dykes, which fold into firmer glacial sands and clays lower down. Reasonably watertight clay is also intersected with lenses of highly permeable sand running all the way to the surface and with a hydrostatic head to match. This geology results mainly from Ice Age sheet edge deposition, which also left boulders the size of footballs, and bigger, in the clay. The sleech is a more recent marine deposit on top and below is Sherwood sandstone.

Just to make it all the more challenging, there is also ground contamination from tars and oils, and numerous stray wooden piles used over the centuries to build on the soft sleech. This all makes for some highly interesting, and occasionally fraught, tunnelling on the new Belfast Sewers Project, a major scheme to upgrade the city's wastewater infrastructure.

Compressed air has been used several times to repair damaged machines and, unexpectedly, full biological suit protection was required for workers on one section, costing both time and money. As one of the contractor's engineers on the project said: "You have everything here. I've worked in London, Malaysia and Australia and am seeing as many different aspects of tunnelling here as in the other countries put together."

Project background

Client Northern Ireland Water (NIW) is spending around US$175M for the first phase of the project, with potentially more to come in subsequent stages. The main construction contract currently accounts for US$164M, up from an original US$135M after assorted variations and extensions. Work began in September 2006 and was originally scheduled to take 36 months.

Below: Breakthrough of one of the 2.4m diameter Lovat EPBM drives

Just under 10km of new tunnels at up to 30m in depth are being constructed through the city to vastly improve stormwater flows and discharge rates in a system that was sound in Victorian times but is now overloaded. A huge new stormwater storage area and underground pumping station at Duncrue complement the new collector tunnels with a large culvert outfall discharging finally into the famous Belfast Docks.

The scheme is certainly needed. "There are times during storms when the manhole lids will come off the sewers," said one local. Certain areas of the city are plagued with problems and schools have been flooded in the past while house basements fill with backflow during sustained heavy rainfalls. New property developments from the money and investment that has flowed in after the last decade of political stability is adding to demand on the existing system.

So the completed scheme will have a significant positive impact in removing physical and infrastructure irritations from a population that has had more than its share of difficulties. Despite that, or perhaps because of it, "we are keeping a low key presence during the work," says tunnel project manager Paul Ronicle from Morgan Est, half of the joint venture contractor that is designing and building the scheme. Well-known Belfast firm Farrans makes up the party, concentrating mostly on the civil engineering while Morgan completes the tunnelling works. It is however a "true joint venture" with overlapping input and joint responsibility, says Ronicle.

Much of the tunnel design has been done by Morgan Est's in-house team, but local civils consultant Taggart has undertaken the civils structures. Benaim, now part of Scott Wilson, has been geotechnical consultant. Atkins is the client

Above: A muck train exits one of the smaller pipejacking operations
Right: The 40m diameter, 40m deep, twin celled pump station shaft

consultant for the outline design and hydraulic analysis.

There have been relatively few major tunnelling projects in the city, or even the region, since Victorian times. "There is not a subway or much else underground," says Ronicle. As a result underground experience has not been built up locally, for all that the Irish miner is well known in the industry and is well represented on site here as anywhere, along with a thoroughly internationalised workforce with staff from Nigeria to Poland.

Shaft and tunnel construction

Nineteen shafts have been placed around the city, with ten new overflow structures linking the new system to the old. There would have been more shafts but they were value engineered from the scheme; Morgan persuaded NIW that the need for man-entry would diminish in the future as robotics are developed for safer maintenance, and that 2km spacing is sufficient.

The system is a storm surge overflow rather than for dry flow. A Y-shaped network of tunnels feeds collected water through predominantly 1.95m and 2.4m diameter branch tunnels into a 3.8km long, 4m diameter, spine tunnel that terminates at a major existing wastewater treatment site at Duncrue in the docklands. Here there is a new 5000m^3 surge storage chamber and large pumping station, both currently being completed. A simple screening facility is the only treatment needed as storm flows should be quite dilute.

Output from the pumps at full capacity will be 15m^3/sec. "So fast is the flow into the Herdman channel," says Farrans' civil construction manager Kevin Crilly, "that shipping will have to be stopped when it is operating at full capacity." The channel runs into Belfast Lough.

The pump station is situated inside a large circular shaft, 40m in diameter and 40m deep, one of the largest in Europe. Excavating this has used tunnelling techniques for much of its depth. Firstly, 80m deep dewatering wells were drilled to draw down the watertable to just over 40m. Diaphragm wall construction followed, installed by Bachy Soletanche to a depth of 15m-19m, through the soft ground and into the sandstone. The ground was then excavated layer by layer using excavators with hydraulic breakers in the sandstone. Support of the walls was with shotcrete. "It was a true NATM, carefully monitored," says Ronicle.

A concave base was formed and waterproofed with a 2mm thick PVC liner. A 2.5m thick concrete base slab was then poured, with a 1m thick lining for the rest of the chamber. Following completion, Farrans took possession to build the internal structure. The chamber is divided in the centre, creating a dry pumping house on one side and a wet well on the other side, where the 4m tunnel enters.

Meanwhile, tunnelling teams were getting on with the other shafts and the gearing up for the TBM drives. In the first year the main focus was on the shafts, which range from 6m to 15m in diameter. They were formed using jacked caissons. Once down through the sleech and clay to sandstone the remainder of the shafts were constructed by underpinning, to a depth of around 32m.

Like the precast concrete segments for the follow-on tunnelling works, the linings for the shafts were made at Morgan's precast factory, in north Kent, which was first established for Heathrow Airport's Terminal 5 project. A wharf at the factory allowed easy loading onto ships, which delivered directly to the Belfast docks where the wastewater treatment plant is situated. "It cut down on the impact of the project on the city," says Ronicle. With a total 44,500 elements to deliver, it was a significant reduction in trucking.

Most shafts were straightforward, though one needed a "wrapping" – an extra 300mm cast in situ ring around the precast elements. "The shaft was close to one of the legacy buildings in the city, the Seaman's Mission, a masonry building with timber piles, just 15m away," says Ronicle.

Right: Mucking operations underway on one of the smaller pipejacked tunnels

"On the other side was the M2 motorway in viaduct and a railway on viaduct."

Excavation elsewhere has also had to deal with stray piles, which litter the soft ground of the city. At two sites there were also additional problems from organic chemicals in the ground, which required the use of protective clothing and respiratory filter packs for workers. De-watering water also had to treated with sedimentation and carbon filtering.

The problem, which re-emerged more seriously later during tunnelling, resulted from residues left in the ground underneath the city's main gasworks area. This land was redeveloped several years ago into a retail and residential zone and ground remediation was carried out. "But that was only to about 4m and we were advised in the tender to carry out further site investigation," says Ronicle.

Tests showed that there were various volatile organic compounds present, toluenes, xylene and most serious of all, benzenes which are considered a health hazard in any concentration over 1ppm.

Left: A section of cutterhead that had to be removed due to boulder damage

Mixed ground challenges

Once shafts began to be completed tunnelling got underway. Morgan was confronted with vastly mixed ground conditions ranging from extremely soft to very hard and therefore needed a machine that could deal with all – or, rather, machines - one for the 4m drive and one the 2.4m. There is pipejacking too for the smaller 1.9m and short 1.5m sections. "Most of the ground is actually soft, predominantly clay," says Ronicle. But this is urban tunnelling and although alignments are largely under streets, the tunnels are still close to various historic buildings including the famous "leaning tower" Albert Clock.

The JV decided on two EPB machines, both from Lovat "and fairly well powered". They are robust and reliable, says Ronicle. The larger 4m diameter machine "Lucille" was previously used on the Lower Lea Valley Cable Tunnel project, in East London, and has now been reconditioned with a new cutterhead fitted with scrapers and rippers. "The choice is a head to deal with mainly soft ground and softer rock," says Ronicle. Tools can be changed from behind however and the site carries a spare set of discs that can be fitted, as required, to deal with harder rock in the dolorite intrusions expected every now and then.

"In actuality we got through the dykes with the rippers," says Ronicle. The machine has just finished the second of two drives. The first was from the centre of the alignment northwards to the pumping station, where it was dismantled and taken back to the same shaft before heading off again south, towards the forked connection with the smaller drives.

A diesel locomotive and rail car skip system was used for mucking out with spoil going to a nearby landfill site, conveniently located only about 3km away, run by the city. Being mostly clay it was used for capping the nearly full site.

Lining for the tunnel is a six segment precast concrete ring. This is grouted through the segments rather than from the tailshield. "It is an older machine and tail grouting is less economical at smaller diameters," explains Ronicle. "You have to overcut to make the space for the grouting equipment and on a small tunnel that is a relatively large increase."

Currently the machine is parked just before a shaft that connects with the 2.4m drives, while the other machine finishes its work. It arrived there slightly later than scheduled as, despite relatively good drives, it ran into a problem last autumn. Quite late on in the second leg, ground started to enter through the rear articulation joint. "It can be quite aggressive ground here," says tunnel agent Richard Merriman, "and comes at you." In the sand lenses particularly, with high hydrostatic pressure "if you have any leaks at all you can lose a lot of ground quite quickly."

It was impossible to get at the joint without the risk of a major inflow and so the JV mobilised compressed air equipment on site. It had taken the precaution of a long-term hire of equipment from UK firm Specialist Plant – including decompression chambers and airlocks – at the outset of the project, but with the hope of not needing it.

Ultimately, several of the shafts on the 2.4m drives needed pressurisation in order to breakout the lining segments at the base to form the "soft eye" entry point for the TBM. Running sand near the shaft walls meant there was a danger of destabilisation otherwise. Pressures between 0.3-1.1 bar over atmospheric were used, says Tony Ridley of Tony Ridley Hyperbaric Associates who controlled the interventions, monitored decompressions and consulted on health and safety issues. Most important of these is use of oxygen decompression for all the work at 0.7 bar or more. Decompression lasts up to 2 hours for these levels.

For the machine too the only way to get at the joint, believed to have been damaged during passage through a dolorite dyke, was to pressurise everything, fitting a bulkhead back along the tunnel. A four week operation was needed for the repairs, though Ronicle says this did not disrupt the overall schedule too much as it had taken less time than predicted to traverse the hard dykes.

The critical path is the 2.4m tunnelling, with four relatively short drives of a few hundred metres each mostly completed and one long 2.7km drive now underway. Ronicle is pleased with the progress of "Lady Jane", another reconditioned Lovat EPBM, and particularly with the guidance system used. Unlike the bigger machine

Above: Tony Ridley Hyperbaric's engineers install an airlock for TBM intervention

Above: **A total of 44,500 precast segments have been required for the project**

that has a TACS laser system – "good but expensive," says Ronicle – Morgan Est has fitted a gyroscopic system. This replaces a laser system, which creating difficulties on the 50m radius bends required. "The problem with small machines is that the laser envelope is tight," he says. Equipment is tightly packed and line-of-sight down the walkway is constantly being blocked by operators' movements. A system developed originally for Iseki has been refined for Morgan by Ted Janes, who began development of the original system while working with contractor Lilley.

But the smaller Lovat has had other challenges. Its first two drives also had to cope with the organics found during shaft construction, particularly during a 360m stretch under the former gasworks and a 100m long section under the river Lagan, where groundwater movement seems to have carried the contamination.

"The concentrations were around 10ppm for benzene, which is well over limit and meant full biological suits were needed," says Ronicle. That meant tunnellers working in normal industrial clothing with sealed overalls over the top and a forced air fed helmet. The disposable suits had to be washed down and disposed of every shift break. "As you can imagine it was uncomfortable," he says "especially in the summer months of the drive and with the heat that comes off the TBM. They were like boiled chickens." On top of normal chilling for the TBM water supply, super chillers were added, and the ventilation was also fitted with refrigeration. Shift times were also cut back.

The small machine now has its own compressed air intervention underway following jamming of the screw conveyor, thought to be from a boulder or a tool knocked from the head by hard ground.

Jamming boulders have also affected Lovat pipejacking operations for the smaller diameter feeder tunnels. These were less deep and Morgan persuaded the client to bring them up another couple of metres with a redesign of the hydraulics. An extensive ground investigation had discovered a lot of larger boulders at the original horizon and found they were smaller higher up, at around 400mm instead of 700-800mm. Even so the boulders have caused some problems, twisting a hefty steel plate within the cutterhead mechanism completely back on itself for example.

Ronicle is philosophical about all these issues; it is the nature of the game he says. He will still be talking to the client about it however, to get some more recognition of the turmoil in the ground. T&T

A burned out truck in a fire damaged wagon exiting the portal

Rapid Repair

A mature and rapid maintenance culture has enabled fast repairs in the Channel Tunnel following the major fire of September 2008. Report by Patrick Reynolds

The Channel Tunnel should start building towards full operating service from early February, slightly less than five months after the major fire in the North running tunnel of the 50km long Anglo-French rail link. Owner and operator Eurotunnel had set a target date of mid-February for the 650m long damaged section to be fully restored.

The incident, on 11 September 2008, resulted in the one third of the North tunnel, a 17km long operational section known as "Interval 6" between the French crossover and portal, being taken out of service. Fire damage to the 7.6m i.d. tunnel's segmental lining and fixed equipment was concentrated approximately 11km from the portal.

Recovery plans were announced about a month after the blaze as repair works contracts were agreed as the last of the damaged shuttle train was finally extracted and official investigators released Interval 6. Work got underway in late October to remove weakened and damaged concrete, clear debris and install rockbolts before structural repairs then proceeded with renewed steel reinforcement and then shotcrete fill.

The main civils works – shotcreting – was underway by early December and completed in a little over a month, ahead of schedule. By holding onto the programme lead during the final electro-mechanical tasks, the entire repair package was completed slightly faster than the four months initially envisaged.

Repairing and returning the damaged Interval to service was successfully accomplished at least a month faster in comparison with recovery after the first major fire, in 1996, some two and half years after the fixed crossing became operational. Then, a package of comparable works was executed in the middle of the South tunnel (see box p22).

No incidents are the same, of course, even with both fires having occurred on the same kind of train, the 800m long freight shuttles that carry trucks and loop between terminals at Folkestone and Coquelles. Both trains had also stopped on the French side of the border that bisects the link, which dictated the lead authorities in the investigations.

There are four investigations underway – a French judicial enquiry; by the railway authorities of France (BEA-TT) and UK (RAIB); by the Channel Tunnel Safety Authority (CTSA), part of the Intergovernmental Commission, which is due to report in September 2009, a year after the fire; and, Eurotunnel's own probe.

September 2008 incident

The crossing was designed and built over 1986-93, and officially opened in mid-1994. The link - some 37km of which is undersea – consists of twin running tunnels with two crossover caverns, creating six operating "Intervals" of similar length. From the UK, the North tunnel has Intervals 2,4 and 6, and the South tunnel Intervals 1,3 and 5.

Below: Spray cleaning underway in soot covered polluted parts of the North Tunnel

Between the tubes is a 4.8m i.d. service tunnel. The three tunnels are linked by cross passages every 375m. Piston relief ducts are spaced at 250m intervals.

Last year's fire broke out on a lorry freight shuttle bound for France and the train stopped approximately 4km beyond the French crossover cavern, in Interval 6 after Chainage 48200. The stoppage procedure was introduced following the '96 incident, partly to avoid risk of power loss through catenary damage. Three following trains were reversed out. Emergency ventilation kept the air clear for 32 passengers and crew to escape without injury to the service tunnel.

Fire fighters came from the portal, Kent and Pas-de-Calais, respectively. The emergency ventilation was blowing to keep the front of the train clear of smoke but it had also fanned the fire. The supporting French crews arrived some 75 minutes after the alert was given, the UK crews more than 45 minutes later still. Only by next morning was the fire brought under control.

The South tunnel was unaffected.

Initial service recovery

After the '96 incident, almost two weeks were to pass before train and shuttle services began to resume, building gradually from late November to early January. Services reached about half normal levels although there was less impact on the Eurostar passenger trains that transit the link between London and Paris/Brussels.

Following last year's incident, Eurotunnel said it was focused on resuming limited operations as soon as possible. The rail authorities had not given any immediate recommendations over safety. Services began to move again – through the South tunnel only – within two days with Eurostar trains among the first to restart, other services quickly resuming albeit at more

Left: Conjet hydrodemolition equipment in an area of highly spalled lining
Above: The roof crown at segment joint showing exposed concrete and rebar after hydrodemolition cleaning

restricted frequency.

Recovery work with a cleaning train got underway in the stretches of the North tunnel coated with soot and smoke pollutants, blown along by emergency ventilation, but otherwise undamaged. Interval 2 was brought back into service 11 days after the fire, and improved service capacity by half to 170 trains per day, which was helped also by use of the UK crossover.

The more heavily polluted, middle stretch – Interval 4 – was open by late September, increasing overall capacity by almost a quarter again to 210 trains per day.

By mid-December, while structural repair works were well underway, available capacity of services was overall at 50% of normal though load factor was high. In its Q3 results, Eurotunnel said the disruption had hit revenues for an estimated US$28.6M to 30 September.

Repair strategy

Jacques Gounon, chairman and chief executive of Eurotunnel, wanted the repair works to be 'industrially intensive'. Logistics would be key especially as he wanted the works to be completed faster and at less expense than the recovery following the incident in '96 even though there was more damage this time.

Of the 650m of damaged lining, there was mild to severe spalling, of 100mm-300mm deep, at some walls and the roof that left rebar either exposed or weakened over a distance of 550m.

Gounon's previous experience of managing businesses with civils infrastructure led him to believe the repairs could be undertaken more efficiently than last time. He tells of being 'astounded' that manual methods, such as hammer and picks, were used then to remove much of the damaged concrete.

There was a seasoned maintenance team and culture with natural momentum to draw upon. A dedicated team was carved out under maintenance director Christian Maquaire, who has a mining background, to deliver Interval 6 to target.

Records from the '96 incident were referenced and parties involved consulted, such as project manager SETEC and contractor Freyssinet. A quick tender process for the civils works was executed, during which Eurotunnel held discussions with a UK and two French bidders, and special access was provided for visual inspection only in the uncleared tunnel.

By 10 October, contracts were agreed with SETEC to supervise the works and Freyssinet would act as contractor group

Fire – November 1996

The first major fire in the Channel Tunnel was on 18 November 1996, in the middle third – Interval 3 – of the South tunnel, approximately 19km from the French portal, when a train bound for UK was spotted to be on fire just before it went underground.

After delays due to heavy smoke, emergency ventilation was activated and all 33 passengers and crew were evacuated to walkways, almost half an hour after the train had stopped. They reached the service tunnel as the first fire fighters arrived. While only one lorry was burning, by then the fire had been fanned and spread to other rear wagons due to activation of the supplementary ventilation system and other trains' movements.

With temperatures having reached up to 1000 degrees C in a few spots but 1300 degrees C where worst, mostly the range was 700-800 degrees C. Along the nearly 500m of affected tunnel there was serious damage over approximately 280m, the most severe over a stretch of 46m. Spalling was 100mm-200m on average. In the worst sections only 170mm depth was left, and in a few places only 20mm, the rear rebar and undamaged grout.

Colliery steel arches were installed at 1.5m centres with a canopy of light steel mesh to keep workers safe from risk of falling debris as clearance got underway.

Proposals for recovery work were submitted to CTSA a week after the fire was extinguished. Approval for the repairs was given by CTSA later that month.

The affected stretch of tunnel was closed off at each end with airtight temporary bulkheads to isolate the works from operational parts of the tunnel. Workers accessed to site from the service tunnel. To ensure logistical needs of the structural repair work caused only minimum disruption to commercial operations, all materials and equipment were taken in on a single train, in late January 1997.

Structural repairs involved; grit blasting and hand-working removal of damaged or weakened concrete; replacement of damaged rebar; lining replacement with both plain and fibre-reinforced shotcrete; and, profiling. Freyssinet completed the work two months later.

Electro-mechanical works were undertaken in a similar way, supplied by a second train. Eurotunnel's own teams did that work and finished after a further two months, in May 1997.

leader and undertake the civils works. Track and catenary works would be done by Eurovia Travaux Ferroviaires, and other equipment needs would be fulfilled by Vinci Energies. The total cost was expected to be less than US$77.2M.

Plans and site investigations

The plan for the repair works had a number of similarities to the '96 approach but also variations due to location and technological developments, and also the need to ensure greater flexibility in logistics. For example:

- With an open, straight run available from the French portal into Interval 6, dedicated works trains would be used to shuttle to the repair site; the service tunnel was not to be used, to ensure its ongoing maximum availability for operational safety needs.
- With the dedicated single-track line and equipment, permanent authority for works access was also put in place.
- Dedicated project hub offices for a single team environment were established near the portal. Dedicated works yards were created in or near the normal maintenance areas at Coquelles.
- To remove damaged concrete lining, remote controlled hydrodemolition equipment would be used, the technology having developed to prominence in the decade after the '96 fire, and was a faster process.
- Concrete debris was lifted by a vacuum vehicle that is commonly employed in maintenance-type activities.
- Shotcrete would be used, like before, but unlike last time it would not be applied from a dedicated, bespoke cleaning and repair train. Inside the tunnel there would not be rail-mounted operations but instead tyre-based vehicles would be used.
- On the roadbase would be built a "portal-shaped" scaffold framework up to 550m long to provide access to walls and roof for the repairs. The system also provided shelving for materials and tools storage, and mounting for strong lighting.
- Diesel locos and flatbeds in the normal maintenance fleet would not be used to ensure such works, and other needs, did not suffer. Separate vehicles were sourced: three locos, 26 flatbeds plus five special wagons to take equipment for shotcrete production.

Given the bespoke nature of the transport link, it was quickly clear that procurement requirements, though, would be on the critical path of the recovery programme. Key items would include negotiating with a French cement supplier to ensure availability of the critical, low water-cement ratio product for shotcrete, and this was done by rescheduling a planned production shutdown.

Further vital procurement tasks included acquiring 21kV cables and their supports, which are not common stock. In addition, the works would require new catenary and track and these also had to be sourced early and be available before the completion of civils works.

By mid-October, the last of the damaged shuttle train was removed, enabling site investigation and repair to get underway a few days early.

The strength of the lining was checked with more than 70 cores taken to sample concrete, grout and the chalk bedrock. The 60mm diameter samples found the lining competent.

With equipment delivered, a load test was carried out of the rings using 3m long expandable resin injected bolts. Convergence was only 1mm, much less than the tolerance limit of 3mm.

The repair works

For the repair works, extra support to the tunnel was provided by installing 1078 resin-grouted rockbolts. Pumping capacity of up to 2000m^3/hour was available to handle groundwater leakage, but seepage has only been 40m^3/day.

Work in the tunnel was round-the-clock in three shifts, each a full eight hours in the work zone. To the core work time was added travel at shift change. Each shift had about 85 workers, and there were about 300 people on the project per day, says Maquaire.

Pre-contract discussions between Maquaire and Freyssinet's Philippe Zanker, who has delivered the works, had developed the roadbase concept as a flexible method for the repair works. To make up the 610m long roadbase the contractor placed approximately 3,200t of ballast on the cleared tunnel floor and then 3.5m long timber sleepers laid on top, abutting the raised concrete walkways which were covered for protection.

With the roadbase in place, concrete removal French subcontractor Philippe Lassarat hired Doornbos Equipment to undertake the hydrodemolition works. The high pressure jets removed C45 concrete to a depth of 30mm where needed, averaging 650m^2 per day. In total, approximately 9,500m^2 was treated, including 350m^2 of roof over the main site of the blaze. Four Conjet robots were employed and a Hammelmann "Dockmaster" unit was also used in the works. Lassarat then repaired and replaced steel rebar.

Mix design tests with the shotcrete were done using steel and PP fibres, and it was decided that they were not needed to achieve sufficient strength or for workability. The shotcrete was mixed by a crew of five, says Maquaire, and pumped to the team of three on the scaffold to spray in layers onto the walls and roof. Works progressed about 20m along the tunnel per day.

Top: Shotcreting; Bottom: Fixing and repairing the exposed lining rebar

Outside of the heavy shotcreting zone, lighter skim repairs over two stretches of 50m was applied using a cherry picker. Following the main works, the holes for the core sampling through into chalk were grouted, and the tunnel profile was accurately re-established. In total, approximately 4,000t of shotcrete was used on the repair works.

Following completion of the structural repairs, the ballast was removed using another vacuum-based system. Like for the debris cleaning, such kit is not easy to source, notes Jean-Luc Pochet of Eurotunnel's project team.

With the base cleared, the electro-mechanical works the took over and upon completion the re-commissioning tests were performed early this month. T&T

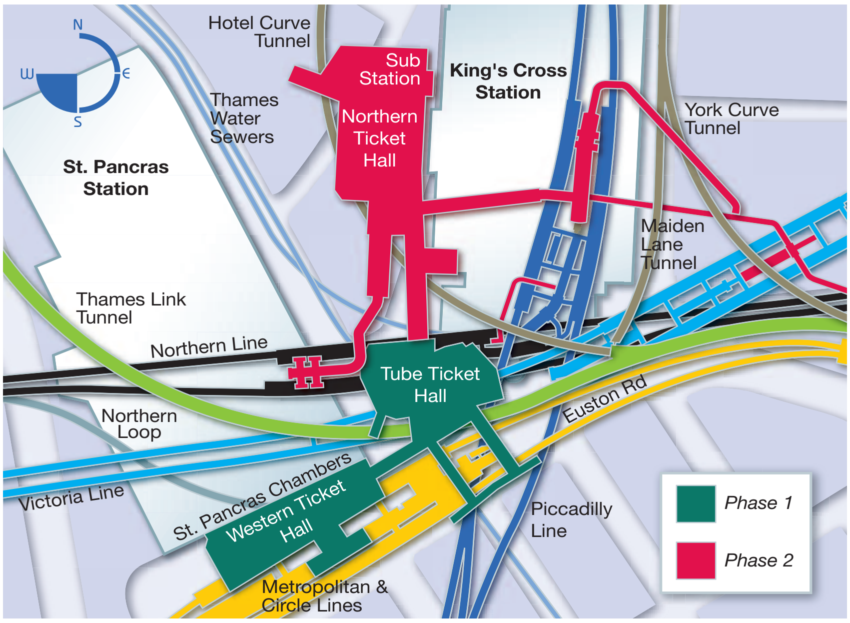
King's X tunnelling

T&TI reviews the recent upgrade of London's King's Cross Station, undertaken to bring it in line with today's growing passenger demands

The King's Cross area is a busy part of Central London and a major transport interchange. Recent regeneration has seen it change from a seedy, deprived, run-down part of the city into a popular location for new offices, apartments, bars and restaurants. There are the King's Cross and St Pancras railway stations at the surface, and the King's Cross St Pancras underground station. Also, there are several very busy major roads in the area. The underground station is often closed in rush hour due to overcrowding. It was considered desirable to upgrade the underground station to improve access, increase capacity and to provide a station fitting to a capital city in the 21st Century.

King's Cross St Pancras underground station is an interchange for several London Underground lines: the Northern Line, the Piccadilly Line, the Victoria Line and the Metropolitan and Circle Lines. The project provides new connections from a proposed new Northern Ticket Hall directly into the platforms of the Northern, Piccadilly and Victoria Lines, and step-free access for mobility-impaired persons to the Piccadilly and Victoria Lines. All works were undertaken for this contract by the Morgan Bemo JV, a joint venture between Morgan Est and Beton- und Monierbau, are shown in red on Figure 1 and Table 1.

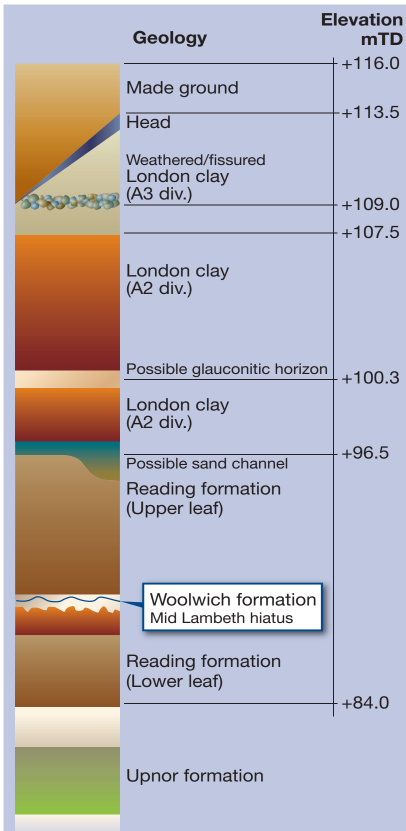
Now that the tunnelling has been finished, work has begun on the fit out of the services, escalators and lifts and the ticket hall superstructure. As well as providing a more

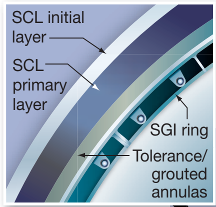


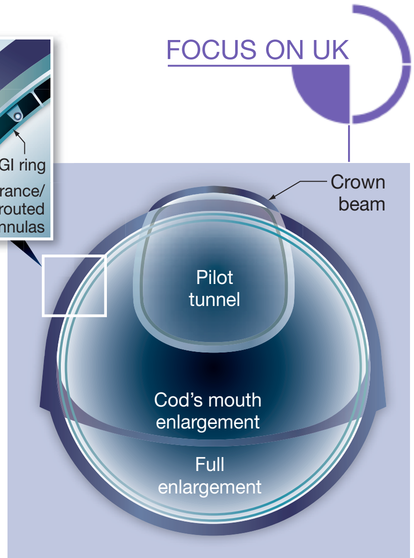
Area	Tunnel name	Approx length (m)	Tunnel ID (mm)	Total excavated diameter (mm)
Northern Line Access (NLA)	NLA Escalator	25	8650	9800
	NLA Link Passageway to Over bridge	17	5000	5850
	NLA Link to Stairs	7	5000	5850
	NLA Stairs	10	5750	6700
	NLA Lower Concourse	11	6500	7500
Piccadilly Line Access (PLA)	PLA Link Passageway to NTH	74	5750	6600
	PLA Link Passageway to the VLA	49	5750	6600
	PLA Escalator Upper Machine Chamber	8	8650	9650
	PLA Escalator Inclined barrel	16	8250	9400
	PLA Escalator Lower Machine Chamber	3	8250	9400
	PLA Lower Concourse	16	6500	7500
	VLA Upper lobby and stairs		4500	5350
	VLA Lift Upper Lobby area		3500	4380
	VLA Lift Lower Lobby area		3500	4380
Temporary Thameslink Spur Passageway (TTSP)	Temporary Thameslink Spur Passageway	126	400	4300
	Temporary Thameslink Spur Passageway Stairs	25	4850	5200

Left: Fig 1 & Table 1 – The King's Cross Station redevelopment scheme

Below: Fig 2 – Typical geological column at King's Cross







Left: Spraying concrete using the Tunnel Beamer system

Right: Fig 3 – Cross-section showing typical construction sequence

spacious and pleasant ticket hall, the new passenger access routes to the Piccadilly Line and Northern Line platforms are at the opposite ends of the platforms to the existing entrances, allowing a more even distribution of passengers and more passengers to board each underground train. In this way, capacity will be increased.

Project challenges

The main challenges faced by the project were the constricted site areas, the proximity of sensitive structures at the surface and below ground, and the numerous connections with live tunnels. The small site areas meant that most deliveries had to be made on a just-in-time basis from a logistics hub in Southall in West London, some 40 minutes drive away, although with traffic this could be much longer. A batching plant was set up at the Milk Dock site to supply sprayed concrete at any time of day or night, which was also where the site offices were located. The Piccadilly Line Access and Northern Line Access were constructed from the Hub Shaft, and the Victoria Line Access was constructed from Site I. At times, the pedestrian traffic along the pavement in front of the Hub Shaft site gates could be so great that as many as six traffic marshals were required to allow trucks to enter the gates safely during peak times.

Contract and interfaces

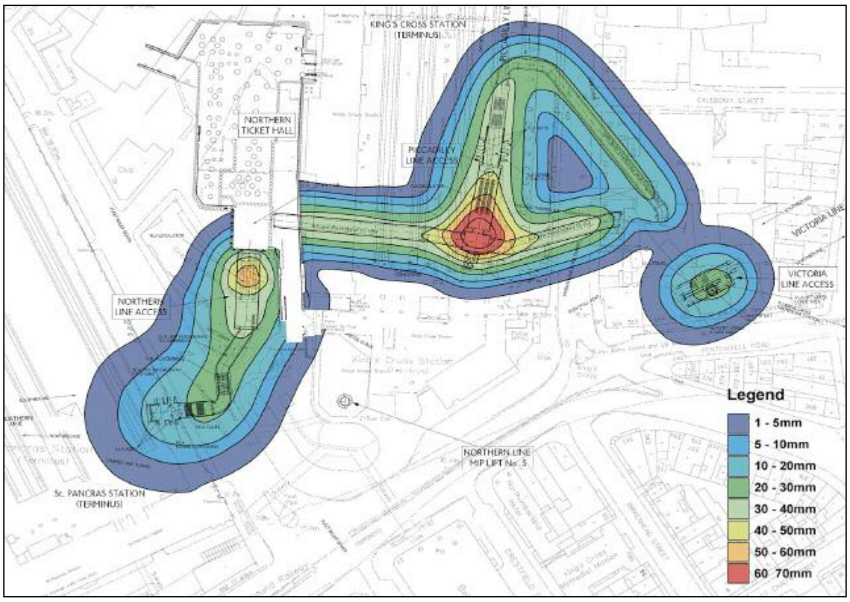
The client for the project was Metronet, who manage the Victoria Line and the Metropolitan and Circle Lines and King's Cross St Pancras underground station. Morgan Bemo JV were brought in early on in the project to aid with design development (particularly of the sprayed concrete works) and to establish appropriate working methods. This arrangement also meant that early discussions with third parties were based on a well defined scheme design and programme. Key third parties included Thames Water; whose Fleet relief sewer would be driven under by the Northern Line Access, Network Rail, who manage King's Cross railway station directly above the tunnelling works, Tubelines, who manage the Northern and Piccadilly Lines and Camden Borough Council, from whom environmental permits had to be sought and traffic management plans agreed. Ove Arup was lead designer and responsible for the permanent works design. Metronet also employed ABBT as Project Manager.

The tunnels works is located under a number of sensitive grade 1 and 2 listed structures including just 7m cover between the 9.7m diameter 30 degree incline Northern Line escalator barrel, and the Grade 2 listed Great Northern Hotel.

The ground conditions underlying the whole of the Phase II tunnels area is summarised in Figure 2.

The ranges of depths (m.TD) over which the tunnels have been excavated are: Northern Line Access -102.7m highest level, 83m lowest level; Piccadilly Line Access - 106.5m highest level, 88.5m lowest level; Victoria Line Access - 107m highest level, 97.6m lowest level.

Below: Fig 4 - Plot of predicted vertical ground movements, VL =2%, Ks =0.5



Lining solution and tunnel strategy

The permanent tunnel structure consists of a segmental lining composed of Spheroidal Graphite Iron (SGI). This was constructed within a temporary lining of Sprayed Concrete. Neither layer was designated as a waterproof barrier although the SGI lining was fully caulked. Provision was made within the tunnel fit-out to provide a space for collection and removal of any water which penetrated the structural lining.

The LaserShell (TunnelBeamer) sprayed concrete lining (SCL) method was chosen as the primary means of ground support for the majority of the tunnelling as it carried the least risk, both to the workforce and to the nearby existing structures. The tunnels would initially be constructed using a pilot tunnel which was then enlarged to form a fully circular section (figure 3). On completion of the full circular section a segmental lining made from spheroidal graphite iron (SGI) was then constructed inside and grouted up.

Sequence of construction

The four main elements of construction for King's Cross were:

- Piccadilly Line Access (PLA)
- Northern Line Access (NLA)
- Victoria Line Access (VLA)

• Rail Interface Works (RIW)

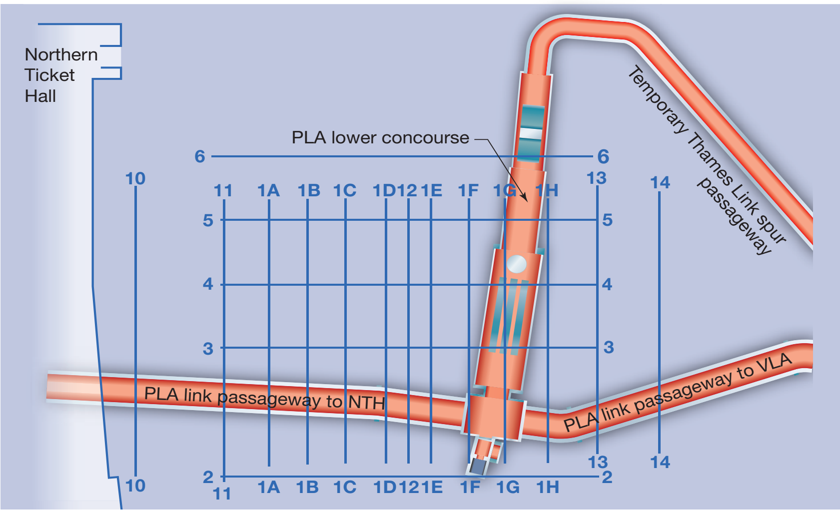
The Northern Line Access and Piccadilly Line Access were both driven from the Hubshaft which formed part of the new Northern Ticket Hall. The Hockeystick and the VLA were driven respectively from shafts sunk in an existing disused brick railway tunnel, Maiden Lane and York Curve tunnels.

PLA - The first tunnel to be built was the Hockeystick diversion tunnel which allowed the existing Thameslink passageway to be closed and filled with foam concrete whilst still allowing passenger access to the Piccadilly Line platforms. During this time the PLA was driven from the Hubshaft towards the Hockeystick and approximately half way along an interchange known as the Cruciform was constructed to allow for a Mobility Impaired Person (MIP) lift and an escalator barrel to be constructed to the Piccadilly Lines. For the MIP lift, because of the tight spaces where excavations had to be made, it was not possible to use sprayed concrete as the primary support therefore timber headings were used. The MIP lift shaft went down between a push/pull vent tunnel, an operational relay room, a cross passage and a passenger concourse tunnel. The timbers were pushed against the ground by wedging them off steel frames, which were later concreted in as part of the permanent works.

NLA - The NLA was driven towards the Northern Line (NL) and en route the tunnel intersected the crown of the existing Southbound NL running tunnel to create an overbridge. To accommodate this overbridge the area above the existing NL tunnel was also formed using handwork and traditional timber heading methods. On completion of the overbridge the NLA was then continued towards the existing NL.

VLA - The VLA works were constructed by sinking an oversized oval shaft using SCL incorporating the connections towards the existing Thameslink passage and Victoria Line cross passage. A MIP lift and stairs were created using SGI, with the final connections being constructed using handwork and timber headings.

Below: **Fig 5 & Table 2 - Cross section used in back analysis and results**



Rail interface works

The rail interface works involved engineering hours works and possessions to create opening sets within the existing tunnel lining. In addition, other works were completed within the station, including:

King's Cross underground station redevelopment - Phase II tunnels

End of excavation - Vertical ground movements at the underside of foundations

Tunnel name	Affected asset	Section no.	Excavated diameter	Tunnel axis (m. TD)	*Maximum predicted settlement (mm)	*Maximum measured settlement (mm)	Volume loss V%	Trough width coefficient K^S
PLA Link Passageway NTH to Cruciform	Train shed - Track 1	1-A	6600	102.55	33	11	0.94	0.75
PLA Link Passageway NTH to Cruciform	Train shed - Track 2	1-B	6600	102.60	33	12	0.66	0.45
PLA Link Passageway NTH to Cruciform	Train shed - Track 3	1-C	6600	102.65	33	No data available		
PLA Link Passageway NTH to Cruciform	Train shed - Track 4	1-D	6600	102.70	33	12	0.83	0.64
PLA Link Passageway NTH to Cruciform	Train shed - Track 5	1-E	6600	102.70	40	14	0.91	0.69
PLA Link Passageway NTH to Cruciform	Train shed - Track 6	1-F	8800	102.50	45	12	1.06	0.94
PLA Link Passageway Cruciform to the VLA	Train shed - Track 7	1-G	8800	102.50	48	15	0.83	0.67
PLA Link Passageway Cruciform to the VLA	Train shed - Track 8	1-H	6600	102.70	41	14	0.98	0.73
PLA Lift - Upper Lobby	Train shed	2	6830	102.50	12	6	0.66	0.36
PLA Upper Escalator	Train shed	3	9750	100.91	48	17	0.6	0.44
PLA Lower Escalator	Train shed	4	9350	95.30	43	16	0.67	0.48
PLA Lower Concourse	Train shed	5	7450	96.18	20	15	1.27	0.44
PLA TTSP Stairs	Train shed	6	5650	99.18	24	17	1.26	0.49
PLA Link Passageway NTH to Cruciform	Western Range Building External	10	6600	102.28	39	7	0.48	0.84
PLA Link Passageway NTH to Cruciform	Western Range Building Internal	11	6600	102.46	39	11	0.86	0.87
PLA Link Passageway NTH to Cruciform	Spine wall	12	6600	102.70	41	11	0.81	0.81
PLA Link Passageway Cruciform to the VLA	Eastern Range Building Internal	13	6600	102.70	41	11	0.93	0.81
PLA Link Passageway Cruciform to the VLA	Eastern Range Building External	14	6600	102.90	38	9	0.89	1.06
NLA Lower Concourse	St Pancras Facade	15	7450	90.30	22	5	0.31	0.41

**All predicted settlement were calculated using the following parameters:-*
Volume Loss (VL) = 2.0%
Trough width coefficient (K^S) = 0.5

- Installation of temporary decking for access for constructing the opening sets
- Infilling of the Thameslink passageway
- Installation of pedestrian protection measures
- Installation of the overbridge

Compensation grouting

A compensation grouting array was installed at an intermediate level in the Hub Shaft to mitigate settlement of the Great Northern Hotel arising from the NLA escalator tunnel construction. Similarly a compensation grouting array was installed from the Maiden Lane tunnel above the Piccadilly Line Access passageway, cruciform and escalator to mitigate settlement of King's Cross railway station directly above.

Prior to the tunnel works, ground movement predictions were carried out to estimate the risk of building damage to all those structures within the 5mm settlement contour. These ground movement predictions used a volume loss of 2% and a Trough width parameter of 0.5 (figure 4).

During the works a comprehensive network of instrumentation was installed (figure 5). These provided a large volume of data to allow ground movement to be monitored in real time and for subsequent back analysis. The results (Table 2) represent the initial results of the back analysis, joint funded by London Underground and Arup.

The range of volume loss percentages calculated is 0.31 to 1.26 with an arithmetic average of 0.83. The trough width parameters calculated has a range between 0.41 to 1.06, with an arithmetic average of 0.66. These results are both for the end of excavation stage of the works and have been chosen to represent the settlement case most onerous to overlying buildings.

Lesson learnt

The early engagement of MB JV was proved vital as it allowed build ability to be reviewed as the scheme developed. Also, promoting the appointment of an independent monitoring contractor as a single point of data gathering is encouraged. Finally, back analysis has shown that ground movement predictions for sprayed concrete tunnels in London Clay can move away from a default position of 2% volume loss. T&T

Roy Patrick Burgess

OBITUARY

It is with great sadness that we report the death of Roy Burgess on 29 December 2008, aged 86, after suffering a long illness with Parkinson's Disease.

Roy spent his whole working life with Edmund Nuttall, starting as office junior and tea boy, rising to main board Director and Managing Director of subsidiary company Robert L Priestley.

As with many of his generation the war years interrupted his education and he never possessed any professional qualifications. He briefly left Nuttall during the war serving initially in intelligence and finally in Burma where he helped build bridges with the aid of Japanese prisoners. Roy was an exceptional manager and designer who commanded high respect from his staff with his hands-on approach and easy manner. Whilst Chief Engineer of Edmund Nuttall he was involved in major projects such as the hydroelectric power stations at Aberthaw and Loch Awe, Tyne Tunnel, the first Dartford tunnel, the Victoria Line experimental tunnel and Ely-Ouse Aqueduct and held many patents for his tunnelling inventions. People who worked with him in those days fondly remember his innovative and passionate approach to engineering and many working in the tunnelling industry today owe a considerable amount to their time spent working under Roy's guidance and expertise.

In 1968 Edmund Nuttall purchased manufacturing company Robert L Priestley in Gravesend, Kent. The Nuttall Chairman at the time, the late Sir Nicholas Nuttall, purchased Priestley on the sole basis that Roy Burgess went there as Managing Director with the object of expanding the capabilities within the tunnelling equipment market.

During his spell in charge of Priestley many notable tunnelling achievements were established. It should be recognised that Roy Burgess was designing tunnelling machines prior to the market leaders of today such as Herrenknecht and Lovat. Amongst these designs were the 100 inch full face tunnelling machines that were used on the Ely-Ouse Aqueduct Tunnel Project in 1969, on which 435m of machine driven hand-erected segmentally lined tunnel was achieved during a five day week. This remarkable world record is still held today.

Another notable achievement was the design and manufacture of the first European pressurised face Bentonite Slurry Tunnelling Machine used on the Experimental Tunnel Project at New Cross, London, for London Transport Executive in 1971.

In the 1970's, when work within the UK market was very poor, Roy expanded Priestley tunnelling machines into foreign markets such as Italy, Spain, Egypt, New Zealand and Czechoslovakia. He was always interested in new ideas and research. He worked closely with Professor Ted Potts of Newcastle University for research programmes on disc and drag bit cutting applications for tunnel boring machines and was an external examiner for numerous PhD theses on these subjects.

A highlight event for Roy Burgess and Priestley was winning the order to design and manufacture the 1974 Channel Service tunnel boring machine for Cross Channel Contractors. Though the Government cancelled the project a 300m section of tunnel was constructed, which proved the TBM's high performance capability and suitability for the project. Twelve years later Roy was tempted out of retirement to design four of the highly successful boring machines manufactured by James Howden in collaboration with his old Priestley colleagues. This prestigious tunnel project is a lasting testimony to his engineering talents.

In retirement Roy enjoyed sailing his dinghy, golf, painting and bowls. He enhanced his engineering skills by building model boats and aircraft and maintained a passion for repairing old clocks and watches until he was unable to do so due to his disability from Parkinson's disease.

Never one to seek for the limelight Roy Burgess was unquestionably a gifted and talented tunnel engineer. Without doubt he was one of the most respected and admired figures in British and world tunnelling throughout his illustrious career. His contributions to the industry are too numerous to mention but will be remembered by all of those colleagues and associates who were fortunate enough to know him well.

Roy leaves a widow Jean, daughters Lesley and Jill and three grandsons. He will be sadly missed by all of those who knew him. He was one of the tunnelling industry's pioneers and a real gentleman. T&T


The 4.9m Robbins TBM was launched from a shaft in downtown Philadelphia, USA, requiring the main beam to be split in two

Urban TBM tunnelling

Desiree Willis of the Robbins Corporation, and Dennis Ofiara, chief engineer for Robbins, explain how TBM modifications can provide urban tunnelling solutions

In the heart of downtown Philadelphia, USA, crews are working to excavate a new storm water relief tunnel in multiple, short headings. The tunnel passes under residential and commercial businesses, heavily trafficked roads, a railway with low cover, and a historical site from the 1800's.

"We're trying to launch a TBM from a postage stamp piece of land. The trick is transporting and launching large pieces of equipment without disrupting the public roadway," said Jerry Pordon, site superintendent for contractor JayDee Constructors. The challenges at the Dobson's Run Sewer Project exemplify those of urban tunnelling projects worldwide - small launch sites, multiple headings, and vulnerable nearby structures. These issues are echoed on recent projects including subway tunnels in New York City and a landslide prevention tunnel on densely populated Hong Kong Island.

Most complications at urban tunnelling sites are due to common factors. Restricted jobsite space means many projects must be launched from shafts or very small sites. These limitations often require TBM modifications or specially designed launch sequences. Proximity to existing structures is also expected in these areas, and requires a range of modifications and monitoring systems depending on the geology and vulnerability of the structures. Obtaining easement rights from landowners is another challenge, resulting in tunnel layouts with sharp corners that follow the same path as roadways. Many other projects, such as rail tunnels, often consist of multiple 'blind' headings with no breakthrough point, requiring the machine to be pulled back and launched on consecutive small tunnels. Both sharp corners and multiple headings often result in TBM modifications that allow the machine to be retracted past installed rock support structures.

Dobson's Run

Directly beneath residential and commercial structures, as well as the historical Laurel Hill Cemetery in downtown Philadelphia, the Dobson's Run Sewer Reconstruction Project is one of the area's unique construction sites.

Run by the JayDee/JPC JV, the project consists of two tunnels 244m and 823m long at a 90 degree angle to one another. The 4.9m diameter Robbins Main Beam TBM must bore the first 244m heading, then be retracted past all roof support structures and transported to the second site. The first site, measuring about 183m long x 61m wide, required the construction of a shaft approximately 27m deep and 10m in diameter. Crews excavated soft ground sections of the shaft with liner plate and steel ribs, then used controlled blasting for a 10m section of hard rock.

The small shaft diameter necessitated a specialised launch sequence and TBM modifications. "We had to essentially slice the main beam in two so it could be lowered down the shaft, then bolt the two halves together at the bottom," said Pordon. The main beam, originally 13m long, was split into two 7.7m and 5.6m pieces for assembly in the 16.7m long starter tunnel.

Once at the bottom of the shaft, the machine began boring in October 2008 without a conventional back-up system. 180-metric ton hydraulic jacks propelled the TBM forward in 2.7m strokes, while an umbilical system connected the machine to the first five back-up decks operating at the surface. During each TBM stroke, muck is dumped from the shortened machine belt conveyor to one of four $10m^3$ capacity muck cars, which is then lifted to the surface by a high-capacity crane. Once the machine has bored ahead approximately 30m, back-up decks will be lowered and progressively added.

Multiple headings

At the end of the first 244m long heading, the Robbins TBM must be retracted past steel ribs and other support structures before transportation to the second jobsite. Specially designed steel ribs consist of a

Above: **The Robbins TBM at the Dobson's Run Project was launched from a shaft using umbilicals and 180-ton hydraulic jacks**

Below: **The East Side Access Project in New York City is utilising two Robbins TBMs to bore just 1.5m beneath active subway tunnels**

270 degree strip of 127mm thick steel, with an invert ring consisting of 25mm steel plate. The design gives the TBM more room during retraction, though further elements must be modified. The bolted outer cutterhead segments will be removed, and the roof shield will be removed and bolted to the tunnel ceiling using rock bolts.

"The cutterhead support was modified to more easily remove the roof shield. The support neck is split in two so the shield slides out with removal of just two bolts," said Pordon. Once the outer structures are removed, the TBM will be retracted through the bored tunnel using specially designed Robbins transport dollies, which allow the TBM to be 'walked' backward without major disassembly. The machine will then be transported about 800m away to the second jobsite.

Vulnerable nearby structures

The machine will be retracted out of the first heading and shipped to the second launch site in the first quarter of 2009. The small second site, at only 18m wide by 46m long, sits at the side of a four-lane road running alongside the Schuykill River. The 84m long TBM and back-up will again be launched using umbilicals, and will bore through a concrete wall directly beneath Laurel Hill Cemetery. Crews will work with the owner, Philadelphia Water Dept, and the Philadelphia Dept. of Transportation, to negotiate any necessary road closures.

During the bore, vibration will be monitored and a probe drill will be used a minimum of 6m ahead of the cut. The machine will bore in a pattern, probe drilling 20m ahead, then TBM mining 15m, probe drilling 20m, and so on. Boring is expected to be complete by the end of 2009.

East Side Access Project

The East Side Access Project involves construction of a new 6.7km subway line needed to relieve heavy traffic congestion between the boroughs of Queens and Manhattan in New York City, USA. The project consists of twin tunnels, including a 2.6km long section in hard rock, running from the East River to underneath Grand Central Station in Manhattan.

Two Robbins TBMs (one a 6.7m diameter Main Beam TBM, one a rebuilt 6.7m diameter Double Shield machine) are boring the tunnels for the Dragados/Judlau JV, each consisting of multiple headings in restricted working spaces. Neighbourhood restrictions stated that no surface access could be built in Manhattan, so the machines were launched on the other side of the East River from an open cut site in Queens. Equipment was taken in through the Queens pit and transported about 2.6km through existing tunnels to the starting face in Manhattan.

The existing tunnels, including a submersed tube under the East River, had a restricted, rectangular cross section measuring just 4.5m wide by 4.5m high. To deal with the cross-section, the machine was transported through the tunnel without outer cutterhead components, leaving the rectangular inner core to travel through the submersed tube.

Vulnerable nearby structures

Assembly and launch chambers for the TBMs were prepared by drill and blast at the new starting face. There were severe restrictions on the drill and blast operations due to the urban location, and the proximity of existing 'live' subway tunnels directly above the assembly chambers. Restrictions were particularly severe for the westbound tunnel, as the existing subway tunnel was only about 1.5m above the crown of the new tunnel.

Due to the proximity of the subway line a large assembly chamber with cranes was not feasible. Instead, the TBM was designed with an "inner core" and "outer component" construction. The inner core was assembled in the Queens pit to fit through the submersible tube. The inner core was designed to be as complete and intact as possible, and included all power and control systems. Thus, the TBM inner core and the back-up could be self-propelled through the small access tunnels. Power was provided by an onboard genset and power units. The outer components were staged in position in the small assembly chamber, making assembly with small lifting gear relatively easy once the inner core was rolled into place.

Monitoring systems are another crucial factor where subway tunnels and existing utility tunnels are in close proximity to the construction area. At East Side Access, extensive monitoring was required both prior to and during excavation. Tunnel design consultants drilled exploratory boreholes, installed piezometers to monitor groundwater levels, and conducted laboratory and in situ testing for rock permeability. Temporary closures of utilities, roadways and subway tunnels were required to conduct the tests.

The rock in the Manhattan tunnels was determined to be a combination of schist, gneiss and granite, with a UCS of 80 - 200MPa and two fault lines. The rock classification necessitated cast-in-place lining in weak areas, and a combination of steel ribs, wire mesh, and rock bolts in other areas as a temporary lining.

Monitoring meters were installed inside some of the boreholes located in pre-existing tunnels, subways and structural foundations. The instruments transfer real-time data via telephone lines to a computer center in order to monitor vibration, temperature, and movement during the tunnelling operations.

Multiple headings

Like the Dobson's Run Project in Philadelphia, the East Side Access tunnels consist of multiple headings requiring a retractable machine design to squeeze past rock support structures.

Both TBMs are boring multiple headings underneath Grand Central Station, including the parallel 2.6km main tunnels plus two miles of auxiliary tunnels. The boring sequence, consisting of three separate headings, requires a design that allows for swift retraction and re-launching of the TBM. Launched in December 2007, the Robbins Main Beam machine excavated the 2.6km main tunnel to Grand Central Station, and was then retracted through the newly bored tunnel to a large crossover cavern.

Above: **The Po Shan Road Project utilised a Robbins 3.5m TBM launched from a confined 25m wide x 27m long jobsite**

The machine was recently re-launched at a "Y" shaped intersection to bore another 610m tunnel at a slightly higher elevation. After the second heading, the machine will be retracted the full 610m, leaving all tracks and tunnel support structures in place before embarking on the third heading.

The Main Beam machine has been designed using a segmented, bolt-on cutterhead for swift disassembly. For full retraction, first the outer components of the cutterhead are removed. The shielded front section of the TBM, designed as an "umbrella", is then retracted using hydraulic extensions. The extensions allow the bottom, side, and roof supports to move radially inwards, reducing the machine diameter from 6.7m when fully extended to just 6.1m with removal of the shield assemblies. The machine is then walked backward using Robbins transport dollies.

Po Shan Road

The Po Shan Road project is a landslide prevention project on Hong Kong Island aimed at controlling groundwater accumulation during storms. The tunnels, for the China State/China Railway JV, were TBM-driven due to the location of condominium buildings less than 50m from the jobsite. Boring restrictions in the heavily populated area also limited TBM excavation to eight hours a day.

Two TBM tunnels, 260m and 190m in length, were driven from a small worksite about 25m wide by 27m long using a 3.5m diameter Robbins Main Beam TBM.

With the short tunnel lengths and limited space, TBM modifications were necessary to launch and retrieve the machine as simply as possible.

The machine bored both tunnels without a conventional back-up system - hydraulics were modularised and placed directly behind the TBM while electrical equipment was kept at the tunnel portal and connected to the TBM with an umbilical. The umbilical was suspended on a roller system for easier handling of the large cables.

Muck removal was accomplished using a series of conveyors on wheels, which emptied into a steel silo for removal by dump trucks. Though slower than a conventional setup, the TBM still excavated a best day of 22m in less than six hours before completing the tunnels in March 2008.

Though urban tunnelling projects present multiple challenges, many solutions exist. These include retractable TBMs, modified launch sequences to start from shafts or restricted work areas, and monitoring programs to protect nearby structures. With the majority of today's tunnelling projects in urban settings, successful modifications are sure to become more advanced and efficient for specific site conditions. T&T

Right: **Robbins TBM 'inner core' at East Side Access Project was transported through a rectangular immersed tube**

Away with pen and paper from mapping

We all now the problem, mapping sheets being soaked with water dripping from roof and walls in the tunnel, ink floating all over the sheets makes the recognition of tidy mapped and drawn notes from the tunnel mapping difficult. The research foundation SINTEF has in close cooperation with the University of Science and Technology in Trondheim (NTNU) developed a program and concept for electronic mapping and storage of gathered information from the geologic mapping underground. The program is called TunnDoc and is based on a standard, commercial PDA with a 3.5-inch touch screen and Windows mobile.

This concept will eliminate today's methods for documentation of the geological conditions underground making the process more time and cost effective.

Before starting to use the TunnDoc in a project, the geometry of the tunnel can be inserted from XML-files enabling the mapping to be done on the actual tunnel geometry. Instead of the ordinary pencil and paper solution the geologist brings the PDA with TunnDoc installed for tunnel mapping. All geological information such as joints and weakness zones, foliation, rock type boundaries etc, together with strike and dip can be electronically recorded by drawing on the screen.

TunnDoc allows the geologist to record the Q-values identified along with the mapping. Various values in the Q-system are included in the software and can be specified through pull-down menus. In this way a systematic documentation of the rock mass quality as mapped by the geologist is secured. In addition the geologist can record information of rock types, exposure, weathering etc. into the PDA. SINTEF/NTNU will be looking at enabling the TunnDoc to also take into account other rock mass classification systems.

Upon returning to the office the geologist transfers all the recorded data from the PDA to a PC. The recorded data will be stored in a MS Access database from where pre-formatted mapping sheets of the tunnel can be printed with all the recorded information.

One major advantage of the TunnDoc is that it eliminates the need of pencil and paper in dark and wet tunnel conditions. The major advantage though is that it eludes the manual procedure of converting handwritten geological notes to an electronic format. With TunnDoc all geological recordings are in an electronic format once the geologist has mapped the features in the tunnel.

Personnel who are used to handle such geological data in AutoCad or similar CAD-software may find it useful to export the mapped information from TunnDoc to DXF-format. The drawing can then be processed further prior to implementing the data in a predefined format. Anyway, the data can then be printed as "As-built" documentation on geological conditions.

Having the geological mapping electronically recorded and stored through TunnDoc it is convenient to transfer the data to electronic archives which makes it easy to retrieve the information whenever needed. For future inspections and maintenance and in case of specific incidents the stored data can be transferred to a PDA with TunnDoc for use as a tool for the tunnel visits, and for comparison.

SINTEF/NTNU is currently working on a new software module of TunnDoc which enables rock support to be included. Future modules might be such as probe drilling and grouting. In the same way, the possibility of adding facilities for mapping of open cuts and pits, surface geology and so on, are also foreseeable.

Some unfortunate incidents have been experienced in tunnels during recent years, where information from the construction phase has been difficult to retrieve and mostly appearing in different formats and standards. With this tool a nation-wide database can be established, which could benefit tunnelling projects in the future. The tool ensures that a minimum of information is collected and is easily available whenever needed.

SINTEF/NTNU believes that this concept has a great appeal to the tunnelling industry. TunnDoc enables an improved effectiveness in the mapping work and makes the storage and information handling easier and more reliable.

SINTEF
Web: www.sintef.com

Minova solves China woes

China's Bashiyidaban Tunnel is part of the Yili River Project, and is used for transporting water from the Northern regions towards the South. The 40km long tunnel has a 7m diameter and is being constructed using a Herrenknecht TBM.

During excavation, problems constantly occurred with water ingress at the face and soft collapsing ground which prevented progress. Discussions were held with the Ruichy Minova Engineering Support Division and the solution agreed was to supply specially designed Bevedol WFA and 20 times foaming Bevedol S. The Bevedol WFA would be used for sealing against strong water ingress while the high foaming Bevedol S would be used for ground consolidation ahead of the TBM. The high foaming characteristics of the Bevedol S allowed it to be injected through the shield without the resin sticking to the TBM.

This combination proved to be very successful and several hundred tonnes of products were applied while the TBM negotiated the problematic ground. Due to the remote location of the site and the urgency of the work, Ruichy Minova ensured all equipment and personnel were based on site and on call 24 hours a day.

The success at the Bashiyidaban site has led to further projects including the Chengdu Metro Tunnel, South China and the ongoing rail tunnel repair for the Shenhua Mining Group in Inner Mongolia.

The Shenhua Jiminyi rail tunnel had problems with severe water leaks and failing of the concrete tunnel lining. Minova's Bevedol WF and WFA was used to stop the water and to seal the fissures while Tekroc polymer modified repair mortar was used to repair and reinforce the broken segments.

Additional ground injection was carried out along several sections using Bevedol WF to consolidate the loose and friable ground, which was causing pressure and loading onto the concrete segments, resulting in the segments failing. The ground, once consolidated with the Bevedol WF, formed a strong protective band around the segments, resulting in better load transfer characteristics.

Minova
Web:
www.minovainternational.com

Refuge chambers for HK

Amidst the backdrop of the recent tunnel collapse in Hangzhou, Eastern China, TBM manufacturers Herrenknecht have incorporated two purpose-built refuge chambers into their emergency plans for the Hong Kong Drainage project, to help protect personnel from potential hazards.

In November 2007 the Hong Kong Drainage Services Department (DSD) awarded the construction of its West Drainage Tunnel to the JV of Dragages-Nishimatsu, with a contract value of US$355M. The 11km, 6.25-7.25m diameter drainage tunnel will be built in two sections – West to East of Hong Kong Island – by two converging TBMs.

As designers of the two Double Shield TBMs to be used in the project, Herrenknecht, incorporated two custom-built Refuge Chambers to sit within each TBM gantry.

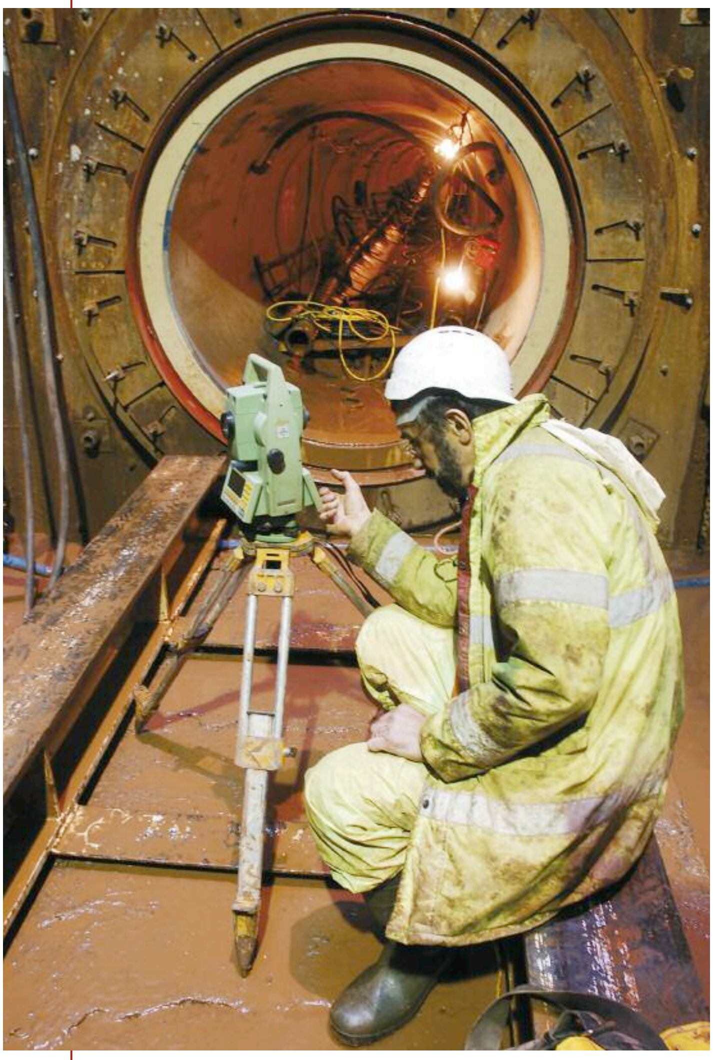
The CE certified refuge chambers have been developed by MineARC Systems of Australia, who also design and manufacture hard-rock and coal chambers for use in underground mining operations around the world.

Each chamber is designed to be fully self-sustaining; providing a minimum of 24 hours refuge for up to 20 occupants, including oxygen supply, carbon dioxide/monoxide filtering, gas monitoring and air-conditioning to

maintain internal temperature. Rail-mounted, remote-controlled chambers are also available for the tunnelling industry.

MineARC
Email: mike.lincoln@minearc.com.au
Web: www.minearc.com.au

Advanced laser tunnel guidance



UK contractor Morgan Est has made the move away from the industry standard of a laser guidance system for its tunnel alignment control and embraced an advanced technology, TEDSS, on its multi-million pound contract to upgrade Belfast's sewer system for the client, Northern Ireland Water. The project includes the construction of some 10km of tunnel (see p16 for a full project report) in the centre of the city.

The Tunnel Engineers Directional Software System, (TEDSS), is owned by Alignment Surveys Ltd, and is a result of many years of development and testing in the field by the company's principal, EW Janes (pictured left). He went on to advance his own developmental work at university resulting in the award of a Doctorate in 2004.

After various problems in 2008 Morgan Est discussed the suitability of the TEDSS system with Dr Janes, which resulted in a highly successful test period.

After these trials, when Morgan Est was completely satisfied that the system would facilitate a reduction in downtime and improve safety standards, the TEDSS became the preferred system on the challenging sewer project.

Given that most tunnel-drives for utility projects are getting longer, with more complex alignments and/or curves, the laser systems, as demonstrated in Belfast and other contracts do have limitations.

The TEDSS system can be used for a tunnel project affected by the tight alignments and also for more conventional alignments thereby offering a complete tunnel guidance system in any environment.

In two of the common systems used in tunnelling, pipe jacking and the fixed lining method, the use of 'new technology' gyros for azimuth (heading) information will benefit TBM operations by reducing downtime caused by system guidance failures and TBM survey checks.

Additionally the reduction of manual survey checks and 'survey control' advance within the often extremely cramped environment of both tunnel types will also enhance the safety standards of all TBM operations applicable to the technology.

The rate gyros used for TEDSS are laser gyros. They are very compact and are believed to be more reliable than mechanical gyros providing greater accuracy coupled with the consumption of less power.

These are for use as a stand-alone unit within a pipe jack tunnelling environment or as part of an integrated system, incorporating a Robotic Total Station, for use within conventional mechanised tunnelling.

Alignment Surveys Ltd
Email: info@alignmentsurveys.com
Web: www.alignmentsurveys.com

Breath of air

Total Protection UK, are proud to launch the brand new range of MSA AirGO Pro breathing apparatus and full composite cylinders. Its rugged reliability, flexibility and great value for fire brigades, plant, sub-surface or offshore use.

Sales and Marketing director at Total Protection UK, Mark Haylett said, "One of the main problems encountered with breathing apparatus is that of stress and fatigue. The AirGo Pro even has the comfort angle covered by offering an ergonomically designed back plate, which evenly distributes weight and keeps the unit close to the body, which in turn reduces strain.

Since stocking the AirGo Pro, we have experienced a huge demand from a wide range of industries wanting the unit for numerous uses ranging from sub-surface to fire fighting."

Approved to EN 137:2006 [2] standards, the AirGo Pro also features a comfortable, padded shoulder straps and hip belt, which can be easily adjusted to suit all users

Total Protection UK
Web: www.totalprotectionuk.com

MultiPoint Button Bits

Rockmore International, a global manufacturer of rock drilling tools, has developed a revolutionary new carbide insert design for their button bits, the MultiPoint.

In percussion drilling, penetration rates depend on efficient crack propagation. With a conventional hemispherical insert, there is a single tangent point striking the rock, resulting in the rapid development of wear flats. Rockmore's exclusive new carbide insert design provides multiple strike points for more efficient rock fracture and longer insert life.

Extensive rock-drilling trials showed that Rockmore's button bits with MultiPoint inserts last up to 20% longer than the standard hemispherical design, and measured increased penetration rates by 10%. Wear flats appeared slower and later in the insert life than with hemispherical inserts. Testing also revealed that the MultiPoint inserts provided smoother bit rotation and drill advancement.

With the new Rockmore MultiPoint design, there is better transfer of energy, imparting more effective rock fracture. Button wear is reduced and overall bit life enhanced in even the most abrasive and hardest rock conditions.

The MultiPoint design is currently available in 1/2" to 3/4" (12 – 19mm) diameter carbide inserts, in Rockmore's DTH and top-hammer bits, 3.5" to 10" (89 – 254mm) diameter.

Rockmore International
Email: info@rockmore-intl.com
Web: www.rockmore-intl.com

Jumbos to hydro project in Chile

Six Sandvik DT series tunnelling jumbos will be used by the Hochtief-Tecsa JV to excavate the tunnels on La Confluencia, a US$350M run of river hydroelectric project that is being built in the Chilean Andes. The jumbos will be delivered to the site in the second half of this year.

The Hochtief-Tecsa JV, started work on their contract in October last year.

La Confluencia is being developed 150km south of Santiago by the Tinguiririca Energia. Located in the Tinguiririca Valley in the foothills of the Andes, the 158MW La Confluencia is a run-of-river project involving the design and construction of a powerhouse to install two turbines, approximately 20km of tunnel, and two river diversions.

La Confluencia is located on the Tinguiririca, Portillo and Azufre rivers and consists of intakes and conveyance systems on two branches diverting flows to a surface powerhouse. The Portillo branch includes an 11km low-pressure tunnel, whilst the Tinguiririca branch involves construction of a 9.3km low-pressure tunnel.

Both the Tinguiririca and Portillo branch tunnels will terminate at a concrete lined vertical shaft dropping to the open-air powerhouse via a concrete and steel lined high-pressure tunnel.

As the Andes are characterised by uplifted sedimentary, volcanogenic and intrusive units of highly variable nature, it has not been possible to predict with certainty the rock conditions that the contractor will find once tunnelling begins. Nonetheless, fast progress is necessary and as there will be up to 10 active fronts in the two tunnels during the greater part of the construction period, the tunnels will require intensive management.

The six jumbos are all Sandvik DT 720C units, and will be working on the two main tunnels, the surge chamber, and other tunnelling work on the project. Built on diesel-driven carriers, they are electro-hydraulically powered and equipped with two booms designed for extremely fast rock drilling across a maximum cross-section of $70m^2$, and will be working at a maximum height of 7m and width of 11m.

The jumbos will mainly be equipped with Sandvik R32 drilling tools of 45mm diameter, fitted with nine-button RT300 bits.

In each of the two main tunnels, three Sandvik DC300 rigs will follow the jumbos to carry out reinforcement drilling, using a Sandvik R32 drilling tool of 51mm diameter for the central hole on each section and an R32 of 38mm for the surrounding holes. Once the reinforcement is done, the tunnel will be lined with shotcrete.

The projected rate of tunnel advance will be 9m per day, to be achieved in two cycles of drilling, blasting, cleaning and reinforcing per 24-hour period.

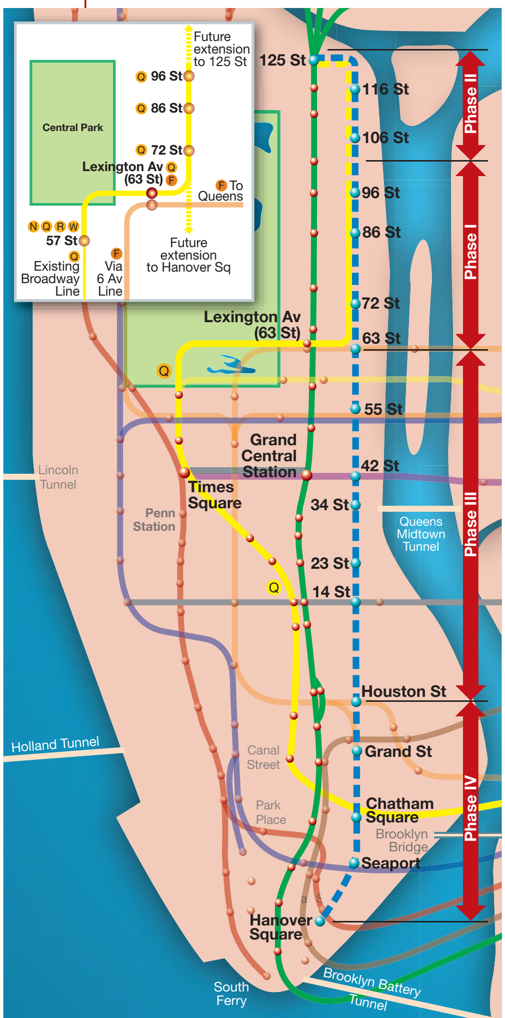
The construction period for La Confluencia is expected to be three years, depending largely upon the rock conditions encountered.

Sandvik
Web: www.sandvik.com

Second Avenue steps up

The joint British Tunnelling Society and British Geological Association meeting of November 2008 saw Peter Chamley of DMJM + Harris/Arup JV give a presentation on the geotechnical design and construction challenges on the Second Avenue Subway Project in New York City

With the east side of Manhattan being relatively poorly served by New York's subway system, Second Avenue Subway was first proposed back in 1929. With the new subway line in mind, the elevated train that existed on Second Avenue was demolished, in 1942.



However with WWII and several other crises, including the 1975 fiscal crisis, only several small cut and cover sections of the scheme were ever constructed.

With the resurrection of the scheme at the beginning of this century, preliminary engineering was completed in December 2004 and final design started in April 2006 with construction beginning in April 2007. The existing cut and cover sections are being incorporated into several phased sections of the current project.

Background to the project

The Client for the project is New York City Transit, Programme Management is undertaken by MTA Capital Construction, the Designer is DMJM+Harris/Arup JV and Construction Management is undertaken by Parsons Brinckerhoff.

The full length of the Second Avenue Subway will be 8.5 miles with 16 stations. In 2002 the cost was estimated at $16bn. Recognising that funding limitations and disruption caused by constructing this line all at once would be unacceptable, the project has been split into four phases.

Phase 1, costing US$4.05bn, will have an estimated daily ridership of 191,000. The benefits of this section are that it will relieve the most crowded section of the Lexington Avenue Line with a connection to the existing system at 63rd St. It also allows early use of one of the tunnel sections built in the 1970's with new stations at 72nd St, 86th St and 96th St and a refurbished and expanded existing station at Lexington Avenue/63rd Street (figure 1). Planned completion of this section is by 2015.

Phase 2 will cover 125th St to 96th St, Phase 3 will cover 63rd St to Houston Street and Phase 4 will cover Houston Street to Hanover Square in the Financial District.

The scope of the Phase 1 section of the project includes the following:

- Tunnels from 92nd St to 62nd St
- Stations at 96th St, 86th St, 72nd St and existing Lexington Avenue /63rd St
- 63rd St Subway connection
- Track & systems from 105th St to 63rd St
- Service between 96th St and Brooklyn via Broadway Line

Phase 1 has also been packaged as 12 contracts:

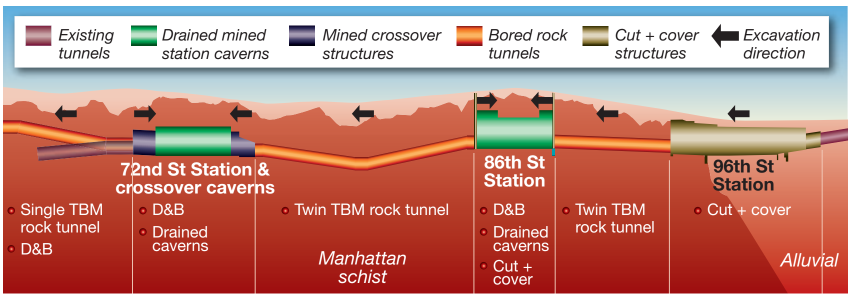
- Bored tunnels + cut and cover box
- 96th St Station (excavation, structure, MEP/finishes)
- 86th St Station (utilities, cavern, MEP/finishes)
- 72nd St Station (utilities, cavern, MEP/finishes)
- 63rd St Station upgrade
- Systems

At present the 96th St Station diaphragm wall and excavation is in negotiation.

Geology and investigations

The geology of Manhattan is largely highly competent Manhattan Schist though overlain with glacial silt, sand, gravel and

Left: Fig 1 – Project map with phases
Below: Fig 2 – Construction methods along Phase 1



decomposed rock in the valleys (figure 2). The rock is typically strong 40-80MPa competent gneiss and schist with pegmatite. Peter Chamley gave some representation of the complex geology caused by the last glacial events. Evidence of the glaciation can still be seen on the heavily striated rocks in Central Park.

Due to the high profile of the rock strata, the 72nd St Station and 86th St Station are being constructed as caverns. With a fault to the north of Manhattan the rock dives away quickly and is replaced by glacial infill material hence 96th St Station is being constructed as a cut and cover station and connects into one of the existing tunnels constructed by cut and cover techniques in the 1970's using steel and concrete bents spaced at 5ft centres. The following ground investigation has been undertaken:

- 346 borings
- 12,200m core
- 37 CPT tests
- 66 acoustic televiewer holes used to map the structure
- Insitu stress testing using hydrofrac techniques
- 800+ existing borings

The acoustic televiewer was used to map all the cored holes in the schist, which allows a map of the borehole to be taken so every joint and feature can be orientated with the core. This also allows the polar plots to be produced of the jointing. This data led to the relocation of the 72nd St Station away from a heavily faulted zone. In addition, lab tests including uniaxial compression, point load strength, deformation properties, cerchar abrasivity, drill rate indexes, bit wear indexes and cutter life indexes were used. This information was made available to the tunnelling contractors. Direct shear strength tests were also done on the foliation joints and cross foliation joints to provide parameters for the rock joint properties.

It was explained that the soft ground conditions are generally uniform:

- Made ground 3-10m
- Organic silt/silty clay 1-5m
- Silty sand 2-4m
- Varved silt/clay to 25m with 85% silt and clay seams 3mm-10mm

The predominant tool for ground investigation design was the SPT (N values). Though there was some spread on the results they were around 10 blows/ft though for unknown reasons the archive borings had higher values. The material properties meant that the ground was treated as a silty sand with the groundwater being typically at a depth of 3m.

Cut and cover structures

The 96th St Station is around 565m long and 20m in depth and this is where the TBM will be launched to head south into Manhattan on the two tunnel drives. This is being constructed by the Skanska, JF Shea and Schiavone JV.


A fault in the Manhattan Schist

The shallow depth of the station has meant that there have been constraints on the head room for the rail structure and also room near the surface for utilities.

Where the soil is present at depth, diaphragm wall techniques have been used to construct the station walls, whereas where the rock is closer to the ground surface, secant piles have been installed with a permanent box structure within. The stations are designed with a mezzanine ticket floor and escalators and lifts to take passengers to a central island platform.

During construction a temporary road deck has been placed over the top of the excavation which also acts as a strut. The contractor has to draw down the water to no less than hydrostatic head but limit drawdown outside the structure. The diaphragm walls have been extended in this regard to act as a cut off to the groundwater flow.

For each stage of excavation, a seepage analysis has been run, a full scale pump test was undertaken and from that a reasonable estimate of horizontal and vertical permeability was obtained so at each stage of the excavation design seepage was allowed to take place. The groundwater pressures were then recalculated internally and externally to the excavation and then proceeded to the next excavation stage.

The controlling factor on the design has been the displacements primarily due to masonry construction with shallow foundations alongside the excavation. The base and roof slabs of the station box have been designed as fixed and the mezzanine slab pinned. The bottom 5ft of the slurry walls have been unreinforced. Using about 1.5" (37mm) of allowable deflection in the slurry walls, this has been used for building assessments which determined that any effects on the structures would be very slight to slight. The sequencing of excavation has also been modelled to determine the effects on deflections.


Above: Extremely cramped conditions at 96th St Station requires very careful positioning of diaphragm wall cages

The limits on ground movements are:
- Vertical 25-37mm
- Horizontal 10-15mm
- Angular Distortion 1:1000

For certain historic structures, the limits have been set lower to less than 0.5" (12mm). Groundwater drawdown outside the station has been limited to between 0.6m to 1.0m.

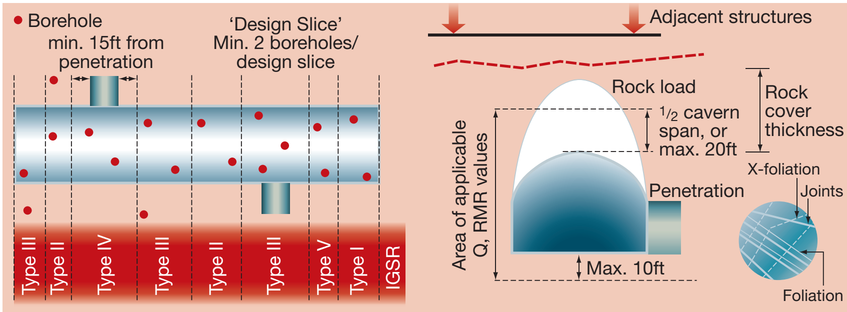
With a building line to building line width of only 100ft (30m) and a requirement that 4 traffic lanes are kept open, plus pedestrian walkways, this has presented a challenge to the station construction with the contractor only having a working space width of 12m.

Automatic total station units have been installed to monitor any building movement with hundreds of targets installed and results obtained in real time. Additionally, inclinometers and piezometers have also been used to monitor the effect of the works.

Structures either side of the excavation include turn of the 20th Century masonry structures consisting of walls front and back with floors spanning in between. These have been subject to movement over the years and obviously need to be closely monitored. The other buildings are largely 1960's structures with piles to bedrock, which are of less concern.

Secant pile construction is underway for the box where the TBMs will be launched as well as diaphragm wall construction being undertaken by Bencor.

The biggest challenge with such constrained sites is the handling of the diaphragm wall reinforcement cages. These are 20ft (5m) in length and 10ft (30m) in depth. The original design was for the cages to be split horizontally but the contractor has decided to split them vertically so each panel would have two 10ft (2.5m) wide cages, 30m in depth. The photo of the panel being lifted into position by two cranes so close to the buildings either side drew gasps from the audience (see p37). It was explained that the panels will be installed at a closest distance of 3m from the building facades. It was however, pointed out that it has been agreed that traffic will be stopped during cage lifts. The joints between diaphragm wall panels include a waterstop and though the technique is common in the rest of the world, it has not been extensively used in North America.



Above: **Fig 3 – Initial ground support requirements, assessed for each design slice**

Rock caverns

For the 86th St Station, cavern excavation techniques are being used. The height of the cavern has been increased at the station ends to accommodate the necessary services in the tunnel which takes up about 40% of the tunnel cross section. This reduced the rock cover to span ratio to 0.15 in places hence the station will be lowered to increase this.

The cavern is 260m in length with a 21m wide excavation and 13m in height.

The design approach for the caverns has been empirical design for the initial support, verified by numerical analyses (UDEC, FLAC). Bolt loads and shotcrete stresses are checked and wedge analyses used to confirm the bolt length.

The rock load and initial support were established in five support classes based on the following design features (figure 3):
- Cavern size and shape
- Q rock mass classification including impact of penetrations (Barton, Grimstad)
- RMR classification system (Bienawski)
- Rock cover (limited to 1/3 of excavation span)
- Rock mass classification (Cording et al)

Five support types were then devised using shotcrete and bolts with lattice girders and arches used for the higher support types.

Initial ground support requirements are used for each design "slice" of the station which uses parameters including RMR, rock cover, and Q.

More sophisticated numerical analyses are used for determining joint properties including Mohr-Coulomb for overburden materials and Barton-Bandis joint models. From UDEC shotcrete forces, rockbolt loads, bending moments in shotcrete and displacements are checked. With such shallow cover, rather than the rock behaving as an arch, it behaves as a beam, which can cause difficulties and has resulted in deepening the alignment to improve the span/cover ratio.

The rockbolts have also been yield checked to ensure that they are not taking too much load. This has included 3D modelling using UDEC in areas of complex geometry. Additionally the interactions with buildings having deep basements has been looked at. The final step is to look at block analyses, including wedges and ensuring the bolt lengths are long enough to hold these up.

With these methods the contractor is be given a fully worked up initial support design prior to commencing excavation.

The presentation was concluded with some photographs of cavern excavation being undertaken for Line 7 which will be similar to that proposed for 72nd St and 86th St Stations. T&T

QUESTIONS FROM THE FLOOR

Philip Wilson of Metronet asked what monitoring is being used for PPV near sensitive structures.

It was explained that the Fire Department deal with sensitive structures and this is being discussed. Previous projects will be used as precedence and data is still being assimilated. Public perception is also an important factor.

David Hartwell asked if the scattering of the SPT results were actually representative of the material or was it just difficult to perform SPT tests?

Most material is loose to dense silt. The Americans were more confident using SPTs The CPTs provided more of a calibration test.

John Hislam of Applied Geotechnical was concerned about the diaphragm walling close to existing buildings and wondered why secant methods had not been used particularly with the logistics of reinforcement handling.

The Client will not accept secant walls as permanent structures and only recently it was accepted that diaphragm walls could be classed as permanent.

Tony Deane of Mott MacDonald asked why there were so many construction contracts but only one systems contract.

There were originally 6 contract packages per station but this pushed the value of the individual contracts to high values. The Client also wanted the competition for the contracts to be increased.

Rapporteur: Andrew Hindmarch

In recent years, an increasingly popular technique, has been that of online pipe replacement. Technical journalist Ian Clarke reviews this family of techniques that include pipe bursting, pipe eating and pipe reaming

Online pipe replacement systems

When first developed the pipe bursting technique was largely based around the use of specially adapted impact hammers (also known as impact moles or earth piercing tools depending on where you are in the world).

This entailed fitting the leading end of the impact hammer with a 'bursting head' designed to be of larger diameter than the pipe being replaced so that when the hammer is activated the impact force drives the hammer forward into the old pipe breaking it up in the ground. The directional stability of the bursting unit is maintained by connecting the front end to a winch cable at the reception end of the burst run which applies a continuous tension as the bursting head advances. The bursting head shatters the pipe material and the shards created are then forced into the surrounding ground by an expansion head that is fitted behind the bursting head. In the same manner as normal impact moling the new pipe is drawn into the void created by the bursting action behind the impact hammer. Typically the range of diameters that can be replaced using this technique is from around 150 mm to about 1 m, although in some individual cases it is understood that this has been exceeded.

Whilst the technique is effective it does have certain drawbacks. First, the old pipe material has to be relatively easy to fracture, like un-reinforced concrete, asbestos cement, cast iron, some plastics or clayware. Second, depending on the size of the pipe, its wall thickness, the ground conditions and pipe depth, the repetitive high impact energy applied by the hammer can cause disturbance to the surrounding environment and in particular adjacent utilities. This can be in form of vibration which can be felt at surface or movement in the alignment of the adjacent services as the nearby ground is compressed which could cause failure. It

Above: A pneumatic pipe bursting head ready to commence a bursting run with the new pipe attached to the rear of the bursting system (Hammerhead).
Below: A pneumatic pipe bursting unit bursting pipe (Hammerhead).

Above, left: **An example of an expansion shell pipe burster bursting pipe during a demonstration (Perco).** Above, right: **Rod based bursting machines set up for bursting runs (Ditch Witch).**

is very important that a full understanding of the ground conditions, nearby structures and other services, their location and depth is known if this technique is to be applied safely and without potential problems.

Sometime shortly after the development of the impact hammer technique the use of hydraulic expansion shell pipe bursters occurred. In this technique the bursting head comprises an articulated shell which is winched through the old pipe in discrete steps, normally the length of the bursting head. The shell is remotely controlled from surface and when in position is expanded outwards from its close position to apply an internal force to pipes inner wall. This puts the pipe material in tension and bursting it. The shell continues to expand slightly to push the shards of the pipe into the surrounding ground. The new pipe is pulled into place behind the bursting head. This can be done as continuous length or using threaded or snap-fit joint, discrete length pipes depending on the access availability. This facility does mean that exiting manhole structures can be utilised where available, minimising the need to make access pit excavations and therefore minimising the impact of the work on the local environment, businesses and residents. This system operates in a range of diameters from 100 mm up to 600 mm installing replacement pipes from 185 mm up to 560 mm diameter. Pic 3

Again this technique does depend on the old pipe being made of friable material that can be relatively easily broken in tension and the pipeline being in compressible ground so that shards can be removed a sufficient distance into the surrounding ground to allow the new pipe to enter the void created.

Rod system developments

Overtime the impact hammer and expansion shell techniques have been somewhat overtaken by the development of other methods based largely on the use of rod pulling technology.

Commonly now known as static pipe bursting, these system utilise a rod pulling frame in a launch pit at one end pf the bursting run which access the old pipe to be replaced. At the other end of the run is a second access pit. This is generally the 'pipe end' of the run.

The system operates by pushing a high strength steel rod through the old pipe using the rod pulling frame in the launch pit towards the pipe pit end. A lead guide rod is normally fitted as the rods are played out to ensure that the ends do not snag whilst passing the through the pipe.

Once the rod string reaches the pipe pit end, the lead rod is removed and the bursting head assembly is fitted. This assembly normally comprises the bursting head itself followed by an expansion shell to push shards of the broken pipe into the surrounding ground, a swivel and the pipe string, which is more often than not a continuous plastic pipe.

The pipe can be welded together onsite from discrete lengths or increasingly for smaller diameter pipes is delivered to site as a coil on a trailer. The trailer option reduces the site footprint considerably as there is no need to lay out a long length of pipe on surface.

Once the bursting head assembly is fitted, the rod string is pulled back through the old pipe towards the launch pit by the rod pulling unit. This action forces the bursting head into the pipe 'bursting' it. The expansion shell removes the shards by pushing them into the surrounding ground and the new pipe is pulled directly into the void created. This continues until the bursting head and the new pipe arrive at the launch pit. The bursting head assembly is removed and the new pipe is ready to connect to the remainder of the network.

Most rod burster units are designed to utilise the face of the launch pit as the 'thrust wall' against which the rod pullback operation anchors itself. In earlier units this meant that the bursting head could only pull the bursting head/pipe assembly near to the edge of the launch pit. Most systems now, however, utilise extension sections to the pulling unit or other arrangements which allow the rod puller to pull the pipe fully into the launch pit.

Rod based systems can be used to replace pipe from as little 50mm diameter up to 1,000mm diameter over length up to 200m depending on prevailing conditions, and can be used on mainline or lateral and service pipes.

More recently bursting head development has led to the capacity to replace not only friable pipes but also ductile and steel pipes using a technique that is commonly known as pipe splitting. Rather than 'bursting' the old pipe this system utilises a selection of 'scoring' blades to weaken the pipe and a cutter blade that 'splits' the pipe along the score line. The expansion shell then prises open the old pipe to create the new void for the replacement pipe. These cutter heads have also become fairly widely used in the replacement of old cast iron pressure pipes that have been fitted with steel leak repair collars. Whilst the majority of the pipe is burst conventionally, the repair collars are split using the steel cutter head. This adaptation developed after early attempts to using pipe bursting encountered some difficulties where the repair collars failed to burst and were simply dragged through the ground as the burst progressed. Where numerous repair collars built up along the bursting rods as they burst the old pipe, this sometimes led to the burst failing as the power of the rod pulling frame could not pull the collection of repair collars through the ground. The use of the pipe splitter head enabled the steel collars to be 'burst' insitu with the rest of the pipe so eliminating the problem.

In situations where the footprint of the rod burster systems was too big and access was too restricted companies address the problem by developing wire cable based pulling systems. These units are able to work from very small access pits, from within existing manholes if the dimensions are sufficient or from surface using an additional support framework. Working in a similar fashion to the rod bursters, the pulling cable is fed through the old pipe to be replaced from the machine to the pipe-side pit. A bursting head, expander and pipe are attached and the cable is retracted by the pulling unit. This action pulls the bursting head into the old pipe bursting it, the expansion shell removes the shards and pushes then into the surrounding ground and the pipe is pulled into the void created. Generally these systems are suitable for bursting existing pipe diameters from 50 to 150 mm. They can be used with coiled pipe or short length sectional pipes.

Pipe eating

A well as the pipe bursting techniques, over the years, other technologies have been developed to facilitate the replacement of pipelines in their existing 'corridor'. One of these techniques was that of 'Pipe Eating'.

Whilst not as popular as it once was due to the developments in the bursting sector, this technique should still be recognised as available to engineers given the right conditions and circumstances.

Essentially pipe eating utilises microtunnelling techniques not only to create a bore into which a new pipe can be jacked but to also remove the exiting pipe as the bore progresses. One of the advantages of this system is that it has, in the past, been shown to be able to remove and replace reinforced concrete pipes, by adapting the microtunneller cutter array to handle and cut down the reinforcing bar. Also whereas the using of standard pipe bursting or splitting follows the exact route of the existing pipe, pipe eating can use the directional control of the microtunneller to realign a pipe route that may be suffering from troughs etc due to ground movement or other external forces.

Normally when pipe eating, ahead of the front end of the microtunneller, a seal is utilised that fits tightly to the diameter of the old pipe. This allows the microtunneller to be used without the need to fill the existing pipe with the circulation slurry that removes spoil from the cutter face and supports the surrounding ground as the process advances.

Below: **A 'splitter' head cutting through the wall of a steel pipe (Hammerhead).**

Pipe reaming

In the same way that microtunnelling has seen adaptation for use in the pipe replacement sector, so has Horizontal Directional Drilling (HDD).

In this instance, the HDD rig is set up at an access point atone end of the pipe being replaced and instead of drilling a pilot bore through new ground, through which the new pipeline would normally be installed, the drill string is played out through the existing pipe. This allows the HDD pipe string to act as the 'rod pulling' system as in the more traditional pipe bursting systems.

A special 'reaming' head is then fitted to the drill string that is designed to handle and cut down the type of pipe that it is required to remove. The HDD rig then pulls back the reaming head arrangement with the new pipe attached to the rear via a suitable swivel. As the drill string is retracted the reaming head is rotated cutting out or grinding down the old pipe, the remains of which are removed using the HDD circulating drilling fluid system.

It is understood that reaming heads of up to 1,200 mm have been utilised using this technique.

Advantages and disadvantages

As well as being able to utilise existing utility corridors for the installation new pipe to replace older generally deteriorated pipe, all of the above systems have a significant advantage in that they offer the facility to upsize (increase the diameter and therefore the capacity) of the existing service. This of course is provided that the existing service or pipeline runs within a ground structure that will allow the upsize to take place and that no other buried services will be adversely affected by such an installation.

With the rod based systems this is generally achieved by using an oversize expander shell to create a void big enough to allow the new larger pipe to be installed. The ground conditions are a vital controlling factor for this. Also if such an upsize is to be undertaken it may also require a higher power rod pulling frame to provide the capacity to create the larger void in the first instance and to pull in the larger pipe with its greater weight and to overcome the increased friction forces with the surrounding ground.

With pipe eating, whilst still needing to take note of nearby services, upsizing can be affected by simply arranging the

Above: **A cable based, small footprint pipe burster set up for a bursting run in a small access pit (U Mole)**

cutter head to be of the required size to create a bore that will fit the new pipe diameter. The spoil created alongside that of the old pipe being removed would simply be collected and removed in the same way as if it were a standard microtunnel project. Similarly with pipe reaming, the larger the bore required the larger the reaming head required. For both pipe eating and pipe reaming the slurry/drilling fluid would need to be designed with the additional spoil generation/removal requirements in mind.

On the downside, it has been known for shards created during the bursting process to 'slump' back into the void created by the expansion shell and, having often sharp edges, cause damage to the new pipe as it is pulled in. This can be a problem, particularly with pressure pipes where any damage to the new pipe may subsequently cause its rating and therefore pressure carrying capacity to fall short of that for which it was originally designed.

There are various options that can be used to overcome this possible problem. First is to utilise a standard pipe with a thicker wall, or over engineer the pipe to makes allowances for possible damage. The second option is to over expand the void to make more room for the new pipe to pass through even if some shards do slump into the void slightly.

More recently some pipe manufacturers have introduced a design of pipe that has a sacrificial skin outside the main plastic pipe. This allows for the harder shell to take the damage should it occur without damage to the actual service pipe within.

The latest system to try to address this problem is one where, during ht bursting and new pipe installation process a separate pump system is utilised to feed a grout into void at the point where the expansion shell forces the shards into the ground. This system is designed to keep the shards in place once they have been forced into the surrounding ground and prevent them 'slumping' back into the void.

So, old and new techniques and developments of existing ones are taking the technologies of pipe replacement to increasingly broader markets whilst enabling engineers to continue to re-utilise existing utility corridors in our increasingly congested subterranean world. T&T

Curved pipe jacked flood relief

Ian Clarke explains how pipe jacking resolved a serious flooding threat in the UK

On Longlands Road in Sidcup, Kent, UK the basements of some 20 properties are at risk of foul water flooding given the right circumstances. Being in the area of responsibility covered by Thames Water, the properties were originally served by an existing foul sewer that needed to be reconstructed and the network expanded to alleviate this flooding risk. Thames Water decided to establish a project to complete an upgrade of the existing sewer network and to install a storage tank as well as additional manholes and realignment of certain collector flows. The new storage tank was designed with a capacity to handle flows generated by a 30-year return period storm. The project is known as Main Road, Sidcup FWFAS.

Re-installation, construction and realignment of the majority of the network flows was to be undertaken by the main contractor appointed for the works, Dean & Dyball, with much of the works being completed in open cut. However, approximately 60m of auger boring along was required along with the construction of the new storage tank facility to complete the new sewer network. The tank facility required the installation of a completely new 1,800mm diameter pipeline over a length of some 197.5m. It was decided that pipe jacking techniques were most suited to this part of the works. This part of the project was sub-contracted to AE Yates Trenchless Solutions (AE Yates TS), a contractor with specialist knowledge of and experience in the application of trenchless technology solutions.

Pipe jacking works

The ground conditions that were expected to be encountered over the length of the storage tank drives comprised mainly clay with sand veins and some sands and gravels. Having experienced similar ground conditions on other drives over its years in the industry, AE Yates TS opted to utilise an open face backacter tunnelling unit for the excavation work. In this instance the company chose to use a 1,800mm id hydraulic drive Herrenknecht MH3 – open faced backacter unit.

To utilise this machine AE Yates TS was required to sink an 8m by 4m cofferdam (designated as MRS5) from which two drives were to be installed. The first drive was approximately 97.5m long and included a right hand curve of 375m radius. The second drive, with a 395m radius left hand curve was approximately 100m in length. The pipeline, which was to be jacked into place behind the tunnelling unit, was to comprise Macrete-manufactured 1,800mm id concrete jacking pipe with 316 stainless steel bands at the joints. Both drives ran at a depth of around 3.5m below road level.

Right: **A view along one of the Sidcup pipe jacked storage tank drives from the launch cofferdam looking through the shove ring and over the muck skip**

The jacking frame comprised four main hydraulic jacks each with 300t jacking force capacity, which was manufactured by AE Yates TS using Herrenknecht Rams.

Whilst the installation was not expected to be the most difficult of drives, given the proximity to local residents, prevailing ground conditions and depth, and with both drives being curved, a sophisticated guidance system was required to ensure the drive alignment remained correct. This guidance system was hired for the project from specialist guidance system manufacturer, Germany-based VMT.

Guidance system

The VMT navigation system used for the storage tank drives was an SLS Microtunnelling G. The SLS-G is a gyro based navigation system which operates in combination with an electronic hose levelling system, which was developed for works in small diameter bores and situations where there was a complex-design tunnel axis.

The system works so that at any time the exact position of the TBM and the deviations from the designed tunnel axis, as well as the predicted movement tendency of the TBM are available to the machine operator. The gyro compass provides the horizontal position and direction of the TBM, whilst the hose level determines the precise height of the TBM.

All components of the system are compact to install and there is no requirement to have a 'line of sight' connection between them. The influences of refraction which can affect some other types of guidance systems do not occur within the measurements taken using the SLS-G system.

The hardware comprising the SLS-G system is robust and tunnel-proven over many years of use in the industry. It is easy to handle and utilises user-friendly software with a permanent recording facility for all important drive data. This allows operators to quickly become familiar with the handling of the system.

The information high content of the displayed data ensures an optimum control of the machine position in order to keep deviations from the designed tunnel axis to a minimum. The system also provides the machine operator with a constant display of the position, orientation and tendencies of the machine. The precision of each of these factors means that vertical (if required) and horizontal curves can easily be achieved. Furthermore the system provides a complete and permanent recording of all geometric advance data for future documentation.

Above: **Inside the first drive showing the right hand curve**

For the Sidcup operation, the SLS-G system was supplied together with a VMT specialist guidance engineer.

Installation

With the cofferdam sunk (amongst existing services), the pipe jacking rig in place and the tunnelling machine in position the first drive commenced.

To ensure that the installation ran as smoothly as possible the pipe jacking operation utilised bentonite injection along the pipe chain to lubricate the pipe and minimise friction between the pipes and the surrounding ground. The bentonite materials were provided by Baroid IDP with the lubricating slurry being delivered to the pipe chain using a standard bentonite mixing and pumping system. The lubricating mix flows were manually adjusted injected into the pipe annulus at every fourth pipe.

AE Yates TS contacted Baroid IDP to design a lubrication slurry appropriate for the ground conditions for the project. Based on the information provided from borehole logs along the line of the drive, the lubrication slurry mix formulated comprised BORE-GEL sodium Wyoming bentonite, with EZ-MUD GOLD, a unique beaded readily dispersible anionic polymer. Information from tests indicated that the ground water was slightly acidic having a pH around 6. To counteract the detrimental affects of low pH on the bentonite and polymer additives, Sodium Carbonate was added to the slurry mix water. As the first drive approached the exit shaft the ground conditions became less stable and more porous, therefore N-SEAL, a fibrous inert

Right, top: **Removing the Herrenknecht MH3 tunnelling unit at the end of a drive, with the shield removed**

Right, bottom: **The Water Level of the VMT SLS-G system installed in the crown of the tunnelling machine, with the operator readout to the right of the picture**

Above: **The surface setup at the start shaft for the Sidcup drives**
Right: **Holing on the first of the Sidcup drives**

mineral additive was included in the slurry mix to minimise loss to the ground and promote stability around the pipe.

As the installation progressed and the face was excavated by the Herrenknecht MH3 unit, the spoil generated was removed from the face by the backacter. The spoil was then pulled up onto a conveyor which passed it into a ‘roll over’ skip. Winches were used to pull the track-mounted skip into and out of the pipe jack. At shaft bottom, the skip was lifted out of the cofferdam with a lifting beam and emptied into the back of a trailer pulled by a tractor. Access to the trailer was via a purpose made scaffold platform. The spoil was then taken to a designated loading point some 500m from the work site where it could be loaded onto 8 wheeled tipper trucks for final removal from site.

Below: **The rear of the muck removal conveyor system**

In advance of the project and during the course of the works a number of public relations requirements and associated utility operations were required to be undertaken. Several meetings were held to keep local residents informed of the project progress and how it would impact on their day-to-day activities. There was also significant consultation undertaken with Bexley Council, the local water supply company (in respect of a water main diversion that was required) and the local gas company (in respect of existing pipes which lay within the pipe jacking pit).

Other aspects of the project required sensitive handling and planning to minimise local and wider disruption given that the works would take place on busy London streets with traffic re-routing, road closures and limited working space. Crane movements on the site were to be kept to a minimum to avoid slewing pipes for example.

To assist in minimising the effects of the work site itself on the local area both Day Time and Night Time compound set-ups were utilised. This was designed to ensure that during the evening whilst work continued underground, the surface area and therefore the impact of the site was smaller allowing as many residents as possible easy access into their properties.

The project, which has been completed in various phases between the main contractor and AE Yates TS started in February 2008. With the second drive completed on 21 October 2008 the completion date for all the works was December 2008.

Commenting on the project for AE Yates, Andy Carnell, project manager said: “The relationship between all construction parties have been good throughout the project with a successful completion.” T&T

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This International Symposium on Rock Mechanics and Geoenvironment in Mining and Allied Industries is being convened to assess and understand the interface of different aspects of the theory, tools and practices. Contact: Sanjay Kumar Sharma; tel: +91 9450 787 274; email: sksharma.min@itbhu.ac.in; web: http://www.itbhu.ac.in/min/conferences/

02-03 MARCH
Shotcrete for South Africa
Johannesburg, South Africa
Sponsored by the ITA, one of the themes of this conference is to the merits of introducing a nozzleman certification scheme in South Africa. Presentations will include a review of at least six different nozzleman accreditation schemes being used in other parts of the world. Contact: SAIMM; tel: +27 11 834 1273; email: raymond@saimm.co.za; web: http://www.saimm.co.za/events

11-12 MARCH
Multi-System Utility Tunnels (MUT)
Haifa, Israel
The first international conference in the developing field of design and construction of underground multi-system utility tunnels (MUTs) will present existing experience regarding planning and construction in Haifa and other towns worldwide. Contact: Diesenhaus Unitours; tel: +972 3 5651324; email: conven4@diesenhaus.com; web: http://www.multiutilitytunnels.com/

26-27 MARCH
China Tunnel Summit 2009
Beijing, China
The China Tunnel Summit aims to provide a platform for discussion of new tunneling technologies and challenges in a warm and professional atmosphere. This year's Summit will focus on Safety in Construction and Sustainable Development. Contact: Merisis; tel: +86 21 6247 8608; email: marketing@merisis-asia.com; web: http://www.merisis-asia.com/tunnel/

18-20 MAY
8th Iranian Conference on Tunneling and Underground Spaces
Tehran, Iran
"Underground Spaces for Safety, Better Environment and Energy" is the theme for this year's conference, which aims to offer a platform for exchange of knowledge and information on state of the art tunnelling development and practices. Contact: IRTA; tel: +98 21 886 304 95; email: info@irta.ir; web: http://www.irta.ir/conference2009/

23-28 MAY
2009 ITA World Tunnel Congress
Budapest, Hungary
The 35th ITA General Assembly and Congress will be held in Budapest. With a large amount of tunnelling underway and in planning, the organisers are confident it will be a successful event. Contact: Diamond Congress; email: secretariat@wtc2009.org; web: http://www.wtc2009.org

07-10 JUNE
Shotcrete for underground support XI
Davos, Switzerland
Engineering Conferences International, in conjunction with the ITA, the Swiss Tunnelling Society and several other European Associations is sponsoring the Shotcrete for Underground Support XI. Bringing together specialists from around the world, state-of-the-art of shotcrete methods will be discussed. Contact: ECI; email: info@engconfintl.org; web: http://www.engconfintl.org/9as.html

14-17 JUNE
RETC 2009
Las Vegas, Nevada, USA
RETC is recognised as a leading international tunnelling event for contractors and engineers. Last year, conference attendance exceeded 1500 professionals from more than 30 countries and the exhibition sold out in record time. With a venue of Las Vegas, 2009 is sure to be even more of a success. Contact: SME; web: http://www.retc.org

22-25 JUNE
5th Symposium of Strait Crossings
Trondheim, Norway
Organised by SINTEF and the Norwegian University of Science and Technology, this major symposium aims to act as a forum for the exchange of information, research, new technology and recent experience. The event will also include an exhibition. Contact: NTNU; email: sc09@adm.ntnu.no; web: http://www.straitcrossings.com

09-11 SEPTEMBER
IBTTA 77th Annual Meeting
Chicago, USA
The International Bridge, Tunnel and Turnpike Association's (IBTTA) 77th Annual Meeting and Exhibition will bring together more than 1000 toll agency professionals for 3 days of networking and innovations in toll industry. Contact: IBTTA: Tel: +1 202 659 4620; web: http://www.ibtta.org

13-16 SEPTEMBER
EURO:TUN 2009
Bochum, Germany
The 2nd International Conference on Computational Methods in Tunnelling is organised by the Institute for Structural Mechanics. Contact: Conference Secretariat: Tel: +49 234 32 29051; web: http://www.eurotun.rub.de

16-18 SEPTEMBER
Tunnel Construction and Underground Structures, Ljubljana, Slovenia
Slovenia's 9th International Conference on Tunnel Construction and Underground Structures is sponsored by the Slovenian Society for Underground Structures. Contact: SSUS: tel: +386 1470 4617; email: jakob.likar@ntf.uni-lj.si; web: www.drustvo-dpgk.si

01-03 DECEMBER
STUVA TAGUNG'09
Hamburg, Germany
Every two years the STUVA conference takes place with various topics from the fields of tunnelling and underground construction. The conferences are attended by approximately 1,500 tunnelling experts from more than 30 different countries. An exhibition accompanies the event. Contact: STUVA: email: info@stuva.de web: http://www.stuva.de/

BRITISH TUNNELLING SOCIETY

19 MARCH: **Disputes in Tunnelling Contracts**
Speakers will consider the common causes of contractual disagreements on tunnelling schemes. Presented by Nigel Legge, Garry Crossley and Caroline Pope. 6pm start at the ICE

16 APRIL: **Harding Prize 2009**
Presentations will be given by the three finalists in the biennial competition open to engineers under the age of 33. The winner will be awarded the Harding Prize after the presentations. 6pm start at the ICE

17-19 MARCH 2010
ISTSS 2010
Frankfurt, Germany
The 4th International Symposium on Tunnel Safety and Security. Manuscript abstracts should be submitted to the Secretariat by 01 June 2009, poster abstracts by the 01 October 2009. Contact: Anders Lönnermark, SP Technical Research Insitute of Sweden; tel: +46 10 516 56 91; email: anders.lonnermark@sp.se; web: http://www.sp.se/en/units/fire/news/ISTSS2010/

14-20 MAY
2010 ITA World Tunnel Congress, Vancouver, Canada
Prior to the 2010 Winter Olympics, the International Tunnelling Association (ITA) visits the spectacular city of Vancouver, British Columbia, for its yearly conference and exhibition. Contact: web: http://www.wtc2010.org

8-10 JUNE
InterTunnel 2010
Turin, Italy
Tunnelling exhibition aimed at companies and suppliers involved in building and equipping tunnels and firms providing the systems and expertise for their safe and efficient operation. Contact: Mack Brooks Exhibitions; web: http://www.intertunnel.com

A DATE TO REMEMBER...

If you know of a tunnelling related conference, event, seminar or exhibition that is not listed here, we would be delighted to hear from you. Please contact the editor by post, email, fax or through our web site: Tris Thomas, 'Tunnels & Tunnelling International', Progressive House, 2 Maidstone Road, Sidcup, Kent DA14 5HZ, United Kingdom.
Fax: +44 208 269 7840
Email: tthomas@tunnelsonline.info
Web: www.tunnelsonline.info

Contacts

HEAD OFFICE
Progressive Media Markets
Progressive House
2 Maidstone Road
Sidcup, Kent
DA14 5HZ
United Kingdom

WEB
www.tunnelsonline.info

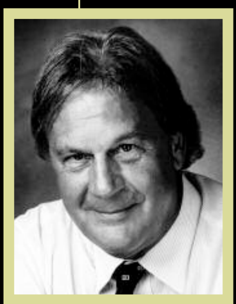
TEL
+44 20 8269 7789

FAX
+44 20 8269 7840

Tris Thomas

Amanda Foley

Gary Tween



David Wildman

HOW TO CONTACT US

EDITORIAL

EDITOR
Tristan Thomas BSc (Hons)
Tel: +44 20 8269 7893 Fax: +44 20 8269 7840
Email: tthomas@tunnelsonline.info

DEPUTY EDITOR
Amanda Foley
Tel: +44 20 8269 7789 Fax: +44 20 8269 7840
Email: afoley@tunnelsonline.info

CONTRIBUTING EDITOR
Patrick Reynolds MEng
Tel: +44 20 8269 7748 Fax: +44 20 8269 7840
Email: patrickjreynolds@hotmail.com

DESIGN
Natalie Kyne

TECHNICAL ILLUSTRATOR
Nick Stenning

PRODUCTION CONTROLLER
Loraine Lee
Tel: +44 20 8269 7799 Fax: +44 20 8269 7840
Email: llee@progressivemediagroup.com

ADVERTISING

GROUP ADVERTISEMENT MANAGER
Gary Tween
Tel: +44 20 8269 7849 Fax: +44 20 8269 7840
Email: gtween@tunnelsonline.info

NORTH AMERICAN MANAGER
Steven Caming - Granite Media Services
Tel: +1 603 447 1187 Fax: +1 603 447 6166
Email: granitemediaservices@yahoo.com

EUROPEAN MANAGER
Randolf Krings
Tel: +49 611 5324 416 Fax: +49 611 5324 519
Email: t&t@emcmedia.de

ITALIAN OFFICE
Ediconsult
Tel: +39 02 477 10036 Fax: +39 02 477 11360
Email: milano@ediconsult.com

PUBLISHING

PUBLISHING DIRECTOR
David Wildman
Tel: +44 20 8269 7778 Fax: +44 20 8269 7840
Email: dwildman@progressivemediagroup.com

HOW TO SUBSCRIBE

Tel: +44 845 155 1845 7511 Fax: +44 20 8606 7301
Email: progressive@optimabiz.co.uk

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